Fred A. Luchette
Jay A. Yelon
Editors

Geriatric Trauma and Critical Care

Second Edition

Springer

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Contents

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Changing Demographics of the American Population

1

Stephanie Gordy

Summary

- The geriatric population comprises about 15 % of the American population.
- The elderly population is getting increasingly older even within itself as the >85 population is expanding.
- The aging population will increase the cost and complexity of medical care.
- Trauma is the fifth leading cause of mortality in the elderly.
- Comorbidities, concomitant medications, and unique physiology add complexity to the care of the geriatric trauma patient.
- Conversations regarding advance directives and end-of-life care are of paramount importance.

Introduction

Geriatric citizens in the United States are the most rapidly growing segment due to the aging baby boomer generation. This generation will live longer than the preceding and will have access to improved healthcare. Because these physically active elderly will remain living independently and longer, traumatic injuries can be expected to increase. In addition, there are numerous physiologic alterations that occur with aging, and special consideration should be given to the elderly patient from a medical and surgical standpoint. The use of multiple medications and presence of multiple comorbidities may also be present in this population leading to higher complications, longer hospital stays, and a higher case fatality rate. Moreover, disposition barriers often exist and include the need for short- and long-term rehabilitation. Finally, traumatic injuries have the ability to change the patient's independent living status and increase the need for admission to skilled nursing facilities. Complex end-of-life decisions and discussions are often also required in this population. Trauma and acute care surgeons should be knowledgeable about the specific needs of the geriatric critically ill patient.

The Aging Population

The definition of elderly has not been definitively established in the trauma literature, but the consensus is that it lies somewhere between the ages of 45 and 75 years [1]. In 2013, the population over 65 years of age was 44.7 million. This represented 14.1 % of the American population at that time. As the "baby boomer" generation reaches the golden years, this demographic is expected to show continued growth. The 15.3 % increase from 2000 to 2010 in the over 65 portion of the population was nearly double the increase (8.7 %) for all ages younger than 65. It is projected that by 2020, this number will increase by 36 % to 55 million. In 2010, the 65–74 age category was ten times larger than in 1900 at 20.8 million. In contrast, the 75–84-year-old demographic was 17 times larger at 13.1 million. Moreover, the >85 group was 45 times larger at 5.5 million. This reveals that the elderly population itself is getting increasingly older even within itself. By 2020, the population over the age of 85 years is projected to increase from 5.5 million in 2010 to 6.6 million. Furthermore, the centenarian (greater than 100) population is steadily increasing. In 2010, 53,364 persons were 100 years old or greater which is greater than a 50 % increase from the 1990 values [2].

Since 1900, improvements and accessibility to healthcare services in addition to improved life expectancy have allowed the number of individuals over 65 years to more than triple. This is not only due to the post-World War II baby boom but to an increased life expectancy as well. A child born in 2009

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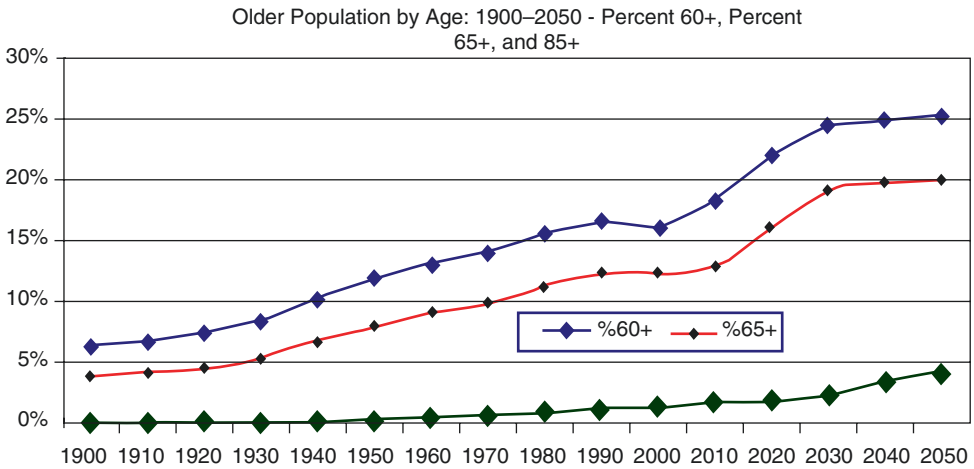

Fig. 1.1 The administration on aging

can expect to live 78.2 years which is 30 years longer than the life expectancy of a child born in 1900. The older population will continue to increase due to maturation of the baby boomer generation (Fig. 1.1). While the population growth slowed in the Great Depression era, it will continue on the upswing as those born between 1946 and 1964 get older. The elderly population will reach its peak by the year 2040 as the greater than 65-year-old population is expected to be 21.7 % of the entire populace [3]. As this segment of the population increases, the number of injured elderly will also grow [1].

The Cost of Caring for the Elderly

As the elderly population increases, the need for healthcare services and the cost of healthcare are expected to rise. The elderly represented 40 % of all hospitalized adults in 2008 [4]. Similarly, even though this population comprises only 13 % of the citizens in the United States, nearly half of all healthcare dollars spent are on the elderly. Additionally, the population over 85 years of age represents only 1.8 % of the total population but accounts for 8 % of all hospital discharges. Hospitalizations and healthcare spending for older adults are expected to rise as the number of elderly increases [5].

More healthcare resources will be necessary to care for the aging population which will pose an additional burden on an already strained federal budget. This cost will not only be reflected in dollars but in resource utilization including acute and long-term care. In 2002, the elderly made up 13 % of the US population, but they consumed 36 % of the total US personal healthcare expenses. The average healthcare expense in 2002 was $11,089/year for elderly people but only $3352/year for those younger than 65 years [6]. Furthermore, older Americans spend 13.2 % of their total expenditures on health, more than twice the proportion spent by the younger citizens (6.6 %) [2]. The five most costly illnesses include heart disease, cancer, trauma, mental disorders, and pulmonary conditions. Heart disease and trauma ranked first and second as the two costliest diseases in terms of total healthcare spending [7].

Thirty percent of total Medicare payments each year are for 6 % of the beneficiaries who died that year. Payments for the last 60 days of life constitute 52 % of the total dollars spent annually by Medicare. Inpatient services consume 70.3 % of the Medicare budget of which the majority of the funds are spent on critical care [8]. In summary, the sickest, eldest patients with a high incidence of morbidity and mortality consume the majority of the Medicare budget [9].

Effects of Aging on Organ Function

Understanding the medical physiology pertinent to this population is particularly important, because it affects the physiologic reserve and compensatory mechanisms required to respond to a traumatic injury, an acute illness, and major operations. The elderly population has a high incidence of comorbidities which can confound the physicians' ability to assess for injury. In injured geriatric patients, the incidence of preexisting medical conditions is 66 %. Moreover, 81 % of nonagenarians have medical comorbidities [10]. Nearly every organ system is affected by changes due to aging. A detailed discussion of this is beyond the scope of this chapter but a brief synopsis follows.

Traumatic brain injury (TBI) has a bimodal age distribution, with the first peak at 15–19 years and the second appearing in those over 65 years of ages. The most common cause of TBI in older patients is falling from standing. Despite this low-energy mechanism, the brain is more susceptible to injury due to the progressive volume loss and atrophy that results in increased space for shear injury [11]. Elderly patients with traumatic brain injuries have worse outcomes when compared to similar injuries in the young [12].

Cardiovascular changes that occur in this population include arterial atherosclerosis which can lead to an elevation in baseline systemic vascular resistance (SVR). Disruption in coronary autoregulation from scarring can result in ischemia. The typical tachycardia in response to hypovolemia may also be blunted in these patients due to medications. The increase in SVR may produce a falsely elevated blood pressure. If these patients are chronically hypertensive, a normal systolic blood pressure (SBP) may be relatively hypotensive for an individual patient and may result in end-organ ischemia [13]. The effect of age on the pulmonary system is impaired gas exchange due to a reduced alveolar surface area [14]. Chest wall compliance is decreased and may result in a blunted cough reflex leading to increased risk for aspiration [15]. There is also a risk for renal failure following trauma. The renal tubular function declines with increasing age as indicated by a decrease in the glomerular filtration rate (GFR). Chronic diuretic use may predispose to electrolyte abnormalities and a contracted plasma volume. The collecting tubules may not concentrate or retain appropriate electrolytes and are at risk for acute kidney injury/failure due to medications and/or ischemia [16]. Changes in the gastrointestinal system result in increased reflux disease and dysphagia resulting in a higher risk for aspiration in the elderly. Aging causes a slower transit time and colonic disturbances ranging from constipation to diarrhea. The musculoskeletal system is also affected. Lean body mass decreases at a rate of 10 % per decade after the age of 50. The reduction in the number and size of myocytes results in progressive weakness with increasing age. This loss of muscle mass combined with osteoporosis leads to an increased risk of fall-related fractures. Hip fractures are a common injury in the elderly and result in an eightfold increase in all-cause mortality within 3 months after the fall [17]. The endocrine and immune systems are also affected by aging. Extensive hormonal changes occur and thermoregulation may be impaired. Elderly patients are also more susceptible to infections and concomitantly are less able to mount a normal immune response. Moreover, malnutrition is common in the elderly requiring nutritional supplementation to prevent profound catabolism [18]. In summary, every organ system is affected by the aging and predisposes to injury, infection, and disability. Medications for preexisting illnesses may also complicate the physiologic response to injury and resuscitation. It is paramount to take these changes into consideration when caring for a geriatric trauma patient.

The functional decline that occurs with aging can lead to an increase in traumatic injuries due to changes in the ability to do activities of daily living (ADLs). ADLs include bathing, dressing, eating, and mobilization. They are important in assessing an individual's ability to function independently. In noninstitutionalized Medicare recipients, 27 % had difficulty in performing one or more ADLs. The ability to conduct ADLs is worse for institutionalized recipients, and 95 % reported difficulties with one or more activity. Additionally, 74 % of those surveyed had difficulty with three or more activities. Limitations in ADLs related to chronic conditions that increase with age and can predispose to traumatic injuries [2]. An increase in the frequency of ground-level falls in this group can reflect a decline in the ability to perform daily activities. This decline in their ability to perform ADLs suggests that the elderly may become more prone to injuries with advancing age.

Trauma in the Elderly

Trauma is the fifth most common cause of death in the elderly. The mechanism of injury in this demographic is primarily blunt forces, and falls are the most common mechanism of injury in this group (Figs. 1.2, 1.3, and 1.4) [1]. The increased population of older adults with active lifestyles has led to a dramatic increase in geriatric traumas. In 2008, adults in the United States aged 65 years and older accounted for more than 5.8 million emergency department visits for injuries, contributing to 30 % of all visits by older adults and almost 14 % of all injury-related emergency department visits [19]. The increase in life expectancy and independent living will lead to an increase in elderly drivers. It is estimated that between 20 and 30 million licensed drivers are currently older than 65 [20]. This number is projected to increase to 50 million by 2030. This explosion in geriatric drivers will be associated with an increase in motor vehicle collisions and/or pedestrians struck and result in an increase in the mortality rate.

The geriatric trauma population poses a special challenge to the trauma team. The mechanism of injury is different than those seen in younger patients. Injuries sustained are more severe in older versus younger adults, and with the increased presence of comorbid disease and independent effects of age, this leads to increased morbidity and mortality in older patients [21]. Several studies have reported an age-related increase in mortality rates, for all injury mechanisms and ISS [22–24].

Multiple mechanisms that result in trauma exist in the elderly population. Of those patients that fall, it is usually a repeated occurrence, and 71 % of falls result in an injury requiring medical care [25]. Additional mechanisms of blunt trauma include motor vehicle collisions, pedestrians struck, and burn injuries. According to the NTDB, less than 5 % of deaths are due to penetrating injuries in this age group [26]. Elderly patients who sustain blunt chest trauma with rib fractures have a morbidity and mortality rate twice that compared to those younger than 65. For each additional rib fracture in the elderly, mortality increases by 19 % and the risk of pneumonia by 27 % [27]. Moreover, when considering

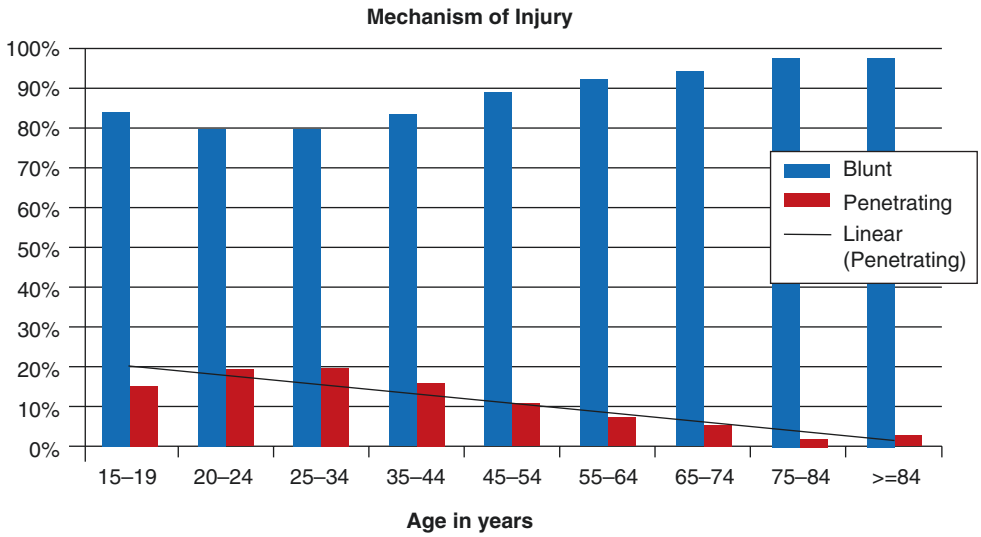

Fig. 1.2 Mechanism of injury in the elderly [1]

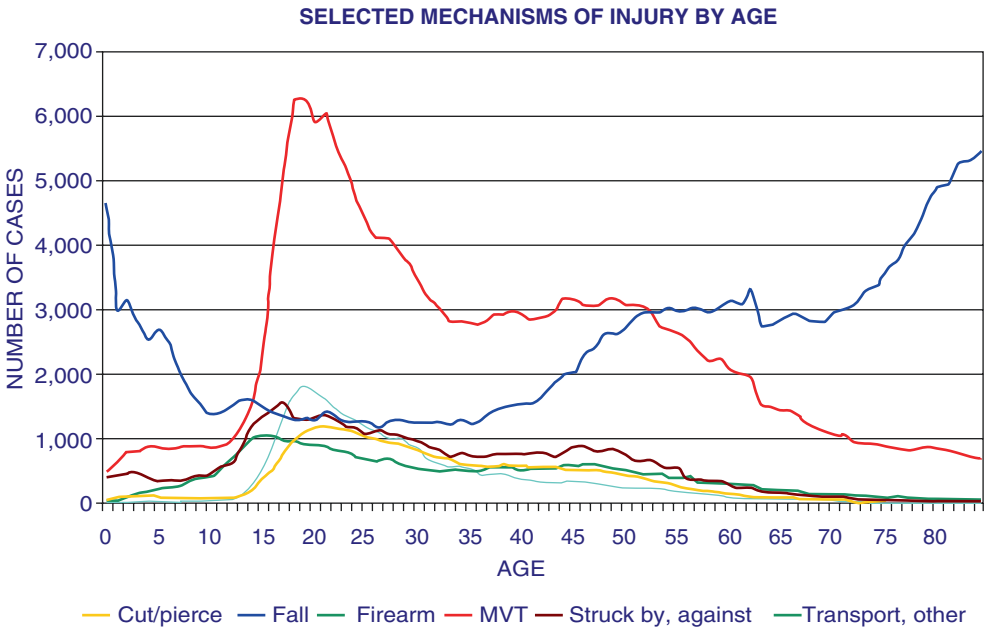

Fig. 1.3 Mechanism of injury by age

rib fracture injuries, "elderly" has been shown to be as young as 45 and older [28]. Clinical pathways that aggressively treat the pain and attempt to prevent the associated respiratory complications have shown to be successful in reducing morbidity and mortality [24].

Once an elderly person is injured, the prehospital system is not reliable in identifying those that are severely injured. This results in a significant undertriaging of these patients. Demetriades et al. found that 63 % of elderly patients that were severely injured (ISS >15) and 25 % of those critically injured did not meet the trauma center's standard trauma activation criteria. They concluded that patients older than 70 years should be considered for trauma team activation based on age alone [29, 30]. The EAST guidelines recommend that geriatric patients should be triaged to a trauma center, but do not use age as an impetus to activate the trauma team [31]. The state of Ohio has implemented a specific geriatric triage based on age [32]. Furthermore, once the elderly are in the emergency department, they may not be easily identified as in shock. Physiologic changes that occur in the elderly may alter the typical physiologic signs and manifestations of shock. Scalea et al. studied patients older than 65 involved in motor vehicle collisions and found their physiology allowed them to present with a higher than expected systolic blood pressure (SBP) due to an elevated systemic vascular resistance (SVR). Of those initially deemed hemodynamically stable with a normal SBP at presentation, 43 % were found to actually be in cardiogenic shock, and 54 % of these patients died [33].

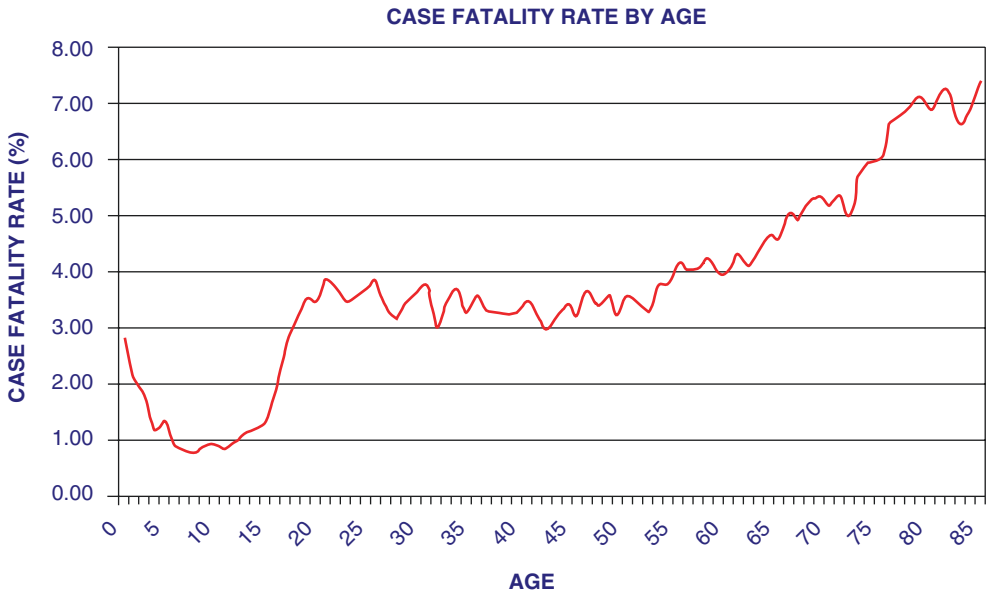

Fig. 1.4 Case fatality by age

Accordingly, base deficit may correlate better with mortality in the elderly trauma population. In those older than 55 years, a base deficit greater than 10 was associated with an 80 % mortality rate. In contrast, a base deficit between 3 and 5 equated to a mortality rate of 23 % [34]. Geriatric blunt trauma patients warrant increased vigilance despite normal vital signs on presentation. It has been suggested that criteria for the elderly include a heart rate greater than 90 or a systolic blood pressure less than 110 mm [35]. The National Trauma Triage Protocol (NTTP) has additionally recognized that SBP less than 110 mmHg may represent shock in those older than 65 years, and practitioners should be vigilant when such a patient presents [36].

Additionally, medications taken prior to an accident can confound the diagnosis of significant injury as well as the need for resuscitation of these patients. Over 80 % of patients that fall are treated with a drug that could have contributed to the fall including antidepressants, antihypertensives, and sedatives [37]. Beta-blockers prescribed for hypertension can blunt the normal tachycardiac response to hemorrhage resulting in a false sense of security that the patient is stable. Anticoagulants, including warfarin, Plavix, aspirin, and new novel anticoagulants, can result in increased bleeding. This can be especially detrimental when traumatic brain injuries are present and expeditious reversal should occur. Patients that do present while on an anticoagulation medication have a higher risk of death [38]. Moreover, increasing numbers of elderly Americans take novel anticoagulants such as direct factor Xa inhibitors ("xabans," rivaroxaban) or direct thrombin inhibitors (dabigatran) for a variety of indications. Although these therapeutic agents benefit patients at risk for thrombotic or embolic events, they increase the risk for post-injury hemorrhage and alterations in the post-discharge destination [39]. Additionally, patients taking these medications have a higher risk of death if they present with a head injury and should speak with their prescribing physicians regarding the risk/benefit of taking these oral anticoagulants, especially if they are prone to falls [40].

Furthermore, delirium, which is common in the elderly, may add to the difficulty in assessing the injured patient in the emergency department. Delirium affects up to 10 % of elderly patients presenting to the emergency department and can confound assessment of these patients. Delirium is often the first presentation of sepsis in the elderly and is unrecognized which may lead to an increase in mortality [15]. As early sepsis can result in falls and therefore traumatic injuries, sepsis screening in the emergency department should be implemented early in these patients [41].

Once admitted to the hospital, geriatric patients pose a unique challenge to the trauma service due to their abnormal response to shock and injury. Bradburn et al. established a geriatric protocol that significantly reduced mortality in their patient population. The protocol included a geriatric consultation, a lactate level, arterial blood gas, and echocardiogram [42]. An additional study by Lenartowicz et al. showed that a proactive geriatric consultation resulted in decreased delirium and short time for discharge to long-term care facilities [43].

In a large series of elderly patients, mortality was demonstrated to correlate closely with ISS. It was also influenced by blood and fluid requirements as well as the GCS score. Regression analysis revealed that ISS predicted adult respiratory distress syndrome, pneumonia, sepsis, and gastrointestinal complications; fluid transfusion predicted myocardial infarction; and need for surgery and transfusion requirements predicted sepsis. These complications, in turn, were significant risk factors for mortality [23]. Additionally, geriatric

patients requiring intubation and blood transfusion or suffering from head, C-spine, or chest trauma have an increased likelihood of death. Inhospital respiratory, gastrointestinal, or infectious complications also predict a higher mortality [44]. A prognostic tool for geriatric mortality after injury called the "Geriatric Trauma Outcome Score" (GTOS), where GTOS = [age] + [ISS × 2.5] + [22 if transfused any PRBCs by 24 hours after admission], has been developed, and the data available at 24 hours post-injury accurately predicts inhospital mortality for injured elderly patients [45].

Early Inpatient Rehabilitation

Weakness associated with impaired function is commonplace in the injured elderly patient. Admission to the intensive care unit (ICU) often results in increased muscle weakness, and the need for short- and long-term rehabilitation is frequent. Implementing early physical therapy in the ICU can result in increased strength as well as decreased length of ICU and hospital stay. More importantly, preventing core muscle wasting and preserving strength can reduce mortality [46].

Multiple hospitalizations increase in the last few months of life, as does the use of intensive care services, suggesting an increase in intensity of care. Other studies have also found an increase in the aggressiveness of care at the end of life. On the other hand, the sustained growth in hospice payments indicates that palliative and supportive care services are becoming utilized more as well. Some patients receive both types of care, undergoing aggressive treatment for some time and then entering a hospice program a short time before death. The relationship between hospice utilization and other services is unclear. Whereas hospice may substitute for more aggressive care in some cases, it may be used in addition to conventional care services in others [47].

Geriatric trauma patients have an overall higher mortality rate for equivalent injuries when compared to younger patients. Additionally, their likelihood of dying within 5 years after an injury increases significantly with time. Despite this elevated mortality rate, a portion are able to go home and resume a good quality of life. Of those that are discharged from the hospital, 52 % are to home, 25 % are to skilled nursing facilities, and 20 % are to rehabilitation facilities. The discharge process can be complex from a financial and emotional standpoint as a traumatic event often results in the need for additional care and loss of independence.

End-of-Life Issues

Advanced care directives and honoring a patient's end-of-life wishes are salient in the geriatric population. Laws regarding these medical decisions arose to preserve a patient's autonomy in a critical care scenario. Patients often fear prolonged suffering, emotional and financial burdens on their families, and concerns about lack of control of their end-of-life care [48]. Of 3746 older adults (>60 years old), 42.5 % required end-of-life decision-making. Of these patients, 70.3 % lacked capacity. Patients with an advance directive were significantly more likely to want limited or comfort care and have their wishes honored [49]. Additionally, the elderly are more likely to have a do-not-resuscitate (DNR) status at the time of death. The increased rate of DNR could be either a reflection of increased injury or poor physiology and inability to tolerate resuscitation [31].

As the elderly portion of the population has increased, the prehospital presence of advanced directive decisions has also increased. In 1994, the SUPPORT study showed that only 21 % of seriously ill patients had an advanced directive, while a 2010 study revealed that 67 % had an advanced directive [50]. A retrospective study by Trunkey et al. evaluated the decision-making process for those geriatric patients that were at risk for death. This study revealed that the elderly frequently have more concerns about long-term disability rather than death. Notably, the families were initially reluctant to discuss the topic of end-of-life care, but ultimately the majority of end-of-life discussions centered on withdrawal of therapies and establishing comfort care measures. Moreover, surgeon input regarding the projected quality and quantity of life was also instrumental when family members were establishing goals of care [51].

The legal aspects of end-of-life care vary from state to state. The POLST form was implemented in Oregon in 1991. This advanced directive addresses four treatment options: code status, transportation wishes, desire for antibiotic administration, and tube feeding. This form is an easily identifiable bright pink form, and the data collected is entered into a central database that can be easily accessed by EMTs and emergency physicians in case of injury. Multiple studies have evaluated this program's effectiveness in preventing unwanted treatments, hospitalization, and resuscitations. In a review of nursing home patients, 91 % had DNR orders, which were ultimately honored. Additionally in a survey of EMTs, 93 % of them regarded the POLST form favorably, and greater than half reported using the POLST to change a patient's treatment plan [52]. While this plan is more applicable to those in nursing home facilities, it can aid in decision-making when the elderly are injured. Advanced care planning should be addressed upon admission as soon as the patient or their surrogate is present. It belies the trauma team to be proactive in addressing these issues early so the patient's autonomy is protected and specific interventions are not performed.

As the post-World War II generation continues to age and the geriatric population expands, our medical system must

likewise mature to provide optimal care for them. The cost of healthcare will continue to increase and will place new strains on an already stressed system. As trauma is a major cause of morbidity and mortality in the elderly, efforts to improve all aspects of acute care should increase to match the growing demands. A high index of suspicion is needed when caring for these patients as they may not follow the standard physiologic response when injured. Additionally an increasing number of elderly patients are prescribed novel anticoagulants, adding complexity to their care. Furthermore, end-of-life discussions are paramount when caring for the elderly. Goals of care should be established early with the patient or their representative in order to maintain the patient's autonomy and to honor their wishes. Expansion of geriatric-centered strategies to improve trauma prevention, triage, resuscitation, critical care, and rehabilitation in the elderly is necessary to meet the needs of this rapidly expanding, complex population.

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Effect of Aging on Cardiac Function Plus Monitoring and Support

2

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Key Points

- Elderly surgical patients are common and often require evaluation and support of the cardiovascular system.
- Aging significantly impacts ventricular and vascular anatomy resulting in altered cardiac functionality.
- Physiological changes of aging include a blunted baroreflex and altered beta-adrenergic responsiveness resulting in a decreased dependence on chronotropy and an increased reliance on stroke volume in response to stress.
- Monitoring of the elderly cardiovascular system is valuable and can be achieved in a number of noninvasive and invasive methods.
- Management of shock in the elderly benefits from an understanding of the needs of the specific patient and a recognition of the risks/benefits of each cardiovascular medication.

Introduction

As the world's population continues to grow, advanced age has become an increasingly important risk factor influencing morbidity and mortality. It is estimated that in the United States alone, approximately 20 % of the population will be over the age of 65 by the year 2030 [1–3]. As the fastest-growing population, specialized attention to the physiology of these aging patients is paramount to the successful treatment of the elderly. Specifically, cardiovascular disease remains the most prevalent and influential comorbidity affecting outcomes in the elderly surgical patient. Half of all heart failure cases in the United States are older than 75, and 90 % of heart failure deaths occur in adults older than 65 [4]. Heart failure is also the leading cause for hospitalization in Medicare beneficiaries. With advances in the care of chronic diseases and longer life expectancy, familiarity with the effects of aging and how to treat elderly patients in all fields of medicine is required to successfully treat this population. The unique physiology of the aging cardiovascular system as well as the impact of these changes during the stress of surgery is outlined in Table 2.1. Understanding these changes and their implications to the treatment of the elderly patient will improve care and outcomes in this population.

Effect of Aging on the Right Ventricle

The right ventricle is connected in series to the left ventricle and is therefore obligated to pump the same stroke volume. As the cardiovascular system ages, this relationship is not always maintained, and right heart flow may not always equal left heart flow. Radio-nucleotide studies and echocardiography have demonstrated impairment in both systolic and diastolic right ventricular function. The mechanism for this reduction is believed to be secondary to a gradual age-related increase in pulmonary arterial vascular resistance, clinically evident by increased pulmonary artery systolic pressures [3]. Using M-mode echocardiography in combination with Doppler technology, right ventricular impairment is demonstrated by observing a reduction of tricuspid annular plane systolic excursion. The tricuspid annular plane systolic excursion (TAPSE) estimates the longitudinal contractile properties of the right ventricle. These modalities demonstrate a significant reduction in TAPSE in otherwise healthy subjects as they age. Pulsed tissue-derived measurements of right ventricular systolic function have confirmed these findings agreeing with findings of older studies demonstrating reduced systolic function on echocardiography.

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Table 2.1 Summary of the effect of aging on the cardiovascular system

Cardiovascular element	Alteration in the elderly
Right ventricle	Reduced systolic function Reduced diastolic function
Left ventricle	Left ventricular hypertrophy Dependence on atrial contribution Age-related impaired contractility and relaxation
Vascular structures	Increased arterial stiffness Systolic hypertension
Cardiac output	Preserved resting cardiac output Preserved ejection fraction
Changes in physiology	Blunted baroreceptor reflex Decreased adrenergic responsiveness
Response to stress	Decreased reliance on heart rate Increased cardiac output due to increased stroke volume

Inefficient rotational motions and non-longitudinal muscular movement contribute to the age-related decrease in right heart systolic function.

The aging process also affects right heart diastolic function. Diastolic functional properties can be characterized by determining right atrial pressure (RAP), tricuspid inflow velocity (E), myocardial early diastolic velocity (Ea), and atrial peak velocity (Aa) [5, 6]. Age is significantly correlated with progressive increases in Aa and decreases in Ea. Additionally, there is a negative relationship between the Ea/Aa ratio and increasing age, indicating less filling velocities in the ventricle despite higher atrial velocities [5, 6]. In the same way that systolic functional decline is attributed to increasing stiffness of the pulmonary vasculature, diastolic functional changes are attributed to increased right heart afterload [5].

Effect of Aging on the Left Ventricle

Years of ongoing stress on the heart result in changes in cardiac function related to increased workload. As aging blood vessels stiffen leading to elevated systolic blood pressure, the left ventricle (LV) changes in response. The heart is required to perform greater amounts of stroke work (stroke volume times blood pressure) in the presence of sustained elevations in systolic pressure resulting in LV wall thickening in elderly patients [7]. Structural changes observed on cardiac MRI demonstrate a significant increase in myocardial thickness as a result of increased cardiomyocyte size. The overall shape of the heart also changes from an elliptical to spheroid shape with asymmetric increase in the intraventricular septum as opposed to free wall hypertrophy [8, 9].

Resting diastolic filling rates decline with age as evidenced by studies utilizing M-mode echocardiography and gated blood pool scans. Diastolic filling of the ventricles occurs in passive and active phases. As individuals age, the heart fills more slowly, and the bulk of ventricular filling shifts to late diastole, with less passive filling. As a result, ventricular filling during diastole becomes more dependent on the active phase. Atrial enlargement is observed as atrial contraction contributes more and more to ventricular filling [8].

Studies using cardiac MRI have investigated LV structure and function. These studies have demonstrated the development of LV hypertrophy and fibrosis leading to diastolic dysfunction and heart failure with preserved systolic function. Indices of cardiac function (such as ejection fraction and ejection velocity) were preserved despite reductions in both LVEDV and LVESV [10]. It appears that modest hypertrophic changes in the left ventricular wall are adaptive to preserve cardiac function at rest. However, exercise capacity is reduced. Fibrotic cardiac remodeling plays an important role in the development of diastolic heart failure with age, and adaptive changes to maintain cardiac output play a pivotal role in senescent cardiac function [9, 11]. These adaptations of the aging LV to maintain cardiac output include prolonged contraction, atrial enlargement, and increased contribution to LV filling [12].

Effect of Aging on Vascular Structures

Increasing arterial stiffness is the predominant change that occurs within the cardiovascular system in the setting of advanced age. The degree of arterial stiffness is proportionally greater in the diseased cardiovascular system. Potential energy released during the cardiac cycle stretches elastin fibers in the arteries and subsequently transmits this energy smoothly downstream to the muscular arterioles and capillary beds [13]. The aging process causes elastin to become depleted and replaced with increased amounts of non-distensible collagen and calcium [14].

The depletion of elastin and replacement with calcium and collagen results in systolic hypertension syndrome that is characterized by an increase in systolic pressures with a lowering or maintenance of the diastolic pressure level resulting in a widened pulse pressure [15]. These changes in the walls of vascular structures predispose to non-laminar and turbulent blood flow, which increases tensile and shear forces on the vessel wall resulting in progressive injury. To compensate for arterial stiffening, cardiac changes result in increased blood velocity to overcome the increased afterload of the stiffened central arterial tree [16].

Vascular changes that occur due to aging result in compromised diastolic filling and subsequently the ability of elderly patients to tolerate the stress of injury or surgery. Central arterial elasticity decreases with age and is paralleled by increased pulse wave velocity occurring in the forward and backward (reflected) direction. Based on the intrinsic compliance of their vessels, young patients have pulse wave

reflections occurring in diastole that augment coronary perfusion and ameliorate tensile shear forces of pulsatile blood flow [16]. Blood flow in less compliant vessels has enhanced shear due to turbulent flow and does not augment diastolic filling of coronary vessels that are already at risk due to atherosclerosis. A widened pulse pressure is the manifestation of stiffened central arteries due to a cardiac impulse transmitted downstream with greater force, causing reflected waves to return at end or peak systole [16].

Effect of Aging on Cardiac Output

With healthy aging the overall resting systolic function does not change. Cardiac imaging utilizing both echocardiography and radio-nucleotide studies has confirmed the preservation of systolic function [11]. The maintenance of myocardial performance was felt to be due to increases in left ventricular thickness, a prolongation of contraction times, an enlargement of the atria, and an increase in the contribution of the atrium to left ventricular filling [17]. With the development of cardiac MRI has come an advanced understanding of the performance of the heart in the elderly. It is now recognized that although older myocytes do increase in size, there is an overall myocyte depletion that is associated with increased collagen deposition and nonenzymatic cross-linking [18]. While the older ventricle increases in overall mass, it does not increase in functional mass, as evidenced by increasing left ventricular mass to volume ratios and associated declines in LVEDV in relation to left ventricular mass. Although the resting EF is preserved, absolute stroke volume does not remain comparable [19]. While both LVEDV and LVESV decrease with age, the decrease in LVEDV is proportionally greater than the decrease in LVESV, which leads to an overall age-related decline in resting stroke volume [19]. It was previously felt that the preservation of EF meant that elderly patient could respond to stress similar to their younger counterparts. Though the preservation of the net systolic function remains unaltered, with exercise the effects of aging are more evident. The reduction of cardiac reserve is a result of multiple factors including increased vascular afterload, arterial-ventricular mismatch, reduced contractility, impaired autonomic regulation, and physical conditioning.

Effect of Aging on the Beta-Adrenergic Response

The response of the cardiovascular system to surgical stress relies greatly on adrenergic stimulation. Exercise and stressors stimulate sympathetic output to increase heart rate, augment contractility and relaxation, and decrease afterload. Unfortunately, one of the consequences of the normal aging process is a decreased responsiveness to beta-adrenergic stimulation. Maximal heart rate (HRmax) decreases in the setting of aging and is responsible for decreases in aerobic work capacity. Decreases in HRmax are independent of gender, regular exercise, and other factors [6, 20]. This attenuation of heart rate responsiveness contributes significantly to an age-related reduction in maximal cardiac output and therefore determines aerobic exercise capacity [20].

The decrease in chronotropic responsiveness (HRmax) to exercise seen throughout the normal aging process remains poorly understood [20]. Proposed mechanisms for the decreased cardiovascular response to adrenergic stimulation are alterations to the conduction pathways as well as decreased receptor expression. With generalized increase in collagenous tissue and fibrosis of the cardiac myocytes, changes in the cardiac conduction system develop. Variable degrees of fibrosis and calcification of the cardiac skeleton can impact AV nodal conduction as well as the development of atrioventricular conduction block. Fat accumulation around the SA node is also observed with aging. This may cause partial or total separation of the SA node from the surrounding atrial tissue and may lead to decreased intrinsic heart rate. However, SA node dysfunction is not always identified in the setting of myocardial remodeling and instead may indicate a molecular change in the pacemaker cells [21]. The number of pacemaker cells also significantly declines with advanced age further decreasing the cardiovascular response to adrenergic stimulation [8]. Other observations have shown reductions in calcium channel proteins, which may lead to decreased sinus node depolarization reserve and thus suppression of action potential formation and propagation [22].

Another mechanism proposed for the decreased adrenergic responsiveness is a decrease in cardiac adrenergic receptor density. Elevated adrenergic neurotransmitter levels have been observed in the elderly and appear to be a compensatory response to decreased receptor expression and deficient NE uptake at nerve endings [8]. With prolonged adrenergic expression and deficient uptake, neurotransmitter depletion can contribute further to the blunted cardiac response and LV systolic performance seen with exercise and stress in the elderly.

Effect of Aging on the Baroreflex Response

In the normally functioning cardiovascular system, the baroreflex serves as an efficient component of a complex feedback loop that maintains adequate cardiovascular function. The effect of aging on the baroreflex has been studied by relating pulse interval to changes in systolic blood pressure after phenylephrine injection. This work revealed a linear relationship between pulse interval and change in systolic

blood pressure as well as a distinct decrease in the baroreceptor reflex sensitivity in the elderly [23, 24]. Others have found that an age-related decline in baroreflex sensitivity is independent of systolic blood pressure and systemic adrenergic levels [25]. Decreased baroreceptor reflex sensitivity was also demonstrated in a study of healthy volunteers examining cardiac response to angiotensin II (ANG II) infusions. The elderly, unlike younger patients, do not exhibit decreases in heart rate when blood pressure is increased via ANG II infusion [24, 26].

Effect of Surgery on the Geriatric Cardiovascular System

Much of what we know about the response of the aging cardiovascular system to surgery has been elucidated from a body of work evaluating the impact of exercise. Surgery results in a substantial amount of physical and metabolic stress on the body due to blood loss, the inflammatory response, and the effects of anesthesia. The effects of stress vary greatly depending on the age of the patient and the presence of associated comorbidities. Exercise provides a controlled stress state that allows some understanding of the effects of surgery on the elderly.

The normal response to exercise and presumably to surgical stress consists of an increase in cardiac output to meet the elevated metabolic needs of the body. Initially, it was believed that the elderly demonstrated a depressed cardiac output. Subsequent studies that excluded patients with coronary artery and myocardial disease showed a more appropriate increase in cardiac output although the mechanism appears to be different than in the young [27, 28]. Older patients cannot increase cardiac output with the typical increases in heart rate secondary to decreases in HRint and B-adrenergic responsiveness. The elderly optimize the Frank-Starling mechanism by increasing their end-diastolic volume and stroke volume during exercise, thereby increasing cardiac output without substantially increasing heart rate. While the elderly are able to augment stroke volume during exercise, the increase in ejection fraction is less than that observed in younger counterparts secondary to a decreased ability to reduce end-systolic volume. This physiologic response is similar to that which is seen in young patients administered with exogenous beta-blockade and then stressed with increasing exercise loads.

Surgery and injury are frequently associated with hypovolemia secondary to blood loss and capillary leak commonly leading to cardiovascular compromise. Free water loss, chronic poor oral intake, pharmacologic vasodilation (home medications), and decreased plasma oncotic pressure (poor nutrition) also commonly lead to further intravascular volume depletion. Given the dependence on the Frank-Starling modulation of cardiac output rather than chronotropy, the elderly patient is particularly sensitive to preload reductions. While Shannon and colleagues showed that elderly patients mount a blood pressure increase and slight HR increase similar to younger patients during tilt tests, this response is negatively affected by hypovolemia [29]. When the same test is performed after preload reduction with diuretics, elderly patients sustain a symptomatic fall in blood pressure due to an inability to mount a tachycardic response in contrast to younger patients who exhibit an appropriate increase in both heart rate and blood pressure [29].

The body of literature evaluating the effects of exercise on the aging cardiovascular system has demonstrated the ability to maintain cardiac output in response to the stress of surgery [27, 28]. The mechanism appears to depend upon stroke volume by increasing end-diastolic volumes and contractility rather than through the augmentation of heart rate [31]. Newer technology including cardiac MRI and pulsed tissue Doppler echocardiography in 2D and 3D has shown that while elderly patients can mount a cardiac output response to stress, this is of lesser magnitude than in their younger counterparts due to decreased cardiac reserve [12, 30, 31]. It is clear that elderly patients generate increased cardiac performance in the face of stress; however, the magnitude of this response is attenuated and less robust than that of younger counterparts.

Effect of Comorbidities on Cardiovascular Function: Atrial Fibrillation

Elderly patients rely heavily on prolonged contraction times and increased atrial contribution for adequate left ventricular filling. Atrial fibrillation (AF) is particularly problematic because atrial arrhythmias result in inconsistent and often inadequate ventricular filling due to limited contraction and decreased filling time. Age-related increases in left (and right) atrial size in older patients are a risk factor for the development of AF [32]. Additional age-related risk factors include inflammatory cytokines, local and systemic stress, altered calcium handling, and electrical remodeling on a chronic basis [33]. In the acute setting, pulsatile mechanical atrial stretch and inflammatory cytokines (from surgery, injury, or sepsis) contribute to arrhythmogenesis [33]. Numerous cytokines may contribute to the development of AF including interleukin-6, interleukin-8, and hsCRP [33]. These same cytokines are present in high levels in the serum of injured patients and can be used to predict progression to multiple organ failure in the injured patient [34]. Surgical patients are exposed to other risk factors including large-volume resuscitation causing atrial stretch, increased endogenous catecholamine release, rapid fluid and electrolyte shifts, hypoxia, and hypercarbia [35, 36]. Another common

risk factor is withdrawal from chronic beta-blockade in the elderly following surgical procedures.

Atrial fibrillation significantly impacts elderly surgical patients and frequently complicates the postoperative course. Chronic AF should be managed with the main goal being control of heart rate as this results in more optimal long-term outcomes [37]. Maintenance management of AF usually consists of beta-blocker, calcium channel blocker, or antiarrhythmia medications such as amiodarone. These should be continued through the perioperative period as much as possible although this can be challenging in the setting of hemodynamic compromise and limited gastrointestinal function. In the setting of significant surgery or severe injury, acute AF is common and results in prolonged hospital length of stay. There is no superior treatment regimen, and therapy is usually tailored to meet the unique patient care needs present at the time of diagnosis. Trauma patients have been found to benefit from beta-blockade due to the commonly high levels of catecholamines present at the time of injury [38]. For postoperative patients, beta-blockade and calcium channel blockade are the most common and efficacious approaches in the presence of adequate perfusion. Patients with hemodynamic compromise at the time of AF onset may require synchronized cardioversion or the initiation of antiarrhythmics such as amiodarone. Often, therapy for acute AF is only needed during the perioperative period of time and can be discontinued as the body heals and the cytokine environment returns to normal. Nevertheless, AF should be diagnosed and managed expeditiously in the elderly due to greater expected reductions in cardiac output secondary to loss of atrial kick and need for longer diastolic filling times.

Effect of Comorbidities on Cardiovascular Function: Ischemic Heart Disease

Surgical patients are at significant risk for acute myocardial ischemia given the associated endogenous catecholamine release, systemic inflammation, and increased myocardial oxygen demand. Additionally, hyperdynamic blood flow during resuscitation and its associated turbulent and non-laminar blood flow increase vessel wall shear forces. This increased shear may cause the rupture of coronary atherosclerotic plaques and predispose to myocardial infarction (MI) [39]. The risk of MI is compounded in the elderly in whom arterial pulse wave indices do not support diastolic filling of coronary vessels and arterial stiffening only exacerbates conditions of turbulent arterial blood flow. Elderly patients are also at greater risk due to preexisting coronary artery and intrinsic cardiac disease. Perioperative MI represents an important disease entity to address as it is associated with worse outcomes especially in the aged [40].

The elderly are the most at risk to experience an MI after surgery, are the most likely to suffer poor MI-related outcomes, and subsequently are the most likely to benefit from intervention. Due to atypical symptomatology and presentation, MI is difficult to diagnose in the critically ill elderly patients. A high index of suspicion and liberal use of diagnostic modalities such as ECG and serial troponin measurements are required to identify acute myocardial ischemia. Myocardial ischemia should be considered in the setting of unexplained vital sign decompensation after hemorrhage and hypovolemia are ruled out. Echocardiogram may be valuable to identify wall motion abnormalities in the face of non-diagnostic troponin elevation [41]. Cardiology consultation should be obtained liberally in the setting of acute coronary syndrome as the patient may be a candidate for reperfusion with coronary intervention.

Effect of Comorbidities on Cardiovascular Function: Heart Failure with Preserved Ejection Fraction

Heart failure (HF) with preserved EF is defined as heart failure with an ejection fraction equal to or greater than 50 % and represents up to 40 % of patients with heart failure [42]. This clinical condition is important because patients will appear normal when at rest and this resting EF is often erroneously used in these patients as a surrogate for achievable cardiac performance under stress. Several exercise studies of patients with HF with preserved EF demonstrated an inability to adequately increase LV systolic elastance. Further, these patients demonstrate lower peripheral resistance, increase heart rate, and reductions in ventricular-arterial coupling that result in an intolerance of submaximal and maximal exercise workloads [42]. Patients with HF express maladaptive inotropic, lusitropic, chronotropic, and vasodilatory responses to the physical stress of exercise and are believed to have similar inadequate responses to the physical stress of surgery.

Monitoring the Aging Cardiovascular System

Due to the significant anatomic and physiologic limitations described above, the elderly cardiovascular system often requires multiple monitoring techniques to provide the necessary support during the perioperative period of time. The elderly do not have the same reserve as the young surgical patient and therefore require more exact maintenance of preload, contractility, and afterload to ensure adequate cardiac performance. The initial question that must be answered for any surgical patient should always be, “Is the patient in shock and underperfused?” The answer to this question is provided

by clinical examination (mental status, peripheral pulse quality, skin temperature, urine output) as well as laboratory studies. Comorbidities often present in the elderly may mimic clinical findings such as dementia/delirium, chronic peripheral vascular disease, and chronic renal insufficiency. Laboratory findings such as lactic acid and base deficit remain valuable indicators of global hypoperfusion. At a minimum, an arterial catheter is required in any patient in shock with marginal hemodynamics to provide continuous assessment of systolic and mean arterial blood pressure. More invasive monitoring techniques are often necessary to determine the intravascular volume status as well as cardiac and vascular abnormalities that may be present. It is important to recognize that the value of any monitoring technique is highly dependent on the ability to correctly interpret the results of the device to make therapeutic decisions. The decision to implement a more advanced monitoring device should simply occur when the clinician can no longer confidently describe the patient's intravascular volume status.

Modalities that provide the ability to monitor intravascular volume status as well as intrinsic cardiac function include arterial pulse waveform/indicator dilution analysis, pulmonary artery catheters (PACs), and echocardiography. A central venous catheter measuring central venous pressure (CVP) provides the most basic assessment of intravascular volume status. Unfortunately, CVP is limited greatly by any factor that affects intrathoracic pressure such as mechanical ventilation. Therefore, CVP can be valuable when low, but a normal to elevated level does not rule out intravascular volume depletion. Systems that analyze arterial pulse waveforms attempt to determine the variability to stroke volume based on changes in the arterial waveform. Increased stroke volume variability can be used as an indicator of decreased intravascular volume that may benefit from volume expansion. Similarly, indicator dilution techniques utilize the peripheral arterial catheter by measuring the dilution of an injected substance from the time of venous injection to arterial sampling. This technique is capable of providing an indication of cardiac flow (CF) although this and arterial pulse waveform analysis methods depend upon peripheral arterial blood flow and may be limited in the setting of peripheral arterial disease. A PAC provides pressure measurements from the pulmonary vasculature which better correlate with left heart filling although can still be affected by mechanical ventilation. Newer generation PACs provide calculated measurements of end-diastolic and end-systolic volumes as well as blood flow and right heart ejection fraction that may be of greater assistance in optimizing intravascular volume status and cardiac performance. Despite studies challenging the value of PACs, when used correctly these devices continue to provide valuable information used to guide resuscitation especially in the elderly patient. More recently, besides echocardiography used for resuscitative purposes has become more popular due to the ability to directly image the left heart. Both transthoracic and transesophageal methods are now available that allow the surgeon to visualize the left heart frequently without the challenges of obtaining formal echocardiography. These resuscitative echocardiographic techniques provide the ability to visualize and measure left heart filling as well as the associated ejection fraction. Repeat imaging after volume expansion or inotrope/vasopressor manipulation allows the clinician to immediately determine the impact of the recent interventions on improving cardiovascular function. The main challenge has been the education required to have adequate numbers of clinicians capable of obtaining the necessary images and the associated interpretations.

Support of the Aging Cardiovascular System

The failing elderly cardiovascular system requires a careful determination of the cause of the inadequate perfusion. Most importantly, each patient should receive what he or she needs to correct the cardiovascular abnormality that is present. Unlike young patients, the elderly will often be intolerant to under- or overcorrection again due to the lack of reserve and the unique physiology that occurs with aging. Most surgical patients, whether young or old, require expansion of intravascular volume to optimize cardiac function. The elderly are more sensitive to hypovolemia, as described above, and therefore an early decision to institute invasive monitoring may be required to ensure the proper amount of volume expansion. Given that over-resuscitation may be deleterious to the elderly surgical patient, this monitoring provides an opportunity to administer the appropriate amount of fluid. In the absence of portal hypertension physiology, crystalloid remains the most efficacious, safe, and inexpensive choice of fluid for volume expansion. Despite theoretical benefits, colloid has yet to demonstrate superior outcome results when compared to crystalloid alone.

When optimization of volume status fails to correct global hypoperfusion, correction of contractility and/or afterload with the initiation or modification of inotropes/vasopressors is required. The choice of agent to use remains a point of discussion throughout the surgical community. There is very little data supporting one agent over another, and the clinical scenario is likely more important than having standard medications of choice. Nevertheless, each of the agents has unique attributes that make them more or less appealing given the circumstances. Patients that have isolated contractility problems may benefit from dobutamine due to the specific myocardial stimulation that is provided via $beta_1$ stimulation. Unfortunately, dobutamine can cause profound tachycardia that in the elderly may not be tolerated due to the significant increase in myocardial oxygen demand and the risk of

precipitating atrial fibrillation. While not as effective, milrinone provides enhanced myocardial contractile function without the effects on heart rate. Further, milrinone is appealing in the elderly due to its non-adrenergic mechanism of action given the presence of poor adrenergic responsiveness.

In the setting of decreased afterload, norepinephrine and vasopressin are commonly used to support hemodynamic function. Norepinephrine provides strong afterload augmentation via alpha-adrenergic stimulation while offering minimal beta stimulation on the heart. For this reason, norepinephrine is the most common vasopressor used in the setting of septic shock when there is a marked reduction in afterload. The result is an increase in blood pressure without affecting heart rate or contractility. Similarly, vasopressin is a non-catecholamine hormone which results in significant vasoconstriction and can improve blood pressure. Vasopressin does not function through adrenergic stimulation and therefore is appealing in the elderly patient who has blunted adrenergic responsiveness. Both norepinephrine and vasopressin benefit from increasing blood pressure without significant increases in heart rate, thus making them less arrhythmogenic. Nevertheless, it is important in the elderly, who have limited contractile reserve, to avoid implementing unopposed afterload augmentation that might result in myocardial decompensation and decreased cardiac performance.

When monitoring of the cardiovascular system reveals findings consistent with reduced contractility and afterload, epinephrine may be a valuable agent to select to provide support. Epinephrine stimulates both alpha- and beta-adrenergic receptors resulting in enhanced contractility and vasoconstriction. The result is increased cardiac output and blood pressure as well as improved coronary blood flow. With that said, tachycardia is common resulting in increased myocardial oxygen demand and a greater likelihood of AF. Nevertheless, epinephrine is a valuable agent to employ but should be selected carefully and the results monitored closely.

Summary

The elderly surgical patient presents challenges related to anatomic and physiological changes as well as preexisting conditions. Altered cardiovascular function is common in the elderly surgical patient resulting in an inability to adequately perfuse the organs of the body. The elderly cardiovascular system exhibits a blunted response to adrenergic stimulation due to reductions in intrinsic heart rate and beta-adrenergic responsiveness. The ability to increase cardiac output during surgery relies more on increased ventricular filling and stroke volume than on increases in heart rate and EF. The elderly also demonstrate decreases in baroreceptor reflexes that make them more sensitive to hypovolemia and hemorrhage. Atrial dysrhythmias are common and must be rapidly diagnosed and treated due to a reliance on atrial contributions for adequate ventricular filling and cardiac output. Monitoring of cardiovascular function may be more beneficial than in the young due to the importance of achieving optimal volume status. When inotrope/vasopressor agents are necessary, careful selection based on the specific needs of the patient is important given the unique risks and benefits of each medication. Frequent reassessment after initiating or modifying cardiovascular medications is required to ensure achieving improved perfusion but to also monitor for untoward complications.

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Pulmonary Anatomy

3

Joseph S. Hanna, Marissa DeFreese,
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Case Vignette

A 60-year-old male presents following a motor vehicle collision during which he sustained bilateral second to eighth rib fractures resulting in a floating sternum as well as a comminuted distal tibia/fibula fracture. He was admitted to the surgical intensive care unit for multimodal pain control and aggressive pulmonary toilet given an estimated mortality of >70 %. Despite these efforts, objective measures of adequate analgesia to facilitate good pulmonary toilet, including incentive spirometry volumes and ability to cough, indicated impending respiratory failure. He was brought to the operating room urgently for open reduction and internal fixation of his right and left rib fractures on sequential days. His postoperative course was notable for a remarkable improvement in his ability to cough and deep breath. The need for mechanical ventilation and a prolonged intensive care unit course was averted, and the patient was discharged shortly thereafter on room air in good condition.

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Introduction

The respiratory system facilitates gas exchange and diffusion across the alveolar membrane to support aerobic metabolism and ATP production. This elegant system provides for interaction with the environment while protecting against injurious elements (noxious stimuli, pollutants, infectious agents) and maximizes efficient gas exchange while minimizing saprophytic losses, as well as participating in systemic homeostatic mechanisms [1]. The respiratory system is composed of the nose, oropharynx, trachea, lungs, chest wall, diaphragm, and abdominal muscles. Specifically, the thorax includes the sternum, ribs, intercostal muscles, thoracic vertebrae, two pleural cavities containing the lungs, and the mediastinum. The mediastinum consists of the pericardium, heart, esophagus, trachea, great vessels, thoracic duct, and thymus [2]. During the aging process, normal respiratory function is impaired; in the unperturbed system, gas exchange is maintained through compensatory mechanisms with little deleterious effect. However, when injured or in illness, these compensatory mechanisms may fail, resulting in a mismatch between gas exchange and physiologic demand. The global population is aging at a rapid rate, with an anticipated doubling of those age 60 or greater by 2050 [3]. Furthermore, more than half of all ICU days utilized in 2000 in the United States were by patients 65 and older [4]. A solid foundation in the age-associated changes which affect the respiratory system is essential to the management of this rapidly expanding population. Basic lung anatomy, physiology, the consequences of changes associated with aging, and several airway diseases will be reviewed.

Anatomy

Lung Anatomy

The lungs are paired organs invested with visceral pleura within the thoracic cavity which is lined with the parietal

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pleura. The visceral pleura is contiguous with the parietal pleura at the hila, and invaginations form the fissures which divide the lung lobes. The left lung is divided into two lobes which are subdivided into ten segments following lobar and segmental branching. The right lung is composed of three lobes, superior, middle, and inferior, also subdivided into ten segments [5]. Air is conducted to the lungs from the nose and oropharynx via the tracheobronchial tree which has incomplete cartilaginous rings which provide circumferential support. The bronchi are lined with columnar ciliated epithelium and mucous-secreting goblet cells which are responsible for propelling debris and foreign material upward toward the oropharynx to be expelled. This system is commonly referred to as the mucociliary elevator. Further subdivision of the airways beyond the bronchi terminates in the bronchioles and ultimately the alveolar ducts and alveolar sacs. It is estimated that adults have approximately 300–500 million alveoli providing an estimated 75 m^2 of gas exchange surface [6–8]. Alveoli are lined with respiratory epithelium (Type I cells) which are covered in a thin film of surfactant (secreted by Type II cells) which decreases surface tension and prevents alveolar collapse. Type II cells also participate in lung repair after tissue injury by replacing damaged Type I cells. The respiratory epithelium is intimately associated with pulmonary capillaries to facilitate the ready diffusion of gases.

Chest Wall

The bony thorax and muscles of respiration comprise the chest wall. It provides protection to the thoracic viscera from injury and provides fixation points for the associated musculature. The ventral aspect of the chest wall includes the manubrium, sternum, and xiphoid process. The first seven pairs of ribs articulate directly with the sternum via the costochondral joints, the next three pairs articulate with the lower border of the preceding rib via cartilaginous extensions, and the last two are free floating, terminating in the flank and back. Posteriorly, the ribs articulate with the 12 thoracic vertebrae at the transverse processes. The ribs are joined by three distinct muscles and a neurovascular bundle. The intercostal muscles begin superficially with the external intercostal muscle, then the internal intercostal muscle, and the innermost intercostal muscle, which is adjacent to the parietal pleura. The intercostal muscles are composed of slow ($MyHC_1$)- and fast ($MyHC_{2a,\ 2x}$)-twitch skeletal muscle fibers. The predominance of $MyHC_1$ fibers is essential for maintaining slow, consistent, rhythmic contractions, while the $MyHC_2$ fibers support increased respiratory demand by allowing for augmentation of the respiratory rate and depth (higher velocity and force generation) [9]. Blood supply to the sternum, intercostal muscles, diaphragm, and chest wall is provided by the intercostal vessels which course along the inferior edge of each rib as well as the internal mammary arteries [2].

Diaphragm

The diaphragm is a thin, dome-shaped fibromuscular organ which powers the respiratory cycle by expanding the thoracic cavity and separates the thoracic and peritoneal cavities. This is accomplished by displacing the abdominal viscera inferiorly and raising the lower ribs cephalad and anteriorly [10]. This creates a negative intrapleural pressure gradient which allows for air to move into the lungs. The diaphragm has multiple attachment points to the thoracic cavity. Anteriorly, it inserts on the xyphoid process and along the anterior costal margin; posterolaterally, fibers insert onto ribs 9–12; bilaterally, two appendages (crura) insert along the lumbar vertebral column (L1–L2); and medially, the muscle fibers insert in the central tendon [5]. Similar to the intercostal muscles, the diaphragm is composed of both $MyHC_1$ and $MyHC_2$ skeletal muscle fibers [9] to sustain regular rhythmic respiration at rest, with the ability to augment minute ventilation as needed. The phrenic nerves, originating predominantly from the fourth cervical nerve with contributions from the third and fifth cervical nerves, provide sensory and motor innervation to the diaphragm [11].

Pulmonary Physiology

The primary function of the respiratory system is gas exchange to support aerobic metabolism. The respiratory cycle is comprised of two discrete phases. During inspiration, gas is brought into the pulmonary system via active muscle contraction. The diaphragm descends into the abdominal cavity and lifts the lower ribs anteriorly and cephalad; the external intercostal muscles further assist in displacing the ribs anteriorly. Combined, these actions increase intrathoracic volume, resulting in a negative intrapleural pressure relative to atmospheric pressure. Once the pressure gradient is sufficient to overcome the resistance in the airways, air flows into the lungs. During quiet breathing, the diaphragm is responsible for the majority of the respiratory work effort. To augment tidal volume as needed and overcome airway resistance or intrinsic pulmonary restriction, accessory muscles of respiration (external intercostals, scalenes) are utilized to further increase thoracic cavity volume. Expiration occurs passively at rest when the diaphragm and external intercostal muscles relax. Intrinsic static recoil forces of the chest wall and lungs result in an increased intrapleural pressure and airflow out of the lungs. Minute ventilation may be augmented as needed by active contraction of the internal and innermost intercostal muscles which provides for forceful exhalation.

Gas exchange occurs within the alveoli with oxygen and carbon dioxide crossing the alveolar membrane into the high capacitance pulmonary capillary bed. There is differential ventilation and perfusion (V/Q) throughout the lung paren-

chyma because of increasing alveolar ventilation and pulmonary capillary blood flow from the apex to the base. As a result, maximum oxygenation occurs at the lung bases. Thus, processes that affect the bases such as dependent atelectasis or lower lobe pulmonary emboli typically have a profound effect on oxygenation. V/Q matching throughout the lung is facilitated in part by pulmonary capillary flow modification by alveolar oxygen tension. Alveolar hypoxia results in pulmonary vasoconstriction, thereby reducing the shunt fraction (blood not exposed to alveolar oxygen) and maximizing V/Q [10]. It is important to note that in the absence of alveolar membrane disease, such as in adult respiratory distress syndrome, the exchange of oxygen and carbon dioxide is perfusion limited. In other words, the gas diffusion rate exceeds alveolar capillary red blood cell transit rate [12].

In addition to gas exchange, the pulmonary system performs several other critical functions for overall homeostasis. The highly distensible pulmonary vasculature provides a reservoir to compensate for significant changes in venous return which may be encountered during postural changes or exercise. Thus, lung blood volume may shift from 500 to 1000 ml over short periods to support systemic needs. In addition, the pulmonary vasculature is a physical filtration system preventing microembolism (e.g., fibrin, gas bubbles, foreign material). Importantly, the pulmonary parenchyma participates in the regulation of the coagulation cascade by producing fibrinolysin activator and heparin. Furthermore, the lung is an important extrahepatic site for cytochrome P450-mediated drug metabolism. Finally, the lung is involved in the metabolism of various vasoactive amines, vasoactive peptides, and prostaglandins [1], thereby participating in the control of systemic vascular tone and blood pressure.

Effects of Aging

Normal aging creates structural and physiologic changes in the respiratory system that alter pulmonary function and efficiency. The chest wall undergoes several physiologic changes as the patient ages. Calcification of the costochondral joints and thoracic vertebral articulations results in a decreased compliance and elastic recoil of the chest wall. Loss of height within the thoracic spine secondary to compression fractures and intervertebral disk degeneration results in increasing thoracic kyphosis (curvature). An increased anterior-posterior diameter and concomitant kyphosis result in decreased mechanical advantage for the diaphragm further impeding inspiration [8, 13]. In addition to these chest wall changes, the static elastic recoil of the lung decreases with age. Thus, in the elderly at rest, tidal volumes decrease, and respiratory rate is increased to maintain minute ventilation. Cumulatively, these changes result in an estimated 20 % increase in breathing-related energy expenditure in the geriatric individual [8].

In addition to these structural changes, sarcopenia, the age-associated loss of muscle mass, results in a selective loss of $MyHC_2$ fibers, decreased muscle energy production as measured by VO_{2max}, and decreased muscle protein synthesis [14]. A reduction in neuromuscular junctions and selective denervation of $MyHC_2$ fibers further exacerbate the functional consequence of losing fast-twitch muscle fibers [15–18]. This results in a significant reduction in the ability to augment and maintain an increased tidal volume and/or minute ventilation under stress or during strenuous activity. Furthermore, these changes have been demonstrated to result in a significant decrease in maximum inspiratory and expiratory pressures generated in the elderly [8]. Sarcopenia has been associated with an increase in the number of ventilator-associated days in the critically ill [19].

Independent of age-associated chest wall changes, several derangements occur within the airway and pulmonary parenchyma. Bronchiolar diameter decreases with age creating an increased resistance to airflow [18]. There is a concomitant enlargement of the alveolar airspace diameter similar to that observed in emphysema resulting in a significant reduction in alveolar surface area (75 m^2 at age 30 and 60 m^2 at age 70) [8]. However, unlike traditional emphysematous changes, there are no inflammatory cell infiltrates identified in healthy older lungs. Furthermore, the reduction in supporting tissues surrounding airways <2 mm in diameter results in dynamic collapse during the expiratory phase, resulting in an obstructive pathology. "Senile emphysema" is the term applied to these pathologic changes. These changes result in a predictable and measurable decrease in arterial oxygen tension, decreased carbon monoxide diffusion capacity, and increased work of breathing with age.

In addition to these anatomic changes, neurochemical alterations further impair the ability of elderly individuals to compensate for significant increases in pulmonary demands. The response to hypoxemia and hypercapnia is significantly reduced as compared to younger patients. It appears that this is likely secondary to altered chemosensory function compounded by an inability to adequately augment respiratory function to compensate [8, 20]. Further exacerbating this blunted and maladaptive response is a diminished perception of added resistive load. This change appears to occur within the central nervous system resulting in the absence of a compensatory response in ventilation [20]. Cumulatively, in the critically ill, these changes not only hinder an adequate compensatory response, but may also mask signs and symptoms of impending respiratory collapse requiring a heightened level of vigilance.

Finally, several changes result in a diminished ability for the lungs to adequately clear deleterious agents and pathogens. The age-associated decrease in ciliary motility and mucus production within the bronchi result in a significant impairment of the innate immune response [20]. Additionally, an impaired cough reflex as well as reduction in $MyHC_2$

muscle fibers in the chest wall and concomitant decrease in the maximum expiratory pressure [8] result in a further reduction in the ability to clear irritants and pathogens from within the airway. Moreover, age-associated alterations in pulmonary immunity have been identified. These include a blunted cytokine release profile in response to pathogens, alterations in *Toll-like* receptor function, reduction in monocyte reactive oxygen species generation, and derangements of the adaptive immune system [13]. Taken together these derangements likely predispose geriatric patients to pulmonary infections.

Pulmonary Function Testing

Utilization of pulmonary function tests provides practitioners with objective data about lung function. The data determined by these tests help healthcare providers diagnose and monitor various airway diseases. The major types of pulmonary function tests include spirometry, measurement of lung volumes, and diffusion capacity. Airflow into and out of the lungs is measured during different breathing maneuvers to gauge expiratory flow rates and volumes. Spirometry creates a tracing of the relationship between maximal expiratory airflow and time, termed a spirogram. It is the most common measure of ventilatory lung function. Good-quality test results are based on accurate equipment, good test procedures, an ongoing program of quality control, appropriate reference values, and good algorithms for the interpretation of results. Variability in spirometry is often based on patient cooperation and ability. The interpretation of lung function tests usually involves comparing values measured in patients with reference ranges obtained from populations of healthy nonsmokers [21]. Diffusing capacity for carbon dioxide (D_{LCO}) evaluates the alveolar membrane. D_{LCO} measures the ability of the lungs to transfer gas from inhaled air to the red blood cells in pulmonary capillaries. This test is useful for the differential diagnosis of restrictive and obstructive lung volumes. Patients are instructed to rapidly inhale gas that is a combination of carbon monoxide (usually 0.3 %) and a tracer gas. The test gas is held for 10 s and then the subject exhales. During the breath-holding period, the carbon monoxide continuously moves across the alveoli into the blood. A low D_{LCO} correlates with a low mean lung tissue density. This is often found in emphysema. Conversely, a normal or high D_{LCO} is seen in airway obstructive disease such as bronchitis or asthma. Lung disease is typically classified as being either obstructive or restrictive. Obstructive lung disease carries a primary criterion of a reduced percent of FEV_1/VC. In a restrictive pattern, the lungs are small. The primary criterion for this diagnosis is a decreased total lung capacity (TLC). The presence of restriction is inferred from vital capacity since the TLC is calculated indirectly. Pulmonary function tests are often performed at baseline and then with the administration of medications, frequently a bronchodilator. In airflow obstruction, the pulmonary function measurements may improve. This helps guide the medication prescription and monitoring of disease progression. As patients age, utilization of pulmonary function tests becomes more complicated. Patients may be unable to cooperate with the test secondary to physical frailty or cognitive decline. Decreased physiologic reserve in older patients reduces the airflow measurements that are not necessarily indicative of underlying pulmonary parenchymal disease. Data for healthy older patients is unavailable for a reference to determine what an expected change in airflow measurements should be [21]; thus, pulmonary function test results should be interpreted with caution.

Chest Wall

Rib Fracture

Falls are the most common mechanism of fatal and nonfatal injury in the elderly; nearly one third of elderly Americans will suffer a fall annually [22, 23]. The most common fracture in the elderly trauma patient is rib fracture. Diagnosis is made preferably with CT imaging of the chest as plain radiograph sensitivity is <50 % [24]. Pain resulting in decreased tidal volumes, impaired cough, and paradoxical chest wall movement with concomitant flail segments increase the risk of pneumonia and mortality for all comers. However, the elderly are at a significantly higher risk for dying from rib fractures as compared to a younger cohort [25]. The mainstays of treatment include aggressive multimodal analgesia including parenteral narcotics and epidural analgesia as well as aggressive pulmonary toilet. Admission to a critical care unit should be considered for elderly patients with greater than three rib fractures as the estimated mortality is >35 % [25]. Objective criteria such as incentive spirometry (>10 cc/kg) and ability to cough are essential in the evaluation of adequacy of analgesia. Finally, consideration may be given to operative rib fixation in those patients who are failing traditional therapy with worsening respiratory compromise or development of pneumonia. However, caution is warranted as robust data has not yet been published to address the efficacy and safety of rib fixation in the geriatric population.

Airway Diseases

COPD

Chronic obstructive pulmonary disease is the fourth leading cause of death among Americans. The Global Initiative for Chronic Obstructive Lung Disease (GOLD)—a report

produced by the National Heart, Lung, and Blood Institute (NHLBI)—and the World Health Organization (WHO) define COPD as a preventable and treatable disease with some significant extrapulmonary effects that may contribute to the severity of disease in individual patients. The airflow limitation is usually progressive and associated with an abnormal inflammatory response to noxious particles or gas. Risk factors for development of COPD are directly associated with exposures to fumes, gas, cigarette smoke, or cooking fire. There are several different types of COPD that include emphysema, asthma, and bronchitis. There is significant overlap between the disease processes, but there are hallmark features that classify them as COPD. Clinical features that identify COPD are respiratory symptoms: coughing, sputum production, wheezing, and exertional dyspnea. The manifestations of disease are variable in each patient based on disease progression, risk factors, and comorbidities. Spirometry is essential for diagnosis once symptoms raise suspicion of COPD. When the FEV_1/FVC ratio is less than 0.70, it generally indicates airway obstruction. Decreased inspiratory capacity and vital capacity, accompanied by increased total lung capacity, functional residual capacity, and residual volume, are indicative of hyperinflation. This can also be demonstrated on diagnostic imaging such as plain radiographs and computed tomography [26].

Alveoli

Emphysema is defined as abnormal and permanent enlargement of the alveoli. Most commonly, emphysema is the result of long-term cigarette smoking. It typically develops in the sixth and seventh decades. A key component of emphysema is destruction of airspace walls associated with an inflammatory cellular infiltrate. This creates loss of elastic recoil, persistent dilation of the alveoli, and dynamic collapse of smaller bronchioles during expiration secondary to the loss of surrounding parenchymal tissue which helps maintain airway patency.

Bronchioles

Bronchitis is a persistent inflammation of the bronchial tree. It can be divided into acute and chronic subtypes. Chronic bronchitis is defined as a productive cough that is persistent for at least 3 months in 2 consecutive years. The cough is due to a loss of normal mucociliary function and reduced ability for expectoration of mucus. Cigarette smoking is a common cause of both emphysema and chronic bronchitis.

Management of COPD starts with limiting exposure to exacerbating factors. The addition of short-acting bronchodilators with or without inhaled corticosteroids should be considered. Furthermore, pulmonary rehabilitation should be incorporated into a treatment program as tolerated. The addition of chronic oxygen therapy is reserved for those with refractory disease and associated hypoxemia [27].

Asthma

Asthma is a chronic inflammatory disease of the airways. It is one of the most common chronic diseases of childhood, affecting more than six million children. Key components of asthma include airway edema, bronchoconstriction, airway hyperresponsiveness, and airway remodeling. Airway inflammation contributes to airway hyperresponsiveness, airflow limitation, respiratory symptoms, and disease chronicity. Acute and chronic inflammation can affect not only the airway caliber and airflow but also underlying bronchial hyperresponsiveness, which enhances susceptibility to bronchospasm. Clinical manifestations and symptoms are variable, as are responses to treatment [28].

Adults aged 65 or greater have a prevalence of asthma of an estimated 4–8 %. Diagnosis of asthma in this population is more difficult than in younger adults secondary to comorbidities and other etiologies of dyspnea. Doctors may attribute symptoms to other diseases that are more common in old age such as emphysema, chronic bronchitis, and congestive heart failure. Differentiation of asthma versus COPD is important because the management is different. Older adults have two categories of asthma: one form of asthma preexists from childhood, whereas the second form is adult-onset asthma. Often, there is no identifiable cause for adult-onset asthma. However, cigarette smoking is a known risk factor for developing asthma in adulthood [29, 30].

Restrictive Lung Disease

Restrictive lung diseases are a category of parenchymal or extrapulmonary diseases that limit the lung expansion resulting in decreased lung volumes. Clinical presentation is consistent with shortness of breath and cough. Diagnostic testing includes spirometry. FEV_1 and FVC are both decreased from normal. Primary pulmonary diseases that manifest as restrictive lung disease include pulmonary fibrosis, interstitial lung disease, acute respiratory distress syndrome, sarcoidosis, radiation fibrosis, and asbestosis. Restriction to lung expansion can also be secondary to extrapulmonary diseases. Pleural abnormalities and chest wall dysfunction, including neuromuscular diseases like myasthenia gravis, can create this pathophysiology. Treatment choices and prognosis differ based on the etiology.

Pulmonary Embolism

Pulmonary embolus (PE) can be a life-threatening complication. It is defined as blockage of the pulmonary arterial tree by a venous embolus. Pulmonary emboli are most typically associated with deep venous thrombosis, but fat, air, medications, and amniotic fluid can cause the same result. Deep venous thrombi often form at sites of venous stasis or injury.

Continued growth of the thrombus is perpetuated by limitation of venous flow adjacent to the thrombus. If the clot becomes unstable, it can break off and migrate to the lungs. Management of pulmonary embolus is based on prophylaxis, rapid diagnosis, management of concomitant right heart strain/failure if present, and restoration of blood flow to the involved portion of the lung. Clinical symptoms include dyspnea, shortness of breath, chest pain, tachypnea, and cough or hemoptysis [31]. Prophylaxis is recommended for patients that have prolonged immobility or hypercoagulable processes. Incidence rates of VTE increase dramatically beginning at about age 55 and by age 80 are nearly 1 in 100 per year, approximately 1000-fold higher than for those aged 45 or younger. Pulmonary emboli in this patient population may have profound consequences given the compromise to physiologic reserve already observed with normal aging. Risk factors for developing VTE are the same as for younger patients: decreased mobility, trauma, cancer, indwelling venous catheters, surgery, and hypercoagulability states [32]. Diagnosis of pulmonary embolus is based on clinical findings, laboratory findings, and radiologic imaging. Assessing serum D-dimer to diagnose pulmonary embolism is highly sensitive but nonspecific. The absence of elevated serum D-dimer will exclude pulmonary embolus as a diagnosis. Computed tomography angiography (CTA) of the chest is utilized to visualize the vasculature of the lungs. CTA is the gold standard test for the diagnosis of PE with a sensitivity of 83 % and specificity of 96 %. Ventilation/perfusion (V/Q) scans are utilized when there is a contraindication to CTA. This imaging study evaluates pulmonary blood and airflow. A defect in perfusion requires a mismatched ventilation defect. A VQ mismatch is highly specific (97 %) for a pulmonary embolus. Treatment for VTE is with anticoagulation unless there is a contraindication. Unfractionated heparin or low molecular weight heparin is administered in therapeutic doses. If patients have proven or suspected heparin-induced thrombocytopenia, direct thrombin inhibitors should be used. Oral anticoagulation with warfarin is started once a patient is therapeutic on parenteral anticoagulation. Warfarin is titrated to a therapeutic INR (2.5–3.5). The most serious complication of anticoagulation is bleeding. The risk of hemorrhage must be carefully weighed against the pulmonary effects of a pulmonary embolus in all patients. Elderly patients are at an increased risk for falls which can make them more susceptible to intracranial hemorrhage while anticoagulated. Traumatic injuries on anticoagulation can be lethal.

Infections

Pulmonary infections are common in the elderly secondary to normal physiologic alterations to the respiratory and immune systems. Older patients demonstrate a predisposition to aspiration and impaired mucociliary clearance. Up to one third of elderly patients with a community-acquired pneumonia will not manifest leukocytosis. Pneumonia is an infection of the alveolar portion of the lung. It is the fifth leading cause of death in older patients. It can be community acquired or healthcare associated. Several different pathogens can be the source for pneumonia including bacteria, virus, and fungi. Clinical symptoms include cough, fever, shortness of breath, and sputum production. Diagnosis of pneumonia is based on symptoms, physical examination, and radiographic findings. Community-acquired pneumonia can be treated with antibiotics as an outpatient. Patients that have suspected healthcare-acquired pneumonia are at risk for resistant organisms [33]. Empyema is a pleural space infection. Parapneumonic effusions occur when the region of parenchyma involved with the pneumonitis abuts the pleural surface and alters the pleural membranes. In the majority of cases, pneumonia is treated with antibiotics and the parapneumonic effusion resolves. However, 5–10 % of patients hospitalized for pneumonia will develop a persistent parapneumonic effusion that progresses to an empyema. An empyema matures via three distinct phases: exudative, fibrinopurulent, and organization. All pathogens that cause pneumonia can also cause a parapneumonic effusion and empyema. Patients with traumatic injury to the chest are susceptible to pneumonia due to parenchymal damage such as contusion. Placement of a chest tube is independently associated with a higher risk of empyema. Diagnosis of empyema is based on clinical history and chest x-ray or CT scan of the chest. Treatment is drainage of the empyema and antibiotic therapy guided by organism sensitivities. There is a high failure rate for management with chest tube clearance in the absence of decortication of the empyema, particularly when drainage is initiated during the organization phase [34]. Tuberculosis (TB) is an infectious disease caused by the atypical bacteria, *Mycobacterium tuberculosis*. Chronic lung disease and cigarette smoking are significant risk factors for TB. Older patients are at a higher risk for tuberculosis because of abnormal lung function and immunocompromise. Tuberculosis may have two different conditions: latent or active disease. Latent tuberculosis is characterized by infection with mycobacterium but no symptoms. Approximately 5–10 % of patients with latent TB will transition to active disease during their lifetime. Persons with latent TB will have a positive skin tuberculin test or TB blood test. Active disease in the lungs manifests symptoms such as cough, fever, weight loss, night sweats, and hemoptysis. TB can also have extrapulmonary symptoms based on spread of the bacteria. Diagnosis of tuberculosis is based on clinical history, high index of suspicion, radiographic findings, AFB microscopy, and culture data.

First-line agents for treatment of TB are isoniazid, rifampin, pyrazinamide, and ethambutol. Patients need to be followed closely for treatment adherence and response.

Aspiration Pneumonitis

Risk factors for aspiration include altered mental status, dysphagia, and disorders of the upper gastrointestinal tract. Older patients are at an increased risk for aspiration events. Pulmonary aspiration of gastric content will produce a chemical pneumonitis. Most pneumonia arises following the aspiration of microorganisms from the oral cavity or nasopharynx. Diagnosis is based on history and chest x-ray or bronchoscopy findings. Treatment is supportive for aspiration (chemical) pneumonitis. Bacterial infection or pneumonia following an aspiration event should be treated with antibiotics directed at the causative organism [35].

Cancer

The peak incidence of lung cancer is in the elderly. The likelihood of developing lung cancer is 1 in 2,500 in men younger than 39 years of age and 1 in 15 in men between the ages of 60 and 79 years. There is a high mortality rate associated with lung cancer secondary to the inability to diagnose the disease at an early stage, when it may be potentially curable [36]. Lung cancer patients can expect a high symptom burden, particularly from fatigue and breathlessness. The aging patient with a primary lung malignancy has challenging management issues secondary to the high rates of comorbidities found among the aging patient including cardiovascular disease (23 %), COPD (22 %), and other malignancies (15 %) [37]. Risk factors for lung cancer include environmental and lifestyle exposures. Lung cancer is strongly associated with smoking, radiation exposure, and occupational exposure to arsenic, asbestos, nickel, uranium, chromium, silica, beryllium, and diesel exhaust. Cigarette smoking is estimated to account for approximately 90 % of all lung cancers. Diagnosis of malignancy is via radiologic and invasive testing. Patients may manifest common signs and symptoms of lung cancer such as cough, hemoptysis, wheeze, stridor, or dyspnea. Chest x-ray is the initial screening tool based on clinical findings. When an abnormality is identified with initial chest x-ray, CT imaging should be obtained to further characterize the mass. Histologic diagnosis is important prior to staging workup. Depending on the location of the tumor, histology can be obtained with sputum cytology, bronchoscopic biopsy, CT-guided transthoracic biopsy, or operative biopsy. Lung cancer is primarily divided into two categories: small-cell lung cancer (SCLC) and non-small cell lung cancer (NSCLC). Approximately 5 % of malignancies arise from other cell types in the lung. Small cell histology tends to be more aggressive but also more responsive to treatment. NSCLCs include squamous cell carcinoma, adenocarcinoma, and large cell carcinoma. Staging of lung cancer allows for accurate prognosis and treatment options. The staging system for NSCLC is TNM staging. SCLCs are classified as limited disease or extensive disease based on the high likelihood of early metastasis. Positron emission tomography (PET) scanning is utilized for staging and can identify occult metastases. Treatment management for NSCLC is based on staging (Table 3.1). Staging is based on anatomic extent of disease during clinical-diagnostic stage, surgical-pathologic stage, retreatment stage, or autopsy stage. T1 tumors are ≤3 cm in greatest dimension, do not invade the visceral pleura, and are without bronchoscopic evidence of invasion more proximal than a lobar bronchus. T2 tumors are >3 cm but ≤7 cm in greatest dimension, invade a main stem bronchus with its proximal extent at least 2 cm from the carina, invade the visceral pleura, or are associated with either atelectasis or obstructive pneumonitis that extends to the hilar region without involving the entire lung. T3 lesions are larger than 7 cm in greatest dimension; invade the chest wall (including superior sulcus tumors), diaphragm, phrenic nerve, mediastinal pleura,

Table 3.1 Treatment of NSCLC

Stage	Operative intervention	Radiation	Chemotherapy
Stage I	Surgical resection for cure	Primary radiotherapy in patients not fit for operation with intent to cure	–
Stage II	Surgical resection for cure	Radiation with the intent to cure in patients with inoperable disease	Cisplatin-based adjuvant improves survival
Stage IIIA (incidental, potentially resectable, unresectable)	Thoracotomy and potential resection	Adjuvant radiation unclear outcomes	Adjuvant chemotherapy
Stage IIIB	Not surgical candidate	Radiation appropriate	Primary treatment or palliation
Stage IV	Not surgical candidate	Not radiotherapy candidate	Survival improvement with supportive care

Table 3.2 TNM staging of NSCLC

T/M	Subgroup	N0	N1	N2	N3
T1	T1a	Ia	IIa	IIIa	IIIb
	T1b	Ia	IIa	IIIa	IIIb
T2	T2a	Ib	IIa	IIIa	IIIb
	T2b	IIa	IIb	IIIa	IIIb
T3	$T3_{>7}$	IIb	IIIa	IIIa	IIIb
	$T3_{Inv}$	IIb	IIIa	IIIa	IIIb
	$T3_{Satell}$	IIb	IIIa	IIIa	IIIb
T4	$T4_{Inv}$	IIIa	IIIa	IIIb	IIIb
	$T4_{IpsiNod}$	IIIa	IIIa	IIIb	IIIb
M1	$M1a_{ContraNod}$	IV	IV	IV	IV
	$M1a_{P1Disem}$	IV	IV	IV	IV
	M1b	IV	IV	IV	IV

parietal pericardium, or a main stem bronchus less than 2 cm from the carina without invasion of the carina; are associated with either atelectasis or obstructive pneumonitis of the entire lung; or are a separate tumor nodule located in the same lung as the primary nodule. T4 lesions are any size tumor with invasion to surrounding or distant structures. Nodal involvement ranges from N0 to N3. N0 has negative pathology in the lymph nodes. N1 involves ipsilateral intrapulmonary, peribronchial, or hilar lymph nodes. N2 status indicates involvement of ipsilateral mediastinal or subcarinal lymph nodes. N3 involves contralateral mediastinal or hilar lymph nodes or involvement of either ipsilateral or contralateral scalene or supraclavicular lymph nodes. M status describes metastatic extent. M0 has no distant metastasis. M1 is divided into a and b. M1a includes malignant pleural effusion, pleural nodes, pericardial effusion, or contralateral lung nodules. M1b classifies distant metastasis [38]. The seventh edition of the TNM staging system (Table. 3.2) is the most recent version. It was developed by the International Association for the Study of Lung Cancer and approved by the American Joint Committee on Cancer and the International Union Against Cancer. SCLC is often metastatic at the time of diagnosis. Patients with limited disease are typically treated with chemoradiotherapy. Cisplatin, etoposide, and thoracic radiation are used to improve survival. Surgical resection is not a mainstay of treatment for SCLC. Patients with extensive disease are treated with several cycles of etoposide and a platinum-based chemotherapeutic agent. Elderly patients with associated comorbidities and physiologic decline in other organ systems are less tolerant of aggressive treatment options. However, recent studies have shown improved survival outcomes for aging patients when all appropriate treatment options are considered. Chronologic age alone should not be a determinant of the therapeutic decision in patients with lung cancer.

Sleep Disorders

Obstructive sleep apnea (OSA) is a sleep disorder found in adults and children. It is characterized by obstructive apnea or hypopnea; daytime symptoms such as fatigue, sleepiness, and poor concentration; and signs of disturbed sleep like snoring, restlessness, and resuscitative snorts. OSA has a significant impact on neurocognitive function and plays a role in other medical conditions. OSA has been associated with hypertension, cardiovascular disease, atrial fibrillation, congestive heart failure, and stroke [39]. There is a higher incidence of these comorbidities in the elderly [40]. The prevalence of sleep disorders increases with age, with the elderly population between 70 and 80 years having an incidence almost twice that for people younger than 40 years. Traditional risk factors include obesity, neck circumference, snoring, and BMI. The elderly population may not have the same risk factors, and the presentation of OSA may be atypical. This leads to underdiagnosis of OSA in aging patients [41]. There is speculation that the pathophysiology of OSA is different in the elderly population. Anatomic and physiologic changes that occur with aging may increase the risk for apnea in the elderly. Alterations to the pharynx predispose for obstructive physiology. Elderly patients have an increase in parapharyngeal fat deposition, increased length of the soft palate, and a change in the bony structure of the pharynx. Diagnosis of OSA is based on symptoms and polysomnography. Polysomnography is considered the gold standard for the diagnosis of OSA. It is performed by monitoring the patient during a full night's sleep. OSA is diagnosed if 15 or more episodes of apnea, hypopnea, or respiratory effort-related arousals per hour of sleep (i.e., an apnea-hypopnea index or respiratory disturbance index $\geq$15 events/h) occur in an asymptomatic patient or there are five or more obstructive apneic events per hour in a

symptomatic patient [42]. CPAP (continuous positive airway pressure) is the standard treatment for OSA. Positive airway pressure splints the airway open to prevent upper airway collapse. Consistent utilization of nighttime CPAP yields reduced frequency of nighttime apnea, decreased daytime sleepiness, and improvement of quality of life. Surgical options to remodel the upper airway are considered when patients fail CPAP therapy or are intolerant to positive pressure.

Summary

- The normal aging process results in the following deleterious changes to the respiratory system:
  - Decreased compliance of the chest wall
  - Altered chest wall mechanics resulting in decreased volumes
  - Decreased lung compliance
  - Decreased MyHC$_2$ fibers in the muscle of respiration resulting in decreased ability to augment volume and rate
  - Decreased alveolar number, termed "senile emphysema"
  - Decreased response to hypercapnia and hypoxemia
  - Impaired pulmonary immunity
- Pulmonary function tests are essential but should be interpreted with caution in the elderly.
- The elderly are susceptible to increased respiratory complications secondary to a significant reduction in pulmonary reserve, potential underlying sarcopenia, and concomitant age-associated comorbidities.
- Critical care practitioners must account for these changes to achieve optimum outcomes in this at-risk population.

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Renal Function in the Elderly

4

Randi Smith and Lewis J. Kaplan

Introduction

Structural and functional changes occur within the renal parenchyma with advancing age [1, 2]. These changes have been well characterized and allow the elaboration of estimation formulae that are ubiquitous in electronic medical records and laboratory profiles [3]. Understanding how these predictable changes in structure and function impact laboratory profiling, medication dosing, nutritional support, fluid prescription, and decisions regarding renal support techniques for acute kidney injury or acute renal failure are essential for clinicians who care for injured or ill elderly patients.

Renal Biomass and Aging

Advancing age predictably reduces both renal size and functional biomass. Parenchymal loss involved both the cortex and medulla but appears to spare the collecting tubules and renal pelvis [1]. Biomass reduction also involves lean body mass, and there are well-chronicled reductions in muscle mass and proportionate increases in adipose mass in health; of course, disproportionate increases in adipose mass are observed in the clinically severely obese. Nonetheless, reduced lean body mass reduces the measured serum creatinine (Scr) with advancing age [4, 5]. The reduction in Scr from reduced lean body mass renders interpretation of Scr with reduced renal biomass difficult to interpret during critical illness.

Reduced renal biomass limits the ability to clear creatinine. Thus, an individual with reduced lean body mass may have a normal Scr as creatinine is less readily cleared. Alternatively, an elderly individual with a low Scr likely has severe protein-calorie malnutrition as the only way to have a low Scr is to have severely reduced lean body mass in the setting of reduced renal clearance ability. Since fluid resuscitation may also acutely dilute Scr, knowledge of an individual's baseline Scr is essential, as assumptions regarding renal function are fraught with peril when renal function is not normal [6, 7]. Furthermore, using published estimates of renal function such as Cockroft-Gault that is based on gender, age, ideal weight, and a measured Scr is likely inaccurate during acute illness.

Since Scr is also a reflection of plasma volume, thirst may exert a strong influence on the evaluation of renal function. Thirst sensing is reduced in the elderly [8, 9]. Reduced thirst sensation is likely related to reduced hindbrain visceral sensory flow receptor competency, impaired lamina terminalis (osmoreceptor region that resides in the wall of the third ventricle that lacks a blood-brain barrier) responsivity, reduced angiotensin II elaboration (related to reduced renal biomass), cultural norms, and psychogenic influences [8, 10–12]. Additionally, the cingulate cortex is involved in thirst sensing and may be impaired with aging, especially in the setting of stroke [13, 14]. Hypertension also decreases thirst via baroreceptor-mediated reductions in the renin-angiotensin system. Both economic hardship and illnesses such as Alzheimer's and dementia may significantly impair medication compliance, allowing hypertension to exist unchecked. Hormonal influences either support (orexin) or retard (atrial natriuretic peptide, glucagon-like peptide-1) thirst, and their elaboration may be impacted by age [15, 16]. Furthermore, as advancing age reduces mobility through chronic illness including major axial joint arthritis, cerebrovascular accidents, dementia, and Alzheimer's, the ability to satisfy perceived thirst may

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be reduced as well. Therefore, the elderly individual hosts multiple competing influences that generally reduce thirst sensation and thirst satisfaction.

These influences generally leave the acutely or ill elderly patient poorly equipped to manage intravascular volume deficits related to infection, vasodilatation, or hemorrhage. The clinician should be aware that the elderly may present with a volume deficit that includes the intravascular and intracellular as well as extravascular/extracellular spaces due to impaired thirst sensing and satisfaction. Therefore, the resuscitative fluid prescription may be larger than anticipated. Additionally, hypotension may occur earlier than anticipated due to reduced intravascular volume and the reduced ability to compensate for vasodilating influences such as sepsis, severe sepsis, or septic shock. Such knowledge may also inform clinicians with regard to the timing of fluids as opposed to vasopressors.

Evaluation of Renal Function

The principal means of evaluating renal function in clinical practice are as follows: urinalysis and urine microscopy, BUN, Scr, BUN/Scr ratio, urine electrolytes, fractional excretion of sodium (FE_{Na}) or urea (FEUN), 24-h creatinine clearance ($CrCl_{24}$), eGFR, and urinary biomarkers. A detailed discussion regarding the use of urine microscopy is outside of the scope of this chapter.

Urinalysis

This simple bedside assay is rather useful in a variety of fashions. Regarding renal function, assessment of urine specific gravity and pH is helpful in the context of plasma osmolarity and pH. One must determine whether the renal response is appropriate or inappropriate for a given state. One expects that an intact renal system would preserve the ability to both concentrate and dilute urine in an appropriate fashion. For example, an individual with dehydration should not have dilute urine.

Similarly, an impaired renal biomass would lose the ability to concentrate or dilute urine. Such a condition is identified in the post-ATN kidney where the kidney functions as a "pass-through" mechanism with the tonicity of urine approximating that of plasma. Urine in this state generally has a specific gravity of 1.010 and establishes a condition known as isosthenuria. Individuals with "high output renal failure" have such a condition and must be evaluated for unexpected dehydration.

Injured kidneys may shed casts of the tubular system, and these are readily apparent on microscopic examination of urine from such patients; renal tubular epithelial cells may also be readily identified. Similarly, renal inflammation may recruit WBC that are also noted – but are identified generally in the absence of bacteria – when bacteria are present, cystitis and pyelonephritis must also be considered and are aided by urine culture and evaluation of the clinical circumstance. Urine casts may be useful in differentiating ATN from prerenal azotemia in that ATN generally demonstrates renal tubular cell casts, granular casts, and muddy brown or mixed cellular casts. In contradistinction, those with intravascular volume deficit-associated AKI generally demonstrate either no casts or hyaline or fine granular casts. A scoring system to help differentiate these two has been articulated as well [2].

BUN, Scr, and BUN/Scr Ratio

The paired evaluation of blood urea nitrogen (BUN) with Scr is well entrenched in modern medicine. This evaluation tool may be valid prior to medical therapy, but hospital-based therapy may render interpretation difficult or misleading. For instance, nutritional supplementation may artificially raise the BUN while not impacting the Scr establishing a ratio that exceeds the classic cutoff of 20:1 that purportedly indicates prerenal azotemia. In the elderly, reductions in lean body mass may artificially depress the Scr leading to the inappropriate diagnosis of dehydration when it is not present. Alternatively, an increase in Scr from both decreased lean body mass and renal biomass may elevate the Scr impeding the diagnosis of dehydration when it is truly present. Accordingly, in the elderly, the BUN/Scr ratio as well as their individual values may be less reliable than in their more youthful counterparts.

Urine Electrolytes

One modality to aid in the evaluation of renal function as well as plasma volume is the assessment of urine electrolytes. It is important to recognize that there are no fixed normal concentrations as they will change with both dietary intake and the volume of generated urine. In particular, the urinary sodium (UNa) has excellent fidelity in illuminating the renal response to the patient's intravascular volume status and mean arterial pressure. In the absence of a diuretic, a low UNa (<20 mEq/L) indicates intravascular volume depletion, and a high UNa (>40 mEq/L) indicates the absence of depletion [17]. Note that a high UNa does not indicate whether there is any additional volume-recruitable cardiac performance to be garnered. Other electrolytes may be assessed including potassium and chloride but are of less utility in general practice than UNa.

Fractional Excretion of Sodium (FE_{Na}) or Urea Nitrogen (FEUN)

These measures purport to better enable the clinician to determine whether there is intravascular volume depletion or an intrarenal condition such as acute tubular necrosis (ATN) by creating a ratio of U_{Na}, urinary creatinine, plasma sodium, and plasma creatinine such that

$$Fe_{Na} = \left(U_{Na} \times P_{Cr} / U_{Cr} \times P_{Na}\right) \times 100$$

In general, Fe_{Na} is <1 % with plasma volume depletion, congestive heart failure, and acute glomerulonephritis but is >1 % with bilateral ureteric obstruction and ATN; values commonly exceed 3 % with ATN [18]. Fe_{Na} validity is degraded by the presampling administration of diuretics [19]. In that case, the FEUN may be more useful as urea excretion is believed to be more dependent on passive forces but is controversial [19–21].

The FEUN may be calculated in a fashion similar to that of Fe_{Na} where FEUN is represented by the formula

$$\text{FEUN} = \left(U_{Ur} \times P_{Cr} / U_{Cr} \times P_{Ur}\right) \times 100$$

A FEUN <35 % is consistent with the diagnosis of decreased plasma volume [21, 22]. In some studies, FEUN outperforms FE_{Na} in differentiating between acute renal failure due to prerenal azotemia and that due to ATN.

24-Hour Creatinine Clearance ($CrCl_{24}$)

This measure is perhaps the most sensitive indicator of renal function in that it relies on a 24-h collection of urine that is kept on ice to prevent degradation. The 24-h nature of this test accounts for any diurnal or therapy-driven variations in clearance that would be inherent to a spot or 2-h assessment [23]. This assay also allows the clinician to determine whether the patient's native renal function exceeds or fails to reach the clearance that can be achieved by intermittent or continuous renal replacement therapy. The major disadvantage is the time required for collection and the need to keep the entire volume of urine on ice.

eGFR

This ubiquitous measure accompanies every laboratory profile that measures Scr and is accompanied by descriptors of age, gender, and race but does not require height and weight [24]. The currently reported eGFR is derived from multiple studies to replace the eGFR derived from the modified diet in renal disease (MDRD) calculation in patients where the actual GFR exceeds 60 mL/min per 1.73 m^2 body surface area [25]. The original MDRD calculation employs age, creatinine, albumin, urea, gender, and ethnicity in its calculation; a 4-variable modification also exists [25]. The eGFR calculation is represented by

$$\begin{aligned} GFR = {} & 141 \times \min\left(Scr/\kappa, 1\right)\alpha \times \max\left(Scr/\kappa, 1\right) \\ & -1.209 \times 0.993 Age \times 1.018\left[\text{if female}\right] \\ & \times 1.159\left[\text{if black}\right] \end{aligned}$$

where Scr is serum creatinine (mg/dL), κ is 0.7 for females and 0.9 for males, α is −0.329 for females and −0.411 for males, min indicates the minimum of Scr/κ or 1, and max indicates the maximum of Scr/κ or 1 [26].

This test is primarily used as a screening tool to readily follow the trend in renal function and will be useful over time as the patient ages. Cutoffs for eGFR have been articulated to help categorize the stage of renal failure (3, 5, through); stages 1 and 2 are applied to renal function estimates when there is a structural abnormality that is present – otherwise an eGFR of 60–89 is not considered abnormal [26]. eGFR is inaccurate in multiple conditions including but not limited to acute renal failure, age <18, pregnancy, edematous states, severe protein-calorie malnutrition, muscle-wasting diseases, critical illness, and following extremity amputation [27, 28].

Urinary Biomarkers

Since Scr and the measures explored above are insensitive and inaccurate in determining early AKI to perhaps enable early therapy that might change the seemingly invariant mortality rate associated with this injury, a more sensitive marker would be ideal in clinical practice. A variety of biomarkers including kidney injury molecule-1 (KIM-1), N-acetyl-β-D-glucosaminidase (NAG), trefoil factor 3, cyanuric acid, cystatin C, monocyte chemotactic peptide-1, netrin-1, and IL-18 have been proposed as sensitive indicators of renal injury or failure. Only urinary neutrophil gelatinase-associated lipocalin (NGAL) has been made commercially available for clinical application [29, 30]. NGAL, a 25 kDa protein that is covalently bound to gelatinase, is measurable in both urine and plasma with similar performance profile for either measurement source. Of note, sepsis-associated AKI patients have been noted to have higher urinary NGAL levels compared to those with AKI from other causes [31]. NGAL concentrations increase in parallel with RIFLE stage, further validating its use in AKI determination [32]. NGAL outperforms other potential biomarkers as it is both induced/upregulated in terms of concentration and filtered and reabsorbed leading to vast increases in the concentration of the biomarker compared to most others; cystatin C is similarly filtered and reabsorbed but is not induced/upregulated [33].

Limitations in Renal Function Assessment

Recall that the kidney has multiple functions that span, in part, regulation of salt and water concentration, blood pressure, red blood cell production, as well as nitrogenous metabolic product and waste clearance. In general, clinicians only regularly assess those related to salt and water clearance, with a lesser assessment (indirectly) of nitrogenous metabolic product and waste handling. Less frequently, in-depth assessments are undertaken (including, on rare occasion, renal blood flow), but there is little assessment, if ever, in the clinical arena of hormone function (endocrine, autocrine, or paracrine). Similarly, renal replacement therapy is generally limited to nonhormonal functions as well. Thus, assessment of renal function is limited at best.

Epidemiology of Acute Kidney Injury and Acute Renal Failure

An accurate analysis of the epidemiology of acute kidney injury and acute renal failure is hampered by the wide variety of definitions that describe each of these entities. For example, acute renal failure in many clinical investigations has been defined as a doubling of baseline Scr, a Scr >2.0, the need for renal replacement therapy (based on clinician determination, not a proscribed protocol), tripling of Scr, as well as a function of changes in urine flow that is not necessarily coupled with a change in Scr. As a result, comparing across studies is difficult. Further complicating analysis is the fact that the term AKI is relatively new and many patients who were previously labeled as having ARF actually had stage 3 AKI instead [34]. In a related fashion, many terms are used in the literature and describe the same process including acute or chronic renal insufficiency, compromise, or failure. Of course, an acute renal injury may also be a structural injury as a result of trauma. The increased use of CT scans in a wide variety of medical and surgical conditions may also influence the epidemiology of AKI and ARF by increasing the at-risk population to contrast and the well-described radiocontrast nephropathy (RCN) that may follow, especially in elderly patients with concomitant dehydration and diabetes; RCN is more properly termed contrast-induced AKI [35]. The incidence of AKI has increased in recent years as has the survival rate of geriatric patients with renal insults [36]. New nephrotoxic medications, including immunosuppressives and chemotherapeutic agents, impact the number of patients who are at risk for and develop AKI or ARF [37–39]. Thus, the epidemiology of these two entities should be anticipated to be in flux, especially as the population ages [40]. Global access to and delivery of certain diagnostics and therapeutics may establish a geographically biased epidemiology for AKI and ARF as well. Thus, AKI and ARF may occur with disparate frequency in developed compared to developing nations.

Data on AKI and ARF epidemiology does exist for specific hospital domains, including most commonly the intensive care unit. In a fashion similar to that of sepsis and acute lung injury/acute respiratory distress syndrome, the incidence of AKI that does not require renal replacement therapy (RRT) is estimated to be 2000–3000 per million population per year [41]. In contrast, the estimates for AKI that does require RRT are vastly less at 200–300 per million population per year. In order to put these numbers into perspective, 4–5 % of intensive care unit patients receive RRT, and as many as 66 % of intensive care unit patients will develop RIFLE classification-defined AKI [41]. In-hospital mortality strongly correlates with the maximum RIFLE class suffered during that episode of care, as well as with progression through each RIFLE stage of risk, injury, and failure [41, 42]. Despite therapy, RRT-requiring AKI carries a 50–60 % mortality rate with up to one in five sustaining permanent dialysis-dependent renal failure [41].

Certain patient populations may have a higher than population-expected risk for AKI, including those suffering from sepsis or injury. In a large cohort of nearly 10,000 injured patients, the crude AKI incidence was 18.1 % with a greater than twofold increased mortality rate; advanced age, female gender, increased number of comorbid illnesses, and a greater illness severity all increased AKI risk [42]. Similarly, in a study of greater than 120,000 patients, septic patients 27.8 % had a sepsis-related diagnosis; 42.1 % of septic patients developed AKI [43]. Sepsis-associated AKI patients were generally more ill, hypotensive, tachycardic, and demonstrated lower PaO_2/FIO_2 ratio and greater leukocytosis compared to those with AKI of non-septic etiologies. Increased ICU and hospital mortality as well as ICU length of stay were also observed in those with sepsis-associated AKI across all RIFLE categories [43]. These data have important implications for the elderly as they are well represented in the critically ill and injured patient populations. Specific efforts should be pursued at mitigating known risk factors to reduce the incidence and downstream sequelae of AKI in the elderly after critical injury or illness. In particular, AKI predisposes to chronic kidney disease, and the elderly with reduced GFR appear to be at greater risk for this progression than age-matched counterparts with normal GFR [36].

Etiology of Acute Kidney Injury and Acute Renal Failure

The etiology of AKI is complex and multifactorial [44]. Multiple etiologies for the genesis of AKI have been proposed, including, but not limited to, vasoconstriction, leukostasis, venous hypertension, apoptosis, and a disordered

humoral factor milieu including hormones, growth factors, receptors, and intracellular signaling mechanisms. Therefore, multiple etiologies may lead to AKI or ARF. Most AKI appears to be a toxic phenomenon rather than purely a volume-based issue. This observation is easily understood as the contrast-induced (CI) AKI that occurs in the well-perfused and volume-loaded patient. Therefore, AKI may also not respond to plasma volume expansion with regard to hastening resolution. Seemingly paradoxically, AKI may be worsened by excess volume loading as the excess salt and water (and likely starch in patients with sepsis) may lead to renal parenchymal edema and distorted organ pressure-volume relationships. It should be noted that in light of the 6S trial [45], starch use for patients with sepsis has been sharply curtailed and eliminated in many care locations. Instead, albumin and crystalloid use may be accelerated.

Both intra-abdominal hypertension and the abdominal compartment syndrome are increasingly cited as etiologies for AKI and ARF [46]. Several detailed investigations into these entities have been published for the interested reader [47, 48]. Of note, specific mention is made of intrarenal compartment syndrome that may result from renal parenchymal edema (tissue edema and venous hypertension) that may be only incompletely relieved (tissue edema persists) even after abdominal decompression. Thus, AKI may not dramatically or completely improve despite relief of the abdominal compartment syndrome. It is, however, clear that the renal structural and functional changes detailed above place the elderly patient at increased risk for AKI regardless of the cause [49]. Nonetheless, acute kidney injury and acute renal failure all directly impact acid-base homeostasis.

Molecular Underpinnings of AKI

Common themes in AKI include inflammation, altered microcirculation, and bioenergetics adaptive responses. However, the interplay of these elements was not very clear. Using the paradigm of sepsis as a foundation for understanding AKI has led to improved clarity with regard to the molecular events that underpin AKI [50]. In sepsis, damage mediated by pathogen-associated molecular patterns (DAMPs, PAMPs) as well as a host of cytokines circulate and are filtered by the glomerulus. These molecular messengers interact with dendritic cells and neutrophils to augment inflammation. The net effect is to create sluggish peritubular capillary flow that disrupts the microcirculation, increases the exposure time to inflammatory mediators, and activates the endothelium. This local inflammatory cascade also leads to paracrine signaling of the distal tubule, most notably by tumor necrosis factor-alpha (TNF-α) and alarmins, further exacerbating tubular dysfunction. The overall effect is to create S2 segment tubular cell dysfunction that is underpinned by three events: (1) uncoupled respiration leading to oxidant damage, (2) mitophagy, and (3) cell cycle arrest. In sum, these events create a septic AKI phenotype that is focused on survival and decreased energy utilization during a period of extreme stress. It is important to note that while overall renal blood flow may increase during the period of AKI when serum creatinine is elevated, microcirculatory derangements may still lead to cell dysoxia [51].

Strong Ions, Acute Kidney Injury, and Acute Renal Failure

While acid-base balance has been traditionally taught using the Henderson-Hasselbalch approach, it is occasionally unwieldy as it is logarithmically based and requires the six "Bostonian rules" to account for chronicity and to provide correction of the derived data [52]. Recognizing that the human body is complex, this scheme works well in the clinical circumstance. An alternative to the imprecision of the Henderson-Hasselbalch approach has been articulated by Peter Stewart in 1983 that is termed the "strong ion" approach [53]. Strong ions are cations and anions dissociated from their ionic partners in an aqueous milieu in the physiologic pH range. This approach equates plasma ionic charge with pH through the influence of charge of water dissociation. A complete exploration of the intricacies of this approach is beyond the scope of this chapter. The interested reader is referred to one of several thorough reviews on this topic [54–57]. Nonetheless, this approach provides a concise framework to both teach acid-base physiology and be a platform from which to prescribe appropriate fluid therapy.

In the strong ion approach, rendering the net plasma charge more positive is an alkalinizing influence, and reducing the net plasma positive charge is acidifying. Therefore, fluids may be categorized based on charge difference relative to human plasma and their anticipated impact on pH (Table 4.1). Appropriate fluid selection is aided by understanding the patient's pre-fluid infusion pH. By way of example, if a patient has preexisting metabolic acidosis that is due to lactate from hypoperfusion, the choice of fluid may be irrelevant as plasma volume expansion should correct perfusion defects and result in lactic acid metabolism. However, if the acidosis is from organ failure, infusing an acidifying solution such as 0.9 % NSS may be maladaptive. Similarly, if the patient is metabolically alkalotic, then an acidifying solution is an intelligent approach and is well embraced in the concept of a chloride-responsive alkalosis; 0.9 % NSS is the most acidifying solution in common use and provides a gross excess of chloride relative to plasma. This approach has been used in a variety of settings including those focused specifically on the geriatric patient with excellent outcomes [58].

Table 4.1 Commercially available fluids and impact on acid-base balance

Fluid	Na	K	Cl	Lactate	Ca	Mg	Acetate	Gluconate	pH	pH impact
0.9% NSS	154	0	154	0	0	0	0	0	5.0	Acidify
Lactated Ringer's	130	4	110	28	3	0	0	0	6.5	Alkalinize
Normosol-R	140	5	98	0		3	27	23	7.4	None
Plasmalyte-A	140	5	98	0		3	27	23	7.4	None
5% albumin	154 (130–160)	<1	154 (130–160)	0	0	0	0	0	6.4–7.4	Acidify in large volume

The strong ion approach has also been evaluated in terms of outcome prediction. The presence of unmeasured ions, a specific entity that is readily ascertained by that approach, correlates with increased mortality risk in diverse patient populations. These populations include those with major vascular injury, unselected but significantly injured patients, as well as pediatric patients [59–62]. Moreover, the fluid selected for resuscitation may drive unmeasured ion generation [63]. Unmeasured ions are known to accompany a host of critical illnesses including injury, renal failure, hepatic failure, and following cardiopulmonary bypass [55, 64–66]. Outcome modeling using this approach has not been specifically undertaken in the elderly, but offers a potentially fertile domain for future investigation.

Conclusions

Predictable changes in renal function are expected with aging. The clinician should be cognizant of these expected changes as they may directly impact the evaluation of renal function, medication dosing, fluid selection, and the management of acute kidney injury and acute renal failure. Recognizing that acute kidney injury may be both a toxic process and a flow-dependent process that has molecular underpinnings including cell cycle arrest and unexpectedly high flow during the injury phase may curtail some of the common practice of plasma volume expansion for patients with AKI. The articulation of renal biomarkers may better enable the bedside clinician to accurately identify elderly patients with a clinically inapparent renal injury and initiate therapy or protective strategies in an earlier time frame than was traditionally possible. Each of these aspects will be aided by an expanded understanding of the molecular events that drive renal aging and acute kidney injury.

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The Gastrointestinal Tract

5

Young Kim and Timothy A. Pritts

Abbreviations

AAST	American Association for the Surgery of Trauma
ATLS	Advanced Trauma Life Support
CCK	Cholecystokinin
CDI	*Clostridium difficile* infection
CT scan	Computed tomography scan
DNA	Deoxyribonucleic acid
EAST	Eastern Association for the Surgery of Trauma
ENS	Enteric nervous system
FAST	Focused assessment with sonography for trauma
GI	Gastrointestinal
HSC	Hematopoietic stem cells
ICU	Intensive care unit
IDSA	Infectious Diseases Society of America
LOS	Length of stay
NK cell	Natural killer cell
NSAID	Nonsteroidal anti-inflammatory drug
OIS	Organ injury scale
SHEA	Society for Healthcare Epidemiology of America
TLR	Toll-like receptor
VTE	Venous thromboembolic event

Introduction

The average life expectancy in the United States is 80 years [1]. With advances in healthcare extending the length and quality of our lives, injuries in the geriatric population continue to be increasingly common. This population harbors multiple medical comorbidities and a decreased physiologic reserve, resulting in higher morbidity and mortality rates following acute trauma [2]. Gastrointestinal injury and illness can be especially devastating among the elderly. The following discussion highlights age-related changes in gastrointestinal physiology, the management of gastrointestinal injury, and other common gastrointestinal diseases affecting the elderly.

Age-Related Changes in Gastrointestinal Physiology

The gastrointestinal system spans multiple organs and is intricately involved with all other systems. While its chief function is digestion and absorption of nutrients, these organs also play vital roles in immunity, fluid and electrolyte balance, detoxification, expulsion of waste, and the neuroendocrine axis. Advanced age confers a natural decline in each of these functions. Reviewed in this section are the effects of aging on gastrointestinal motility, the enteric nervous system, gut mucosa, enteral absorption, and mucosal immunity.

Gastrointestinal Motility

Gastrointestinal motility refers to the transit of ingested food throughout the alimentary tract. After the ingestion of food and other nutrients, coordinated muscle contractions propagate caudal movement of digested material. These involuntary contractions are termed peristalsis. Aging diminishes motility in each of the luminal organs to varying degrees. In the esophagus, advanced age is associated with a decrease in functional peristalsis, and an increase in nonfunctional propagations [3].

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Esophageal resistance is also heightened with age [3]. The lower esophageal sphincter, located between the esophagus and stomach, serves to protect the esophagus from gastric secretions. In healthy adults, this sphincter naturally relaxes with swallowing to allow for the passage of food. Swallow-induced relaxation becomes increasingly impaired with advanced age [4]. Each of these changes is implicated in the development of dysphagia among elderly patients, which may contribute to an overall malnourished state [5].

The stomach is similarly affected by age in several ways. The primary change is hypochlorhydria, or diminished secretion of gastric acid [6]. Because the acidity of digested chyme allows for absorption of iron and certain vitamins, hypochlorhydria may result in iron-deficiency anemia or other hypovitaminoses. Gastric motor function is mostly preserved with aging, with minimal changes in gastric emptying [3]. Fundal compliance is reduced, however, limiting food capacity and further affecting overall nutrition [6].

Once digested food has left the stomach, it enters into the small intestine. The small intestine is subdivided into the duodenum, jejunum, and ileum and is the primary organ responsible for nutrient absorption. Like the esophagus, coordinated smooth muscle contractions mediate the passage of chyme through the lumen. With advanced age, these migrating motor complexes become less frequent in nature [3]. Furthermore, animal models have demonstrated an increase in intestinal length and circumference [7], in addition to increased levels of intramuscular collagen [8], which may affect the strength of intestinal peristalsis. Despite these changes, transit time through the small intestine remains unaffected with healthy aging [3].

The colon is primarily responsible for the reabsorption of water, and delayed colonic motility often results in constipation. Unlike stomach and small intestine, colonic transit time is significantly prolonged with advanced age [9]. Human studies have found a decreased number of myenteric neurons in the colon with aging [10], as well as a proportional increase in abnormally appearing myenteric ganglia [11]. These changes contribute to a decreased number of high-amplitude contractions [12], which may explain the reduced propulsive capacity of the aging colon [13]. Not surprisingly, constipation affects half of community-dwelling elderly and the majority of nursing home population [14].

Enteric Nervous System

The enteric nervous system (ENS) is one of three major subdivisions of the peripheral nervous system. It plays a central role in the coordination of gastrointestinal motility and secretions [15]. Anatomically, the ENS consists of a network of interconnected neurons, arranged into two major plexuses – Auerbach's myenteric plexus and Meissner's submucosal plexus. These plexuses exist within the wall of the alimentary organs themselves. The ENS develops from neural crest cells [16] and continues to develop postnatally over the course of the host life [17]. Like the autonomic nervous system, the ENS functions involuntarily and is affected by a variety of external factors. These factors include the host environment, endocrine system, autonomic nervous system, and specialized gastrointestinal pacemaker cells known as the interstitial cells of Cajal [18].

The principal age-related change in the enteric nervous system is neurodegeneration [8, 19]. As compared with the rest of the nervous system, neurons of the ENS are more susceptible to age-related degeneration and death [20]. Some studies have suggested that age-related neuronal loss does not occur in other parts of the nervous system [21]. Neuronal loss in the ENS is most pronounced in cholinergic neurons within myenteric plexus [3, 22]. In contrast, the submucosal plexus is not affected by age-related decline [23]. Interstitial cells of Cajal also demonstrate an age-related decline within the stomach and colon [24], as do the autonomic nerves associated with the ENS [3]. Intestinal smooth muscle cells innervated by the ENS are similarly affected with aging [25]. Recent studies have proposed oxidative stress and mitochondrial dysfunction as the mechanisms of age-related neurodegeneration [3].

As mentioned previously, small intestinal transit time is minimally affected with healthy aging, while colonic motility is significantly prolonged. These findings are supported by literature regarding age-related changes in the ENS. In one animal study, the loss of half of small intestine myenteric neurons did not change feeding or defecating habits [7]. In a separate animal study, age-associated enteric neurodegeneration resulted in delayed colonic transit [22]. Clearly, the effects of aging on the ENS and gastrointestinal motility are synergistic.

Gut Mucosa

Mucosal epithelium lines the entire alimentary tract and serves multiple functions. In the stomach, the mucosal lining is responsible for the secretion of gastric acid, digestive enzymes, mucous, intrinsic factor, and various enteric hormones. The small intestinal mucosa also secretes mucus but is also involved in vitamin and nutrient absorption. Within the colon, mucosal epithelium functions primarily in water and electrolyte absorption.

In addition, the gut mucosa serves as a barrier to enteric organisms throughout the entire gastrointestinal tract. The stomach itself encompasses numerous defense mechanisms by which it maintains its mucosal integrity [26]. These defense mechanisms are broadly divided into three categories – pre-epithelial, epithelial, and post-epithelial defenses.

Pre-epithelial defense mechanisms include the mucous lining, secreted phospholipids, and an alkaline pH [27]. The gastric mucosal epithelium itself consists of continuously regenerating gastric cells bound by tight junctions, which are responsible for generating these pre-epithelial defenses [27]. Post-epithelial factors include continuous mucosal blood flow and the generation of nitric oxide and prostaglandins [27, 28].

With aging, each of these defense mechanisms becomes attenuated. Gastric glands are atrophied and replaced with fibrous tissue [26]. Mucous and bicarbonate secretion is impaired [29, 30]. There is a reduction in the capacity for prostaglandin generation [31]. Overall gastric blood flow is also diminished [32, 33]. These sums of age-related changes predispose the elderly to gastric injury. Several clinical studies have found advanced age to be a significant risk factor for NSAID-related gastropathy [34, 35]. Even low-dose aspirin, which has a lower risk of drug-related complications, has been linked to gastrointestinal hemorrhage among the elderly [36].

Mucosal cells throughout the intestine and colon also suffer an age-related decline. Mucosal epithelium has a high turnover rate within the intestine, regenerating itself every 4–5 days [37]. Thus, epithelial proliferation and death must be equally balanced. Hematopoietic stem cells (HSC) residing within intestinal crypts are the primary source of mucosal epithelial cells [38]. In animal models, HSC numbers and functional ability are gradually exhausted with advanced age [39].

As with gastric mucosa, aging colonic epithelium is prone to cellular injury [26, 40]. Two cellular mechanisms have been elucidated: increased rates of apoptosis and impaired proliferative potential. Apoptosis, or programmed cell death, is a mechanism by which cells are removed without injuring the surrounding tissue. With old age, colonic epithelial cells alter their protein expression rendering them more prone to apoptosis [40]. These cells also exhibit shortened telomeres [41], which reflect an impaired ability to replicate [42].

Enteral Absorption

Elderly patients are particularly vulnerable to malnourishment, which often goes unrecognized and underdiagnosed [43]. In turn, malnutrition is a significant predictor of morbidity and mortality [44, 45]. Poor nutrition among the elderly can be attributed to two causes: diminished food intake and decreased enteral absorption.

Age-related physiologic decline in food consumption is multifactorial. Sensory dysfunction of taste and smell weakens the appeal of food [46]. Gastric fundal compliance is reduced, which causes pronounced stretching of the stomach with food intake [6]. Aging is associated with elevated cholecystokinin (CCK) levels, which also contribute to early satiety [47]. As the aging stomach becomes hypochlorhydric, the intestine becomes predisposed to malabsorption and bacterial overgrowth [6]. Bacterial overgrowth syndromes, which are more prevalent among the elderly, damage the intestinal brush border and can also contribute a malabsorptive state [48].

Decreased oral intake of food is further compounded by a natural decline in enteral absorption. Cellular senescence within the gut mucosa, as previously described, is the primary mechanism for this decline. Both human and animal models have demonstrated a decreased uptake of macronutrients among the elderly [49]. Impaired carbohydrate absorption has been determined using breath analysis tests [50]. A similar decline in lipid absorption has been linked to a decrease in enterohepatic recycling of bile [51, 52].

Mucosal Immunity

The gut is the largest immune organ, containing the majority of lymphoid cells within the human body [53]. It is also home to an immense number of commensal bacteria. These bacteria, often referred to as the *gut microbiome*, play an important role in host health and disease states [54]. While the interactions between the gut microbiome and its host organism are not completely understood, these bacteria have been linked to obesity [55], diabetes [56], allergies [57], psychiatric disorders [58], and even coronary artery disease [59]. The complex signaling pathways between GI system and its microbiome are still being elucidated [60].

The bacterial composition of the gut microbiome is fluid in nature. Many factors have been linked to changes in the microbiota, including stress, illness, antibiotic exposure, dietary variations, and aging [61]. DNA-based techniques have been used to quantify these population shifts in the elderly, noting a significant reduction in overall microbial load [62].

Like the gut microbiome, mucosal immunity is also attenuated with advanced age. Aging is associated with blunted adaptive immunity and activated innate immunity [63], which lead to a chronic low-grade proinflammatory state [64]. There is an age-dependent variation of lymphocytes within intestinal mucosa, including increased populations of natural killer (NK) cells and double-positive T-cells [65]. Furthermore, immune homeostasis within the alimentary tract becomes imbalanced among the elderly. Intestinal immune homeostasis has been shown to be mediated by negative regulation of toll-like receptors (TLR) [66]. Several studies have shown that the TLR system is dysregulated with advanced age [67, 68]. These age-associated defects in TLR signaling may lead to increased incidence of gastrointestinal infections among the elderly [69].

Gastrointestinal Injury

Gastrointestinal injury refers to traumatic damage to the stomach, small intestine, colon, or rectum. While penetrating trauma is more commonly associated with gastrointestinal injury, blunt abdominal trauma may also harm the alimentary tract [73]. The lesion itself can range from minor hematomas to complete devascularization. The organ injury scale (OIS) was developed by the American Association for the Surgery of Trauma (AAST) as a tool for grading the severity of organ injury and can be found in Table 5.1 [74].

According to the Eastern Association for the Surgery of Trauma (EAST) guidelines, there should be a lower threshold for trauma activation in elderly patients [75]. Once the trauma system has been activated, it is imperative to address life-threatening conditions prior to pursing further diagnostic studies. The Advanced Trauma Life Support (ATLS) primary survey addresses such deficits in ventilation, oxygenation, and circulation and is reviewed elsewhere [76]. It is imperative to note that vital signs are misinterpreted in geriatric trauma victims. For example, normotensive blood pressures may be misleading in a patient with baseline hypertension. Beta blockers, which are commonplace among the elderly, may also blunt the normal adrenergic response to hemorrhage.

Once life-threatening conditions have been addressed, focused assessment with sonography for trauma (FAST) exam is a reliable adjunct for detecting free intraperitoneal fluid. Physical examination is often unreliable due to impaired level of consciousness, neurologic defects, drug or alcohol intoxication, or use of sedatives. Certain physical exam findings, however, should arise suspicion for intra-abdominal injury. These include the seatbelt sign, rebound tenderness, hypotension, abdominal distention or guarding, and concomitant femur fracture [77]. If an intra-abdominal injury is suspected, either by physical finding or mechanism of injury, the hemodynamically normal patient should proceed with computed tomography (CT) imaging of the abdomen.

CT imaging is the gold standard for diagnosis of occult gastrointestinal injury. Findings suggestive of bowel injury include pneumoperitoneum, bowel wall thickening, mesen-

Table 5.1 Organ injury scale

Organ	Grade	Description
Stomach	Grade I	Hematoma <3 cm
		Partial-thickness laceration
	Grade II	Hematoma ≥3 cm
		Full-thickness laceration <3 cm
	Grade III	Full-thickness laceration ≥3 cm
	Grade IV	Full-thickness laceration involving vessels along greater/lesser curvature
	Grade V	Extensive organ rupture
		Devascularization
Small intestine	Grade I	Contusion or hematoma without devascularization
		Partial-thickness laceration
	Grade II	Full-thickness laceration involving <50 % circumference
	Grade III	Full-thickness laceration involving ≥50 % circumference
	Grade IV	Transection without tissue loss
	Grade V	Transection with tissue loss
		Devascularization
Colon	Grade I	Contusion or hematoma
		Partial-thickness laceration
	Grade II	Full-thickness laceration involving <50 % circumference
	Grade III	Full-thickness laceration involving ≥50 % circumference
	Grade IV	Transection without tissue loss
	Grade V	Transection with tissue loss
		Devascularization
Rectum	Grade I	Contusion or hematoma
		Partial-thickness laceration
	Grade II	Full-thickness laceration involving <50 % circumference
	Grade III	Full-thickness laceration involving ≥50 % circumference
	Grade IV	Full-thickness laceration extending into the perineum
	Grade V	Devascularization

teric fat stranding, extravasation of oral contrast, and free intraperitoneal fluid in the absence of solid organ injury. The specificity of CT imaging is greater than 90 % in the presence of these findings, but its sensitivity is only 55 % [78–80]. Because delayed diagnosis is associated with substantial morbidity [80], the patient with suspected bowel injury should be monitored with serial vital signs and abdominal exams regardless of CT findings. Signs of missed bowel injury include abdominal tenderness, peritonitis, abdominal distention, new-onset leukocytosis, hyperamylasemia, and prolonged ileus [81]. Once bowel injuries are detected, treatment is surgical.

Prior to operative intervention, antibiotic prophylaxis and thromboprophylaxis should be considered for all patients. Antibiotics should be directed toward the site of injury for a 24-h duration. Prolonging antimicrobial therapy over 24 h offers no benefit in surgical site or nonsurgical site infection rates [82, 83]. Given that trauma and old age are both predictors of venous thromboembolic events (VTE), mechanical and chemical thromboprophylaxis should both be initiated [84]. Chemoprophylaxis involves either unfractionated or low molecular weight heparin and may be contraindicated with certain patterns of traumatic brain injury.

After prophylactic measures have been addressed, abdominal exploration should proceed in a systematic fashion [85]. Control of intraperitoneal hemorrhage and fecal contamination are of utmost importance and take priority during the initial phase of intraoperative care. Afterward, bowel injury may be assessed and graded according to the aforementioned organ injury scale (OIS). In general, injuries graded OIS I–III may be primarily repaired, while OIS IV and V are resected. A second-look operation may be planned if the viability of a bowel segment is indeterminate. Abdominal closure depends on several factors, including anatomical constraints, the risk of abdominal compartment syndrome, and whether a second-look operation is necessary.

Following surgical exploration, the elderly patient should be monitored in the intensive care unit (ICU) setting. A geriatrician should be consulted for assistance in medical management [86, 87]. Finally, all trauma victims must be reexamined for inventory of any missed injuries.

Gastrointestinal Ileus

Gastrointestinal ileus is defined as a pathologic reduction or absence of intestinal peristalsis. Postoperative ileus is common after surgery in all age groups [88], but elderly patients are particularly sensitive to disturbances in intestinal motility [72]. The pathophysiology of ileus is multifactorial, owing primarily to neurogenic, inflammatory, and enteroendocrine factors [89]. Risk factors for the this condition include advanced age, extensive bowel manipulation, narcotic-type analgesics, and general anesthesia [90]. Furthermore, the intestines are susceptible to age-related neuronal degeneration, placing the geriatric patient at profound risk of prolonged ileus [10, 70, 71].

Signs and symptoms of ileus include lack of flatus, abdominal distention, nausea, and emesis. Postoperative ileus is most pronounced within the large bowel; therefore, flatus is a common sign indicating return of bowel function. Peristalsis within the small intestine and stomach returns to normal within the first postoperative day, but colonic peristalsis may be stunted upward for 72 h [91].

Postoperative ileus is a clinical diagnosis, and its management is largely supportive. Bowel rest and fluid resuscitation are the mainstay of therapy until bowel function returns spontaneously. Nasogastric decompression is theorized to mitigate the risk of aspiration pneumonia in patients with recurrent emesis, though this fact remains debated. Early ambulation is often implemented under the notion that physical motion may stimulate intestinal motility. Minimizing the use of narcotic medications may also accelerate the return of bowel function.

Alvimopan (*Entereg*), a peripherally acting *mu*-receptor antagonist, is the only FDA-approved medication for accelerated return of bowel function [92]. Since opioid medications impede gastrointestinal motility, in theory, peripheral opioid receptor blockade should have the reverse effect. Many studies have analyzed the efficacy of alvimopan on bowel function, with varying results. One multicenter, phase III trial found significantly accelerated return of bowel function and shorter hospital length of stay (LOS) with the use of alvimopan in patients undergoing major abdominal surgery [93]. A separate trial in urologic patients also found significantly decreased hospital LOS, as well as reduced cost per admission [94]. In patients undergoing laparoscopic gastrointestinal surgery, alvimopan reduced the risk of postoperative ileus by 75 %, though there was no significant effect on overall LOS [95]. Colorectal surgical patients benefited highly from alvimopan, with faster return of bowel function, lower incidence of postoperative ileus, shorter hospital LOS, and reduced cost [96]. Further trials may elucidate the optimal use of this promising medication.

Ogilvie Syndrome

Acute intestinal pseudo-obstruction, or Ogilvie syndrome, is an acute-onset, massive colonic dilation in the absence of mechanical obstruction. It is a severe form of gastrointestinal ileus limited to the large bowel. Its pathophysiology is multifactorial and primarily attributed to enteric dysautonomia [97]. Risk factors for Ogilvie syndrome include advanced age (>60 years), trauma, abdominal surgery,

orthopedic surgery, severe medical illness, metabolic derangements, and use of narcotic medications [98]. Thus, like ileus, geriatric trauma victims are at significant risk for developing this condition.

The most feared complication of Ogilvie syndrome is bowel perforation. Once intraluminal pressure exceeds capillary perfusion pressure, the colon is at risk of venous congestion, with resultant tissue ischemia, bowel perforation, intra-abdominal sepsis, and, possibly, death. With timely diagnosis and treatment, mortality rates are less than 20 %. However, this increases to greater than 40 % with delayed recognition and bowel perforation [98]. Therefore, early diagnosis is crucial to patient survival.

Initial evaluation with abdominal X-ray will reveal massive dilation of the colon. Cross-sectional CT imaging can confirm the diagnosis and, more importantly, rule-out secondary causes of obstruction.

Management of Ogilvie syndrome is similar to that of ileus. This includes bowel rest, nasogastric decompression, fluid resuscitation, correction of electrolyte imbalances, and minimizing use of narcotic medications. When cecal diameter reaches 12 cm, the risk of bowel ischemia increases markedly, necessitating chemical or mechanical decompression [99]. Neostigmine, a potent parasympathomimetic drug, stimulates intestinal motility and quickly decompresses the colon [100]. Because geriatric patients are prone to neostigmine-induced arrhythmias, including bradycardia, cardiac telemetry is advised prior to administration [101]. Symptomatic bradycardia is treated with atropine [102]. If neostigmine is ineffective or contraindicated, then endoscopic decompression is warranted [103]. Any evidence of peritonitis or bowel perforation requires surgical exploration.

Summary

Gastrointestinal diseases, such as hemorrhage and motility disorders are much more prevalent among the elderly. Each of these conditions carries significantly higher rates of morbidity and mortality in the older adult. Timely diagnosis and proper management are critical to good outcomes.

Case Vignette

Case 1: An 84-year-old male with a history of hyperlipidemia presents to the trauma bay after suffering a low-velocity motor vehicle collision. His primary survey is intact and his vital signs are normal on arrival. Abdominal ultrasound does not reveal any free intraperitoneal fluid. Physical examination reveals moderate abdominal discomfort and significant ecchymosis across his chest and abdomen, in the pattern of a seat belt. Because of his clinical presentation and mechanism of injury, he undergoes CT imaging of his abdomen, which reveals bowel wall thickening near the terminal ileum along with mesenteric stranding and free fluid in the pelvis. No other injuries are seen. What is the next step in management?

Discussion: The patient should be taken to the operating room for exploratory laparotomy. Gastrointestinal injury should be treated surgically once detected. This may involve primary repair or bowel resection, depending on the grade of injury. Antibiotic and VTE prophylaxis should be considered prior to surgery, as long as no contraindications exist.

Bullet-Point Summary

- Advanced age confers a natural decline in various aspects of gastrointestinal physiology, including gastrointestinal motility, the enteric nervous system, gut mucosa, enteral absorption, and mucosal immunity.
- Gastrointestinal injury is most commonly associated with penetrating abdominal trauma but may also result from severe blunt trauma. Upon recognition of GI injury, surgical intervention is indicated.
- Postoperative ileus can be profound in the geriatric patient.
- Ogilvie syndrome is a severe type of colonic ileus leading to massive colonic distention and may result in cecal perforation with delayed diagnosis.
- In any gastrointestinal condition, peritonitis and bowel ischemia are indications for operative intervention.

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Skin, Soft Tissue, and Wound Healing in the Elderly

6

David G. Greenhalgh

Case Vignette

A 78-year-old man with diabetes mellitus wanted to warm his cold feet so he placed them in hot water for 30 min. He was not sure how hot the water was but he did not have much feeling in his feet for the last 5 years. He had felt that the hot water would also be good for the 2 cm ulcer on the sole of his right foot at the second metatarsal. Several hours later his wife noted that his feet were red, were weeping, and had sloughed some skin. She convinced him to visit his local doctor who noted red, nonblanching burns that were demarcated from a line just above the ankles to the soles of his feet. He had pulses on his feet but the vessels were not compressible. He was sent to the burn center and found to have full-thickness burns. He was taken to the operating room where he underwent routine excision and grafting. The grafts looked good on postoperative day 5 and he was sent home 4 days later. He was seen in clinic a week later where he complained that his grafts were draining fluid and had turned dark. Examination of his feet revealed near total graft loss and exposed tendons on the dorsal feet. Several toes had turned black and two others developed flexion contractures. He was taken to the operating room where further debridement revealed exposed bones on the ankles. The plantar ulcer was also draining pus. He eventually required bilateral below-knee amputations.

Introduction

In the industrialized world, the birth rate is down, and with modern healthcare people are living longer so that the elderly are occupying a much larger percentage of the population. US census results reveal that in 2010 24 % of the population was greater than 55 years of age and 13 % was greater than 65 years of age. These values are projected to be 31.1 % >55 years, 20.2 % > 65 years, and 4.3 % >85 years in 2050 [1]. All practitioners are going to be exposed to more geriatric patients so familiarity with skin problems will become essential knowledge. Not only are the elderly at greater risk for skin breakdown, but they also have skin changes that alter their ability to heal. Many treatments for diseases in the elderly (steroids, chemotherapy, and radiation) impair tissue repair. Chronic wounds – diabetic, vascular, venous stasis, and pressure ulcers – are much more common in the geriatric population. Chronic wounds are a huge economic burden for today's healthcare and for the individual; they frequently accompany the person for the rest of his or her life. Pressure ulcers are considered a "never event" by governmental health agencies that, if they occur, may lead to loss of reimbursement. Since simple injuries often lead to major wounds that fail to heal, prevention efforts are essential to reduce the burden of chronic wounds in the elderly. While there are increased problems with healing in the elderly, their wounds can be treated and lead to successful outcomes. This chapter will review the factors that increase the risks for wounds in the elderly, describe the pathophysiology of chronic wounds, discuss prevention, and describe so strategies for treating those wounds.

Skin Changes with Aging

The skin changes related to aging are well documented in the dermatology literature [2–7]. Typically, skin alterations due to aging are classified into "intrinsic" and "extrinsic" changes. *Intrinsic* changes are those that occur "within the

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body" as part of the normal aging process and are independent of environmental exposure. *Extrinsic* changes are those alterations that induced by environmental forces – most notably the ultraviolet portion of sunlight. While it is difficult to differentiate which factors are totally intrinsic versus extrinsic, it is clear that extrinsic factors accelerate the degenerative changes in the skin. Everyone is aware of the changes that occur in the skin that is abused by sun exposure or just poor self-care. The skin becomes thinner, dryer, more wrinkled, sags, and has variable pigment changes. Clearly, sun exposure increases the risks of skin cancers of all types. While these changes will occur with aging, good skin care, especially protection from the sun, will slow these changes.

The structural changes of the skin that occur with aging are well documented. The epidermis tends to become thinner with aging but thickens in response to ultraviolet light damage. The dermal-epidermal junction becomes flatter. The flattening of the normal rete pegs of the dermal-epidermal junction weakens the resistance to epithelial shear. In other words, the elderly are more prone to superficial wounds from minor shear forces. There are also significant changes to the normal skin adnexa – hair follicles, oil glands, sebaceous glands, and other dermal appendages. Sebaceous glands are decreased which leads to more dryness of the skin. In addition, there is decreased replacement of lipids in the stratum corneum which interferes with the normal barrier function of the epidermis. Hair follicles clearly change in many parts of the body. They heal more slowly and change in distribution. Clearly, male and female alopecia (baldness) is the most recognizable hair change, but hair follicles increase in size and decrease in density [6].

The significance of the dermal appendage changes is that healing of superficial wounds is impaired. To heal a partial-thickness wound (such as a superficial burn or blister) the dermal appendages are required. Normally, re-epithelialization takes place in two areas of the skin: the edge of the normal skin and from dermal appendages [8]. At the edge of the wound, the basal cells of the bottom layer of the epidermis are stimulated to migrate across the wound by three factors: loss of cell-cell contact, stimulation by growth factors (epidermal growth factor, transforming growth factor-α, and keratinocyte growth factors 1 and 2), and contact with proteins of the exposed wound (fibronectins, collagen type 1). Migration from the original wound edge stops after around 1–2 cm in a full-thickness wound, and the remainder of the closure is by contraction. In a superficial wound, epithelial migration also occurs in the epithelial cells of the dermal appendages, especially hair follicles. The higher the hair follicle density in a wound, the faster it can re-epithelialize. As an example, if a hair-bearing scalp is used as a split-thickness skin graft donor site, it will heal within 4–5 days. If the skin adnexa are sparse in number, such as what occurs in a lower leg with impaired circulation, then healing may take weeks. Thus, the problem with the decreased density of dermal appendages in the elderly is that their ability to re-epithelialize a wound is impaired. I have observed very superficial wounds in a hairless, elderly patient that never re-epithelialize and thus are said to "convert" to full thickness. They did not "convert," but instead had no ability to re-epithelialize.

There are significant dermal changes in the skin due to aging. The dermis is also the main target of ultraviolet light damage [2]. With increasing age there is a decrease in dermal cells (macrophages, fibroblasts, mast cells) and a decrease in antigen-presenting cells (Langerhans cells) which results in a decrease in immune function. The dermis becomes thinner and the collagen becomes less organized. The collagen molecules actually become larger but have more fragmentation and less orientation along lines of stress. The activation of matrix metalloproteinases by ultraviolet light exposure may contribute to these collagen molecule changes. This degradation in collagen is reflected in studies which demonstrate that the tensile strength of skin is decreased with age [9]. The dermal hydration decreases, and while the amount of elastin changes little, it becomes more fragmented. Thus, skin becomes less elastic, more wrinkled, and more prone to tearing or lacerations. Everyone knows that with aging comes looser skin that sags with gravity. While looser skin is considered undesirable in our society, it does benefit the healing of the elderly with small full-thickness wounds. These wounds heal by contraction so that the loose skin tends to not interfere with this process as it would in a younger person. Tension tends to interfere with wound contraction so the process may be augmented with looser skin. Clearly, contraction can lead to contractures if it occurs over functional areas such as joints. Since looser skin allows for closure with less tension, the elderly have a lower risk for contracture. In other words, allowing a wound to contract may be an alternative to surgical repair.

Besides the actual structural changes to the skin, there is a generalized decrease in sensation, decreased vascularity, and impaired lymph flow with aging. The sensory changes occur in a distal to proximal fashion and are especially related to decreased cold/warm sensory abilities [10]. There are actual decreases in the density of thermal sensory receptors, and some suggest that there is a decrease in peripheral nerve density. Studies suggest that there is altered angiogenesis associated with decreased cutaneous vascular reactivity [2–7]. In response to sun damage, there may be an increased angiogenic response, but the new vessels are more disorganized and more prone to leaking proteins. With impaired lymph flow, there is an increase in edema – which impairs healing. In addition, impaired lymphatic function decreases the ability to fight infections or contract wounds. There are obvious pigment changes that occur in skin with aging. Melanocytes decrease in numbers, but with ultraviolet light

exposure, there are more spotty areas of hyperpigmentation. Many cells develop mutations that alter local areas leading to "age spots" such as keratoses and nevi. While not covered in this review skin cancers increase with aging. All of these changes are accelerated with sun exposure. In addition, increased bruisability from the use of antiplatelet drugs or anticoagulants will often lead to pigment changes from the retained heme products.

Finally, changes beneath the skin contribute to the risk of skin injury in the elderly. There is a tendency to lose muscle mass from either decreased exercise or activity. Fat stores are often (but not always) reduced with aging. These changes are clearly accelerated with malnutrition – a factor that impairs wound repair. The significance of these changes is that the loss of padding tends to expose bony prominences to increased pressure and chronic breakdown. Incontinence of urine or stool increases the risk for maceration which increases the risk of shear injury. As people age, they become slower in their ability to respond to a dangerous situation. Their reflexes tend be slower so that they have more difficulty escaping an injury. I have observed many elderly patients who were unable to extinguish flaming clothing or escape scalding water. This slowing of reflexes and an impaired ability to respond to injury lead to more extensive and deeper wounds. We know from burn studies that the elderly have a much lower ability to tolerate large wounds so a small injury can be fatal. Finally, people at the extremes of ages become more dependent on others for care. An unfortunate consequence of this unwanted dependency is that there is an increase in the risk for elderly abuse. One must always be wary if an injury does not fit the "story" of how it occurred. Just as for children, caregivers are obligated to report suspected abuse.

Diseases of the Elderly Affecting Wound Healing

Fortunately, healing processes remain fairly normal in healthy people until the extremes of ages. Since many elderly take good care of themselves they tolerate surgery and minor injuries quite well. It is important to recognize, however, the factors or diseases that impair tissue repair. These inhibitors of wound healing affect all age groups, but they are, unfortunately, more common in the elderly population. One must be aware of these factors that may delay or prevent healing if he or she is planning surgery or treating a wound.

Malnutrition

Studies have shown for over 100 years that malnutrition impairs wound healing [11–14]. The impairment exists with total protein/calorie (marasmus) malnutrition or with protein (kwashiorkor) malnutrition. Simply, if one holds nutritional support at the time of wounding, a marked impairment in tensile strength will result within 1–2 weeks [15]. The clinical significance of malnutrition relates to the risks of complications with surgery such that if a patient has lost weight from a malignancy or from an inability to eat, then there is a much higher risk for dehiscence. The hidden side of this healing impairment is that altered healing could lead to a bowel anastomosis leak which in turn may lead to an abscess. Since the metabolic reserve is reduced in the elderly, this complication of failing to heal often leads to sepsis, multiple organ dysfunction syndrome, and ultimately death. The clinician can reduce complications by assessing the nutritional status of the elderly and providing supplemental nutrition prior to surgery. In addition, an aggressive approach to perioperative nutrition may make the difference between normal healing without complications and a rocky course and ultimate death.

There are some vitamins and micronutrients that influence tissue repair. Vitamin C is essential for the hydroxylation of proline or lysine in the formation of normal procollagen triple helices [16]. When there is a deficiency, collagen is not properly produced, and people may suffer from scurvy. Since there is a balance between collagen formation and breakdown during the maturation phase of scar formation, recently healed wounds may break down. In addition, vitamin A has been found to augment tissue repair [17, 18]. Several minerals such as zinc [19, 20] and copper [20] are essential for normal healing, and when they are deficient, problems may result. We have noted that patients with subnormal copper levels have impaired healing of their burn wounds [21]. A deficiency in arginine may also lead to altered tissue repair [22].

Diabetes Mellitus

Diabetes mellitus is a major cause of healing problems in people of all ages [23–25]. Since the disease is seen more commonly in the elderly, it is important to know its impact on tissue repair. Some statistics are important to emphasize its impact on the development of chronic wounds. Twenty percent of hospital admissions in diabetes are related to wound healing problems. Twenty-five percent of diabetic patients will have a foot ulcer during their lifetimes, and 50 % of all nontraumatic amputations are related to diabetes mellitus. A common scenario is that a diabetic patient will not notice a pebble in their shoe due to their impaired sensation. This will create a small wound that goes unnoticed, and eventually a wound is noticed and not properly treated. When the patient finally seeks care, the wound is infected with purulence tracking up the fascial planes of the foot. This patient often presents with cellulitis or invasive infection that leads to an amputation.

Even if a wound is detected, early tissue repair is significantly impaired. As an example, Margolis reviewed several clinical trials that tested treatments for diabetic ulcers [26]. He collected the "controls" which received "standard" treatment. What he found was that only 31 % healed within 20 weeks of aggressive therapy. It is likely that the two-thirds that did not heal stayed open for the remainder of their lives. There are several reasons why tissue repair is impaired in patients with diabetes mellitus [23–25]. First of all, *peripheral vascular disease* is increased in this population. Diabetics not only suffer from *macrovascular* disease but also from *microvascular* disease where there is thickening of the capillary basement membrane. This *microvascular* disease leads to impaired delivery of oxygen and nutrients from an increase in edema and impaired diffusion. This process also impairs leukocyte migration into the wound. If the patient suffers from renal disease, healing is inhibited further by *uremia* and its resulting edema [27].

The second factor that contributes to alter healing in diabetes mellitus is its tendency to cause peripheral *neuropathy*. Loss of sensation progresses from distal to proximal so that the feet are usually involved first. As stated earlier, people with neuropathic feet do not sense injury, and thus minor injuries tend to worsen or fail to recognize that they are injured. We have recently reviewed our 10-year experience with diabetics who burn their feet [28]. It is common for them to walk outside on hot pavement or try to warm their "cold" feet with hot water or by placing them near heaters. We admitted 68 patients with burns to their feet during that period, and the incidence is increasing. As for other types of diabetic wounds, the patients admitted for burns to their feet tended to have prolonged hospital stays and frequent graft failure. Another often unrecognized consequence of neuropathy is that the foot loses its normal feedback to maintain the arch. The foot thus tends to flatten which leads to increased pressure on the first or second metatarsal head. The classic diabetic foot ulcer is a wound that is on the plantar surface on the first or second metatarsal head. The final consequence of neuropathy is that with loss of normal sympathetic innervation, the skin loses its ability to sweat and thus tends to dry and crack. These cracks may lead to a site for infection. Patients should be tested for neuropathy using a 10-g Semmes Weinstein monofilament, 128-hertz tuning fork, vibration perception threshold testing, or a good neurologic exam for sensory loss [29].

There is an increased risk for infection for wounds that form in the diabetic patient. It is well known that hyperglycemia leads to an impaired ability to fight local infection and that avoiding wide swings in glucose levels improve [30]. There are also studies that suggest that leukocyte migration and function is impaired. The inability to fight infections predisposes diabetics to a higher risk for amputations. In addition, there are several metabolic factors that may contribute to impair healing that are covered in other reviews [25, 31]. One interesting concept is that hyperglycemia may lead to deposition of glucose byproducts known as advanced glycosylation end-products (AGES) in the tissues. There are "receptors for advanced glycosylation end-products" (RAGES) that detect these products of hyperglycemia and stimulate an inflammatory response. One theory is that activation of RAGES may lead to the chronic inflammatory state ("metabolic syndrome") of diabetes mellitus and obesity [32]. This chronic inflammatory state may also contribute to impaired tissue repair.

Since healing is impaired in diabetic patients, it is essential that prevention efforts are made to prevent a wound from developing. The Wound Healing Society has published guidelines for the treatment and prevention of diabetic wounds, and new guidelines should be published in 2016 [33, 34]. All clinicians who treat diabetes mellitus should discuss the risks of foot ulcers with their patients. Diabetics should inspect their feet daily and be extremely careful with the care of their nails. Podiatrists are extremely helpful in these matters. Diabetics with neuropathy should always wear well-fitted shoes and be especially vigilant after the first few days of wearing new shoes. Any new wound should be treated aggressively and early. People with diabetes mellitus should always avoid walking outside while barefoot and never warm their insensate feet with any heated agent. Once a wound develops, they should be treated with something that "off-loads" the pressure point on the wound (metatarsal head). "Total contact casts" have been found to be effective [35]. Studies suggest that topical growth factors or skin substitutes may be effective, but they are extremely costly [36–38]. Vascular disease should be treated if present. Unfortunately, our success with treating these wounds is only marginal, so prevention is essential. Anyone who is fortunate to heal a diabetic foot ulcer should practice extra precautions because the recurrence rate is up to above 50 %. Those patients should wear protective footwear and have daily inspections of their feet for the rest of their lives [39–41].

Therapies That Alter Wound Healing

Wound healing involves the recruitment and rapid proliferation of many different cell types. It makes sense, then, that any drug that impairs rapid proliferation of cells alters tissue repair. Unfortunately, the strategy for dealing with many diseases includes suppressing the inflammatory response, which also requires rapid proliferation of cells. *Steroids* have been known for decades to impair tissue repair, and their use should be minimized if possible to allow for better healing [42, 43]. The treatment of cancer also involves the killing of rapidly proliferating malignant cells so it is also obvious that *chemotherapy agents* [44, 45] or *radiation* [46, 47] impairs tissue repair. In the advent of neoadjuvant therapy (chemotherapy and/or radiation) combined with surgery, it is clear that one must be

extremely careful with the healing of these patients. One must optimize their nutritional status if they are to undergo these combined treatments. There are very few agents that augment healing in these situations, but vitamin A has been shown to at least partially reverse impairments due to steroids or radiation [17, 18]. Growth factors may also play a role in improving healing, but these are based on animal studies [48–54].

Neurologic Diseases

Neurologic diseases do not impair wound healing, but they do predispose the elderly to the risk of developing wounds. Dementia leads to forgetfulness and risky behavior that may lead to injury. The person may forget to turn off stoves or fail to practice safe techniques for self-care. People with dementia have a more difficult time with cleanliness and maintaining a diet and thus may not clean wounds and tend to be more malnourished. Neuropathies have previously been mentioned as a risk for many types of wounds. Any loss of sensation clearly predisposes a person to pressure sores, since pain is the main warning sign of chronic pressure. Tremors may predispose the elderly to spills and an inability to quickly react to a dangerous situation. Incontinence may lead to maceration of the skin which in turn increases the risks for abrasions or tears with moving. Seizures are risky in people who cook or around hot items since during the seizure they will not react to an injury. People who seize while cooking or bathing frequently sustain very deep burns.

Problem Wounds of the Elderly

There are specific types of wounds that all practitioners must know about when treating the elderly. These wounds are relatively easy to prevent but are particularly difficult to treat once they are present. These chronic wounds are a significant burden to society in cost and interference with normal living. They may occur in any age group but they are more common in the elderly. Since they are a major contributor to morbidity in the elderly, one must know how to diagnose and treat these problem wounds. The Wound Healing Society has recently published consensus guidelines in the prevention and treatment of these problem wounds, which provide hundreds of references [55–60]. New and revised guidelines are scheduled to be published in 2016.

Pressure Ulcers

Pressure ulcers may develop at any age, but they are commonly manifested in the elderly as they develop reduced ability to move or after the development of neuropathy [55–61]. These wounds are found in around 10 % of inpatients. The pathophysiology is simple; any pressure on the skin and underlying tissues of greater than 30 mmHg that persists for a prolonged period of time can lead to enough ischemia to create a pressure ulcer. Normally, pressure produces pain which leads to a shift in the body to redistribute the pressure to another area. When we sleep we are constantly and subconsciously moving. Even intoxicated people will move to prevent these wounds. When people lose sensation, such as after paralysis, or when so ill that they are unable to move (such as in an intensive care unit), they are prone to pressure ulcers. Nurses play a major prevention role by rolling patients from side to side. Not uncommonly, however, pressure ulcers develop where bony prominences create pressure. The classic sites are in the presacral region and the occiput and on the heels. There are scoring systems that grade the severity of pressure ulcers that are useful for documentation. Pressure ulcers are staged as 1 when the skin is intact but just reddened for a prolonged period, 2 when the skin has been broken, 3 when the ulcer has become full thickness, and 4 when the wound tunnels into deeper tissues [61, 62]. The wound management becomes more difficult with increasing severity. The usefulness of this paradigm has been recently challenged [63]. It is unclear of the relevance of a stage 1 ulcer, and the pathophysiology varies between stage 2 and stage 3 or 4 ulcers. Stage 2 ulcers result from damage from the "outside in," and higher staged ulcers are produced from the "inside out." Irrespectively, the staging system is helpful for documentation and management strategies.

The factors that predispose the elderly to pressure ulcers include the loss of padding with aging, malnutrition, loss of sensation, thinner skin, and incontinence. People with more fat are slightly more protected. Like all wounds, prevention is essential with frequent shifting of the patient, frequent inspection, maintaining normal nutrition, preventing maceration, and getting people out of bed. One recommendation that may reduce presacral ulcers is to leave the head of the bed as flat as possible, but this recommendation is in conflict with recommendations to minimize ventilator-associated pneumonia (keeping the head of the bed at 30°) [64]. The use of special padding in hospital beds may also assist with the reduction of these ulcers [65]. The Braden Score is the most commonly used screening method to determine the risk for pressure ulcers [66]. The score is based on six parameters: sensory perception, moisture, activity, mobility, nutrition, and friction/shear. Pressure ulcers have become such an important issue that they have been declared a "never event" that requires documentation and monitoring in hospitals. The Centers for Medicare and Medicaid Services (CMS) has set up guidelines that result in fines of up to $10,000 per day if compliance is lacking. Once a pressure ulcer develops, it is very difficult to heal. Clearly, one must eliminate pressure from that area, but it is often difficult to prevent people from

bearing weight on bony protuberances. Studies suggest that pressure sores may have improved healing with growth factors [67, 68]. Frequently, plastic surgeons will perform various myocutaneous flaps to try to cover these wounds, but once they develop, they have a high incidence of recurrence. If there is no closure after a prolonged period, then surgical closure is recommended.

Arterial Insufficiency Ulcers

These ulcers are the result of ischemia that results from vascular insufficiency [57, 58]. In fact, pure arterial insufficiency ulcers are rare, but usually tissue hypoxia contributes to the failure to heal in wounds caused by other etiologies. It is clear that hypoxia leads to impaired tissue repair. Since peripheral vascular disease is a major problem in the elderly (around 30 % of people over 75 years), it is important to remember that if a wound lacks a blood supply (or oxygen), then it will not heal. One of the major indicators for operating on peripheral vascular disease is for a "limb at risk" from failing to heal. The elderly should have a proper assessment of their pulses if they have a wound that does not heal. Other signs of peripheral vascular disease include loss of hair, shiny and dry skin, mummified or black toes, devitalized soft tissue with a moist or dry crust, thickened toenails, purple skin color with dependency, and cool skin. As a rough rule, if the region around the wound has a transcutaneous partial pressure of oxygen ($PtcO_2$) of less than 40 mmHg, it will have difficulty healing, and if the level drops below 20 mmHg, then healing will not occur. Revascularization will often remedy this problem. All lower extremity wounds must be evaluated for an adequate blood supply in order to treat them. Simple ankle/branchial indices are helpful, but the assistance of Doppler studies is also helpful. Once an arterial ulcer has formed, there are really only two options for treatment – revascularization or amputation. Vascular surgeons are experts in the evaluation and treatment of peripheral vascular disease and should be consulted as necessary. Prevention of arterial ulcers really involves all of the standard means of reducing atherosclerosis – cessation of smoking, reducing hyperlipidemia, exercise, and others. Unfortunately, once one leg requires revascularization of an ulcer, then there is a 20 % chance of the other leg developing an arterial insufficiency ulcer [69].

Venous Stasis Disease

These wounds are not a sole problem of the elderly but are important to discuss in this chapter. Advanced venous disease, manifested by edema, pigment changes (lipodermatosclerosis), and ulceration, affects 2.5 million people per year in the United States and cost around 3 billion dollars in 1997 [59, 60, 70–73]. The predisposing problem for these ulcers is venous valvular insufficiency that usually results from deep venous thrombosis. The loss of valves leads to ambulatory venous hypertension that interferes with local blood flow to the distal lower extremities. The classic venous stasis ulcer occurs above the medial malleolus with a surrounding hyperpigmented region. As for all venous insufficiency, edema contributes to the problem. With a column of blood coursing from the heart to the feet, there is a large amount of venous pressure that tends to interfere with capillary blood flow. The resulting increase in hydrostatic pressure leads to increased capillary leak and more edema. Any edema creates a greater distance for nutrients to travel from the capillaries to the cells and an increased risk for local hypoxia. Local capillary leaks tend to deposit fibrin which may lead to further hypoxia and impaired nutrient delivery or may "trap" leukocytes leading to persistent inflammation. The actual mechanism of the creation of the wound is not clearly known. There are many theories that need to be proven or disproven [74].

The diagnosis of venous leg ulcers depends on the history of deep venous thrombosis and/or diseases suggestive of venous valvular insufficiency such as varicose veins. A history suggestive of other diseases such as arterial insufficiency, sickle cell disease, or others should make the diagnosis more difficult. Examination of the legs is essential to determine whether there are varicosities, edema, and pigment changes. Color duplex ultrasound scanning that checks for abnormal venous reflux or obstruction should be performed in the standing and supine positions [75].

Venous ulcers tend to increase with advancing age but may occur in younger age groups with venous insufficiency. Once the ulcer develops, it can be healed, but since the underlying venous hypertension persists, it tends to recur. Treatment is conceptually simple. The leg must be elevated to reduce venous pressure and edema. Compression plays a major role in healing by reducing edema [76]. "High-compression" systems such as multilayered elastic compression or inelastic compression should be used. The "Unna boot" (fine mesh gauze with calamine lotion and zinc oxide) has been used with some success for years. Intermittent pneumatic compression devices may also help. Clinical studies suggest that growth factors [77–79] and biologic skin substitutes [80, 81] may help with closure, but nothing has reduced recurrences. Skin grafts may temporize the wound but they have a high failure and recurrence rate [82].

There are several options for dealing with the etiology of venous stasis disease. Surgery that interferes with venous backflow ("subfascial endoscopic perforator surgery") may be helpful [83, 84]. Currently, noninvasive techniques are often preferred. "Pathologic perforating veins" associated with a nonhealing venous ulcer and that have an outward flow of >500 ms of duration and are >3.5 mm in diameter

may be eliminated using percutaneous methods (ultrasound-guided sclerotherapy, endovascular thermal ablation, or laser). This therapy should be combined with compression [85, 86]. If there is ilio-caval obstruction, the possibility of recanalization with a stent may be considered [87]. What is needed is some way of repairing venous valves but this has not yet been accomplished.

Principles of Wound Healing of Chronic Wounds

There are repeated themes for the treatment of all chronic wounds irrespective of the etiology. These principles should improve the healing of all types of nonhealing wounds:

- Control the underlying etiology causing the failure to heal the wound:
  - Tight glucose control for diabetes mellitus.
  - Reperfuse ischemic limbs.
  - Eliminate pressure from all wounds (especially in pressure ulcers and diabetic foot ulcers).
  - Eliminate venous hypertension by eliminating incompetent perforators, relieving venous obstruction, and potentially repairing venous valves.
- Healing in a moist environment is always preferred.
- Control infection:
  - Wounds with $>10^5$ bacteria usually fail to heal.
  - Remove biofilms – bacteria in biofilms are more resistant to treatments.
  - Treat underlying osteomyelitis with debridement of necrotic bone and 2–4 weeks of antibiotics (preferably) or prolonged antibiotics if unable to debride the bone.
- Debride the wound of any nonviable and chronic, unchanging tissue:
  - All studies show that a freshly debrided wound heals better than one that has not been debrided.
- Wounds that fail to show signs of improvement within 4–8 weeks should be reassessed for a different diagnosis:
  - Infection should be ruled out.
  - Ischemia should be ruled out (transcutaneous pO_2 should be >40 mmHg).
  - Wounds that are more painful or darker in color may have a different diagnosis:
- Pyoderma gangrenosum, IgA monoclonal gammopathies, Wegener's granulomatosis, cutaneous chronic granulomatous disease, mycobacteria or fungal infections, and malignancy
  - Biopsies for histology and culture should be obtained.
- Treatment strategies should change when chronic wounds do not improve:
  - Adjuncts to wound healing may improve the outcome:

    Growth factors, cytokines, platelet-rich plasma, cellular and acellular skin equivalents, negative pressure wound therapy, electrical stimulation, ultrasound, hyperbaric oxygen, and extracorporeal shock wave therapy have all been studied and have varying efficacy.
  - Prevention is essential to prevent initial and recurrent ulcers:

    Screening for early signs of wounds (feet, pressure areas).

    Maintaining adequate nutrition.

    Maintain glucose control.

    Maintaining hygiene – cleanliness and cutting toenails.

    Maintaining health through exercise and activities (get off pressure areas, improve calf muscle activities in venous ulcers).

    Wearing proper fitting footwear.

    Continual compression for edema and venous disease.

    Avoid exposure to heat or other risky environments.

    Avoid obesity, smoking, and other high-risk behaviors.

Burns in the Elderly Population

There are several reasons why elderly patients are at increased risk for burn injuries. Many of these have been described earlier and make the geriatric population more prone to any form of injury. Many risky behaviors that were practiced when younger are carried into the later years of life. Many patients have voiced that they have done the same thing for years, but this time, they were not fast enough to escape. For instance, many people will use gasoline as an accelerant to burn leaves or trash. The patient may have avoided injury for years when performing this extremely dangerous practice; however, when he slowed down from aging, he could not avoid the flames. Slower reflexes clearly are predisposing factors for many of these injuries. In addition, any decline in decision making, especially with dementia, may cloud decision making and increase the risk for burns. Neuropathy is another factor that increases the risks for burns. As stated earlier, patients with diabetic neuropathy do not realize that they are burning their feet when walking barefoot on a hot surface [28]. In addition, it is common for their feet to "feel" cold, so many burns occur when warming them in hot water or with prolonged exposure to heaters. Forgetfulness will also increase the risk for kitchen fires as people forget to turn off stoves.

There are typical patterns of burn injury that accompany any age group. Toddlers typically explore their world with their hands and mouths. Therefore, they have many palm burns and are at risk for commissure burns when chewing on power cords. The elderly patient is at a high risk for the

massive flame burn when they use accelerants or fall asleep while smoking. With reduced ability to escape, their burns may become massive and lethal. A common burn pattern involves cooking over a flame. The typical pattern involves women with loose clothing leaning over a gas stove and catching their sleeve on fire. This burn pattern leads to third-degree burns to the chest, axilla, and arm. Another common elderly burn involves patient who smoke while using nasal oxygen. The oxygen ignites a brief flame that burns the central face. Fortunately, these burns are relatively small, and we try to avoid endotracheal intubation if at all possible. People with tremors or increased weakness are also at risk of spilling hot liquids such as tea or coffee that while being superficial can lead to prolonged healing. Finally, as elderly patients become more infirm and dependent on others for their care, there is an increase in burn-related abuse such as being "dipped" in hot water.

The approach to treating burns in the elderly has some important differences than when treating the younger population. As the skin ages, there is a greater risk for full-thickness burns – simply because the skin is thinner. Another issue is that as skin ages, there is a decrease in the skin adnexa – especially hair follicles. When there is a loss of these adnexa, even the most superficial burns will not re-epithelialize. While many people may claim that the burn "converted" to full thickness, in reality it never had a chance to heal due to the loss of skin adnexa. Both of these factors are important to remember when trying to get partial-thickness burns to heal. In addition, one must be more careful when planning skin grafting in the elderly since a split-thickness donor site would not heal if there were no hair follicles. Surgeons must select donor sites that have thicker skin such as the upper thighs or back. In addition, any vascular insufficiency or diabetes mellitus will reduce the ability of a skin graft to "take." There is one benefit of aging, however, since loose skin has greater laxity to tolerate contraction without forming contractures. Many patients with high risk for surgery will contract sizeable burns, literally over months, and still do fairly well in the end. Fortunately, most elderly patients can be treated with selective skin grafts, and the outcomes continue to improve in the elderly population.

One of the greatest concerns as one gets older is the reduced ability to tolerate the metabolic response to burns. It is well known that the older one is, the more difficult it is to tolerate major injuries. The burn community uses the LA50 to describe the ability to tolerate a burn. The LA50 provides the size of burn that leads to a 50 % survival for a specific age group. For instance, surgeons have stated that for a teenager, an 85 % total body surface area (TBSA) burn has a 50 % chance of survival. The LA50 drops as one ages so that an 80-year-old has 50 % mortality with only a 10 % TBSA burn. It is not fully known why the elderly population has such decreased tolerance to an injury, but there are some theories that make sense [88, 89]. Cells have a limited number of divisions that they can undergo before they are unable to replicate. With aging, the percentage of cells with the ability to replicate has to decrease. It has been shown that there is a cumulative damage and a decreased ability to repair DNA over time [90]. The epigenetic controls of DNA also wear out over time [91]. Therefore, there is an increase in mutations that lead to the risks for tumors and other age-related changes. It makes sense that the ability for tissues to completely repair themselves is also compromised. As one ages, especially in one who is exposed to austere conditions, there is an accumulation of injuries that lead to increased scarring. With increased scarring and fibrosis, there is impaired organ function, which also contributes to the inability to handle major stress. Another problem is that mitochondria lose the ability to repair themselves so that there is a gradual loss of energy supplies to the cells and tissues [92]. Several years ago, there was a paper that described cardiomyopathy as an "engine running out of fuel". Since the metabolic demands of burns are so great, patients with any nutritional or even metabolic compromise will have a decreased chance for survival.

A burn injury is the most profound form of stress that anyone can handle so even a younger patient is maximally stressed. Burns greater than 60 % TBSA may double the metabolic demand on a patient. I often tell patient's families that surviving a major burn is like running a marathon. The marathon, however, does not last a day but instead, several months. A younger patient can be pushed to provide the energy and endurance to survive. While an elderly person may start off fairly well, eventually the heart loses the ability to provide enough cardiac output, the liver no longer can produce the proteins, and the other organs fall behind. There is a gradual failure of organs that is known as multiple organ dysfunction syndrome. As the organs gradually fail, the patient seems to fail as a whole and eventually die. Maybe in the future, ways to improve the metabolic energy of the elderly will improve. Right now, however, geriatric patients have a much greater mortality than the younger population.

Prevention

It is clear that prevention is by far better than treating a wound in the elderly. It is interesting that teaching prevention is helpful but that despite understanding prevention principles, people often do not follow those principles. People often take shortcuts or risks that lead to injury. The most effective prevention means is through regulations and legislation. Many laws have saved thousands of lives. An example is the law that requires all buildings to have smoke detectors. Voluntary efforts were only moderately successful in reducing fire-related deaths, but with the introduction of regulations requiring smoke detector use, deaths from fires have

decreased markedly. The legislative efforts to reduce chronic wounds really do not exist. The intention of making pressure sores a "never event" that is reportable should at least make hospital personnel more aware of the risks of pressure sores. I am very doubtful that they will be eliminated.

Prevention efforts for the elderly should include close monitoring for the maintenance of adequate nutrition. Education and training about dangerous behaviors will help. Their living quarters should be made as safe as possible to reduce falls, the risk for burns and other injuries. As the elderly lose the ability to manage themselves, especially with dementia, caregivers should be provided to at least monitor their care. The elderly must be made aware that their reflexes may be slower so that they are less able to respond to a dangerous situation. I have treated many aged people who have placed logs onto fires "just as they had for years" but due to a slower response time they could not react in time to prevent their clothes from catching on fire. Simple matters such as avoiding loose clothing over flames may reduce injury. Lowering water heater temperatures to 120 °F will prevent many accidental scald burns. As stated earlier, those people with neuropathies should have their feet checked on a regular basis. Simple actions such as these may prevent many lifelong wounds.

Outcomes for Wounds in the Elderly

It is known that the metabolic reserve of a person decreases with increasing age. Fortunately, people are taking better care of themselves, and more people are living to the 80s, 90s, and even over 100 years old. One must not assume that all individuals are the same at the same age. We all know relatively young people who have not treated their bodies well and appear greater than their stated age. There are just as many elderly who have done very well with managing their fitness. We have treated older patients who have tolerated moderately sized burns who have done amazingly well. The elderly who have been able to avoid many of the risk factors for impaired healing (diabetes, peripheral vascular disease, malignancy) tend to tolerate significant injuries. It is clear that with sound principles of treating wounds, the elderly can heal their wounds.

Summary

- There are *intrinsic* changes to the skin as one ages. The skin becomes thinner, looser, and loses hair follicles. These alterations due to aging can be accelerated by *extrinsic* factors such as ultraviolet light.
- Diseases common to the elderly impair wound healing:
  - Malnutrition, even short term, impairs tissue repair.
  - Diabetes mellitus leads to altered vascularity, neuropathy, and impaired ability to fight infections, all of which impair healing.
  - Treatments of malignancy and steroids impair tissue repair.
  - Neurologic changes predispose the elderly to severe wounds.
- Problem wounds are a major burden to society:
  - Pressure ulcers
  - Arterial insufficiency ulcers
  - Venous stasis ulcers
- There are principles of improving healing that apply to all chronic wounds.
- Burns in the elderly:
  - The elderly are at high risk for burns.
  - There are specific burn patterns common to the elderly.
  - Healing of burns is more difficult.
  - The elderly are less capable of handling large burns compared to younger patients.
- Prevention of all wounds is essential for the geriatric population.
- Outcomes are improving for the elderly with wounds and burns.

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Immunologic

7

Jeffrey A. Claridge and Brenda M. Zosa

Introduction

The immune system is comprised of two mutually dependent cellular lines: an innate system and adaptive system. The innate system is the host's first line of defense and is largely responsible for orchestrating the appropriate response for a given pathogen. It consists of neutrophils, monocytes, dendritic cells, and natural killer cells. The adaptive system consists of B cells and T cells. These cells interact with the products of the innate immune system to recognize new pathogens, undergo clonal expansion, combat a multitude of pathogens, and revert to memory cells which can be reactivated rapidly upon reinfection.

As a patient ages the immune system undergoes complex remodeling with declines in innate and adaptive immunity, as well as activation of low-grade chronic inflammation. Chronic disease, malnutrition, and living circumstances, in addition to physiologic and functional changes, all contribute to this population's susceptibility to infection [1]. A decline in immune function with aging is shown in Table 7.1.

Table 7.1 Impact of aging on the immune system

Innate
Macrophage
Reduced phagocytic activity
Reduced generation of nitric oxide
Reduced generation of superoxide
Neutrophil
Reduced phagocytic activity
Reduced generation of superoxide
Dendritic cells
Reduced pinocytosis and endocytosis activity
Reduced phagocytosis of apoptotic cells
Impaired cellular migration
Natural killer cells
Increased total cell number
Reduced cytotoxic ability
Reduced cell proliferation after interleukin-2 exposure
Cytokines
Increased production interleukin-6
Increased production TNF-α
Increased production IL-1β
Adaptive
T cells
Reduced naïve cell population
Increased memory cell population
B cells
Reduced antibody isotype switching
Reduced dendritic cell stimulation
Reduced naïve cell population
Increased memory cell population

Aging of the Innate Immune System

Neutrophils

Neutrophils play a critical role in the acute inflammatory host response. These short-lived phagocytic cells are recruited from the peripheral blood via a gradient of chemokines and cytokines produced locally at the site of infection. Aging per se does not have a known effect on the number of neutrophils in the blood or the number of neutrophil precursors in the bone marrow [2]. Despite their preserved quantity, most other aspects of neutrophil function are diminished such as phagocytosis and the generation of reactive oxygen species [3, 4]. There is conflicting data on the effect of aging on chemotaxis with some studies showing no effect [5, 6] and others demonstrating decreased chemotaxis [7–10].

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Macrophages

Macrophages have many integral functions in the innate immune system. They function as sentinels for microbes in tissue; through the release of effector molecules, they orchestrate the adaptive immune response and play an essential role in wound healing. Macrophages function as first responders to invading microbes. They reside in numerous tissues, such as Kupffer cells in the liver, microglia in the brain, osteoclasts in the bone, and as undifferentiated monocytes in the blood. They detect pathogens by recognizing specific pathogen-associated molecular patterns (PAMPs) present on the microbes. They phagocytose invading bacteria, fungi, parasites, protozoa, and apoptotic cells and destroy them via both oxygen-dependent and oxygen-independent pathways [11].

Although the number of circulating blood monocytes in elderly and young subjects is similar, there is a significant decrease in macrophage precursors and macrophages in the bone marrow [12]. Macrophages in the elderly have reduced levels of MHC class II, which may contribute to poorer T-cell responses [13]. The macrophage's phagocytic function and its chemotactic ability are also diminished with age [14, 15]. Additionally, the ability of aged macrophages to destroy microbes via products of the respiratory burst is diminished; this impaired bactericidal capacity may increase the duration of infection in the elderly [16].

Natural Killer Cells

Natural killer (NK) cells are responsible for destroying host cells that have been compromised by tumor or viral infection. The number of NK cells increases with age; however, cytolytic activity and production of interferon-γ are decreased [17]. The cytotoxicity of NK cells is facilitated by releasing perforin and granzymes which activate caspases that induce apoptosis. The loss of cytotoxic ability is thought to occur as the result of decreased perforin secretion and production [18, 19]. However, antibody-dependent cell cytotoxicity (ADCC) by NK cells appears to be preserved [20]. Clinically, these changes in the NK cell often result in a net increased risk of infection, morbidity, and mortality in elderly patients [4, 21].

Dendritic Cells

Dendritic cells serve as a bridge between the innate and adaptive immune systems. Acting as antigen-presenting cells, they capture microbes through phagocytosis, process extracellular and intracellular antigens, and migrate to lymphoid tissue to stimulate T cells. Dendritic cells also have a regulatory function as demonstrated by their production of type I interferons in response to viral infection and the TNF-α inducible nitric oxide synthase (iNOS) production to defend against bacterial infection [22, 23]. In addition to eliciting immune response, dendritic cells also provoke immunological tolerance by inducing deletion or anergy, thereby limiting autoimmunity [24, 25].

Aging dendritic cells generated from peripheral blood monocytes have been shown to be deficient in pinocytosis and endocytosis when presented with an antigen challenge [26]. Additionally, dendritic cells from aged patients display impaired migration and have an impaired capacity to phagocytose apoptotic cells [27]. Phagocytosis of apoptotic cells produces an anti-inflammatory effect by inhibiting pro-inflammatory cytokines [28]. Clinically, the impaired uptake and inefficient removal of apoptotic cells by dendritic cells from aged patients may result in the inflammation and autoimmunity commonly seen with aging [14, 27].

Aging of the Adaptive Immune System

T Lymphocytes

T lymphocytes, also known as T cells, play a central role in cell-mediated immunity. These cells recognize and eliminate cells that have undergone viral or malignant transformation. T cells are differentiated from B cells and natural killer cells by their expression of a T-cell receptor (TCR) on their surface membrane; this receptor binds to antigen and CD3. Progenitor cells from the bone marrow migrate to the thymus where they undergo a highly selective elimination process based on the ability of the cell's TCR to recognize major histocompatibility proteins, degree of affinity for normal self-antigens, and the magnitude and duration of TCR signaling [29]. There are primarily two types of naïve T cells that leave the thymus: CD4+ helper cells and CD8+ cytotoxic T cells.

T cell responses are initiated in secondary lymphoid tissues by exposure to dendritic cells which present antigen. T cells that possess the specific antigen are then induced to proliferate and differentiate into effector cells that reenter the circulation from the lymph system and disseminate to the site of infection. After the infection is eradicated, the vast majority of the effector cells are destroyed with only a few cells remaining as long-lived memory cells [30].

T-cell function is significantly altered in the aging process through multiple factors including thymic involution and shifts in T-cell subpopulation types [31]. Thymus involution reaches its maximal level at age 50, resulting in the replacement of the lymphoid component and epithelial matrix of the thymus with fibrous and adipose tissue [32]. The net result of these changes is that generation of naïve T cells is severely compromised beginning at the age of 40 years [33–35].

Additionally, there is also a loss of diversity as a substantial shift from naïve T cell to memory T cell occurs, especially after age 65 for CD8+ T cells. Naïve CD4+ T-cell numbers are well maintained until age 70 after which their numbers begin to contract [36]. Elderly patients tend to rely on memory T cells for their primary T-cell response, which may result in compromised immune response following vaccination [37, 38].

B Lymphocytes

B lymphocytes, or B cells, mature in the bone marrow and function in the humoral immune response. During B-cell development, genetic rearrangement of immunoglobulin light and heavy chains occurs to produce the antigen-binding region of the B-cell receptor (membrane-bound immunoglobulin). B cells that react with self-antigen are removed by a process of apoptosis or inactivation in the bone marrow [39]. At this point the B cell enters the peripheral blood and lymph circulation as mature naïve B cells, where antigen activation occurs. Further differentiation is dependent on activation by antigen and signaling from helper T cells [40]. Mature naïve B cells can become either plasma cells, which produce and secrete large quantities of antibodies or memory B cells, which are long-lived cells capable of responding to reactivation by the same antigen.

While the number of precursor B cells and peripheral B cells do not decline with aging, there is a shift toward more antigen-experienced B cells and fewer naïve B cells [41, 42]. There is also a diminished ability for antibody isotype switching resulting in a shift in antibody isotype from IgG to IgM [43]. Isotype switching maintains the same antigen specificity but changes the effector functions of the antibody. Additionally, B cells in elderly patients are less efficiently stimulated by dendritic cells than younger patients due to their relative deficiency in the expression of co-stimulatory molecules CD40 and CD27 [44, 45]. The net effect of these changes is that elderly patients are forced to rely on a B-cell repertoire which lacks optimal diversity and have a low affinity to antigens and are therefore less protective [46].

Inflammaging: Age-Related Subclinical Chronic Inflammation

The aging immune system is characterized by a low-grade, chronic systemic inflammatory state sometimes referred to as "inflammaging" [47]. With aging, there is an increased production of pro-inflammatory cytokines such as interleukin 6 (IL-6), tumor necrosis factor-alpha (TNF-α), and IL-1β [48–51]. This subclinical inflammation may be caused by chronic antigenic stimulation, oxidative stress, and other age-related changes [54]. Additionally, the accumulation of senescent cells exhibiting the "senescence-associated secretory phenotype" (SASP) may contribute to this state by secreting pro-inflammatory cytokines which affect other immune cells and cause damage to the surrounding microenvironment [52–54]. The complex mechanisms behind inflammaging are not fully understood, but the resulting increase in pro-inflammatory cytokines is associated with significant morbidity and mortality in aging adults. Increased IL-6 levels are associated with lower muscle mass and strength in healthy elderly adults [55, 56]. Elevated levels of IL-6 and TNF-α have been associated with increased disability in older adults and have been identified as predictors of 10-year all-cause mortality in this population [55, 57, 58]. Inflammaging has also been implicated in the pathogenesis of various age-related disease, such as Alzheimer's, osteoporosis, atherosclerosis, macular degeneration, and degenerative arthritis [59–62].

Risk Factors for Infection

Chronic Obstructive Pulmonary Disorder (COPD)

COPD is the 3rd leading cause of death for all patients 65 and older [63]. The causative agents associated with COPD are cigarette smoking, biomass exposure, and the resulting inflammatory response orchestrated by neutrophils, macrophages, and CD8+ T cells [64]. COPD has been shown to be an independent risk factor for developing infections after traumatic injury or thoracic surgery [65–67]. Mucosal lesions of the tracheobronchial tree in the presence of mucous hypersecretion promote bacterial adhesion, colonization, and growth that then impede mucociliary clearance. These changes in the histology of the airway in patients with COPD increase the risk for pneumonia [68, 69]. The majority of cases of community-acquired pneumonia (CAP) in COPD patients are caused by *Streptococcus pneumoniae*, followed by *Chlamydia pneumoniae*, *Haemophilus influenzae*, *Legionella pneumophila*, *Streptococcus viridans*, *Coxiella burnetii*, and *Mycoplasma pneumoniae* [70]. COPD patients hospitalized with CAP have higher 30-day and 90-day mortality rates compared to patients without COPD [71].

Diabetes Mellitus

Increasing age and diabetes work in concert to further weaken an elderly patient's response to infections. Diabetes is known to increase the risk of surgical site infection (SSI) and nosocomial infections [72–77]. These infectious complications occur in 20–23 % of all patients presenting with

postoperative sepsis [78, 79]. Large population studies have concluded that diabetes mellitus increases the risk of cystitis, pneumonia, cellulitis, and tuberculosis [73, 80, 81]. Recent studies have described an association between perioperative and postoperative hyperglycemia with increased risk for a SSI [82–85]. Controlling hyperglycemia has been shown to reduce perioperative nosocomial and wound infections in diabetic patients [85–87].

The increased risk of infection in diabetics is the result of deficiencies in neutrophil and humoral function [88]. Neutrophil functions such as adhesion, chemotaxis, intracellular bactericidal activity, and phagocytosis are impaired [88–92]. Total IgG levels are lower in both uncontrolled diabetic patients and insulin-treated diabetics but not those on oral medications [93, 94]. Furthermore, diabetic patients are less likely to develop a protective antibody response following hepatitis B vaccination [95–97]. Revaccination with 1–3 additional doses of hepatitis B vaccine can safely increase the proportion of adults that achieve protective antibody levels [98]. The duration of protection against symptomatic and chronic hepatitis B virus infection has been shown to last for more than 22 years in healthy vaccine responders [99]; however the duration of immunity among persons with diabetes is unknown. Data on vaccine response to influenza is less clear. Diabetic patients showed fewer activated lymphocytes but no reduction in antibody response following influenza vaccination [100, 101]. Although age has been associated with diminished immune response to influenza vaccination, elderly type 2 diabetics appear to have preserved B-cell responses similar to young healthy controls [102, 103].

Chronic Kidney Disease and End-Stage Renal Disease

It is estimated that approximately 40 % of adults over the age of 60 meet the current definition for chronic kidney disease (CKD) [104]. Overall mortality rates are declining for patients with end-stage renal disease; however infection remains a common cause of death, with rates peaking 2–3 months after starting dialysis [105]. Rates of hospitalization for infection are higher for patients with chronic kidney disease for every major organ system than for patients without kidney disease [106, 107]. Chronic dialysis patients often fail to respond to standard vaccination protocols and may require augmented regimens to achieve a protective effect [108–110]. Despite being a high-risk group for infection, vaccination rates for influenza and pneumococcal pneumonia in end-stage renal patients are far lower than recommended [111, 112].

End-stage renal disease and its precursor chronic kidney disease are associated with marked systemic inflammation and diminished immune response [113, 114]. Cytokine dysregulation results from kidney dysfunction, as the kidney is the main route for elimination of cytokines [115, 116]. Uremia causes deficiencies of both the innate and adaptive immune systems [114, 117, 118]. Uremic patients have increased T-cell turnover and apoptosis which leads to a depletion of naïve and memory CD4+ and CD8+ T cells [119–121]. Reduced B-cell proliferation and antibody production are seen in uremic patients [122–124]. Uremia decreases the function of antigen-presenting dendritic cells [125, 126]. Phagocytic function in macrophages and neutrophils are also diminished [127, 128]. These alterations in immune function are further exacerbated by aging.

Traumatic Injury

Infections contribute to significant morbidity and mortality in the geriatric trauma population. The incidence of nosocomial infections in elderly admitted trauma patients has been reported to be 39 %, which was twice as high as younger patients [129]. The most common of these being respiratory and urinary tract infections. The development of a nosocomial infection in elderly trauma patients was associated with 3.6 times greater risk of mortality [65].

Recent research has been undertaken to try to elucidate the immunological dysfunction specific to the older trauma patient. A study of older patients with hip fractures (age >65) demonstrated acute neutrophil dysfunction and chronically elevated TNFα [130]. Studies in murine models have demonstrated reduced phagocytic neutrophils in the elderly after traumatic injury, supporting the notion that increased infections in geriatric trauma patients may be due to failure of bone marrow progenitors and neutrophils to mount an appropriate response capable of clearing infection [131]. A study of critically ill geriatric patients with blunt injuries found that patients who developed secondary infections had relatively blunted IL-6 and IL-10 levels. This same study found that geriatric patients who died had a more robust immune response with higher IL-6 and IL-10 levels than geriatric survivors, suggesting that inflammation-mediated end-organ failure may contribute to mortality in this population [132]. These findings highlight the complexity of derangements that occur in the aged immune system in response to traumatic injury, rendering them susceptible to infections and increased risk of mortality.

Challenges in Diagnosing Infection in the Elderly

Elderly patients often do not present with pathognomonic signs and symptoms of infection [133, 134]. Cardinal markers of infection such as fever are often absent in older

patients. Physiologic changes in the skin cause older patients to conserve less of the body heat they generate. As a result, many noninfected elderly patients fail to achieve a normal body temperature of 37 °C [135]. Nearly a third of patients over the age of 65 with infection have temperatures below the threshold of fever (38.3 °C) and by age 80 approximately 50 % of patients fail to reach this threshold [136–138].

Nonspecific symptoms such as change in mental status, decline in functional status, failure to thrive, loss of appetite, and incontinence can all be presenting signs of infection [139, 140]. Additionally, cognitive impairment can render older adults incapable of communicating their symptoms to providers. These nonspecific findings are also commonly seen in noninfectious diseases, making the diagnosis of infection in this population challenging. This is particularly true of residents of long-term care facilities, who are at a unique risk of infection. The Infectious Disease Society of America recommends suspecting infection in elderly long-term care residents when there is a decline in functional status and fever. They defined fever as either a single oral temperature over 37.8 °C, repeated oral temperatures over 37.2 °C (or rectal temperatures over 37.5 °C), or an increase in temperature of 1.1 °C over the baseline temperature [141].

Microbiology of Infection in the Elderly

Infectious diseases in the elderly are caused by a more diverse group of pathogens than in younger patients [140, 142]. Changes in microbiology may be related to age, comorbid disease, and environmental setting, e.g., community, long-term care, and hospital [69, 135, 143–146]. Long-term care residents are at great risk for infection [141]. There are more than 15,000 long-term nursing facilities serving approximately 1.5 million residents in the United States, of these residents 90 % are older than 65 years [147]. Antibiotic use is common among long-term care residents with durations that can vary dramatically from less than 10 days to greater than 90 days [148]. Low dose and prolonged use of antibiotics select for bacterial resistance [149, 150]. This practice has led to the emergence of highly resistant pathogens among residents at long-term care facilities which impacts both empiric antibiotic selection and infection control during periodic hospitalizations [151, 152].

Common Infections

Urinary Tract Infection

Urinary tract infections (UTI) account for 25 % of community-acquired bacterial infections and 30 % of infections from long-term nursing facilities [153]. Age-related changes contributing to increased risk of UTI include thinning of the mucopolysaccharide layer of the urinary epithelium and reduction in the Tamm-Horsfall protein (THP) in urine which covers type 1 fimbriae on gram-negative bacteria. THP reduces bacterial attachment and deterioration of bladder and urethral function [154, 155]. *E. coli* is the most commonly isolated organism in urine from patients in both community and long-term care facilities. Gram-negative polymicrobial infections with multidrug-resistant organisms are more frequent in residents of long-term care facilities [156, 157]. Microbiologic differences are seen in diabetic patients where *E. coli* remains the most common causative agent but to a lesser extent than in nondiabetic patients, and greater proportions of *Klebsiella* species are reported [146, 158, 159]. *Enterococci* and *Staphylococcus* species are the most common gram-positive causative agents.

There is a high prevalence of asymptomatic bacteriuria in residents of long-term nursing facilities ranging from 15 to 30 % in men and 25 to 50 % in females [160]. It is not recommended to initiate antibiotic therapy for asymptomatic bacteriuria, as there is no improvement in survival rate and a tendency toward increased mortality secondary to adverse side effects and super infection with resistant organisms is observed [161, 162].

The treatment of symptomatic UTI should be based on antimicrobial susceptibility testing. The selection of antibiotic agent is similar to that in the younger community-dwelling population taking into consideration the local antimicrobial resistance patterns [163]. In patients with a symptomatic uncomplicated UTI, the current recommendations for antibiotic duration are 3–7 days, whereas, for more complicated UTI, 10–14 days is appropriate [164, 165]. Men with recurrent UTI require work-up for chronic bacterial prostatitis, which could require 6–12 weeks of therapy [166]. For catheter-associated UTI, the Infectious Diseases Society of America suggests 7 days of treatment in patients who have a prompt response and 10–14 days in those who have a delayed response [167].

Respiratory Infections

Influenza and pneumonia ranks as the seventh leading cause of death for patients 65 years and older [63]. In addition to changes in the immune system, age-related changes in oral clearance, mucociliary clearance, respiratory muscle strength, cough reflexes, and lung structure increase the risk for pneumonia in the elderly [134]. A large population study estimated roughly 915,900 cases of community-acquired pneumonia per year in individuals older than 65 years [168]. Several studies examining the etiology of community-acquired pneumonia (CAP) have shown *Streptococcus pneumoniae* to be the most common pathogen, accounting for 20–60 % of cases followed by *Haemophilus influenzae* (3–10 % of cases) [169, 170]. Other causative organisms include the atypical pathogens *Mycoplasma pneumoniae*,

Table 7.2 Healthcare-acquired pneumonia (HCAP) risk factors [174]

Hospitalized in an acute care hospital for 2 or more days within the past 90 days
Resident of a nursing home or long-term care facility
Treated with intravenous antibiotic therapy, chemotherapy, or wound care within the past 30 days
Received hemodialysis at either a hospital or outpatient clinic

Chlamydophila psittaci, and *Legionella* species [171]. Polymicrobial infection and gram-negative pneumonia tend to occur more commonly in patients with COPD and in residents of long-term care facilities [172, 173].

Older patients with CAP can be treated similarly as the general adult population, but special considerations should be taken for the possibility of healthcare-associated pneumonia (HCAP), defined as pneumonia in a patient with an additional risk factor (Table 7.2) [174, 175]. HCAP, as well as hospital acquired pneumonia, and ventilator-associated pneumonia have been associated with higher rates of multidrug-resistant organisms (MDRO), including methicillin-resistant *Staphylococcus aureus* and gram-negative bacteria [172]. Interestingly, a recent study at a large US medical center found a low prevalence of MDRO in HCAP at their institution. However, predictors of MDRO included admission from a nursing home, duration of previous hospitalization in the last 90–180 days, *P. aeruginosa* colonization/infection in the previous year, and antimicrobial use in the last 90 days [176]. Local microbial epidemiology and culture results should be taken into account when choosing appropriate therapy.

Prevention and Potential Therapies

Not surprisingly, diet and exercise seem to play a key role in counteracting the negative effects of aging on the immune system. Regular exercise has been associated with greater T-cell proliferation, lower number of senescent T-cells and inflammatory cytokines, and improved function in neutrophils and NK-cells [177]. Exercise has also been shown to enhance vaccination responses in the elderly [178, 179]. Various nutrients act to temper epigenetic changes that contribute to inflammaging [180]. The "Mediterranean diet," consisting mainly of fruits, vegetables, grains, fish, olive oil, and regular red wine intake, with low consumption of saturated fats has been associated with modifying free radical production and expression of inflammatory mediators, along with other pathways implicated in malignancy and inflammatory responses [181]. There are also a multitude of plant-derived compounds exhibiting anti-inflammatory properties [182]. As we come to understand more about the alterations in immune function that occur with aging, further investigations will be needed to develop effective prevention and treatment strategies.

Summary

Age-related changes in immune function, underlying chronic disease, and environmental factors contribute to the increased incidence and severity of infections seen in the elderly population. Atypical clinical presentations can often confound the diagnosis of infection leading to delays in treatment, whereas environmental factors predispose the elderly to infection by multidrug-resistant organisms. The net effect of this increased susceptibility to infection combined with a relative incapacity to mount an effective immune response contributes to the increased morbidity and mortality resulting from infectious complications following trauma or emergency surgery. However, research demonstrates that targeted nutritional therapies and exercise may stall the process of immunologic deterioration in the aging.

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Hematological Changes with Aging

8

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Bullet Points

- Older patients have a lower baseline hemoglobin and less physiologic reserve to synthesize new blood cells after injury.
- Older patients have a slightly hypercoagulable state following injury.
- Older patients may be receiving anticoagulant therapy. Clinicians should be very aware of each medication's mechanism of action and most efficient reversal strategy.

Case Study

An 80-year-old female presented to an emergency room following a fall approximately 6 h ago. Her family states that since that time, her mental status has been worsening. Her past medical history is significant for congestive heart failure and atrial fibrillation, and she is anticoagulated with warfarin. Her head CT shows a large subdural hemorrhage. What should be used to reverse her anticoagulation? What should be used if, instead of warfarin, she was taking an oral factor Xa inhibitor or a direct thrombin inhibitor?

Introduction

The population of patients experiencing injury is changing. As the "baby boomer" generation grows older, men and women over age 65 are expected to represent nearly 20 % of the total population [1]. With this population comes a unique challenge following injury. The death rate following injury is higher in this older population than any other age groups [2]. Falls are a substantial component of the injury profile, and it is estimated that almost one-third of adults aged 65 and older fall each year [3]. In fact, in 2014, falls surpassed motor vehicle collisions as the leading cause of admission to trauma centers in one US state [4]. Knowledge of age-related changes in the hematologic system is crucial to the care of this distinct cohort following injury.

Anemia

Anemia is thought to be a normal consequence of aging, and its overall incidence increases significantly in patients over the age of 60. Large studies of men and women over the age of 65 show a decrease in hemoglobin levels with age [5–7]. This decrease in hemoglobin was first thought to be secondary to iron deficiency anemia; however, further studies

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revealed that only a small subset of this population had iron deficiency [8]. Subsequent studies have linked the steady decline in blood hemoglobin levels not to the previously believed nutritional elements, but rather to decreased stem cell proliferation. For instance, Lipschitz showed a relative reduction of bone marrow normoblasts with no decrease in progenitor cells [9]. Ershler and colleagues observed a compensatory rise in serum erythropoietin levels to compensate for anemia [10], though the changes are not sufficient to fully compensate. More recent studies [11] failed to reveal an age-related anemia in healthy older adults but did show increased incidence of anemia in the aged population suffering from various medical problems. These older patients with multiple comorbidities are most likely to present to the trauma physician. Therefore, the physician should expect some level of baseline anemia.

Bone Marrow Changes

Within the bone marrow lies the hematopoietic stem cell, which is responsible for replenishing all cell types of the blood. The bone marrow and the stem cells undergo changes with aging that can decrease the physiological response to hematologic insults. For example, the increased incidence of myeloproliferative disorders with age is thought to be secondary to age-related changes to the stem cell [12]. The architecture of the bone marrow shows a significant decline in cellularity with advancing age. Hematopoietic tissue, which usually occupies 40–60 % of the bone marrow space in young adults, subsequently drops to only 20–40 % of this space in older adults. The space remaining is occupied by fat. The stem cell is dependent on this marrow environment for efficient function. Bones from older mice implanted into younger mice show a decreased repopulation of hematopoietic cells, which is likely secondary to post-implantation structural changes [13]. Similar results are shown when young mice are implanted with marrow from old and young mice. The younger marrow assumes the majority of the production burden [14]. The reduced cellularity of the bone marrow with aging could be secondary to a pro-inflammatory state associated with increased age. Age-related inflammation has been shown to cause a decrease in expression of P-selectin, a surface adhesion molecule responsible for populating the bone marrow with hematopoietic stem cells; therefore, population of the older, more fat-laden marrow with stem cells is more difficult [15]. The increase in adipose tissue of the bone marrow is also a negative regulator of the bone marrow environment [16]. These structural changes seen in the marrow associated with aging have a negative impact on the responsiveness of the stem cell, and the body is less able to repopulate cell lines after injury.

Response to Hemorrhage

The hematologic response to hemorrhage is one of the most important factors to consider in the aging population. As stated above, the bone marrow and the hematopoietic stem cell have diminished function with advancing age and, as a result, have a decreased ability to adapt to a hematologic insult. Whether the hematopoietic system undergoes any major changes with aging, the normal individual remains under debate [17]; however, the response of patients treated with chemotherapy has proven that the hematologic system recovers less quickly in older versus younger individuals. Compared with their younger counterparts, older patients treated with chemotherapy experience a greater incidence of life-threatening myelosuppression and treatment-related deaths [18, 19]. The hematologic system of an older patient exhibits an impaired ability to recover following insult. The recovery of the total red cell mass (RCM) after hemorrhage is also decreased in the older population. Boggs and Patrene [20] showed that although anemia was more profound in older mice, it was not secondary to a decrease in the RCM but rather to an expansion in the plasma volume. The overall survival of the red cell was also similar to that in the younger mice. However, when the older mice were subjected to hemorrhage reducing the hematocrit to a nadir of 25 %, the recovery was much slower and reflected a difference in erythropoiesis rather than plasma volume equilibration [20]. This slower return to pre-trauma hematocrit can have negative consequences. Wu and colleagues [21] showed that even mild degrees of preoperative anemia resulted in higher rates of postoperative morbidity and mortality in older patients. While we do not advocate unnecessary blood transfusions because of the potential negative impact in the trauma population, it is important for the physician to understand that older individuals will have slower recovery times from low hematocrit than their younger counterparts, with potential associated morbidity.

Hypercoagulability Associated with Aging

In the acute injury setting, the trauma surgeon is likely more concerned about a hypocoagulable state. This is often seen in the older population secondary to the medications commonly prescribed to this cohort. However, after the initial injury, it is important to understand that older patients tend to be hypercoagulable at baseline, which may put them at risk for a number of complications. Age is an important risk factor for the development of deep venous thrombosis (DVT) in the intensive care unit patient following trauma as well as for other thromboembolic events including myocardial infarction and pulmonary emboli [22]. The physiologic reasons for this hypercoagulable state are multifactorial and

are best understood in the cardiovascular patient population. Thrombotic cardiovascular disease is known to increase with age [23]. Besides the atherosclerotic changes of the vascular endothelium observed with advanced age, hemostatic systems including platelets, coagulation, and fibrinolytic factors all show age-associated changes that result in a relative hypercoagulable state. Platelets, factor VII, and factor VIII activity are all enhanced with increasing age. Bauer et al. demonstrated low-level activation of coagulation that progressively increases with age in healthy men with no vascular disease [24]. In an epidemiologic study of an industrial population of over 3,000 individuals, Balleisen et al. [25] showed an increase in factor VII and factor VIII with age and a significant surge in women after menopause [25]. Mari also showed increased levels of factor VII in centenarians, which suggests an increased coagulation response [26]. One might surmise that if these natural procoagulant factors increase with age, then proportional rises in natural anticoagulants including protein C and protein S might also occur to achieve normality. However, Sagripanti did not find this to be true [27]. The age-related genetic mechanism responsible for increased procoagulant factor levels did also increase production of protein C and protein S, though at a slower rate, resulting in the proportional rise of the procoagulant factors [28]. The increased platelet activity accompanying advanced age is likely related to three separate yet related changes [29]. First, the number of prostacyclin receptors decreases with age, and the inhibitory response on platelet aggregation is subsequently downgraded [30]. Second, an age-related increase in platelet transmembrane signaling (phosphoinositide turnover) or a second messenger accumulation results in increased platelet activity [31]. Finally, an age-related increase in the production of von Willebrand factor results in increased platelet activity [32].

The fibrinolytic system also contributes to the hypercoagulable state associated with aging. There is a prolongation of the euglobulin lysis time [33] as well as an increase in plasminogen activator inhibitor-1 (PAI-1), which specifically inhibits both tissue-type and urokinase-type plasminogen activators [34]. Higher levels of PAI-1 have been noted in mouse models of aging. Yamamoto and colleagues showed increased levels of PAI-1 mRNA expression and PAI-1 plasma antigen in a rapidly aging mouse model compared with normal controls [35]. This finding implies a decrease in fibrinolysis and increased risk of thromboembolic events with advanced age. One of the most interesting findings concerning PAI-1 is its increased production in times of stress. Stress (as seen following trauma and critical illness) results in increased production of glucocorticoids through the hypothalamic-pituitary-adrenal axis. These glucocorticoids have been shown to induce PAI-1 expression [36]. Furthermore, this stress-induced expression is even more profound in aged mice [37].

Medication of an Aged Population That Affects the Hematologic System

While not a natural change with aging, any discussion of the changes in the hematologic system with age, especially related to trauma, would be remiss not to mention the commonly prescribed medications. Antiplatelet therapy with aspirin or platelet adenosine diphosphate (ADP) antagonists (clopidogrel, prasugrel, or ticagrelor) is common in the older trauma population. It is estimated that 50 million Americans are on aspirin therapy [38], and 29 million are prescribed with clopidogrel or similar agents [39]. Pre-injury treatment with these drugs has been shown to increase trauma mortality, especially with head injury [40, 41]. Aspirin inhibits platelet cyclooxygenase-1, which then blocks thromboxane A2 generation and subsequently inhibits platelet function. Clopidogrel-like drugs inhibit the ADP-dependent mechanism of platelet aggregation. Both aspirin and ADP antagonists are reversed by the platelet transfusion. Laboratory studies indicate that while one pheresis unit (six random units) can reverse the aspirin defect, two pheresis units may be needed for ADP antagonists [42]. In vitro data show that platelet transfusions may not reverse the platelet defect of clopidogrel [43]. Desmopressin also has been shown to improve platelet function in the presence of these antiplatelet agents. Rannuci showed improved platelet function from 48 to 71 % by thromboelastography (TEG) with desmopressin therapy [44]. However, data from more clinical trials are required before inclusion of desmopressin in antiplatelet reversal protocols.

Interest is increasing for the use of point-of-care assays such as the aspirin response test (ART; VerifyNow®) to guide reversal therapy for antiplatelet agents. Bansal showed that many patients allegedly on antiplatelet agents have a normal platelet function, and Bachelani showed that these assays may help guide platelet therapy [45, 46]. More widespread use of this type of laboratory testing may help to avoid unnecessary transfusion and better reversal of antiplatelet agents.

One of the leading medical indications for anticoagulation in the older population is atrial fibrillation. The prevalence of atrial fibrillation is steadily increasing [47], and it is estimated that by 2030, four million people in the USA will suffer from it [48]. While studies have shown that, over a lifetime, the benefit of reduced stroke rate with anticoagulation for atrial fibrillation does outweigh the bleeding risk, in an acutely injured patient, anticoagulation can be life-threatening. Warfarin acts by antagonizing vitamin K and thus inhibiting the synthesis of vitamin K-dependent coagulation factors II, VII, IX, and X [49]. Pre-trauma treatment with warfarin has been associated with worse outcomes, especially in patients with intracranial injury [50]. Rapid reversal protocols utilizing fresh frozen plasma (FFP) have

been shown to reduce further bleeding and improve outcomes [41]. While traditional reversal relies on the transfusion of FFP and the administration of vitamin K, the process can be lengthy due to the time needed to thaw the plasma and infuse the product. Another issue is that substantial amounts of FFP are required for adequate reversal (15–20 ml/kg). The large volume of blood products may be detrimental to patients at risk for congestive heart failure and may increase the risk of transfusion complications such as lung injury.

Prothrombin complex concentrates contain variable concentrations of factors II, VII, IX, and X. Since the last edition of this text, a 4-factor prothrombin complex concentrate (4-PCC) has been approved by the US Food and Drug Administration (FDA) (Kcentra®, CSL Behring). Initial studies performed in Europe showed 4-PCC to be an effective method of reversal in patients with an international normalized ratio (INR) ≥ 2. At 30 min post-infusion, 93 % of the patients had an INR ≤ 1.3 [51]. In a controlled study comparing 4-PCC to plasma reversal, rapid INR reduction was achieved in 62 % of the 4-PCC patients versus 9.6 % of the patients receiving plasma [52]. Similar results were again demonstrated by Goldstein in patients requiring urgent surgical intervention with effective hemostasis achieved in 90 % of the 4-PCC patients compared to 75 % of the plasma patients [53]. As expected, the medium volume of 4-PCC (99.4 ml) was less than fresh frozen plasma (813.5 ml) [52].

An example of a rapid reversal protocol for warfarin is shown in Fig. 8.1. All patients also receive vitamin K. Secondary to cost and the thrombotic risk of reversing anticoagulation, 4-PCC is reserved for life-threatening hemorrhage. While no published data exist, anecdotal evidence suggests that 4-PCC is difficult to prepare and usually requires a pharmacist. This has limited the availability of 4-PCC in smaller hospitals and rural settings.

Newer direct oral anticoagulant agents including dabigatran (direct thrombin inhibitor), rivaroxaban (factor Xa inhibitor), apixaban (factor Xa inhibitor), and edoxaban (factor Xa inhibitor) are now being used in the older population. These drugs have advantages over warfarin in that they do not require laboratory monitoring, and they have

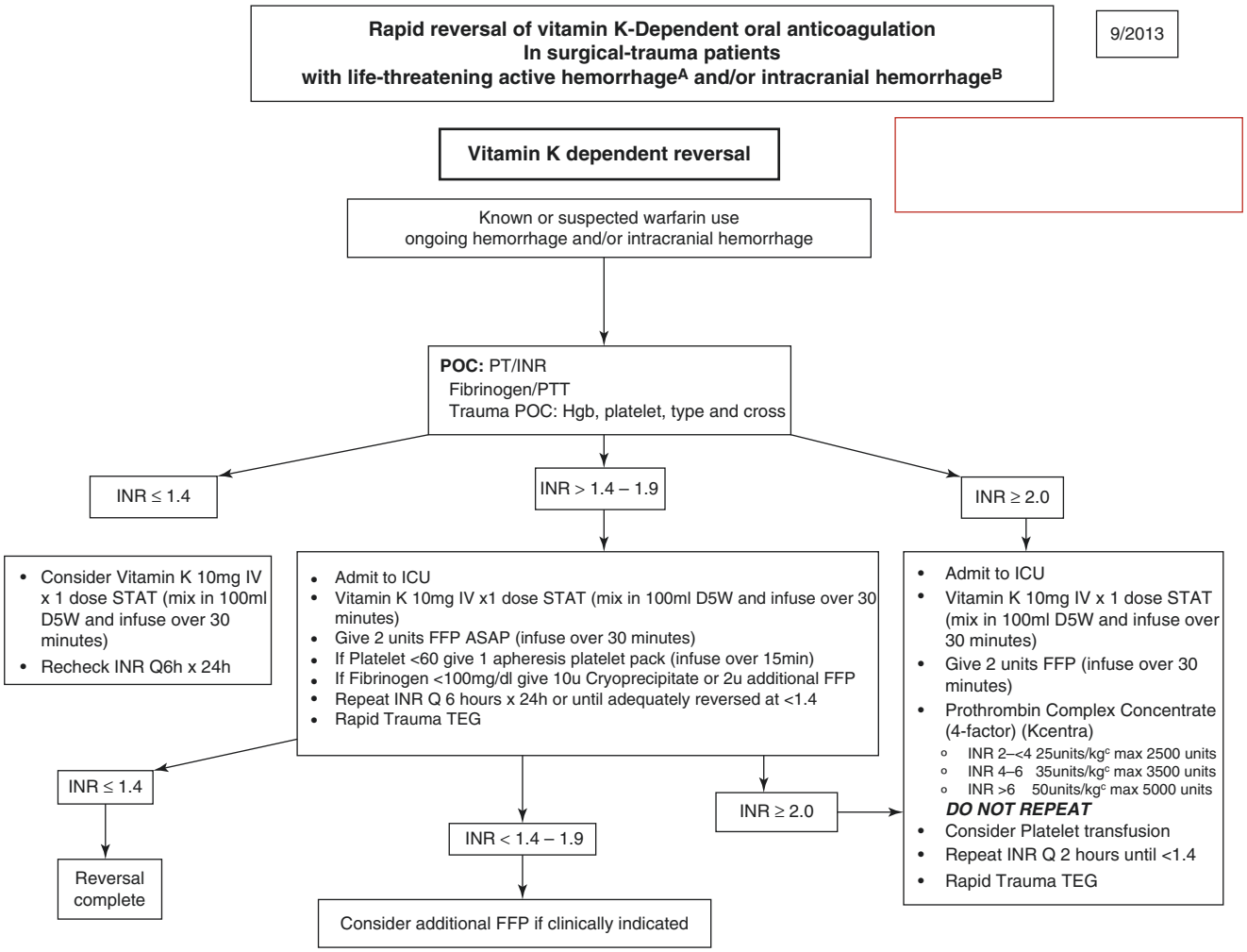

Fig. 8.1 Carolinas Medical Center warfarin reversal protocol

significantly fewer drug interactions and no dietary interactions. All of these agents have been shown to be equal or superior to warfarin in stroke prevention, result in lower incidence of intracranial hemorrhage, and are all options for stroke prevention in atrial fibrillation [54]. In addition, all agents have been shown to be equal to warfarin in the therapy of venous thrombosis and the anti-Xa inhibitors to be safer than warfarin [55].

Reversal of these novel agents has been extremely difficult, but newer reversal agents show great promise. For example, 4-PCC does provide some reversal of factor Xa inhibitors. In a small study of healthy patients by Eerenberg of healthy subjects, 4-PCC completely reversed the effect of rivaroxaban on prothrombin time and endogenous thrombin potential [56]. Unfortunately, 4-PCC had no effect on the direct thrombin inhibitor dabigatran. Idarucizumab was recently approved by the FDA. This monoclonal antibody fragment binds to dabigatran with an affinity 350 times greater than thrombin. In an interim analysis of a larger randomized trial, idarucizumab normalized the dilute thrombin time and the ecarin clotting time (ECT) within minutes in 88–98 % of patients [57]. Frustratingly, the average time for cessation of bleeding was still 11.5 h. Andexanet alfa is a human factor Xa decoy protein that binds factor Xa inhibitors. A bolus of andexanet alfa effectively reduced anti-factor Xa activity in more than 90 % of volunteers treated with either apixaban or rivaroxaban [58]. An example of a rapid reversal protocol for non-vitamin K antagonists is shown in Table 8.1.

Table 8.1 OHSU anticoagulation reversal protocol

Definition of bleeding	
Minor bleeding: any clinically overt sign of hemorrhage (including imaging) that is associated with a <5 g/dL decrease in the hemoglobin concentration or <15 % decrease in the hematocrit felt by the clinician to be related to anticoagulation	
Major bleeding: intracranial hemorrhage or a ≥5 g/dL decrease in the hemoglobin concentration or ≥15 % absolute decrease in the hematocrit resulting in hemodynamic compromise or compression of a vital structure and felt by the clinician to be related to anticoagulation	
Antiplatelet agents	
Aspirin	
Minor – desmopressin 0.3 mcg/kg × 1	
Major – platelet transfusion	
Clopidogrel (*Plavix*®)	
Minor – desmopressin 0.3 mcg/kg × 1	
Major – platelet transfusion, consider 2 units if life- or brain-threatening bleeding	
Prasugrel (*Effient*®)	
Minor – desmopressin 0.3 mcg/kg × 1	
Major – platelet transfusion, consider 2 units if life- or brain-threatening bleeding	
Ticagrelor (*Brilinta*®)	
Minor – desmopressin 0.3 mcg/kg × 1	
Major – platelet transfusion, consider 2 units if life- or brain-threatening bleeding	
Sustained-release aspirin/dipyridamole (*Aggrenox*®)	
Minor – desmopressin 0.3 mcg/kg × 1	
Major – platelet transfusion	
Abciximab (*ReoPro*®)	
Major – platelet transfusion	
Eptifibatide (*Integrilin*®)	
Minor – desmopressin 0.3 mcg/kg × 1	
Major bleeding reversal – platelet transfusions plus infusion of 10 units of cryoprecipitate	
Tirofiban (*Aggrastat*®)	
Minor – desmopressin 0.3 mcg/kg × 1	
Major bleeding reversal – platelet transfusions plus infusion of 10 units of cryoprecipitate	
Heparin and heparin-like agents	
Standard heparin	
Time since the last heparin dose	*Dose of protamine*
<30 min	1 unit/100 units of heparin
30–60 min	0.5–0.75 units/100 units of heparin
60–120 min	0.375–0.5 units/100 units of heparin
>120 min	0.25–0.375 units/100 units of heparin
Infusion rate should not exceed 5 mg/min. Maximum dose is 50 mg per dose	

(continued)

Table 8.1 (continued)

Low molecular weight heparin
Reversal of bleeding – protamine works just as well with LMWH as heparin. If within 4 h of dose, 1 mg of protamine for each 1 mg of enoxaparin or 100 units of dalteparin and tinzaparin. Repeat one-half dose of protamine in 4 h. If 4–8 h after dose, give 0.5 mg for each 1 mg of enoxaparin or 100 units of dalteparin and tinzaparin
Fondaparinux (*Arixtra*®)
Major bleeding reversal – protamine ineffective; rFVIIa (90 mcg/kg) may be of use
Dabigatran (*Pradaxa*®)
Reverse if patient shows signs of life-threatening bleeding and had an elevated aPTT
1. Idarucizumab 5 g; administer as two boluses of 2.5 g
Rivaroxaban (*Xarelto*®)
Reverse if patient shows signs of life-threatening bleeding and has an INR >1.5
1. Profilnine (factor IX complex) 4000 units (50 units/kg for patients under 80 kg) *plus* 1 mg of rFVIIa
Apixaban (*Eliquis*®)
Reverse if patient shows signs of life-threatening bleeding
1. Profilnine (factor IX complex) 4000 units (50 units/kg for patients under 80 kg) *plus* 1 mg of rFVIIa
Edoxaban (*Savaysa*®)
Reverse if patient shows signs of life-threatening bleeding
1. Profilnine (factor IX complex) 4000 units (50 units/kg for patients under 80 kg) *plus* 1 mg of rFVIIa
Thrombolytic therapy
Reversal – immediate infusions of equivalent of 6–8 units of platelets (or one platelet pheresis product), 2 units of plasma, and 10 units of cryoprecipitate. No value in infusing antifibrinolytic agents

Conclusion

Considering the complexity of the hematologic system, its function is very well preserved during the aging process, but the trauma physician must be aware of the changes that impact older patients. An older patient will likely present with a lower baseline hemoglobin. It will be more difficult for the patient to recover from any hemorrhage secondary to the bone marrow and hematopoietic stem cell changes that are part of normal aging. After the initial injury, the older patient will return to a slightly hypercoagulable state, which is important to consider in the course of recovery. Finally, with the prescribing practices in the USA, the older patient may be taking certain medications that affect the hematologic system and may negatively impact post-injury recovery.

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Geriatric Psychology and the Injured Elderly

9

Robert D. Barraco and Joseph J. Stirparo

Introduction

Psychological disorders and other cognitive impairments adversely affect outcomes in hospitalized elderly [1]. This has also been demonstrated in those with orthopedic injury [2–5]. Dependence in activities of daily living and moderate-to-severe cognitive impairment were independent risk factors for in-hospital mortality [6]. Despite these known associations, there continues to exist a dearth of information in the trauma literature. Conflicting results may be related to inaccuracies in the diagnoses of dementia and delirium [7]. In this chapter, we discuss the essentials of several neuropsychiatric disorders prevalent in the geriatric trauma patient.

Cognitive Disorders/Dementia

The DSM-IV describes dementia as the development of multiple cognitive deficits that include memory impairment and at least one of the following:

- Aphasia – Inability to understand or express speech
- Apraxia – Inability to perform purposive actions
- Agnosia – Inability to interpret sensory inputs
- Disturbance in executive functioning

The cognitive deficits must be sufficiently severe to cause impairment in occupational or social functioning and represent a decline from a previous higher level of functioning. If the deficits occur only during the course of delirium, the diagnosis of dementia should not be made. Both may be diagnosed if the dementia is present at times when the delirium is not present [8].

Despite increased awareness, dementia is often moderate to severe by the time it is diagnosed. Overall, women exhibit dementia and cognitive impairment more often than males. Alzheimer's disease (AD) is more common in women, and vascular dementia is more common in men.

Elderly with dementia are more likely to be admitted for fractured femurs, lower respiratory tract infections, urinary tract infections, and head injuries than those without dementia. Mean length of stay for admissions for patients with dementia was 16.4 days compared to 8.9 days for those without dementia. Additionally, elderly with dementia were more likely than those without to be readmitted within 3 months. Mortality rates and transfers to nursing home care were higher for those with dementia than without. Outcomes were more pronounced in younger patients with dementia (Table 9.1) [1].

Types of Dementia

Dementia is characterized by an acquired and persistent deficit in cognitive domains that interferes with daily functioning. There are several different types of dementia. Alzheimer's disease is the most common type of dementia representing 50–70 % of cases. Vascular dementia can have a number of different etiologies and is second most common. Frontal lobe dementia and Lewy body dementia round out the most common causes. It is estimated that one in three seniors will die with a diagnosis of dementia.

Alzheimer's Disease

Alzheimer's disease (AD) is progressive and irreversible and eventually leads to death [9]. At least 5.3 million people in the United States are affected. It is the sixth leading cause of death in adults. One in eight adults over age 65 and half of those over age 85 have the disease. Direct costs for patients with Alzheimer's disease are $200 billion, of which Medicare and Medicaid pay $140 billion. By the year 2050, over $1.1 trillion are estimated to be spent on Alzheimer's disease [10].

Neurofibrillary tangles and neuritic plaques are the characteristic lesions in brains with Alzheimer's disease. Beta-amyloid protein is present in these lesions and may play a

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Table 9.1 Comparison of common types of dementia

	Alzheimer's	Lewy body	Frontal lobe	Vascular
~% of cases	50%	20%	<10%	20%
Pathology	Neurofibrillary tangles	Lewy bodies in cortex and amygdala	Degeneration of frontal regions	Varied vascular
Distinct features	Progressive memory loss	Parkinson-like symptoms; hallucinations; transient loss of consciousness	Behavioral and personality changes	Varied depending on location
Potential medical treatments	Cholinesterase inhibitors and memantidine	No specific treatment; cholinesterase inhibitors for cognitive symptoms; Parkinson's meds for motor symptoms	No specific treatment; Alzheimer's meds may worsen symptoms	No specific treatment, prevent ongoing vascular events

central role in the disease as a deficit of acetylcholine and cholinergic areas [11, 12]. A history of head trauma as well as vascular disease increases the risk of Alzheimer's disease. Clinical features include progressive memory loss, impairment of language, visuospatial ability, and executive function. As in most dementias, behavioral and psychotic symptoms may occur.

Vascular Dementia

The term vascular dementia applies to many causes of dementia, including multi-infarct dementia and small vessel disease. About one-fifth of all cases of dementia are vascular. Many of the same things that put one at risk for cardiovascular disease also put one at risk for vascular dementia. These include diabetes, hypercholesterolemia, hyperhomocysteinemia, hypertension, cigarette smoking, and physical inactivity. The effects of these risk factors may vary depending on the type of vascular dementia. Some types are related to specific gene mutations but are rare.

The presenting symptoms and signs will depend on the location of the lesions. Left hemisphere lesions usually cause language problems, and right hemisphere lesions generally cause visuospatial problems. The course may be stepwise, either with abrupt declines or more insidious. Memory or mood complaints are common in both vascular and Alzheimer's disease. Recognition memory is often preserved in vascular dementia, not in Alzheimer's. Isolated psychotic symptoms, apathy, and higher cortical disturbance with intact memory may also be seen in vascular dementia.

Lewy Body Dementia

Lewy body dementia is characterized by Parkinson-like symptoms, recurrent visual hallucinations, neuroleptic sensitivity, fluctuating cognition, falls or syncope, and a transient loss of consciousness. Lewy body dementia may account for up to 20 % of dementia in the United States, affecting up to 1.3 million people. Only 30–50 % of cases are accurately diagnosed [13].

Hallmark lesions are protein deposits known as Lewy bodies. These deposits are located in the cortex and amygdala in Lewy body dementia, as opposed to Parkinson's, where the deposits are in the brain stem and substantia nigra.

Both the cholinergic and dopaminergic systems are severely disrupted. Other causes for cognitive decline in the setting of parkinsonism should be excluded with testing.

Frontal Lobe Dementias

Frontotemporal dementias are a heterogeneous group of disorders that involve degeneration of different regions of the frontal and temporal lobes. Clinically, behavioral and personality changes may predominate over cognitive deficits. These include a loss of personal or social awareness, a lack of insight, inappropriate and stereotyped behaviors, aggression, distraction, a loss of inhibitions, apathy, or extroverted behavior. Some cases involve language and aphasia as primary characteristics. The majority of cases of this group of disorders occur in those under 65 years of age.

As this is a group of disorders, the pathophysiology is not well understood.

The cognitive, neuropsychiatric, and behavioral symptoms depend on the regions of the brain involved. Though beginning as a regional process, as the disease progresses, the atrophy and pathology become more generalized.

Cognitive Screening Tests

One must first rule out potentially reversible cognitive deficits due to underlying disorders. Laboratory and imaging tests should be done as indicated. Examples of acute reversible disorders resulting in cognitive deficits include hypercapnia, hypoxemia, hypoglycemia, electrolyte disturbances, sepsis, and traumatic brain injury. Disorders that can mimic dementia include depression, delirium, anticholinergic medications, and toxic metabolic encephalopathy.

There are several standardized screening tests for cognitive impairment. One of the oldest and most well-known is the Mini-Mental State Examination (MMSE) [14]. It is a 30-point questionnaire which takes about 10 min to complete. It can be used to evaluate a patient at a point in time and then repeated to check response to treatment. Categories assessed are orientation to time and place, registration, attention and calculation, recall, language, repetition, and complex commands. A score of 25 or greater is normal. Scores of 21–24, 10–20, and ≤9 indicate mild, moderate, and severe cognitive impairment, respectively. Adjustments may need to be made to the raw score for educational level and age.

The Mini-Cog is a quick and simple method of screening for cognitive dysfunction [15]. It takes about 3–5 min to complete. It consists of three-item recall and clock drawing. Clock drawing was used to clarify scores when memory was

intermediate. Recall of none of three items signified dementia. Recall of one or two items signified dementia when accompanied by an abnormal clock drawing test. Recall of all three items was considered normal. When compared to the MMSE, the Mini-Cog had better sensitivity at 99 % and correctly classified the greatest percentage (96 %) of subjects. Its diagnostic value was not influenced by education or language [15].

The Montreal Cognitive Assessment (MoCA) is a one-page 30-point test that takes about 10 min to complete [16]. The domains assessed are short-term memory recall, visuospatial abilities, executive functions attention, concentration and working memory, language, and orientation to time and place. MoCA may be better for mild cognitive impairment and early dementias as well as other neurological disorders that affect younger patients such as Huntington's and Parkinson's diseases [17–21].

The Saint Louis University Mental Status (SLUMS) Examination is an alternative to the MMSE. In a large study comparing the two tests, SLUMS was able to better detect mild neurocognitive disorders [22]. Sensitivity and specificity of the two tests are comparable. The test takes about 10 min to administer and includes a clock drawing test.

Overview of Treatments

Treatment of dementias is complex and varies both on type of dementia and severity of symptoms. Due to this complexity, treatment is best when practiced with a multidisciplinary approach including geriatricians, pharmacists, and neurologists. A brief overview of potential treatments is provided below. Practitioners should discuss treatment plans with a multidisciplinary team.

Alzheimer's disease had several FDA-approved drug therapies. The cholinesterase inhibitors and memantine are used to address cognitive symptoms. Patients may survive as long as 20 years with Alzheimer's disease, but many patients succumb in the early or middle stages of the disease.

Lewy body dementia has no FDA-approved treatment. As there are cholinergic losses and relationship with Alzheimer's disease, cholinesterase inhibitors were found to have a role and have become standard treatment for cognitive symptoms [23]. Low doses of Parkinson's medications, i.e., levodopa, may help motor symptoms, but caution must be used as higher doses can worsen neuropsychiatric symptoms. Average duration of illness is 5–7 years but with much variability.

Frontal lobe dementias have no specific treatments or cures. Not all cases have the same underlying pathology. Cholinesterase inhibitors and memantine may worsen behavioral and psychological symptoms. Long-term care is necessary as the average duration between onset of illness and death is 7 years.

There are no specific treatments for vascular dementia. Control of vascular risk factors is primary. Behavioral and psychological features are treated as necessary.

Behavioral and psychological symptoms including depression occur in the majority of patients with dementia. Psychological symptoms include delusions, hallucinations, paranoia, anxiety, and apathy. Behavioral symptoms include wandering, aggression, hostility, insomnia, inappropriate eating, and abnormal sexual behaviors [24].

Non-pharmacological strategies should be employed in all acute care facilities and are the first-line therapies for behavioral and psychological symptoms in dementia. These consist of environmental and behavioral interventions such as regularly scheduled routines for meals, sleep, and bathing. Reorientation with a clearly visible clock and calendar is indicated. Caregivers should use clear instructions and make frequent eye contact with patients. Sensory impairments, such as vision and hearing loss, should be minimized. These will be addressed in more depth in the section on delirium.

Pharmacological interventions are variable depending on the type of dementia. When medication is necessary, neuropsychiatric symptoms in many dementias have been treated with antipsychotics. Atypical antipsychotics may be better than typical [25]. Quetiapine has been used for psychosis in parkinsonian syndromes [26]. There are concerns regarding the use of these agents. First-generation antipsychotics produce more extrapyramidal symptoms. The second-generation antipsychotics have had a "black box" warning label added by the US Food and Drug Administration for a small but statistically significant increase in cerebrovascular events and death. The older antipsychotics also carry an increased risk of death [27]. A recent cohort study looking at over 75,000 elderly nursing home patients using antipsychotics found that haloperidol had a higher risk of dying when compared with risperidone [28]. Quetiapine users also had a decreased risk of mortality. A dose-response relation was noted with all drugs but quetiapine.

Patients with dementia may have paradoxical agitation when given benzodiazepines. Tricyclic antidepressants may have unwanted anticholinergic effects. Mood stabilizers, especially selective serotonin reuptake inhibitors (SSRIs), may help neuropsychiatric features of frontotemporal dementias.

Cholinesterase inhibitors have been used for neuropsychiatric symptom treatment of Alzheimer's disease and vascular dementias since cholinergic deficiency also appears to be involved in their development [29]. However, when used in frontotemporal dementias, they may worsen these symptoms.

Neuropsychiatric symptoms in Lewy body dementias can be challenging to treat medically. Older antipsychotic drugs may cause worsening of symptoms and neuroleptic malignant syndrome in Lewy body dementias. As mentioned previously, newer antipsychotics seem to be more beneficial. Benzodiazepines, anticholinergics, and some antidepressants may cause sedation, motor impairment, or confusion. Medications for parkinsonian symptoms may also worsen confusion, delusions, and hallucinations in higher doses.

In summary, the first-line therapies for neuropsychiatric and behavioral symptoms should be non-pharmacological, and medications should be used judiciously and with caution. As the principle of geriatric pharmacological intervention states, "start low, go slow but go." Limit medications to necessity, again in a multidisciplinary format.

Delirium

Definition and Epidemiology

Delirium is a transient, reversible syndrome of impairment of consciousness, attention, and perception in the setting of a medical condition that is acute and fluctuating. The roots of the word are Latin with the term coined by Celsus and included in his work *De Medicina*. Deconstructing the work from its Latin root, "de" is for "away from" and "lira" is for "furrow in a field." Literally translated it means "going off track [30]."

Delirium occurs in up to 60 % of hospitalized frail elderly patients [31]. One study found that 89 % of survivors of stupor or coma progressed to delirium [32]. Similarly, in the general surgical population, the incidence of delirium is 37–46 %, and postoperative delirium has been described to occur in 10–60 % of patients [33, 34]. The range in incidence of postoperative delirium depends on the type of surgery and the population studied. For example, the incidence of delirium was found to be 65 % after femoral neck fracture repair [35–37]. Approximately seven out of ten surgical intensive care and trauma intensive care patients experience delirium [38].

There exist three subtypes of delirium: hyperactive, hypoactive, and mixed. Hyperactive delirium occurs when the patient exhibits three or more of the following: hypervigilance, restlessness, fast and/or loud speech, anger, irritability, combativeness, impatience, uncooperativeness, laughing, swearing, singing, euphoria, easy startling, distractibility, nightmares, persistent thoughts, and wandering. For hypoactive, the most difficult to diagnose and identify, the patient must exhibit four or more of the following: unawareness, lethargy, decreased alertness, decreased motor activity, staring, sparse and/or slow speech, and apathy [39]. Mixed, which is the most common subtype, contains features of both.

Delirium has been shown to increase mortality when other factors are controlled for. Studies have shown that the mortality rate for patients with delirium was significantly higher with regard to interval or patient population studied. Mortality rates for patients with delirium compared to those without range from 8 % vs 1 % in hospitalized inpatients, 34 % vs 15 % for 6-month mortality after ICU stay, and 11 % vs 3 % for 90-day mortality in med-surg patients [40–42].

The costs of delirium can be staggering, ranging from $38 billion to $152 billion per year in a study of healthcare costs [43]. Though patients with delirium survived fewer days than those without, they had significantly higher adjusted costs, over 2.5 times the costs of patients without delirium. Costs attributable to delirium were $16,303 to $64,421 per patient.

Causes and Risk Factors

There are many causes and risk factors for delirium. Temporal relationship to clinical events is an important clue to cause. For example, exposure to midazolam is an independent and potentially modifiable risk factor for the development of delirium [38]. Delirium arising after administration of midazolam would point to the drug as the cause.

The cause may also be determined by the clinical situation or condition. Potentially life-threatening conditions which cause delirium can be remembered by the mnemonic WHHHHIMPS. They are Wernicke's disease, hypoxia, hypoglycemia, hypertensive encephalopathy, hyperthermia or hypothermia, intracerebral hemorrhage, meningitis/encephalitis, poisoning, either exogenous or iatrogenic, and status epilepticus.

Other risk factors can be divided into potentially modifiable and non-modifiable. Non-modifiable risk factors include dementia or history of cognitive impairment, age over 65, chronic renal or hepatic disease, multiple comorbidities, and a history of delirium, stroke, neurological disease, falls, or gait disorder. Potentially modifiable risk factors include surgical pain, concurrent illness, acute neurological diseases, medications, immobilization including by catheters or restraints, sensory impairment of hearing or vision, metabolic derangements, environment, emotional distress, and sustained sleep deprivation. The categories of causes can be remembered by the mnemonic I WATCH DEATH. The table explains the mnemonic (Table 9.2). There exists suggestion that length of operative procedure (greater than 3 h), utilization of general anesthesia, intraoperative hypercapnia, and hypotension may increase incidence of delirium [85].

Dementia as a risk factor was discussed in the previous section. Two studies help accentuate its importance. Wahlund and Bjorlin in 1999 found that approximately 70 % of elderly patients admitted to a specialized delirium ward had either dementia or mild cognitive impairment [44]. In

Table 9.2 Causes of delirium

Categories	Examples
Infectious	Encephalitis, meningitis, pneumonia, urinary tract infection
Withdrawal	Alcohol, sedative-hypnotics
Acute metabolic	Acidosis, alkalosis, electrolyte disturbances, hepatic or renal failure
Trauma	Heat stroke, burns, surgery
CNS pathology	Hemorrhage, seizures, stroke, tumors, vasculitis, hydrocephalus
Hypoxia	Hypoxia from cardiac or pulmonary cause, anemia, carbon monoxide poisoning, hypotension
Deficiencies	Vitamin B12, niacin, thiamine
Endocrinopathies	Disorders of glucose, cortisol, thyroid and parathyroids
Acute vascular	Hypertensive encephalopathy, shock
Toxins or drugs	Medications, toxins
Heavy metals	Lead, manganese, mercury

a study of total joint replacement patients, all demented patients postoperatively developed delirium, compared with 31.8 % in the non-demented patients [37].

Age is a major risk factor for delirium and deserves special mention. One study suggests this relationship is linear after age 65. In mechanically ventilated patients, the probability of developing delirium increased by 2 % for each year over age 65 [45]. Hypoxia is a well-known risk factor for delirium. Not only poor oxygenation but also poor oxygen delivery, i.e., anemia, can contribute to delirium [46, 47]. Hypoxia can come from many causes, even obstructive sleep apnea [48].

Many medications have the capacity to cause delirium. This is especially true of those with psychoactive effects and those with anticholinergic effects. There appears to be a direct relationship between a drug's anticholinergic properties and the development of delirium [49–51]. A study by Han et al. found that exposure to anticholinergic agents was an independent risk factor for the development of delirium and an increase in symptom severity [52].

Dr. Mark Beers created the first Beers Criteria list in 1991 with a consensus panel of experts. It has been updated several times, most recently in 2015 as the American Geriatrics Society Updated Beers Criteria for Potentially Inappropriate Medication Use in Older Adults. The list identifies medications or classes of medication that are potentially inappropriate in all older adults, and medications should be used with caution [53]. In older adults with certain diseases and syndromes, the drugs listed can exacerbate symptoms. All practitioners caring for the elderly must be aware of this list and utilize it to the benefit of their patients. The most recent update of the criteria will be used as an educational tool and a quality measure.

Postoperative pain is an independent predictor of delirium after surgery [54]. Narcotic agents may cause delirium as well [55]. Some opioids may be more likely to cause delirium than others, with the data on meperidine being the most consistent [56].

Diagnosis and Screening

Delirium is unrecognized in many cases. The literature estimates that from 65–84 % of cases go undiagnosed. Delirium can mimic many other mental illnesses. A cornerstone of diagnosis is identification of the underlying causes and correcting modifiable ones.

There are a host of objective diagnostic and screening tests for delirium (Table 9.3). In December 2008, the Canadian Agency for Drugs and Technologies in Health published a review of evidence-based guidelines on diagnostic tests for delirium. They reviewed the 2006 Canadian Coalition for Seniors' Mental Health (CCSMH) published evidence-based guidelines for the assessment and treatment of delirium, the 2006 British Geriatrics Society and the Royal College of Physicians' evidence-based delirium guidelines, and the 2007 delirium guidelines for general hospitals by Swiss and French physicians [57–60]. They concluded that early assessment for delirium is needed in hospitalized elderly patients. This early detection of risk factors may prevent delirium and its complications. Physicians and nurses must be educated to recognize delirium in the use of validated screening and diagnostic tools. They suggested that the Confusion Assessment Method be used for screening and diagnosis, and the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV) criteria be used to confirm the diagnosis.

Table 9.3 Objective tests to diagnose delirium

Cognitive Test for Delirium (CTD)
Confusion Assessment Method (CAM and Confusion Assessment Method for the Intensive Care Unit (CAM-ICU)
Confusional State Evaluation (CSE)
Delirium Assessment Scale (DAS)
Delirium Detection Score (DDS)
Delirium Index (DI)
Delirium Rating Scale and Delirium Rating Scale-revised-98 (DRS)
Delirium Severity Scale (DSS)
Delirium Symptom Interview (DSI)
Memorial Delirium Assessment Scale (MDAS)
Short Portable Mental Status Questionnaire (SPMSQ)

In 2010, the National Clinical Guideline Centre of Britain published its clinical guideline titled "Delirium: Diagnosis, Prevention and Management." As to screening and diagnosis, they recommended screening for behavioral changes at presentation and daily during hospital admission. If indicators of delirium are identified, they recommend that a healthcare professional who is trained and competent in the diagnosis of delirium carry out a clinical assessment based on the DSM-IV criteria or Confusion Assessment Method short version (short CAM) to confirm the diagnosis. The CAM-ICU should be used when patients are intubated in the ICU or recovery room postoperatively [61].

The Confusion Assessment Method was unveiled in 1990 and the Confusion Assessment Method-ICU in 2001 [62, 63]. Both have a sensitivity of 94–100 %, a specificity of 89–95 %, and high inter-rater reliability [64]. The CAM has a long and a short version. The long version is comprehensive and screens for nine clinical features. The short version focuses on the four features that have the greatest discriminatory ability to detect delirium from other cognitive disorders. There is also a version designed for use in the Emergency Department, the brief CAM (bCAM). Another rapid rule-out tool is the Delirium Triage Screen (DTS). Validated in Emergency Departments, it is a 20 s tool that is 98 % sensitive and 55 % specific for delirium as diagnosed by a psychiatrist assessment.

The CAM-ICU addresses the same four areas as the short version CAM. It was developed by Ely et al. at Vanderbilt. It takes less than 2 min to complete and can be given to intubated patients. The process is shown in Fig. 9.1.

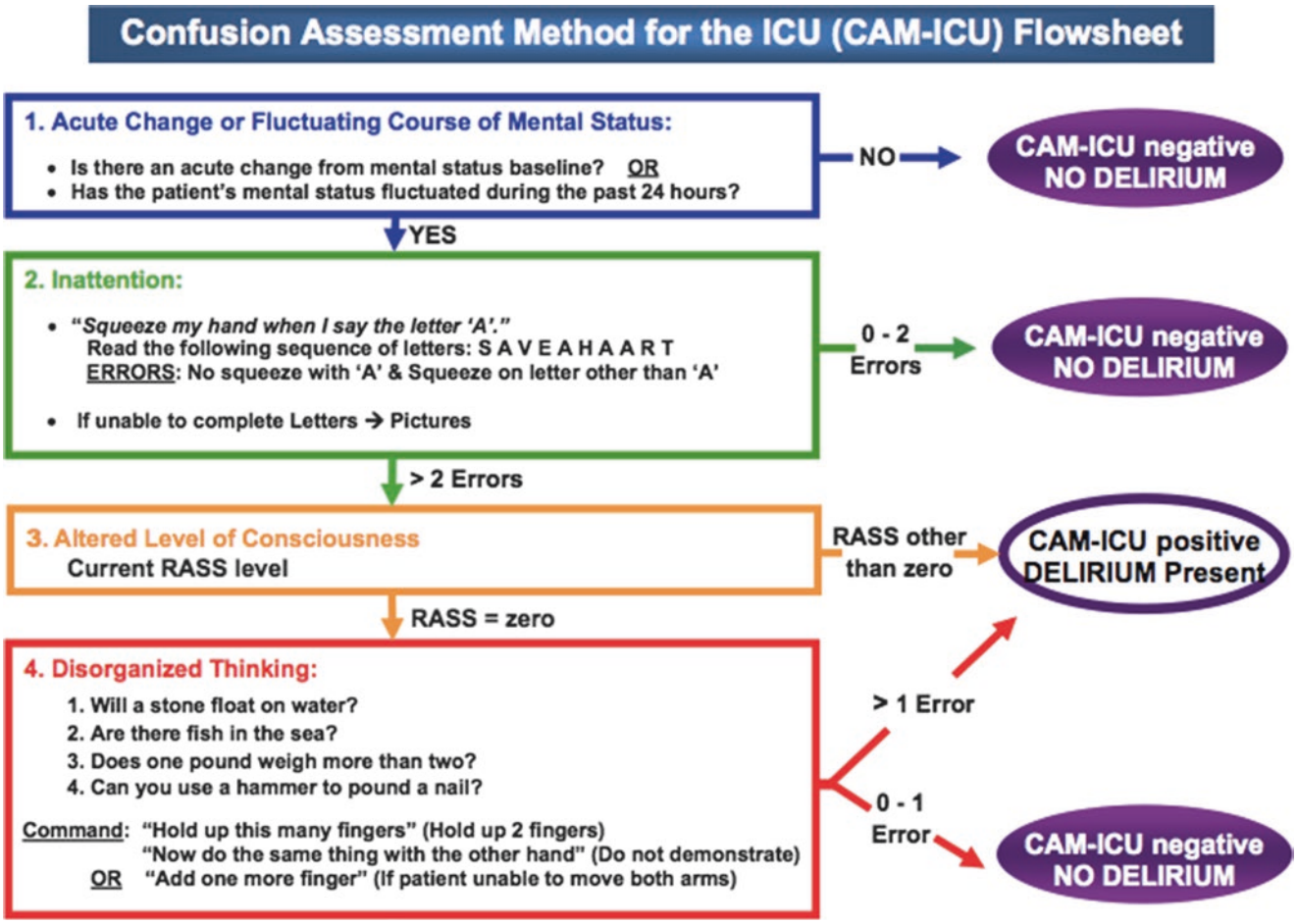

Fig. 9.1 CAM ICU flowsheet

Prevention and Treatment

In the case of delirium, prevention is the best medicine. The National Clinical Guideline Centre of Britain addressed prevention in its clinical guideline titled "Delirium: Diagnosis, Prevention and Management [61]." The American Geriatrics Society published an abstracted clinical practice guideline for postoperative delirium in older adults [84]. The following are a summary of the findings of these reviews supplemented by additional sources as indicated.

Delirium can be difficult to recognize and treat. People at risk for delirium should be under the care of an interdisciplinary team that is "trained and competent in delirium prevention." It would be best if the team were familiar to the patient at risk. Patients at risk should remain with the same caregivers and not change units unless necessary. A tailored multicomponent program should be administered which includes environmental change and non-pharmacological interventions. Rather than recommend a particular program, they chose to focus on the elements that should be addressed. The early assessment of risk is key to this process.

Changes to ensure good sleep patterns include changes to the method of carrying out clinical care. Nursing and medical procedures should be avoided during sleep periods. This includes administration of medication as possible. Noise should be reduced to a minimum during these times as well.

Attention must be paid to medications administered. Utilization of a tool such as the Beers Criteria list mentioned earlier will help identify medications placing the patient at risk and suggest substitutes. Including a pharmacist on the multidisciplinary team can help.

Patients requiring operative intervention should have special attention to perioperative prevention of delirium. Electroencephalographic monitors of anesthetic depth for general anesthesia may decrease delirium incidence. Regional anesthetic should be considered when possible. Postoperative pain control should be optimized. Attention should be paid to non-opioid pain medications whenever possible [85].

Closely assessing for and correcting hypoxia is essential. The same is true for infection. Occult infection can present as delirium. Infection control procedures including reducing use of catheters remain important.

Any sensory impairment that can be improved or resolved should be addressed. Removing impacted earwax and ensuring the availability and use of working hearing and visual aids are among the interventions that can reduce risk.

Lack of or impaired mobility is another risk factor that can be addressed. Early postoperative mobilization should be encouraged whenever possible. Assistive devices should be readily available. Even those who cannot walk should be encouraged to perform active range-of-motion exercises. Physical therapy or rehabilitation medicine can help as part of the multidisciplinary team.

Dehydration and constipation can be detrimental risk factors. Appropriate hydration can be maintained by oral, subcutaneous, or intravenous fluids depending on the status of the patient. Consult as necessary for patients with comorbidities such as heart or renal failure. A bowel regimen should be used with a stepwise approach for prophylaxis and treatment. Nutrition must be maintained. Dentures should be properly fitting and available when needed.

Pain must be assessed by whatever means appropriate. Pain management should be undertaken if not already in place. Pain medication should be reviewed if already being administered.

Environmental and practice changes can address cognitive impairment and/or disorientation. Steps include appropriate lighting, clear signage, and easily visible clocks and calendars. As mentioned earlier, clear communication with eye contact should be the norm when dealing with these patients. Frequent reorientation and reassurance can help. Regular visits from family and friends and activities to stimulate cognition, such as reminiscing, have a positive impact as well.

When patients become agitated or a danger to themselves or others, verbal and nonverbal techniques should be used to de-escalate the situation. When these techniques fail, pharmacological interventions should be considered for short-term use. Haloperidol or olanzapine is recommended in the NICE Guideline. Again, per the geriatric medication mantra, "start low, go slow but go." Cautiously titrate to symptoms. Particular caution must be used with antipsychotics for those with Parkinson's type diseases or Lewy body dementia if they are to be used at all.

One example of an algorithm for prevention and treatment was published by Maldonado in *Critical Care Clinics* 2008 [65]. Recommendations for the pharmacological treatment begin with assessing current medications and discontinuing inappropriate ones. If possible, only use benzodiazepines or barbiturates for CNS-depressant withdrawal, i.e., alcohol withdrawal, or when other recommended agents have failed and sedation is needed to prevent harm.

For the correction of central anticholinergic syndrome, consider acetylcholinesterase inhibitors. Serotonin antagonists (e.g., ondansetron) can be used to control serotonin elevations usually associated with hypoactive delirium.

Consider changing narcotics from morphine and meperidine to fentanyl. Utilize nonnarcotic analgesics whenever possible. Sleep can be promoted by melatonin or its agonists.

Choice and dose of agents differ depending on the type of delirium. For hyperactive delirium, low-to-moderate dose (<20 mg/24 h) haloperidol can be used after ascertaining there are no significant electrolyte abnormalities, other medications that prolong QTc or cardiac conditions. Haloperidol must be discontinued if QTc is prolonged to >25 % of baseline or >500 msec. Atypical antipsychotics should be considered in cases where haloperidol is contraindicated or not desirable. Maldonado suggests there is better evidence for risperidone and quetiapine, and limited data for olanzapine, aripiprazole, perospirone, clozapine, and ziprasidone should be avoided.

For hypoactive delirium, dopamine antagonists may have a place, given the excess dopamine theory. Haloperidol may be used but in very low doses, 0.25–1 mg/24 h. If atypical antipsychotics are used, ones with low sedative properties should be utilized, like risperidone, unless sleep pattern is at issue. In cases of extreme psychomotor retardation or catatonia without agitation or psychosis, psychostimulant or conventional dopamine agonists can be of use. Regardless of the type of medication, prescribed use should be limited to the lowest dose for the least amount of time possible.

Depression

Epidemiology

Depression in the elderly is under-recognized and undertreated. Almost one in five older adults who commit suicide have visited a physician within 24 h of their death, 41 % visited within 1 week of their suicide, and three-quarters of the elderly who commit suicide visited a physician within a month before their death [66, 67]. The incidence of major depression in the community of elderly is reportedly up to 1 in 20. This increases to 11.5 % in the hospitalized elderly and 13.5 % of those receiving home healthcare [68]. It is estimated that five million elderly have some symptoms of a depressive disorder [69, 70]. There is a gender difference with the rate of depression higher for elderly women than men [71]. Depression also lowers life expectancy in this age group.

Periods of feeling blue, sad, or unhappy are normal. When these feelings persist and interfere significantly with the ability to function, they become abnormal. The major depressive disorder is diagnosed by DSM-IV-TR criteria when five (or more) of the symptoms in Table 9.4 have been present during the same 2-week period and represent a change from previous functioning [8]. At least one of the symptoms is (1) depressed mood or (2) loss of interest or pleasure. These symptoms must cause clinically significant distress or impairment in social, occupational, or other important areas of functioning. They cannot be a part of mixed episode and cannot be caused by the physiological effects of a substance or other general medical conditions or better accounted for by bereavement.

Subclinical depression or minor depressive disorder is even more common. This is defined in the DSM-IV-TR as

Table 9.4 Symptoms of depression

1. Depressed mood most of the day, nearly every day, as indicated by either subjective report or observation made by others
2. Markedly diminished interest or pleasure in all, or almost all, activities most of the day, nearly every day
3. Significant weight loss when not dieting or significant gain, or decrease or increase in appetite nearly every day
4. Insomnia or hypersomnia nearly every day
5. Psychomotor agitation or retardation nearly every day
6. Fatigue or loss of energy nearly every day
7. Feelings of worthlessness or excessive or inappropriate guilt (which may be delusional) nearly every day (not merely self-reproach or guilt about being sick)
8. Diminished ability to think or concentrate, or indecisiveness, nearly every day (either by subjective account or as observed by others)
9. Recurrent thoughts of death (not just fear of dying), recurrent suicidal ideation without a specific plan, or a suicide attempt or specific plan for committing suicide

having two to four of the aforementioned depressive symptoms for major depressive disorder. The symptoms must be present for 2 weeks without a history of major depressive disorder. Presentation of subclinical depression may be even more difficult in the elderly. Patients may present with new medical complaints, exacerbation of existing conditions, and a preoccupation with their health.

Changes in life and function can increase the risk of or worsen depression. Chronic pain, poor health from multiple illnesses, loss of independence, children moving away, and death of a spouse or loved one are just some of the factors contributing to the increased risk. Physical illnesses can cause or increase the risk of depression. Dementia, thyroid disease, cancer, and stroke can increase the risk of depression. After a stroke, 25–50 % develop depression within 2 years [72]. About 20–30 % of those with Alzheimer's disease are diagnosed with depression. Half of Parkinson's patients have or have had depression [73]. Various medications can also cause symptoms of depression. Healthcare providers, as well as older adults, can incorrectly assume that depression is normal and an acceptable response to these serious illnesses and life hardships [74, 75].

Suicide is a tragic manifestation of depression. While they make up only 12 % of the US population, people age 65 and older accounted for 16 % of suicide deaths in 2004 [76]. The suicide rate for those age 65 and over is 14.3 of every 100,000 compared to 11 per 100,000 in the general population [76]. Suicide rates increase with age. Suicide rates differ by race (Chart 1). Non-Hispanic white men age 85 and older were most likely to commit suicide. They had a rate of 49.8 suicide deaths per 100,000 persons in that age group. Guns, overdose, and asphyxiation are the most common mechanisms for suicide in the elderly. Older adults are more likely to use lethal means and make fewer attempts per completed suicide.

Factors that increase the risk for suicide are different in older adults. They tend to be more socially isolated [77]. Patients are more likely to have seen a physician prior to their suicide as mentioned earlier [67, 68]. The highest rates of suicide in the elderly are for those who are divorced or widowed. Future factors such as growth in the numbers of the elderly population, health status, availability of healthcare and access to care, and attitudes about aging and suicide will affect suicide rates in this age group.

Risk factors for suicide are present in more than 90 % of older adults who commit suicide. They include depression or other mental disorders, a personal or family history, stressful life events, prior personal or family history of suicide attempt, family violence, guns in the home, incarceration, or exposure to suicidal behavior in other including media figures [78]. Substance abuse, the subject of the final section of this chapter, is a contributing factor to successful suicides in all populations.

Assessment and Screening

Assessment of depression can be challenging. The elderly present differently than younger patients. They are less likely to voice emotions or guilt. The elderly tend to minimize or deny depressed mood. They may be preoccupied with somatic symptoms. Cognitive deficits can be marked. Patients tend to have more anxiety, agitation, and psychosis, and other conditions may mask the depression.

The Geriatric Depression Scale (Table 9.5) is widely used to screen for depression [79]. A short form is available as well as apps for smartphones. A score of 6–9 on the short form suggests depression and 10 or greater is always indicative of depression. As mentioned earlier, the criteria for diagnosing depression is the same as they are in the general population. The

Table 9.5 Geriatric Depression Scale (GDS)

Choose the best answer for how you felt this past week Circle one		
1. Are you basically satisfied with your life?	yes	NO
2. Have you dropped many of your activities and interests?	YES	no
3. Do you feel that your life is empty?	YES	no
4. Do you often get bored?	YES	no
5. Are you hopeful about the future?	yes	NO
6. Are you bothered by thoughts you can't get out of your head?	YES	no
7. Are you in good spirits most of the time?	yes	NO
8. Are you afraid that something bad is going to happen to you?	YES	no
9. Do you feel happy most of the time?	yes	NO
10. Do you often feel helpless?	YES	no
11. Do you often get restless and fidgety?	YES	no
12. Do you prefer to stay at home, rather than going out and doing new things?	YES	no
13. Do you frequently worry about the future?	YES	no
14. Do you feel you have more problems with memory than most?	YES	no

(continued)

Table 9.5 (continued)

Choose the best answer for how you felt this past week Circle one		
15. Do you think it is wonderful to be alive now?	yes	NO
16. Do you often feel downhearted and blue?	YES	no
17. Do you feel pretty worthless the way you are now?	YES	no
18. Do you worry a lot about the past?	YES	no
19. Do you find life very exciting?	yes	NO
20. Is it hard for you to get started on new projects?	YES	no
21. Do you feel full of energy?	yes	NO
22. Do you feel that your situation is hopeless?	YES	no
23. Do you think that most people are better off than you are?	YES	no
24. Do you frequently get upset over little things?	YES	no
25. Do you frequently feel like crying?	YES	no
26. Do you have trouble concentrating?	YES	no
27. Do you enjoy getting up in the morning?	yes	NO
28. Do you prefer to avoid social gatherings?	YES	no
29. Is it easy for you to make decisions?	yes	NO
30. Is your mind as clear as it used to be?	yes	NO
*Count number of CAPITALIZED (depressed) answers Score: _____ (Number of "depressed" answers) Norms ---------- Normal 5 +/− 4 Mildly depressed 15 +/− 6 Very depressed 23 +/− 5		

Comparison of conditions			
	Dementia	Delirium	Depression
Central feature	Memory loss	Confusion	Sadness
Onset	Masked	Acute	Slow
Course	Chronic	Fluctuating	Episodic, possibly chronic
Consciousness	Normal	Altered	Normal
Attention	Normal	Diminished	Possibly diminished
Hallucinations	Rare	Common	Not Common
Psychomotor	No	Yes	No

CAGE questionnaire
1. Have you ever felt that you should Cut down on your drinking?
2. Have people Annoyed you when criticizing your drinking?
3. Have you ever felt bad or Guilty about your drinking?
4. Have you ever had a drink first thing in the morning (an Eyeopener) to steady your nerves or get rid of a hangover?

Brief substance abuse intervention outline: FRAMES method
Giving feedback
Assigning responsibility
Offering advice
Giving a menu of methods to cut down drinking
Expressing empathy
Encouraging self-efficacy

Table 9.5 (continued)

	Comparison of cognitive tests			
	MMSE	Mini-Cog	SLUMS	MoCA
Test	30-point questionnaire	3-item recall and clock drawing	30-point questionnaire	30-point questionnaire
Time to complete	10 min	3–5 min	10 min	10 min
What makes it special?	Can adjust for educational level and age	Better sensitivity than MMSE, not influenced by age or level	Better at detecting mild neurocognitive disorder	Better for mild, early, and Huntington's/ Parkinson's

aforementioned criteria can be found in the DSM-IV-TR. An easy mnemonic to remember is SIG E CAPS. It stands for sleep, interest, guilt, energy, concentration, appetite, psychomotor changes, and suicidality. The vegetative symptoms of sleep, energy, appetite, and psychomotor changes can occur in other medical conditions. The psychological symptoms of interest, guilt, concentration, and suicidality are more reliable in teasing out the diagnosis of depression.

Treatment

Depression in the elderly should be treated, even when accompanying other illnesses. Left untreated, depression can worsen the outcome of the other illnesses. The decreased ability to metabolize drugs and an increased sensitivity to drug side effects make treatment challenging. To lessen the risk of adverse events from treatment medications, the mantra "start low, go slow but go" is effective. Drugs with anticholinergic effects and excessive sedation should be avoided as they can cause confusion and falls among the adverse events. At times, these side effects can be useful to treat symptoms. For example, a patient with significant weight loss and insomnia may benefit from a sedating medication that increases appetite. Those at risk for suicide should be treated aggressively as inpatients.

Electroconvulsive therapy (ECT) may work well when medical therapy has failed or in patients with Parkinson's disease, high suicide risk, or psychotic features. It is very effective in the short term. Though there can be high relapse rates, drug therapy can reduce relapses.

Nonmedical treatments are useful and synergistic with medical therapy. Individual psychotherapy, interpersonal therapy, and cognitive behavioral therapy can be used in this population.

Substance Abuse

Epidemiology

Substance abuse and alcoholism are issues that are often overlooked in the elderly. While it is true that the proportion of people who abuse substances decreases with senescence, about 1 % of elders do abuse alcohol, and up to 16 % of elders engage in heavy drinking (more than two drinks a day for men or one drink a day for women) [80, 81]. This number is expected to increase as the baby boomer generation reaches old age since they have had greater exposure and less stigmata associated with use of alcohol and other substances compared to other age cohorts [82].

Alcoholic elders can be divided into two broad groups: early-onset and late-onset alcoholics. Early-onset users, comprising two-thirds of alcoholic elders, have started using alcohol early in life and have adjusted to their state over time. They have had their first alcohol-related problem in their third or fourth decade of life. Late-onset users begin abusing substances in their middle ages, often after a significant life event such as the death of a spouse or loss of a job [81]. In particular, widows are at a greater risk for increasing drinking, even though women tend to drink less than men at all ages [80]. In general, the late-onset users have achieved a higher level of social class than the early-onset users. Predictors of binge drinking may include younger age, lack of college education, low socioeconomic status, and absence of coronary artery disease [86].

Aging brings a change in the body's ability to metabolize alcohol in a multitude of ways. Lean muscle mass decreases, decreasing total body water and thus decreasing the volume of distribution and increasing the blood alcohol level for a given amount of imbibed alcohol. The liver is slower at metabolizing ethanol due to decreased hepatic blood flow and decreased enzymatic activity. Brain cells also decline in number with age and increase the risk of delirium – either from intoxication or withdrawal. In addition, the risk of falling carries with it much more dire consequences in the elderly. Inhibition of antidiuretic hormone results in urinary incontinence and a free water deficit. Changes in the proportions of gastric cells also predispose the elderly to gastritis [81]. The overall deleterious effects of alcohol use are thus accentuated in the elderly.

Diagnosis and Screening

The stigmata of alcoholism, substance abuse, and withdrawal syndromes are often confused with other conditions endemic in the geriatric patient population such as dementia and delirium; thus, it is important to screen patients for at-risk behavior. Perhaps the simplest and most widely used device is the CAGE questionnaire. This consists of four questions – (1) Have you ever felt that you should cut down on your drinking? (2) Have people annoyed you when criticizing your drinking? (3) Have you ever felt bad or guilty about your drinking? (4) Have you ever had a drink first thing in the morning (an eye-opener) to steady your nerves or get rid of a hangover? With a cutoff score of 2, this test has a sensitivity of 0.48 and a specificity of 0.99 in geriatric patients. This test has been modified to test for substance abuse, as well as with good results [83]. Additionally, several comorbid conditions are common with alcoholism such as depression, insomnia, grief, anxiety, psychosis, and dementia and are worth screening for in alcoholics [80].

Treatment

Treatment for elders can consist of pharmacological interventions as well as counseling interventions. Benzodiazepines are the most commonly used pharmacological intervention, although in the elderly, the potential for adverse effects is heightened. Daytime somnolence, ataxia, and cognitive impairment are all potential adverse effects of benzodiazepine use. Hallucinations can be treated with antipsychotics. Disulfiram should be continued if it has successfully treated alcoholism in the past; however, the elderly have decreased tolerance for the disulfiram/ethanol interaction, and thus it should be started with caution in the elderly. Naltrexone can be used to curb cravings [81]. Brief interventions that follow the FRAMES method (giving Feedback, assigning Responsibility, offering Advice, giving a Menu of methods to cut down drinking, expressing Empathy, and encouraging Self-efficacy) have proven to be effective [81].

Post-traumatic Stress Disorder

Post-traumatic stress disorder (PTSD) occurs after an event or ordeal which causes or has the potential to cause physical harm and is interpreted as terrifying by the individual. Following wartime, PTSD was brought to the public attention. Acute traumatic injuries including but not limited to motor vehicle accidents, mugging, and natural disasters have the ability to cause post-traumatic stress disorder. Elderly patients with underlying psychiatric illness may be more susceptible to PTSD [88]. A small study found that 27 of 100 respondents demonstrated substantial post-traumatic stress symptoms after a fall [87]. There exists a paucity of data with regard to diagnosis, management, and treatment of geriatric patients suffering post-traumatic syndromes outside of wartime. Caregivers should have increased awareness and suspicion of this clinical condition.

Summary/Differentiating Features/Impact on Care

Cognitive and psychological disorders can have a significant impact not only on the care of the trauma patient but on the incidence of trauma. The following summary consists of

quick reference tables and figures that address major areas of this chapter.

Summary table comparing cognitive tests
Summary table comparison of disorders
Summary figure CAM-ICU worksheet
Summary table of depression screening: GDS short
Summary substance abuse screening and brief intervention

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Frailty

10

Cynthia L. Talley and Andrew C. Bernard

Clinical Vignette

An 81-year-old female falls at home, sustaining three rib fractures and a humerus fracture. She is awake and neurologically intact but having pain and dyspnea. Her family reports two falls in the recent past, neither requiring hospitalization. She has hypertension and diabetes and has had a prior hip replacement. She uses a beta blocker, long- and short-acting insulin, and a diuretic. Her family reports forgetfulness, anorexia, and 10-pound weight loss in the last 6 months and less interest in traveling outside the home. She's admitted to the ICU where her oxygenation and urine output are marginal. She is assessed by physical and occupational therapy and found to have a Barthel index of 35/100 (indicating 65 % impairment of activities of daily living (ADLs) performance) and a trauma-specific frailty index of .48 (indicating high risk for discharge to a sub-acute nursing facility). A family meeting is held within 1 day of ICU admission to establish goals of care.

Key Points

1. Frailty is a syndrome of fatigue, loss of strength and weight, decreased physical activity, and exhaustion and is increasing in prevalence.
2. Frailty can and should be measured.
3. Objective frailty measures can be used to predict outcome and guide therapy.
4. Frailty may be modifiable.

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Introduction

Debilitation is a functional impairment that can contribute to or result from acute and/or critical illness. Debilitation is sometimes used interchangeably with frailty, which is a progressive decline in performance that often coincides with aging plus chronic disease, ultimately placing individuals at greater vulnerability to acute illness, injury, disease, and disability.

Frailty is increasing in prevalence as the world population ages. Various tools can measure frailty and debilitation and be used in triage, risk stratification, goal setting, resource allocation, targeting interventions, and predicting recovery and survival [1]. Frailty assessment is recommended routinely in geriatric patients because frailty is more specific than chronologic age in predicting complications and resource utilization [2]. Frailty assessment should also be a component of routine health maintenance and part of any preoperative assessment in older patients [3]. Trauma and critical care providers are faced with the challenge of assessing frailty after a patient is admitted for an acute injury or illness when they are not at their functional baseline.

Definition

A 2013 consensus conference concluded that there are four fundamental principles of physical frailty [4]: (1) frailty is a syndrome; (2) frailty can be prevented and treated; (3) simple screening tools exist; and (4) all persons age 70 years and older should be screened. Frailty is not a moment in time or a threshold that patients cross but rather a gradual progression that increasingly limits physiologic reserve. Frailty is not related to aging alone but rather results from biologic aging influenced by environmental factors including nutrition, exercise, social support, and healthcare, all placed in the context of acute and chronic illness and overlaid by psychological and emotional health and even personality [5] (see Fig. 10.1).

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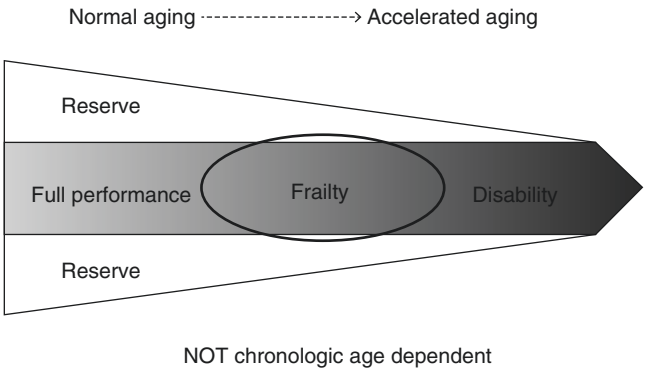

Fig. 10.1 The aging continuum and development of frailty [5]

Diagnosing and Measuring Frailty

Frailty may be measured in many ways. Not every measure of frailty is appropriate for every patient because all variables are not attainable in every patient. At least a dozen frailty measures are relevant to trauma or ICU patients and hold some validity at present (Table 10.1).

Dr. Linda Fried first described frailty as a unique phenotype in 2001 [6]. Fried's frailty phenotype is distinct from either comorbidity or disability and is characterized by three of the following five findings: fatigue, diminution of strength, weight loss (>10 pounds in last year), decreased physical activity, and exhaustion. This definition is now widely accepted, and tallying the components constitutes one of the longest-standing and simplest frailty measures: not frail (score 0 components), pre-frail (1–2 components), and frail (3–5 components) [7]. Fried's criteria correlate with social, psychological, and physical function [8]. Fried score and other tools have been used to predict death and disability in comorbid outpatients and also major adverse cardiac and cardiovascular events in older patients undergoing transcatheter or open cardiovascular procedures [9]. Predictive value of Fried criteria in ICU patients has not been established [10].

Frailty index (FI) is the most studied of all frailty measures. Described in 2001 by Minitski et al., from Montreal, FI was developed using 92 items from the Canadian Study of Health and Aging [11] and remains an important frailty assessment and a validation benchmark for novel frailty measurement tools. FI uses a list of dichotomous and ordinal values expressed over a denominator. If only the dichotomous variables of FI are used (excluding the ordinal variables which grade debilitation on a scale), FI is easier to calculate and maintains high predictive value for mortality, as proven in several large population-based databases [12]. FI and Fried criteria are used frequently in clinical practice and have been expanded upon and modified by many with the resulting tools often being referred to as "modified frailty index" and "modified Fried criteria."

Necessity for easily reproducible, reliable predictors of specific outcomes in specific populations has led to the development of novel frailty assessment tools. Joseph et al. have modified the FI to a shorter, 15-variable trauma-specific FI (TSFI) that reliably predicts unfavorable discharge (discharge to a subacute nursing facility) [13]. The Trauma Quality Improvement Program (TQIP) Geriatric Trauma Management Guidelines recommend a simple test such as the Short Simple Screening Test for Functional Assessment, which, if positive, can then be followed by a more detailed evaluation for functional impairment [14].

Long before Linda Fried's description of the frailty phenotype, the timed "get up and go" test was described by Mathias et al. as an assessment of balance [15]. Also called the "timed up and go" test or TUG, this test is performed by recording the time in seconds required to rise from an arm chair, walk to a line 3 m away, return, and sit again. TUG correlates well with the Berg Balance Scale which measures fall risk and the Barthel index which measures ADL [16, 17]. The TUG has been modified (m-TUG) and expanded (ETUG) and the novel versions evaluated systematically, but these modifications may not significantly change the original TUG's utility for the geriatric ICU/trauma population [18].

The Berg Balance Scale (BBS) is a well-studied and reliable assessment of functional status that focuses on standing from a sitting position, stationary standing, and transfers. BBS cannot be easily applied in patients with limited lower-extremity weight bearing and is therefore most valuable in monitoring progress during rehabilitation [19].

Gait speed can be assessed at a health maintenance visit, preoperatively, or in ambulatory hospitalized patients, in which case it can be used in planning transition of care. Pamoukdjian performed a systematic review of gait speed, both by itself and as a component of the TUG, and found a gait speed of less than 1 m/s over a 4-m distance to be a predictor of early death, disability, falls, and institutionalization [20].

The British Geriatric Society (BGS) has recommended that frailty be assessed in older patients whenever they encounter community health or social service providers and that simple tools like gait speed (<0.8 m/s) and the TUG test (>10 s) be used as indicators [21]. In its recommendations, the BGS suggests that if signs of frailty are identified, they should prompt discussion with patients and families about frailty, direct attention to medical illnesses that could be treated, and suggest those frailty signs serve as a basis for physical conditioning. Such an approach would be ideal prior to major elective surgery, especially in patients who are likely to require admission to the ICU postoperatively.

The Short Physical Performance Battery (SPPB) can be used in community and in acute settings. SPPB assesses

Table 10.1 Current frailty measures relevant to trauma

Test [Reference]	Measured end-point	Key aspects
Fried score [8, 10]	Death and disability	Range 1–5, robust/pre-frail/frail
Frailty index (FI) [11, 76]	Mortality, disposition	Range 0–1, 40 possible variables
Trauma-specific frailty index (TSFI) [13]	Discharge disposition	Range 0–1, 15 possible variables
Short simple screening test for functional assessment [14]	Risk for functional limitation of activities of daily living (ADL)	4 questions regarding ADL
Timed "Up & Go" (TUG) [15–17]	Balance; falls risk; correlates with ADL	3-m walk, sitting to sitting
Berg Balance Scale [19]	Balance, standing, transfers	Range 0–56, balance and imbalance
Barthel index [60]	ADL	0–100 scale, ADL
Gait speed [20]	Early death, disability, falls, hospitalization	5 m, $\geq$ 6 s indicates frailty
Short Physical Performance Battery (SPPB) [22]	Falls, functional dependence, Fried criteria, FI	Range 0–12, functional performance, primary lower extremities
Vulnerable Elders Survey [24]	Complications and death after trauma	Range 1–10, self-report
Grip strength [26]	Physical function, sarcopenia	Continual, performance test
Functional independence measure (FIM) [27]	Functional outcome	7-point scale, functional independence
Score Hospitalier d'Evaluation du Risque de Perte d'Autonomie (SHERPA) [29]	Post-discharge functional status	5 variables: age, ADL performance, prior falls, self-rated health, and cognitive impairment
Assessing Dementia 8 Screening Interview (AD8) [31]	Driving errors	Range 0–8, cognition, screen for Alzheimer's disease
Katz activity of daily living survey/ Katz-6/Katz-15 [32]	Unfavorable health outcomes	Range 0–6, ADL
Short Form 36 (SF-36) [34]	Postoperative complications	36-item, self-report health survey
Life Space Assessment [25]	Community mobility, decreased score coincides with falls	Range 0–120, life space mobility, independence, and frequency
Charlson index [36, 37]	Functional recovery at 1 year; mortality	17 categories of comorbidity
Albumin [39, 40]	Intubation, pneumonia, institutionalization	Serum
Sarcopenia [41, 77]	ICU length of stay, mortality, ventilator days	Multiple methods: imaging, bio-impedance, anthropometrics, physical function

three parameters of physical function: (1) static balance, (2) gait speed, and (3) standing from a chair. Each category scores 0–4 with a composite score of 12. SPPB is a valid, reliable predictor of falls and functional dependence and has been correlated with frailty index and the modified Fried criteria [22, 23].

The Vulnerable Elders Survey-13 (VES-13) predicts complications and death in geriatric trauma patients [24]. The Life Space Assessment (LSA) developed at the University of Alabama at Birmingham assesses mobility over the preceding 4 weeks including mobility away from home, frequency of mobility, and level of independence from assistance or assistive devices. Decreasing LSA coincides with falls, but the LSA's predictive value in hospitalized patients has not been validated [25].

Handgrip strength is commonly used to assess weakness, which is an important adverse effect of hospitalization and one of the Fried criteria for frailty. Grip strength alone predicts ICU paresis and also correlates with Physical Function Intensive Care Test (PFIT) and 6-min walk test (6MWT), though the exact clinical utility of PFIT and 6MWT themselves is uncertain [26]. PFIT, grip strength, and 6MWT can, however, identify trends and thus may be used to measure effect of interventions in the ICU targeted at reducing the harmful effects of ICU stay on functional status.

Functional independence measure (FIM) is a well-validated measure of overall physical function, social and psychological function, and ADL. FIM predicts post-discharge functional status, is worse at discharge in patients with a lower admission FIM score, and correlates with frailty index [27]. The Chelsea Critical Care Assessment Tool has also been assessed in the ICU population and been found to be valid in measuring changes in performance among ICU patients, but its relevance specifically in geriatric and frail ICU patients has yet to be established [28].

The Score Hospitalier d'Evaluation du Risque de Perte d'Autonomie (SHERPA) uses five variables: age, ADL performance, prior falls, self-rated health, and cognitive impairment, to predict functional status after hospital discharge. The SHERPA's utility above other scoring systems remains unproven [29]. Contrary to what one might think, dementia alone may not be a reliable predictor of outcome among ICU patients [30]. However, the Assessing Dementia 8 (AD8), a commonly used screening tool for Alzheimer's disease, correlates with driving errors so therefore is perhaps

relevant to injury prevention measures on discharge among older drivers [31].

Several assessment tools have been used in the primary care, community health, and preoperative settings but because of complexity may not be applicable to the ICU or acute care environments. The Katz Activity of Daily Living Survey measures ADLs, mobility, and instrumental ADL and has been widely validated for a number of outcome measures. Originally known as the Katz-6, it has now been modified to the Katz-15 which predicts unfavorable overall health outcome [32] Green et al. combined the Katz activity of daily living survey with serum albumin, grip strength, and gait speed to derive a novel score predicting outcome after transcatheter aortic valve replacement (TAVR) [33]. The SF-36 correlates with frailty index and postoperative complications [34]. The cognitive mini exam (Mini-Cog) has also been used to predict outcome [35].

Some assessment tools for frailty can be performed without physically evaluating the patient. The Charlson comorbidity score was first reported by Charlson et al. in 1987 and uses diagnosis data from 19 categories to predict long-term outcome, including functional recovery at 1 year in elderly ICU patients [36, 37] Kim et al. developed a predictive model of poor functional status using claims data. The model offers a high level of discrimination and could be used in epidemiologic studies and in understanding resource use across a healthcare system or population [38]. Laboratory and radiology tests can also be used to assess frailty, guide resource use, and predict prognosis. In one recent study, albumin was used as one component, along with COPD, assisted status, tube thoracostomy, injury severity score, number of rib fractures, and CHF, to comprise a frailty score to predict intubation and pneumonia in elderly patients with rib fractures [39]. Albumin has long been used as a predictor of outcome in surgical patients and can predict institutionalization at discharge after surgery among geriatric patients though not as reliably as TUG and overall functional dependence [40]. CRP, IL-6, TNF-α, D-dimer, albumin, IL-1, 25(OH)D, and low cholesterol have all been correlated with frailty and functional decline, but their clinical application is not yet clear [5].

A rapidly expanding body of evidence supports sarcopenia as an ideal objective measure for frailty that can be determined by diagnostic testing. Critical illness and muscle disuse are associated with altered protein synthesis and cell signaling that exacerbates skeletal muscle loss in the acutely and critically ill. The Nutrition and Rehabilitation Investigators Consortium reported sarcopenia to be a reliable indicator of ventilation, ICU stay, and death [41]. Future studies must elucidate the differential roles of preadmission sarcopenia versus sarcopenia as a result of critical illness [42].

Using Debility in Management

Frailty assessment should help guide treatment. Surrogate responses must sometimes be used to assess physical function and frailty because the patient cannot participate completely or at all [43]. Maxwell et al. reported good agreement between patient and proxy on the VES-13, the modified Barthel index, and the Life Space Assessment [43]. Providers should assure that the frailty assessment tool they are using has been validated in the population to which it is being applied and should consider whether surrogate responses are valid.

Frailty assessment may require incorporating providers with geriatric training and experience into the trauma team, but this is not a requirement. Composition of the geriatric trauma and critical care team is a matter of great interest among providers and these compositions are changing. More than half of survey respondents who were members of the American Association for the Surgery of Trauma (AAST) reported that geriatric-specific personnel and resources are rarely or never used at their institution [44]. However, almost half of these respondents felt that further research regarding the "use of gerontologist, geriatric teams, or geriatric centers in the management of trauma patients" should be a high priority.

The American College of Surgeons Trauma Quality Improvement Program Geriatric Management Guidelines and many authors recommend proactive geriatric consultation. Seventy percent of the respondents in the AAST survey report that skilled nursing facilities (SNFs) have become the most common discharge destination, but few agree that SNFs are the best disposition. Geriatric consultation can reduce the risk of discharge to a long-term acute care facility and can also reduce the number of episodes of delirium, decrease inhospital falls, shorten length of stay, and improve functional recovery [45].

Geriatric Rehabilitation Units staffed by a multidisciplinary team, usually led by a physiatrist, can coordinate care of the elderly patient's chronic health issues as well as their environmental factors. Regardless of whether the trauma/ICU team includes a geriatrician, multidisciplinary care is essential in geriatric trauma. The British Geriatric Society recommends a holistic medical review such as a comprehensive geriatric assessment (CGA) for the management of frailty that will diagnose medical illnesses, optimize treatment, apply evidence-based medication review checklists, include discussion with older people and caregivers to include defining the impact of illness, and then create an individualized care and support plan [21]. TQIP guidelines also recommend such CGAs for geriatric trauma patients with certain risk factors. The CGA, which should include a frailty assessment, may then serve as a basis for patient/

family meeting regarding care plans and prognoses. Interventions should be targeted at optimizing physiology, minimizing complications, maintaining functional status, and returning the geriatric patient to their preadmission functional level and environment as often and as quickly as possible. For example, early physical therapy/occupational therapy in the ICU conveys better functional outcome when discharged, shorter periods of delirium, and more ventilator-free days [46].

Frailty assessment can be used to influence end-of-life care and palliative care decisions. Frailty index has been used to predict survival past 30 days in a specialized geriatric ICU. Every 1 % increase in FI correlates with an 11 % increase in mortality. In that study, no patient with FI > 0.46 survived past 90 days [47].

Outpatient Care

Frailty assessment and the CGA can guide the transition of care. The "Continuum of Care for Frail Older People" intervention study by Eklund et al. showed that after hospitalization, nurses with geriatric training who followed frail patients from the emergency room to their home with a multi-professional team were able to double the odds of improved ADL independence [48]. Watkins reported a social worker transitional care model for at-risk elderly patients that performed a home visit within 74 h of discharge to assess the home environment, aided in medical management, and made referrals for other services with follow-up phone calls and visits [49]. This model decreased hospital readmissions by 61 % and showed significantly improved quality-of-life scores [49].

Returning patients to the community after discharge requires that multidisciplinary care continue even as an outpatient. Beland et al. assessed all integrated systems of care for the frail elderly and found that essential to each model is coordination of resources across care providers to ensure continuity of care [50]. Unfortunately, interventions and care models with solid evidence of efficacy are lacking. De Stampa showed that the Coordinating Care for Older People (COPA) model, which integrated primary care and intensive community case management for very frail elderly patients, was able to reduce unplanned hospitalizations, but though the group experienced less depression and dyspnea, planned hospital readmissions increased, so the total hospital admissions did not change [51]. Metzelthin studied the interdisciplinary primary care approach and its effect on disability reduction in the community-dwelling frail elderly patients [52]. Twelve general practices were randomized and delivered a multidimensional assessment of its patients and then a tailor-made treatment plan with regular evaluation and follow-up. Unfortunately, there was no evidence of effectiveness as measured by disability at 24 months [52]. The optimal transition and outpatient care model for frail injured elderly remains to be determined.

Preoperative Optimization

Preoperative comprehensive geriatric assessment optimizes functional status and improves outcome by better management of comorbidity and reducing frailty [53]. Treatment of depression and alcohol abuse and dependence has also been shown to improve outcomes. Preoperative physical activity may positively impact several components associated with frailty syndrome including sarcopenia, functional impairment, cognitive performance, and depression [54].

In order to reduce frailty in an elderly patient, multiple facets of physical function should be assessed including strength, range of motion, mobility, endurance, and flexibility. A physical therapy program should include an exercise plan, necessary assistive devices, and environmental modifications. Innovative interventions show promise including improving physical health of frail elderly patients prior to elective hip surgery through a preoperative home-based physical therapy program [55]. Hoogeboom reported that a preoperative home exercise program was well tolerated and demonstrated improved preoperative functional status but that the improvements were not sustained postoperatively [56]. Home exercise programs have also increased walking speed and scores on the Activity Measure for Post Acute Care tool over a 12-month intervention among 241 community-dwelling older people in Australia [57]. Tai Chi exercises may be even more effective than conventional physical therapy. Tousignant et al. randomized community-dwelling frail elderly to 15 weeks of either therapy, and while both reduced fall incidence, Tai Chi was more protective [58].

Functional circuit training programs including functional balance and lower-body strength-based exercises over 12 weeks improved self-reported fear of falling and physical function and the effects were sustained at 36-week follow-up [59]. In a prior study by this group, functional circuit training in a randomized controlled trial was also associated with significant improvements in function and reduced physical frailty among frail older adults [60]. In 2014, this group performed a meta-analysis of physical exercise intervention studies and found improved normal gait speed, fast gait speed, and the Short Physical Performance Battery when compared to control groups without exercise intervention. However, other parameters were not affected, such as balance, endurance, or ADL functional mobility [61]. Chou et al. performed a meta-analysis in 2012 which demonstrated

that exercise groups increased their gait speed and Berg Balance Scale (BBS) score and improved ADL performance compared to control groups, but that exercise had no effect on timed up and go test and quality of life [62]. So it appears that the answer to whether exercise improves functional status depends very much on the type of exercise and the parameter being tested.

Sarcopenia undoubtedly contributes to frailty, but protein supplementation can improve muscle mass and physical performance [63]. Sixty-five frail elderly subjects were randomized to daily protein or placebo supplements. Skeletal muscle mass did not change in either group, but muscle strength increased in both. Physical performance was significantly increased in the protein supplementation group [63]. In a second study from the same group, protein supplementation combined with a progressive resistance-type exercise training program increased lean body mass but did not increase strength or physical performance compared to the randomized control group of exercise training alone, so the precise role of protein supplementation is still under investigation [64].

Decreased testosterone in aging men may contribute to loss of muscle mass and strength leading to the development of frailty. Testosterone replacement is a potential treatment of frailty proposed by O'Connell et al. in 2011 [65]. This group found that traditional androgen therapy and selective androgen receptor modulators (SARMs) may have similar potent anabolic effects on skeletal muscle mass and function [66]. Marzetti et al. demonstrated that muscle integrity and improved physical performance in late life can be achieved by downregulating myocyte apoptosis through a combination of calorie restriction, exercise training, hormonal supplementation, drugs (angiotensin-converting enzyme inhibitors, acetaminophen, antimyostatin antibodies), nutraceuticals, or genetic interventions (PGC-1a overexpression) [67]. Optimal medical therapy for frailty remains unclear. For example, though the majority of elderly patients with heart failure have frailty and management of comorbidity like hypertension may help prevent frailty, aggressive management may have negative consequences for those already frail [68, 69].

Future Research

Research in geriatric trauma and critical care is highly relevant given the world's aging population, but enrollment and retention in frailty research can be difficult. Lack of perceived benefit, difficulty with subject retention, distrust of investigators, and poor mobility to and from research interventions are just some of the barriers to geriatric trauma research [70]. Fundamentally, a consensus definition is needed for frailty in ICU care [71]. A standard definition for sarcopenia is also needed, including differential effects of preexisting sarcopenia and iatrogenic sarcopenia and their respective treatments [72]. Improved triage of patients to appropriate centers or care areas would logically follow from these improved definitions of the geriatric trauma population [47].

Members of the AAST identified indicators of frailty as a research need along with optimal post-discharge rehabilitation, fall prevention, and the use of gerontologists or geriatric teams/centers in the management of trauma patients [73]. Predictors of mortality exist, like the frailty index which may reliably predict survival among geriatric ICU patients, and other frailty scoring systems may be similarly or more effective at predicting outcome [47].

Assessment and measurement of frailty at baseline, changes in frailty during the care continuum, and the use of frailty scoring in transition of care will remain important as will the use of frailty scoring as a threshold for palliative care consultation. Frailty education does appear effective at improving discrimination, and further research into frailty assessment education is warranted as centers train teams to better care for geriatric trauma patients [74]. Whether frailty can be modified by physical training among hospitalized patients is not known. Mobility programs and other interventions must be studied, like the SOMS study, which was conducted in Germany and Italy with results expected soon [75].

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Health-Care Economics and the Impact of Aging on Rising Health-Care Costs

11

Preston B. Rich and Noran Barry

Trends in US Health-Care Spending

With a gross domestic product (GDP) of $17.9 trillion, the US economy is the largest in the world, representing 22 % of all global economic activity. Currently, US health-care costs represent a larger percentage of this GDP than any other developed nation in the Organisation for Economic Co-operation and Development (OECD) and result in the highest national per capita spending ($9,523) in the world [1]. Historically, US health-care expenditures have progressively outpaced growth in real income and have consistently exceeded GDP expansion by an average of 2.5 % since 1975 [2] (CMS), [3]. US health-care spending has grown from $27.1 billion (5.3 % of GDP) in the pre-Medicare era of 1960 to $3.0 trillion in 2014 (17.5 % of GDP) [1, 6, 7]. Over the same period, the percentage of health-care costs paid for by the US government (federal and state) has progressively increased such that public sources now account for nearly 50 % of all payments [3].

Looking forward, economists project that health-care costs will continue to increase at a rate of 4–7 % per annum (forecasts are highly dependent on public policy and legislative action), a rate that if unabated will expand health-care spending as a percentage of GDP to 30 % by 2035 and will eventually exceed 50 % of all US economic transactions in aggregate by 2080. Federal financing of health care is already facing profound shortfalls, with Medicare Part A payments currently exceeding committed payroll tax revenue. If Medicare costs continue to grow at contemporary rates, the trust fund assets will be depleted by 2029. Given simple economics, it is evident that the rising costs of health care may represent the single greatest threat to the economic security of the US population.

Key Drivers of Health-Care Spending

There is growing consensus that the disproportionate rise in health-care costs is unsustainable and must be controlled given realistic expectations for associated growth in GDP. While the major factors that contribute to cost acceleration can be reasonably well identified and agreed upon, there is more controversy regarding the relative magnitude and economic importance of the various components. The aging of the baby boomer generation is commonly thought to be a major driving force for the increase in overall health-care expenditures. However, despite the increasing proportion of the elderly and the higher per capita spending incurred by this group, most economists attribute only about 3 % of the cumulative increase in health-care spending to this one driver [CBO 2008].

Health care as a commodity is effectively a surrogate for the underlying associated values, which are the quality of health itself and the desire to maximize both individual and collective welfare. There is little doubt that in many cases, health-care spending and resource allocation can be directly translated into the development of productive technological developments, the prolongation of life, the relief of suffering, and a measurable improvement in the quality of health. However, cost, quality, and well-being are not always directly related. From the perspective of economic efficiency and the appropriate allocation of scare resources, this nonlinear relationship necessitates the distribution of our scarce resources within the broader context of efficacy, cost-effectiveness, comparative analysis, and efficiency.

Insurance Although health insurance was initially conceived as a mechanism to reduce the financial impact of catastrophic illness, its role has expanded in attempts to

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make all types of health care financially accessible and available to the population. As health-care costs have continued to rise, the amount of out-of-pocket expenses paid by the end user has almost inversely decreased [KFF March 09]. Although causality in this relationship is difficult to directly establish, a classic experiment conducted by the RAND Corporation from 1974 to 1982 provided strong evidence that reductions in coinsurance lead to more people using health services and more services used per person [8]. On the other hand, cost sharing reduced the use of both inappropriate and appropriate medical services. Whereas this effect had minimal consequences on the health status of the majority of people enrolled in the study, for those who were poor and suffered chronic illnesses, the reduction in health utilization was harmful. The CBO concluded that between 5 and 20 % of the increase in health costs can be attributed to the progressive expansion of more extensive health-care coverage. One economist estimates that the insurance expansion represented by the institution of Medicare in 1965 may explain nearly half of the increase in health-care spending that occurred between 1950 and 1990 [9, 2].

The Patient Protection and Affordable Care Act Enacted in 2010, the Affordable Care Act (ACA) sought to increase the quality and affordability of health insurance and reduce the number of uninsured or underinsured Americans, while ultimately reducing health-care expenditures for both individuals and the federal government. Several economically significant provisions of the ACA were implemented in 2014, including an extensive federally funded expansion of the Medicaid program along with concomitant development of private health insurance products through the implementation of health insurance marketplaces, premium tax credits, and cost-sharing subsidies (Truffer, OMB).

Increased access to health care provided by the various components of the ACA resulted in 8.7 million less uninsured individuals in the USA (a 19.5 % decline) and the highest health-care-insured US population rate since 1987 (88.8 % in 2014) (MSIS, CMS). Simultaneously, programmatic expansion also accelerated national health-care-associated spending across the spectrum of payers (per annum 2014: private insurance 4.4 %, Medicaid 11 %, Medicare 5.5 %), increasing aggregate annual US health-care expenditures by 5.3 % in 2014 and continuing to exceed post-recession GDP growth by 1.2 %. US health-care spending increases associated with the ACA were widely distributed across various cost levers including retail prescription drugs (12.2 %), hospital care and related services (4.1 %), and physician and clinical services (4.6 %) (IMS).

Technology As the USA has transitioned from its manufacturing-based industrial revolution to an economy that is 80 % service oriented, Americans have grown accustomed to rapid disruptive innovation and the development of advanced technological breakthroughs that fundamentally alter the structure and function of markets. In no sector is this phenomenon more evident than in health care. The development of new drugs, devices, services, procedures, and applications not only impacts current treatment paradigms but in many cases also expands possible treatments to new populations. Technological advances often outpace our ability to adequately study their effectiveness, and evidence-based strategies designed to rationally apply them are often replaced by their rapid and unsystematic adoption with unpredictable incorporation into medical practice.

Although the potential exists for innovative technological advancements to decrease the cost of health care by reducing hospitalization or avoiding associated morbidity, most experts agree that the majority of medical technological developments significantly increase the costs of health care [4]. Even when cost reductions are possible, technology expansion and application into broader populations has the net effect of increasing spending. While measuring the direct financial impact of technology can be difficult, the cost contribution of technology on health-care spending can be estimated as the cost residual that remains after accounting for more readily measurable drivers. Using this methodology, the Congressional Budget Office (CBO) estimates that approximately 50 % of the growth in US health-care costs can be attributed to technology, making it the single greatest contributor to health spending [CBO 2010, Newhouse]. It is reasonable to predict that desirable technologies will continue to be developed in the future, perhaps at an even greater pace, further complicating our decisions regarding allocation of our limited resources [2].

Other Costs As medical care and its financial components become more complex, so must the infrastructure that sustains it. While the administrative costs required to deliver health care can be difficult to accurately capture and gauge comprehensively, few would argue that the associated expenditures are rising. Historical estimates attribute 3–10 % of rising costs simply to increases in administrative and support functions in the sector. The CBO found that administrative costs have escalated from approximately 7 % year between 1995 and 2005 to nearly 13.8 % in 2013 as a result of ACA-associated increased enrollment in Medicare and Medicaid [10].

The role of medical malpractice liability on escalating health costs relates both to the measurable impact of rising insurance costs paid by providers and the less quantifiable

but arguably more significant contribution of increased costs related to the practice of "defensive medicine." Because malpractice premiums constitute only 1–2 % of US health-care expenditures, the projected 6 % direct reduction in premiums that would likely result from tort reform would be expected to have only a modest impact on total expenditures [15]. This larger potential issue is also the most controversial – the notion that health-care costs are driven dramatically higher by medical practice that may overutilize medical resources solely to reduce the chance of litigation. Several studies designed to address this issue have provided disparate results, and the relationship between malpractice liabilities and global health-care costs remains in large part unanswered [2].

Because health and wellness are desired states of being, health care as their market-based surrogate is also a desired service. As personal income rises, one's ability to pay for a variety of health-care services increases. Health care is a normal good, such that aggregate demand for it increases as income increases. Furthermore, because there are few substitutes available to replace it, health care exhibits significant price elasticity of its demand function. Consumers are fairly price insensitive, and this effect is further magnified by the relative disengagement of payment and services that occurs from the interposition of third-party intermediaries. A high per capita income in the USA is often cited as one of the key factors that contribute to our comparatively high health-care costs. The true magnitude of this effect is a matter of debate, but economists have estimated the elasticity of US health care at approximately 0.2, meaning that for every 10 % increase in real income, associated health expenditures can be anticipated to rise approximately 2 % [Liu Chollet, CBO 2008].

Chronic Disease and Disability In the USA, health-care resources are not distributed equally among the population. To the contrary, the sickest 5 % of the US population accounted for nearly half of all health spending in 2008 and 2009, and just 30 % of the population account for nearly 90 % of aggregate US health expenditures. The elderly are disproportionately represented among this top decile of spenders, comprising 13.2 % of the population but 42.9 % of the heaviest consumers. Not surprisingly, chronic diseases are more prevalent in the older population, and their presence increases and maintains the elevated costs of health care in this portion of the population [17].

Chronic diseases, which affect older adults disproportionately, are the leading cause of death and disability in the USA, and modifiable conditions such as obesity and smoking are the most significant contributors [18]. In aggregate, the treatment of chronic diseases accounts fully for 75 % of US health-care costs [20, 19]. In the USA, approximately 80 % of individuals over age 65 have at least one chronic condition, and 50 % have at least two [19]. The ten most prevalent chronic disease diagnoses account for nearly one-third of national hospital charges. Of these, the Agency for Healthcare Research and Quality (AHRQ) identified five as sources of potentially preventable hospitalizations given exposure to appropriate health modification strategies and preventive health measures (coronary artery disease, congestive heart failure, diabetes, chronic obstructive pulmonary disease, and asthma). The economic costs of chronic disease are cumulative; treating patients with one chronic condition (25 % of the US population) costs twice as much as treating those without chronic disease. Treating patients who suffer from multiple comorbid conditions costs up to seven times as much as does treating patients burdened by only one chronic condition [18, 20].

In addition to the increasing incidence of chronic disease, the aging process is associated with increasing disability secondary to sarcopenia or progressive loss of muscle mass. Approximately 45 % of Americans over age 65 are sarcopenic, with approximately 20 % of the US population being functionally disabled [21]. When the prevalence of disability and the estimated increased cost for each individual are multiplied by the increasing number of older Americans, the economic burden of sarcopenia alone is estimated at $18.5 billion [21].

The rise in obesity in the USA has been particularly problematic and costly to the US health-care system. Obesity rates in the USA are now the highest in the world and have dramatically increased in all age groups over the last decade [18, 23]. For adults, the obesity rate (BMI>30) has tripled since 1960, while the incidence of morbid obesity (BMI>40) has risen sixfold. Because obesity raises the associated risks of major comorbidities such as cancer, stroke, coronary artery disease, and diabetes, the impact of its effect on health is essentially magnified. In real terms, the relative cost of obesity was $1,429 per year (42 %) higher than caring for the non-obese population in 2006 [9, 22]. When combined with its prevalence, this high cost translated into $147 billion annually by 2008 or roughly 21 % of US health spending – a cost that has now surpassed that associated with smoking [24]. As obesity rates continue to increase in the future, one can expect continued increases in associated chronic diseases and related health costs [CBO 2010].

End-of-Life Care Elderly patients undergoing elective or emergent surgical procedures experience significantly more 30-day serious morbidity and higher mortality when compared to younger patients [25]. Often the perioperative care of the aging occurs in either a medical or surgical intensive

care unit (ICU), and elderly patients account for approximately 50 % of all ICU admissions and nearly 60 % of all ICU days [26]. Intensive care accounts for 20–30 % of overall hospital care costs in the USA, which was approximately $62 billion in 1992 [27]. Of the patients treated in the top decile of expensive hospitalizations which included ICU care, 20 % (2 % of all hospitalizations requiring ICU care) died within 3 months [27]. The elderly account for more than 70 % of all in-hospital deaths according to the Healthcare Cost and Utilization Project (HCUP). The average hospital costs for a stay that ended in death was $23,000, which is 2.7 times higher than for a patient discharged alive [Zhao].

Health-Care Pricing Some estimates attribute between 10 and 20 % of rising health costs to higher price trends prevalent in the health-care sector [35]. While data patterns clearly support a progressive and significant rise in prices over time, an adequate analysis of their relationship to true cost is more challenging. Complicating these conclusions is the lack of an effective and concurrent measure of comparative effectiveness and the impact of economic externalities. Because increases in technology tend to be associated with higher prices, it is unclear how much of a given price rise represents simple price inflation versus a marker of improved care that may be associated with increased quality or even global reductions in total economic cost. It is plausible that some higher prices may generate cost reductions if the higher price yields even higher benefits from downstream associated effects such as increased comparative effectiveness, superior diagnostic quality reducing unnecessary procedures, the avoidance of high-cost care such as hospital admissions or readmissions, or a subsequent decrease in the development or severity of chronic illnesses and conditions.

Market Failures in the Health-Care Sector The US health system has become increasingly complex, particularly from an economic perspective, as its overarching structure has progressively evolved from a fundamentally free-market system into a mixed system that incorporates components of both free-market forces and the command attributes marked by government intervention that are common in many European health-care systems. While Americans typically regard the US health system as a free-market economy, various interventions including the introduction of third-party payer systems such as private health insurance and the development and expansion of government-sponsored programs, like Medicare, Medicaid, and SCHIP, have generated many instances of what economists would refer to as "market failures" endemic in our system.

A market is a place, real or virtual, where sellers and buyers meet to execute transactions. Free markets exhibit qualities of perfect competition, where each and every participant is considered a "price taker," and no party possess the unilateral power to influence the price of a product it either buys or sells. Prices are determined by the laws of supply and demand, where a single price exists whereby the marginal benefit of obtaining one more unit exactly equals the marginal cost required to produce that one additional unit. This price, determined simultaneously by the market participants, is the only price that will effectively "clear" the market. Such a "perfect" market demonstrates "Pareto efficiency," whereby no single market participant can benefit further by additional transactions without simultaneously disadvantaging another member.

Perfectly competitive markets demonstrate several key features that are each necessary to permit the ongoing efficiency of the marketplace. (1) An infinite number of market participants must be present and willing to both buy and produce a product at the market-clearing price. (2) There must be no barriers to exit or entry; any willing participant can freely enter or exit the market. (3) All buyers and sellers must possess perfect information about the prices, quality, and nature of the products represented in the market. (4) Zero transaction costs; buyers and sellers can incur no costs associated with the buying or selling of goods or services. (5) Firms will exhibit profit maximization whereby they strive to produce and sell products at a price where their marginal costs exactly equal their marginal benefit. (6) Products in the market must be homogenous, without variation across various suppliers. When one or more of these conditions are not met, market failure occurs, and the allocation of goods and services in a given marketplace is not economically efficient.

In practice, market failures occur commonly and are often associated with information asymmetries, noncompetitive markets, the existence of significant barriers to entry for new participants, and what are known as principal-agent concerns problems, as occur with moral hazard, conflicts of interests, and misaligned financial incentives. Many would argue that the current system of health-care delivery in the USA suffers from frequent and significant market failures that fundamentally alter its economics and contribute greatly to health disparities, inefficient allocation of scarce resources, and escalating costs that do not represent true market-clearing prices and alter the nature of the relationship between supply and demand.

Information Asymmetry An efficient and free market is highly dependent upon the presence of perfect and inclusive information being readily available to both buyers and sellers about all marketable goods and services transacted upon. Comprehensive information permits market

participants to ascertain value, such that decisions about marginal cost and utility can result in an optimal and efficient clearing price. Perhaps in no situation is information asymmetry as apparent as in health care. The practice of Medicine is a highly specialized and difficult-to-understand field, often with the superimposed potential for life-and-death outcomes, and aggravated by marked time pressure constraints that preclude adequate information gathering. This extreme and almost universal asymmetry of information causes severe market failures, with the result often being inefficient resource allocation and price deflections.

Physicians as Agents Information asymmetry in health care produces an unusual relationship between market participants; patients rely on their providers to act as their advocate or agent, with licensure and professional codes of conduct as quality control measures. However, because physicians also serve as market suppliers with financial motives to provide goods and services, the potential for market failure is always present. This issue may result in supplier-induced demand, whereby providers allocate resources based on the potential for personal financial gain rather than to simply satisfy the health needs of a population.

Barriers to Entry In the 1960s, the American Medical Association (AMA) sought to restrict the supply of health-care providers by introducing the requirement that physicians become licensed to practice Medicine. While this practice sought to ensure a basic standard of competence in the health field, it also restricted the supply of practitioners. In the early 1970s, a report from the Graduate Medical Education National Advisory Committee (GMENAC) predicted an excess of physicians by the year 2000 if medical school and residency positions continued to increase. There were a voluntary moratorium on growth of medical schools and eventually a federal freeze on GME positions in 1997. These decisions were based on projections of US population growth that were in fact underestimates of actual growth and did not take into account the increasing specialization of the physician workforce, both of which have led to an increasing shortage of physicians in the face of a rapidly aging population. The shortage has therefore led to reduced competition in the marketplace and an influx of physicians from alternate educational paths [28].

Moral Hazard The occurrence of illness is an unpredictable and costly event. Insurance markets have been developed in an attempt to mitigate this inhomogeneous risk and to financially prepare a priori for the uncertainty inherent in health and the human condition. By distributing risk among a population-based risk pool, the impact of individual unpredictability is diffused throughout a larger absorptive base. However, having insurance impacts an individual's behavior through a phenomenon economists call moral hazard. Because health-care costs are paid by a third party, regardless of actual cost, insurance tends to induce an overconsumption of health-care resources by the end user. Similarly, health-care providers are subject to moral hazard as well; since prescribed treatments are known to be covered, insurance may induce the over allocation of health care. Both phenomena create market inefficiency and can result in the overutilization of scare resources which is a major driver of rising health costs.

Adverse Selection Insurance providers would ideally accurately price risk into individual insurance premiums to appropriately match cost with utilization. Because information is imperfect, risk assessment is necessarily incomplete. When premiums are set uniformly to reflect an "average" population-based aggregate risk, cost burden is unequal; the sickest users of health care pay less than their actual incurred costs, while the healthiest pay a disproportionately high cost for the goods and services they receive. In such a situation, the healthiest often forgo insurance and accept their lower perceived risk. This "adverse selection" results in only the sickest being insured at relatively underpriced premiums. Attempts to counteract this effect by pricing tiered premiums based on relative risk stratification results in very high health-care costs borne by the greatest consumers of health care, effectively undermining the theoretical advantages of a distributed insurance pool.

Imperfect Competition A free market is dependent upon the presence of large numbers (infinite in theory) of buyers and sellers, none having the individual power to influence supply, demand, or clearing prices. The last decade has witnessed the progressive consolidation of the health sector, with hospitals growing into health delivery systems and insurance carriers merging together in attempts to maximize efficiency through the leveraging of economies of both scale and scope. Consolidation can lead to the development of regional monopolies, which possess the capability of influencing market conditions whereby individual entities set price, effectively becoming "price makers" rather than "price takers." All of these trends have had the effect of reducing competition and altering the dynamic equilibria of supply and demand, generating inefficient allocation of resources and producing incentive for the escalation of health-care prices.

Externalities In economics, externalities are unmeasured transaction spillover effects that represent either costs or benefits of a given market that are not reflected in the price of goods or services. Externalities reflect inefficiencies in a marketplace and can either be positive or negative. Immunization is a classic example of a positive externality in health care. Most consumers purchase vaccinations for the tangible personal benefit of specific disease prevention. However, vaccination provides not only the consumer with benefit but also others in the population who enjoy a reduced chance of infection because the vaccinated can no longer spread the disease. This provides an important degree of social benefit (an externality) that is unmeasured on the individual transaction scale. Because the total benefit is in actuality a combination of individual benefit and the marginal social benefit (which is however unmeasured), society will underestimate the true demand and therefore under-allocate vaccinations. This effect will in turn incur a cost to society. Because of the tremendously complex matrix and inherent interrelatedness of both benefits and costs in health care, externalities are common sources of market failures.

Aging of the US Population As the world enters the twenty-first century, the majority of developed nations face pronounced structural alterations in their demographic profiles marked by a progressive and sustained shift toward an older population. The world's population is aging more rapidly than at any time in our past, a global effect driven primarily by a relative reduction in fertility rate combined with a prolongation in life expectancy [29]. According to the United Nations Population Division (UNPD), the number of individuals over the age of 65 will outnumber those under age 5 for the first time in human history. The life increases in life expectancy seen in Organisation for Economic Co-operation and Development (OECD) countries is indeed profound; populations in developed nations can be demonstrated to increase their life expectancy by one full day out of every four. Globally, life expectancy has increased 3 months per year consistently since 1840 with no evidence of a plateau occurring [30].

An important corollary of the relative expansion of the aging demographic is the simultaneous relative and absolute contraction of the employed labor force which contributes capital for societal consumption. As the leading edge of the expanded baby boomer cohort enters retirement age and produces an increased demand for goods and services, a reduced labor force is left behind to generate the required supply. In 1970, there were 5.3 workers for every postproduction retiree; currently there are 4.6, and it is predicted that the ratio will decline to 2.6 workers per pensioner [29, 31]. As the trend toward decreasing fertility and increasing life expectancy alters the demographic landscape for the foreseeable future, the imbalance between economic supply and demand from a population perspective will become even more extreme [19].

Despite implementation of the comprehensive government-sponsored Medicare program in 1965, associated deductibles, copayments, and uncovered services generate a significant financial burden on the expanding aging cohort of Americans. As both demand and costs continue to increase, the individual economic impact of health care on American seniors will become increasingly significant. Assuming current insurance structure but projecting a systematic *reduction* in recent trends in cost escalation, the yearly out-of-pocket expense for Americans over age 65 will more than double over the next several decades, while the median real income will grow much more slowly [32]. As costs grow disproportionately to income, the percentage of real income required to maintain the current levels of health-care service utilization will increase significantly from 10 to 20 %. The percentage of senior Americans that spend more than one-fifth of their income on health care will increase to 45 % by 2040 [32]. Projections will be more dire for American seniors if cost containment is not achieved and if employers eliminate current levels of retiree health benefits.

Conclusion National health-care expenditures constitute a substantial and continuously expanding component of the US economy. In the context of a complex and rapidly evolving health delivery system, costs are rising at an unsustainable rate, and widespread market failures are exacerbating disparities in the efficient allocation of our scare resources. A meticulous analysis of health-care spending patterns combined with an objective assessment of need can shed important light on how to best restrain rising health-care costs while simultaneously providing appropriate high-quality care.

Systematically identifying and characterizing the relatively small group of individuals that accounts for the largest percentage of US health spending may facilitate the introduction of targeted interventions into key areas where their impact may be most profound. Changing demographics, an increasing incidence of chronic disease and progressive disability, rapid technological advances, and systemic market failures in the health-care sector combine to drive exponential cost expansion, and a comprehensive multidisciplinary approach will become increasingly necessary to balance the delicate relationship between our constrained supply and increasing demand.

In a consensus statement by the Council on Scientific Affairs of the American Medical Association, the authors declared that "one of the most important tasks that the medical community faces is to prepare for the problems in caring for the elderly" [33]. As the USA moves deeper into

the twenty-first century, encumbered by rising national deficits and a cumulative debt that may soon exceed GDP, it is clear that any plan to achieve sustainable quality care for our aging population will necessarily require seamless integration into an overarching strategy for our nation's entire health-care system and the broader economy as a whole.

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Operative Risk Stratification of the Geriatric Patient

12

Jason A. Luciano, Brian S. Zuckerbraun, and Andrew B. Peitzman

Introduction

The elderly represent the most rapidly growing segment of the population. Due to a combination of the "baby boom" and increases in life expectancy, CMS projects that the Medicare population of 52.3 million in people 2013 will expand to 81.8 million in 2030 and will exceed 100 million people by 2065 [1]. Between now and 2030, approximately 10,000 baby boomers will turn 65 every day, and during this period, the percent of the population older than 65 years of age will grow from 13 % to 18 % [2]. Between 2012 and 2050, the number of people aged 85 or greater is anticipated to grow from 5.9 million to 19.4 million [3, 4]. While medical advances have increased life expectancy, cures for many chronic medical conditions are still not available leaving many with ongoing disability or physical limitations. It is currently estimated that 6.5 % of older adults require some form of physical assistance and that 48 % of people over the age of 75 report some degree of physical limitation [5].

Hospital beds are increasingly occupied with elderly patients. While they represented 12 % of the total US population in 2005, they represented 35 % of all hospitalizations and additionally represent a significant percent of the surgical workload [6, 7]. Age has been shown to be an independent risk factor for postoperative complications, and greater than 20 % of elderly patients will ultimately develop an inhospital surgical complication [8–10]. Postoperative complications are associated with a fourfold increased risk for 30-day readmission, increased cost of care, and a twofold increased rate of ultimate discharge to a nursing home or skilled nursing facility [8, 11–13]. Mortality estimates for octogenarians have reported a rate of 8 % for all noncardiac procedures and up to 15 % for patients undergoing emergent major abdominal surgery [9, 14]. Patients who develop postoperative complications, however, have mortality rates of 25 % with comorbid conditions playing a greater role than age in ultimate outcome [9].

While most studies report outcomes in aggregate form, aging affects each individual differently. While some are able to maintain a high degree of physical and cognitive function well past 100 years of age, others develop significant physical or cognitive limitations at a much earlier age. A subset of elderly patients can be classified as being frail, having alterations in homeostatic regulation, metabolism, body composition, and energy balance. These alterations in turn impact physiologic and functional reserve within organ systems and have been shown to be an independent risk factor for poor outcomes [15, 16]. Identification of many of these risk factors, including frailty, can be made during the preoperative assessment allowing for more individualized risk stratification, proper preoperative discussions with both patients and families, and implementation of pre- and perioperative strategies aimed at mitigating some of the risks involved with surgery.

Comprehensive Geriatric Assessment

Evaluation of the geriatric patient builds upon the standard adult medical evaluation. Given the fact that greater than 80 % of older adults take more than eight prescription medications and have more than one chronic medical condition, a thorough examination is essential [6]. In addition to the standard patient history and physical exam that aims to assess the patient's overall health, the comprehensive geriatric assessment takes a multidisciplinary approach to assess the patient's functional as well as their cognitive and psychological status [17–19]. Preoperative evaluation of the geriatric

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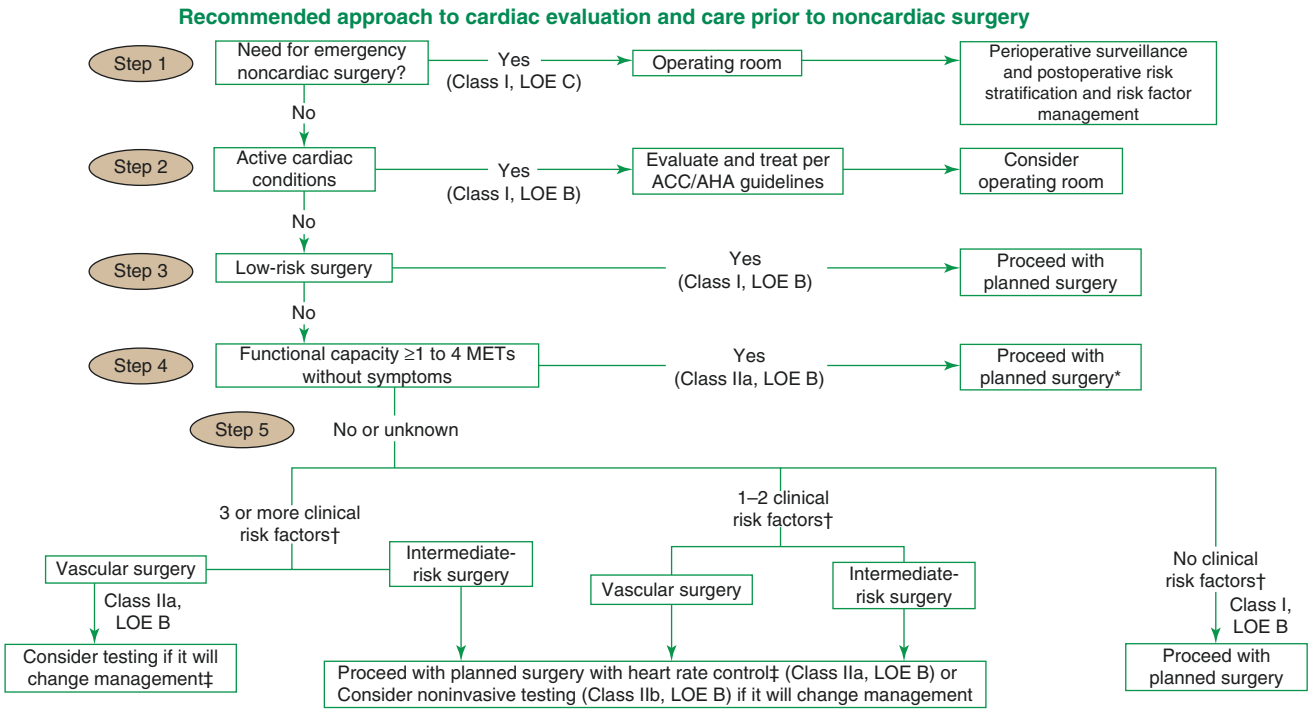

* Noninvasive testing may be considered before surgery in specific patients with risk factors if it will change management.
† Clinical risk factors include ischemic heart disease, compensated or prior heart failure, diabetes mellitus, renal insufficiency, and cerebrovascular disease.
‡ Consider perioperative beta-blockade for populations in which this has been shown to reduce cardiac morbidity/mortality.
LOE = level of evidence; MET = metabolic equivalent

Fig. 12.1 Cardiac clearance. ACC/AHA guideline

patient aims to integrate the patient's physical health along with additional risk factors, including frailty and nutritional status, to adequately assess not only the patient's overall operative risk but also to assess the patient's overall life expectancy, risk for prolonged hospital stay, poor postoperative recovery, and potential inability for discharge of the patient back home postoperatively [20–22].

For patients undergoing non-emergent and elective surgical procedures, a thorough comprehensive geriatric assessment allows both preoperative risk stratification but also identifies potential need for presurgical intervention or optimization and can provide critical information regarding postoperative care. Initial screening tools can be practically performed in the routine preoperative office visit/consultation to indicate which patients would benefit from more detailed geriatric and possibly palliative care discussions prior to a surgical intervention. For the critically ill patient undergoing urgent or emergency surgical intervention, a more comprehensive and informed evaluation may not be able to be fully accomplished preoperatively. In these cases any portion of the evaluation that was deferred preoperatively should be completed when reasonably appropriate postoperatively as each component of the assessment provides information that may alter the medical management of the patient or identify cognitive or functional limitations that may require additional evaluation and attention.

Cardiac Evaluation

Cardiac evaluation of the geriatric patient is an essential component of the examination. Cardiac risk for patients undergoing noncardiac surgery has been well documented with reports of major perioperative cardiac complication rates of 2 % for all patients, 3.9 % for patients with cardiac disease, and exceeding 5 % for high-risk cardiac patients with postoperative myocardial infarctions resulting in inhospital mortality rates from 15 to 25 %, and this increased risk persists for at least 6 months after surgery [23–25]. While these rates are not specific to the geriatric patient population, older patients have been shown to be at higher risk for perioperative cardiac events making the cardiac assessment even more important [26].

The American College of Cardiology and American Heart Association provide a clear algorithm to assess the need for further cardiac testing in patients undergoing noncardiac surgery (Fig. 12.1) [27]. The patient's cardiac risk assessment and stratification are primarily based upon the presence of any active cardiac conditions, previous cardiac interventions, and assessment of the patient's functional status and determination of the patient's metabolic equivalents (METs). Further complicating some patient's functional cardiac assessment is the fact that their physical activity may be

limited by frailty or other factors that impair the ability to fully assess the presence of functional cardiac symptoms [28]. Preoperative cardiology consultation should also be considered for those patients with unstable angina or recent myocardial infarction, decompensated heart failure, severe valvular heart disease, symptomatic arrhythmias, or significant conduction abnormalities. In addition to the 2007 guideline's primary focus on the preoperative cardiac risk assessment, mainstays of perioperative cardiac care include continuation of statins, continuation of β-blockers with titration to a goal heart rate of 60–65 bpm, and management of arrhythmias including both rate control and adequate treatment of the underlying cause [27, 29].

Even in patients without known history of ischemic heart disease or congestive heart failure, it is important to inquire about related symptoms including presence of lower extremity edema, orthopnea, and use of diuretics. Due to age-related changes to the cardiovascular system, including impaired myocardial relaxation, decreased sensitivity and response of the sinus node and baroreceptors, and decreased response to adrenergic stimulation, the geriatric patient is at increased risk for impaired physiologic response to hemodynamic changes. Therefore, despite a lack of significant symptoms under baseline or preoperative conditions, the patient may still be at increased cardiac risk due to the increased physiologic stress as well as the potentially significant fluid shifts that occur during the perioperative period.

Pulmonary Evaluation

Pulmonary complications occur more frequently than cardiac complications with 6.8 % of patients experiencing pulmonary complications following non-thoracic surgery and up to 15 % in patients aged >70 [30]. These complications are associated with higher risk of myocardial infarction, pneumonia, renal failure, and thromboembolic events, as well as both perioperative and 3-month mortality, and result in significant increases in medical costs and longer lengths of hospitalization [31, 32]. In fact when compared to infectious, thromboembolic, and cardiac complications, postoperative pulmonary complications are associated with the highest total hospital costs [12]. Table 12.1 shows patient-related risk factors for postoperative pulmonary complications as well as the weight of each risk factor [30].

Preoperative spirometry has not been shown to accurately predict postoperative outcomes [30]. Therefore, current recommendations do not support the routine use of preoperative pulmonary function testing and instead

Table 12.1 Patient-related risk factors for postoperative pulmonary complications

Risk factor	Studies, *n*	Pooled estimate odds ratio (95% CI)[a]	I^2, %[a]	Trim-and-fill estimate odds ratio (95% CI)[b]
Age				
50–59 years	2	1.50(1.31–1.71)	0.0	–
60–69 years	7	2.28(1.86–2.80)	50.4	2.09 (1.65–2.64)
70–79 years	4	3.90 (2.70–5.65)	81.6	3.04(2.11–4.39)
≥80 years	1	5.63 (4.63–6.85)	–	–
ASA class				
≥II[c]	6	4.87 (3.34–7.10)	0.0	4.87 (3.34–7.10)
≥III[c]	11	3.12 (2.17–4.48)	65.2	2.55 (1.73–3.76)
Abnormal chest radiograph	2	4.81 (2.43–9.55)	0.0	–
CHF	3	2.93(1.02–8.43)	92.1	2.93 (1.02–8.03)
Arrhythmia	1	2.90 (1.10–7.50)	–	–
Functional dependence				
Partial	2	1.65 (1.36–2.01)	82.6	–
Total	2	2.51 (1.99–3.15)	67.9	–
COPD	8	2.36(1.90–2.93)	82.0	1.79 (1.44–2.22)
Weight loss	2	1.62(1.17–2.26)	91.7	–
Medical comorbid condition	1	1.48 (1.10–1.97)	–	–
Cigarette use	5	1.40 (1.17–1.68)	67.5	1.26 (1.01–1.56)
Impaired sensorium	2	1.39(1.08–1.79)	63.0	–
Corticosteroid use	1	1.33 (1.12–1.58)	–	–
Alcohol use	2	1.21 (1.11–1.32)	0.0	–

ASA American Society of Anesthesiologists, *CHF* congestive heart failure, *COPD* chronic obstructive pulmonary disease
[a]For *I2* definition and values, see the Appendix, available at www.annals.org.
[b]Estimates derived from meta-analysis of adjusted odds ratios from multivariable studies
[c]When compared with patients with lower ASA class values

recommend its use in selected patients [17]. Instead, preoperative pulmonary assessment aims to identify patients at increased risk and reduce the risk for pulmonary complications by identifying specific risk factors for which perioperative care can then be directed [33].

Some of these strategies include identification of undiagnosed and/or untreated obstructive sleep apnea (STOP-BANG questionnaire), optimization of pulmonary function in poorly controlled asthmatics or patients with COPD, and smoking cessation [34–36]. Much has been published regarding the optimal timing of smoking cessation. While some studies suggest that cessation within a short time period before surgery results in increased risk for pulmonary complications, most studies agree that smoking cessation is beneficial if done 1–2 months prior to surgery [32, 37–41]. Additional preoperative strategies include lung expansion techniques such as incentive spirometry, intermittent positive pressure breath, continuous positive airway pressure, and chest physiotherapy [33]. In a study of patients undergoing coronary artery bypass surgery, preoperative inspiratory muscle training using individualized combinations of these techniques was shown to reduce pulmonary complications [42].

While not always feasible depending on the planned surgical intervention, additional perioperative strategies can be employed to further reduce the risk of pulmonary complications. When appropriate, regional nerve blocks are preferable as they are less likely to result in complications than general anesthetics, and when general anesthetics are necessary, the use of shorter-acting agents and avoidance of agents such as pancuronium are preferable as residual neuromuscular blockade postoperatively increases patient risk [33, 43]. Additional strategies include use of laparoscopic and other minimally invasive techniques as well as selective rather than routine use of nasogastric tubes. Postoperatively, the use of continuous positive airway pressure and epidural analgesia has been shown to reduce complications [32].

Mental Status and Cognitive Assessment

Cognitive impairment is increasingly prevalent within the elderly patient population affecting 22.2 % of patients 71 years and older [44, 45]. The presence of cognitive impairment dramatically increases postoperative complications and negatively influences both short- and long-term outcomes. Baseline cognitive impairment and dementia are strong predictors of postoperative delirium, increased risk for postoperative functional decline, and increased risk for mortality [46–50]. The use of screening tools for dementia, delirium, and cognitive function is important to identify at-risk patients, thereby allowing for better perioperative care and support as well as more complete discussions with the patient and their families regarding the risks and benefits of the proposed surgical procedure [51].

Dementia

The prevalence of dementia significantly increases with age, from 5 % in those aged 71–79 to 37 % in those aged over 90 [45]. The clinical significance of the cognitive decline can range from subtle cognitive deficits to complete functional dependence. While the majority of elderly patients remain cognitively intact, many may present normally but have evidence of subclinical dementia that despite its subclinical presentation still places them at risk for postoperative complications and likely need for increased postoperative support.

Numerous screening tests have been developed to detect the presence of cognitive impairment and to guide further steps including the Mini-Mental State Exam, the Memory Impairment Screen, and the Mini-Cog [52, 53]. These tests have wide ranged in both the sensitivity and specificity as well as the time required to administer the tests, which ranges from 1.5 to 17 min [54]. The Mini-Cog, which entails a three-item recall and a clock drawing task, is one of the most commonly used cognitive assessment tests given that it requires minimal training to administer, can be performed in less than 5 min, and is appropriate for use in multilingual populations (Fig. 12.2). An abnormal baseline Mini-Cog assessment indicates the presence of a possible cognitive impairment and increased risk for postoperative delirium and increased risk for postoperative complications. When time permits, a positive screen should warrant a more thorough dementia evaluation.

Delirium

Delirium is defined as an alteration in cognition and attention that is acute in onset and related to an underlying medical condition and has variable clinical features when present [55] (Table 12.2). Delirium affects approximately 30 % of hospitalized elderly patients and is associated with increased length of stay, poorer outcomes, increased rates of pulmonary complications, inhospital falls, dehydration, pressure ulcers, and urinary tract infections [54, 56–59]. Development of delirium has additionally been associated with a functional decline in activities of daily living, a higher likelihood for discharge to a rehabilitation facility or a skilled nursing facility, and increased mortality rates for both in hospital and during the months following discharge [56–58, 60, 61].

Risk factors for delirium (Table 12.3) can be divided into predisposing and precipitating risk factors. Predisposing risk factors are patient specific and often cannot be altered, but still important to identify as they can help identify those patients at potentially highest risk for developing delirium while hospitalized. Precipitating risk factors include

Administration:

1. Ask the patient to listen carefully to 3 unrelated words, repeat them to you, and remember them for later. You may repeat the words up to three time until they are remembered correctly.
2. Using a piece of blank paper, as the patient to draw the face of a clock and fill in all the numbers. As the patient to draw the hands to read 11:10 (or any time that utilizes both halves of the clock. Instructions may be repeated, but no additional hints.
3. Ask the patient to repeat the 3 words from before.

Scoring:

1. Give one point for each correct word to calculate recall score, maximum 3 points.
2. Score the clock normal or abnormal. (Normal: all the numbers present and in correct order and position, hands depict the correct time).
3. Determine whether screen is positive or negative for dementia using the algorithm.

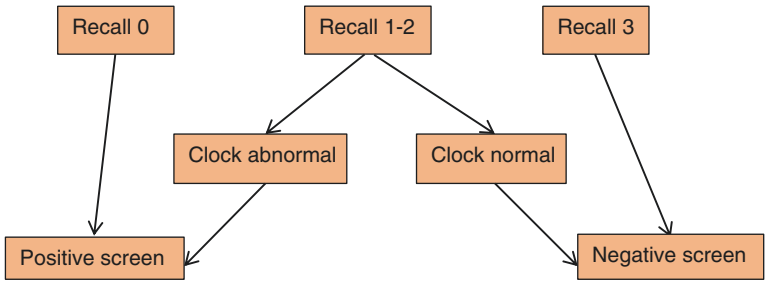

Fig. 12.2 Mini-Cog screening tool for dementia (Adapted from [54])

Table 12.2 Clinical features of delirium

Feature	Description
Inattention	Key feature for diagnosis of delirium
	Difficulty focusing, sustaining attention, maintaining conversation, and following commands
Acute onset	Onset within hours or days
	Often requires reliable third party to provide history
Fluctuating course	Symptoms wax and wane over a 24-h period
	Intermittent lucid intervals are common
Disorganized thinking	Incoherent speech
	Rambling, irrelevant conversation, illogical flow of ideas
Altered level of consciousness	Altered awareness of the environment: vigilant, lethargic, stupor, coma
Cognitive deficits	Disorientation, memory deficits, language impairment
Perceptual disturbances	Illusions or hallucinations
Psychomotor disturbances	Hyperactive: agitation and hypervigilance
	Hypoactive: lethargy, decreased motor activity
	Mixed
Sleep-wake disturbance	Daytime drowsiness, nighttime insomnia, fragmented sleep, or complete sleep cycle reversal
Emotional disturbance	Labile symptoms of fear, paranoia, anxiety, depression, irritability, apathy, anger, euphoria

Adapted from [55]

operative, infectious, and medication-induced effects, which can sometimes be modified. Numerous medications have been identified as contributing to the development of delirium and should be avoided when possible in those patients at risk for delirium. Some of these medications include benzodiazepines, antihistamines, anticholinergics, and

Table 12.3 Risk factors for delirium

Predisposing factors		Precipitating factors	
Demographics	Age	Drugs	Sedative/hypnotics
	Male		Narcotics
Cognitive status	Dementia		Anticholinergic medications
	Delirium		Polypharmacy
	Depression		EtOH withdrawal
Functional status	Dependence	Primary neurologic disease	Stroke
	Immobility		ICH
	Low activity		Meningitis
	Falls	Intercurrent illness	infection
Sensory impairment	Visual		Iatrogenic complications
	Hearing		Severe illness
Decreased intake	Dehydration		Hypoxia
	Malnutrition		Shock
Drugs	Psychoactive medications		Fever
	Polypharmacy		Anemia
	EtOH		Dehydration
Comorbidity	Severe illness		Poor nutrition
	Multiple conditions		Metabolic derangement
	CKD or liver disease	Surgery	Orthopedic
	CVA		High risk surgery
	Neurologic		Prolonged bypass
	Metabolic derangements		Emergency surgery
	Trauma	Environmental	ICU admission
	Terminal illness		Use of restraints
	HIV		Bladder catheter
			Multiple procedures
			Uncontrolled pain
			Emotional stress
			Sleep deprivation

Adapted from [55]

Table 12.4 Strategies to treat delirium

Perioperative geriatric consultation to identify higher risk patients and recommend specific preventive strategies
Use lighter anesthetic regimens to maintain bispectral index (BIS) between 40 and 60 avoiding episodes of deep anesthesia. (BIS< 40)
Maintenance of normal sleep-wake cycles using bright light therapy
Provision of adequate analgesia
Avoidance of benzodiazepines and antihistamines (except for treatment of alcohol withdrawal)
Use of low-dose antipsychotics may reduce the duration of symptoms
Early mobilization, behavioral measures to promote sleep and orientation, communication methods, and adaptive equipment

Adapted from [114]

meperidine. Since both pain and opiates can increase the risk for delirium, pain regimens, which attempt to minimize opiate usage, while still adequately addressing the patient's pain are ideal [62, 63].

Unfortunately, treatment of delirium, once present, is often of limited efficacy. Structured programs have been utilized, however, to decrease the incidence of postoperative delirium, and preoperative geriatric consultation is recommended, when available, to identify at-risk patients and develop preventative strategies to reduce the incidence of delirium [64–66] (Table 12.4).

Depression

Depression in the elderly is common, affecting 16 % of the elderly living in the community, 25 % in a primary care setting and affecting 50–70 % of long-term care residents [67]. Specific risk factors associated with depression in the elderly include disability, new medical illness, poor overall health, and bereavement [68]. The presence of depressive symptoms has been associated with increased healthcare utilization, increased pain perception, and increased analgesic need, delayed recovery in activities of daily living (ADLs), and instrumental activities of daily living (IADLs)

and has been shown to be associated with increased mortality following cardiac surgery [67, 69–72].

While there are readily available treatment options available, depression can go undetected due to the presence of additional cognitive disorders. Screening not only allows the diagnosis of preoperative depression but, when treated appropriately, can result in improved long-term outcomes. Although multiple screening tests for depression exist, the Patient Health Questionnaire-2 (PHQ-2) is a quick, reliable, validated screening test that can be conducted in either a hospital or outpatient setting [73, 74]. The PHQ-2 involves two questions, and a positive response to either question is suggestive of depression with 100 % sensitivity and 77 % specificity [74]. Any patient with a positive screen should be referred to a primary care physician, geriatrician, or mental health specialist for further evaluation and treatment.

Substance Abuse

According to a 2005–2006 survey, 60 % of adults over 50 consumed alcohol within the past year, and more importantly 13 % of men and 8 % of women age 65 and older reported at-risk drinking (14 drinks per week for men, 7 drinks per week for women) [75]. As a result of changes in body composition with age, the elderly experience a greater blood alcohol concentration per amount consumed. Owing to decreased social and occupational interaction, alcohol abuse in the elderly can frequently present as nutritional deficiency, poor self-care, or medical illness [76]. In addition to the risk for withdrawal, patients with significant alcohol dependence are at increased risk for pneumonia, sepsis, surgical site infection, wound disruption, and longer lengths of stay.

Based on these risks, all patients should undergo an alcohol screening test. The CAGE questionnaire is a simple, time-tested screening tool that has been shown to perform well within the elderly population [77]. Any patient with a positive screen should be evaluated frequently for symptoms of withdrawal and given medications or alcohol to attempt to avoid withdrawal. Additionally, all patients with a positive screen or with at-risk alcohol use should be given supplemental folic acid and thiamine.

Nutritional Evaluation

Nutritional status is an independent risk factor for wound healing, infection, and postoperative length of stay [78]. Unfortunately, malnutrition occurs in 23 % of the elderly, ranging from 6 % in the community to over 50 % of patients in rehabilitation facilities, and an additional 46 % of the elderly considered at-risk malnutrition [79]. Commonly used indicators of nutritional status include serum albumin or prealbumin, unintentional weight loss, total cholesterol, body mass index less than 22, and the presence of vitamin deficiencies. Serum albumin and unintentional weight loss greater than 10 % over the previous 6 months, however, are the best predictors for postoperative complications [80]. Concern for the presence of preoperative malnutrition warrants a more complete nutritional assessment as well as the implementation of a preoperative nutrition plan which may include increased calorie and protein intake, use of nutritional supplements, and addressing underlying medical conditions or medications that may be impacting the patient's appetite and food intake.

Geriatric patients are additionally at increased risk for dysphagia during the postoperative period. Postoperative laryngeal swelling as well as reduced compensatory swallowing mechanisms, which can occur with delirium, places the patient at higher risk for both dysphagia and aspiration [81, 82]. Once identified, steps can be taken to modify diet consistency as well as body positioning during ingestion in order to reduce the risk for aspiration. Additionally, consultation of speech therapy for any at-risk patient as well as those patients with prolonged intensive care unit stay or endotracheal intubation can be helpful. Unfortunately, some of the modifications necessary to reduce the risk for aspiration can alter the texture and palatability of the food creating further barriers to proper perioperative nutrition.

Functional Assessment

Preoperative function has been shown to predict postoperative recovery and impact mortality [9, 57, 71]. In a study of Veterans Administration (VA) patients aged >80, functional status was more predictive of 30-day mortality than was age [83]. Additionally, poor functional status and impaired mobility are associated with increased rates of postoperative delirium, surgical site infections, and decreased rate of discharge to home [57, 84, 85]. Functional screening questionnaires aim to assess the activities of daily living (ADLs), which involve functional independence in six areas: bathing, dressing, transferring, eating, continence, and ambulation. Any preoperative deficits should be documented and warrant a more thorough evaluation of functional capacity including whether deficits may be related to pain or physical symptoms or due to an underlying cognitive issue. Additional questionnaires aim to assess the patient's instrumental activities of daily living (IADLs) (Table 12.5).

Table 12.5 Functional assessment

Basic activities of daily living (ADLs)	Instrumental activities of daily living (IADLs)
Dressing	Cooking
Bathing	Shopping
Eating	Transportation
Continence	Finances
Transfer	Telephone
Ambulation	Housekeeping

Table 12.6 Frailty assessment

Frailty factor	Measure	Notes
Shrinking	Unintentional >10 lb weight loss	Self-report
Weakness	Decreased grip strength	Three trials using handheld dynamometer with dominant hand, result adjusted by gender and BMI
Exhaustion	Center for Epidemiological Studies – Depression scale (CES-D)	"I felt everything I did was an effort" or "I could not get going" a moderate amount or most of the time
Slowness	Gait speed	Three trials of walking 15 ft at a normal pace, result adjusted for gender and height
Low activity	Minnesota Leisure Time Activities Questionnaire	Weekly tasks were converted to equivalent kilocalories; total expenditure adjusted for gender

Adapted from [16]

Additional limitations should also be evaluated such as deficits in vision and hearing, swallowing, need for assist devices, and history of falls. Physical disability can be assessed using a timed "up and go" test where the patient is instructed to rise from a chair without using their hands, walk 10 feet, turn and return to the chair, and sit down. Times greater than 15 sec are suggestive of increased risk for falls [17, 86]. In a study by Robinson et al. of elderly surgical patients requiring ICU stay, prolonged up and go times and any functional dependence were the strongest predictors for need for institutionalization at time of discharge [85].

An accurate preoperative functional status can be difficult to accurately assess in those patients who are just "getting by" at home. A thorough evaluation, however, is important to guide discussions to establish realistic functional expectations following surgery, discussing realistic potential for institutionalization on discharge, and can aid in goals of care discussions.

Frailty

Frailty is a multidimensional concept describing a state of diminished functional and physiologic reserve and is a distinct entity from the physiologic changes of normal aging [87]. Frailty includes physiologic impairments associated with sarcopenia, neuroendocrine dysregulation, and immune impairment. These changes leave patients more vulnerable to falls, longer hospital length of stay, repeat hospitalizations, poorer health outcomes, increased discharge to nursing facility, prolonged rehabilitation, diminished mobility, and increased 6-month and 1-year mortality [15, 16, 88–91]. Frailty is more common in women and has an overall prevalence of 7–12 %, with increasing prevalence with age ranging from 3.2 % in those aged 65–70 to over 25 % in those aged 85–89 years [15, 92].

Frailty was first described by Fried in 2001 and subsequently has been validated by Makary for the evaluation of elderly surgical patients [15, 16]. Components of the frailty phenotype include shrinking and weight loss, poor endurance or exhaustion, weakness, slow walking speed, and low physical activity level (Table 12.6). Patients who are identified with two to three abnormal phenotypes are considered as intermediate or pre-frail and those with four or five abnormal phenotypes are deemed to be frail. While studies have validated worse outcomes in those patients who qualify as being frail, patients identified as intermediately frail are additionally at increased risk for postoperative complications and over the following 3 years have a twofold increased risk for becoming frail [15].

While numerous frailty indices have been developed, including the Canadian Study of Health and Aging Frailty Index, the Modified Frailty Index (MFI), and the Frailty Index – Comprehensive Geriatric Assessment (FI-CGA), there is no consensus on the optimum means of assessing frailty in the clinical setting [93, 94]. In addition to the five primary domains proposed by Fried, mentioned above, which have been validated for surgical patients in the 2010 study by Makary, additional frailty indices attempt to assess additional domains including cognition and social support [15, 16, 95]. Many of these frailty indices, although quite reliable and predictive, are time consuming to apply, making them difficult to routinely utilize within a busy clinical setting or while seeing an acute care surgical patient within the hospital.

In 2009, Robinson proposed two alternative definitions for frailty within the elderly surgical patient. One definition included poor nutritional status (serum albumin ≤3.3 g/dL), evidence of cognitive impairment (Mini-Cog ≤3), history of falls (≥1 fall within the past 6 months), and low hematocrit (<35 %). The second definition included the above factors with the addition of comorbidity (Charlson index score ≥3) and evidence of functional impairment (TUGT ≥15 s or ADL dependence) [83].

At this time there is no consensus regarding which index or scoring system is the best. Given that frailty assessment has been shown to outperform more traditional risk assessment tools, it may not be as important which frailty index or scoring system is utilized as that one is utilized in the preoperative assessment of the patient. Once frailty has

Table 12.7 Recommendations for preoperative testing in elderly patients [17, 19, 100–106]

Test	Indications and implications
BUN and Cr	Recommended for all geriatric patients [99, 102] Should be used for all elderly patients to determine creatinine clearance for dosage adjustment of medications Cr clearance is determined by Cr, patient age, and weight Cr > 2.0 mg/dL is predictive of cardiac complications Diabetes, hypertension, cardiovascular disease, medications including diuretics, ACE inhibitors, and NSAIDs increase likelihood of abnormality
Electrolytes	Useful in patients with known renal disease, use of diuretics, ACE inhibitors, or other medications with renal effects [99, 102]
Serum glucose	Patients with diabetes or obesity
Albumin	Recommended for all geriatric patients for nutritional screening [99, 102]
Hemoglobin and hematocrit [99, 102]	Reasonable for all geriatric patients, especially those over 80 years Recommended when history and physical suggest anemia Tachycardia or conjunctival pallor on exam History of anemia, extreme fatigue, cancer, renal disease, cardiovascular disease, or respiratory illness Recommended when significant blood loss and transfusion anticipated 30-day postoperative mortality increases with each percentage point deviation in hematocrit from normal value
White blood cell	Not indicated for screening, but usually part of CBC Helpful when signs of infection or myeloproliferative disorder are present [99]
Platelet count	Useful in patients with history of bruising, bleeding, or history of bleeding with surgery [99]
Coagulation studies	Indicated for history of bleeding or anticoagulant use Useful when even small amounts of blood loss will result in severe complications Malnutrition, malabsorption, or liver disease should prompt assessment [99]
Urinalysis	Indicated in the presence of suspected urinary tract infection or diabetes [99, 102]
EKG	Recommended for [25] History of heart disease, prior MI, arrhythmias, peripheral vascular disease, cerebrovascular disease, CHF, diabetes, renal disease, or pulmonary disease History of cardiotoxic medication exposure
Chest X-ray	Not recommended for routine screening Recommended for [30, 32–34, 104]: History of pulmonary disease including smoking history History of stable cardiopulmonary disease when age over 70 Possible ICU admission to establish baseline
Echocardiogram	Indicated for patients with dyspnea of unknown origin, current or prior heart failure with worsening dyspnea or other change in clinical status [27]

been identified, it can be utilized during discussions with the patient or family and allow more informed decision-making. In addition, this added information may lead to changes in the medical or surgical treatment plan to minimize patient complications. Additionally, once identified, frail and pre-frail patients can undergo pre-habilitation strategies aimed at improving the patient's nutritional status and exercise tolerance, or to counteract sarcopenia with the goal of minimizing the patient's postoperative risk [96, 97].

Laboratory Testing

Basic laboratory tests should be ordered selectively based upon patient risk factors obtained during history and physical exam, comorbidities, and the type of surgery being performed. Routine preoperative screening tests for all geriatric surgical patients should be limited to hemoglobin, albumin level, and renal function testing [98–102]. Although commonly ordered on all preoperative patients, assessment of white blood cell count, platelet count, coagulation tests, and electrolytes is not recommended for routine preoperative assessment [27, 33, 36, 99, 101–105]. Instead these tests should be ordered based upon patient-specific factors rather than on a more automatic basis. The presence of abnormalities in these laboratory tests in otherwise healthy, asymptomatic patients is low and rarely leads to changes in ultimate intraoperative management [100, 105, 106]. Table 12.7 addresses the specific indications for commonly used preoperative testing in the geriatric patient (Table 12.7).

Medications and Supplements

A thorough medication review should be sought from all patients and begins with obtaining an accurate list of all prescription medications; over-the-counter medications; nutritional, vitamin, and herbal supplements; and any other alternative therapies. Over 80 % of elder adults take at least one medication, and one-third take at least five

medications, which is further compounded by the fact that nearly half of elders use at least one over-the-counter medication as well as some sort of dietary supplement [49]. Because of large number of medications being used, elderly patients are at increased risk for drug-disease as well as drug-drug interactions. Inappropriate prescribing, present in up to half of older adults, contributes to cognitive impairment, falls, incontinence, and impairment [47]. Furthermore, despite the widespread recognition of the Beers criteria and its incorporation into many policy and quality measure, many elderly patients continue to be prescribed medications that may be inappropriate for use in elderly patients [107].

During the perioperative setting, many medications can be safely held, while others including β-blockers and other cardiac medications should be continued. Determination regarding the management of anticoagulant and antiplatelet medications, including possible need for bridging, time to restart these medications, or potential to perform the surgery without holding these medications, requires significant care and communication, a thorough review of the medication, the indication for why the patient was on the anticoagulant or antiplatelet agent, and specifics regarding the planned surgical procedure. As more elderly patients are taking non-warfarin-based oral anticoagulants, without easy means for drug reversal, an in-depth discussion regarding optimal duration off of these medications prior to surgical intervention is even more important than in the past.

Additional consideration should be given to medications such as steroids, antiseizure medications, clonidine, selective serotonin reuptake inhibitors, beta-blockers, or benzodiazepines, which can precipitate harmful withdrawal effects if abruptly stopped. Given the increased risk associated with withholding many cardiac medications and the increased risk of continuing certain psychiatric or neurologic medications during the perioperative state, consultation with a hospital pharmacist can be helpful not only in completing the medication reconciliation but also in identifying and reducing potential drug-drug or drug-disease interactions and in identifying medications requiring dose or drug delivery route adjustments due to changes in gastrointestinal, renal, or hepatic function. As a general rule, all nonessential medications should be discontinued, essential medications should be resumed as soon as safely possible, and addition of new medications during the perioperative period should be minimized [48].

Cardiac Medications

The American College of Cardiology (ACC) and the American Heart Association (AHA) have published perioperative cardiovascular care guidelines with regard to statin and β-blocker management [27, 99, 108]. The guidelines support the continuation of β-blockers in those patients already taking them and against the routine initiation of β-blockers for patients undergoing noncardiac surgical procedures who are not already on these medications. When indicated, however, a β-blocker should be started as least a couple days to weeks prior to surgery with the dose titrated to achieve rate control between 60 and 80 beats/min while avoiding hypotension. Additionally, if discontinuation of β-blockers is necessary, they should be slowly tapered to minimize the risk of withdrawal and associated increased cardiac risk.

ACC/AHA guidelines regarding statin therapy include the continuation of statins for those patients already taking a statin preoperatively, and consideration should be made regarding starting statin therapy in those patients with known vascular disease, elevated low-density lipoprotein levels, and abnormal cardiac stress tests and in those patients undergoing intermediate risk or vascular surgical procedures [27, 99, 108]. Care should be taken during the perioperative period to avoid overly aggressive treatment of hypertension. The HYVET trial showed that a less restrictive blood pressure target of 150/80 mmHg in elderly patients was associated with reduced risk for mortality, stroke, and congestive heart failure [109].

Patient Preferences, Decision-Making, and Advanced Directives

In-depth discussions with the patient and/or their surrogates prior to any surgical procedure regarding the risks and benefits are central to obtain informed consent. Appropriate decision-making in geriatric patients needs to take into account the patient's overall goals, their priorities, and prognosis related to any comorbid conditions. The patient's preoperative functional and cognitive status as well as their comorbidities, frailty, and overall life expectancy will help frame the likelihood of achieving the patient's desired goals based upon the various treatment options available. Sometimes palliative rather than curative treatment options are more in line with the patient's stated goals and therefore warrant further discussion.

Multiple prognostic calculators have been developed to help calculate mortality and other outcomes following surgical intervention such as the American College of Surgeons' Surgical Risk Calculator [110]. These calculators utilize large patient databases and can utilize patient-specific information regarding comorbidities and current health status to estimate a patient-specific outcome. This information can be combined with more common discussions regarding surgical risks and expectations for the patient's postoperative functional status to assist in framing discussion and aid the patient in making optimal healthcare treatment decisions.

Decision-Making Capacity

Prior to engaging in any in-depth discussions regarding treatment options, the surgeon should assess whether the patient has capacity to engage in the decision-making process. If they do not, effort should be made to identify a surrogate decision-maker. Decision-making capacity is specific to the health decision at hand and requires the ability to express a choice, understand pertinent information related to the healthcare condition, and express and understand consequences of the chosen treatment option or of not undergoing treatment and the ability to express reasoning for their choice [111]. Unfortunately no specific test exists to determine an individual's decision-making capacity. However, information obtained during the preoperative functional assessment can be utilized to help assess the patient's overall independence and possible need for assistance. If a patient is deemed incompetent for making healthcare decisions, and an advanced directive is not in place, a surrogate decision-maker must be identified, most commonly a family member. Although it varies from state to state, the typical order for surrogate decision-makers is spouse, adult children, parents, siblings, and then other relatives [111]. If there is question regarding who the appropriate surrogate is or if different family members do not agree on ultimate decision, consultation should be placed with the hospital's ethics committee to assist on a case-by-case basis.

Advanced Directives and Code Status

Even those patients with decision-making capacity when seen during a preoperative evaluation may not have decision-making capacity during their postoperative course as a result of delirium, prolonged intubation, or postoperative complications. Given that approximately 18 % of Americans undergo procedures during their last month of life and 8 % during the last week of life, discussions must be held regarding their patient's choices related to end-of-life care [112]. Discussions regarding end of life must be handled with care; the goal of these discussions is not to withhold treatment, but rather to ensure that the treatments are in line with the patient's overall goals of care of either prolonging life, easing suffering, or improving the quality of life. If formal advanced directive, do not resuscitate (DNR), or do not intubate (DNI) orders exist, effort should be taken to obtain a copy of the document to aid ongoing care as well as ongoing care discussions. Patients with active DNR/DNI orders can elect to temporarily rescind their DNR status during the perioperative period, or it can be modified with a detailed list of exactly what procedures the patient will allow during the perioperative period [113].

Summary

Preoperative evaluation of elderly patients requires thorough assessment of the patient's functional status. Patient's preoperative cognitive and functional status may place them at higher risk for postoperative complications, increased morbidity and mortality, longer hospital course, and decreased likelihood for discharge to home following surgical intervention. Thorough preoperative assessments can identify potential medication-related events as well as identify those at increased risk for poor outcomes. More complete knowledge regarding the risks of surgical intervention will aid in the patient's care discussions and increase the likelihood that the ultimate treatment plan is in line with the patient's stated goals of care.

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Appendicitis

13

Dirk C. Johnson and Kimberly A. Davis

Introduction

Patients of advanced chronologic age have predictable changes in anatomy and physiology, often combined with comorbidities muddying the diagnostic process of common surgical problems, complicating their treatment, and negatively impacting outcomes. While acute care surgeons are positioned to evaluate and treat surgical emergencies stemming from a wide range of pathology, the elderly present a particular challenge. In this population, disease states often present diagnostic and therapeutic challenges. Increasing life expectancy is leading to a bourgeoning population of aged patients and makes it critical for surgeons to have a firm understanding of all aspects of the aging process and its impacts on all facets of patient care from initial presentation and workup to recovery. Appendicitis epitomizes this challenging situation.

History

The anatomic discovery of the appendix in humans is attributed to Berengario da Carpi in 1521; however, the appendix was depicted in an anatomy drawing by Leonardo da Vinci [1]. Nearly 200 years later in 1711, Lorenz Heister first described its diseased state, appendicitis, when he speculated that a perforation of the appendix with an adjacent abscess may have been caused by inflammation of the appendix itself [2]. Claudius Amyand performed the first reported appendectomy a quarter century later (1735) on an 11-year-old boy whose appendix was perforated by a pin identified during a scrotal hernia repair [3]. Ironically, it was nearly another century before Francois Melier proposed removing the appendix as a treatment strategy during his description of six cases of postmortem appendicitis in 1827 [2, 4, 5]. Another 50 years passed before Lawson Tait in London presented his transabdominal appendectomy for gangrenous appendix in 1880. In 1886, Reginald Fitz coined the term "appendicitis," described the natural history of the inflamed appendix, and advocated for its surgical removal. Charles McBurney presented his case series of surgically treated appendicitis in 1889 and described the anatomic landmark that now bears his name. In the 1890s, Sir Frederick Treves advocated expectant management of acute appendicitis followed by appendectomy after the infection had subsided; sadly, his youngest daughter developed and later died from perforated appendicitis with this treatment paradigm [6–10].

Epidemiology

Abdominal pain is an extremely common presenting problem with a long differential diagnosis. Appendicitis has long been one of the leading causes. Clinicians associated it more strongly with younger patients because the highest incidence occurs in the second and third decades of life. Appendicitis tends to be less common in extremes of age (<5 years old, >50 years old). However, in recent decades, the incidence of appendicitis in the elderly appears to be increasing. Contributing factors may include longer life expectancies and a rapidly increasing proportion of senior citizens in our society [11–13]. The lifetime risk of appendicitis remains significant with nearly 1 of every 15 persons (7 %) developing acute appendicitis during their lifetime. After the age of 50, the risk of having appendicitis goes down (2 % for men and 3 % for women). Nonetheless, older patients still make up a significant portion of cases.

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Patients older than 60 account for 5–10 % of all diagnoses of appendicitis. Roughly 5 % of all older patients presenting with an acute abdomen will have appendicitis [14–20].

Interestingly, there is substantial variation in the rate of appendicitis between countries. The diagnosis of appendicitis is more common in industrialized countries, which has thrust nutritional and dietary factors into question as a possible variable. Diets with higher proportions of highly refined grains and lower proportions of dietary fiber may have increased risk. Populations of developing regions tend to consume whole foods which are less refined and higher in fiber [21, 22]. Studies on seasonal variations have additionally implicated fiber consumption as predisposing factor [23, 24]. The proposed mechanism is low-fiber diets which lead to less colonic water and inspissated fecal material and, thus, higher colonic pressures. These conditions predispose to the development of fecaliths. Obstructing fecaliths essentially create a closed loop obstruction resulting in eventually appendicitis. However, attempts to confirm this pathophysiology mechanism with case-controlled studies of fiber intake and appendicitis rates are inconclusive. Of note, the evidence for fecaliths as a factor in the development of appendicitis is stronger in children and in cases of uncomplicated appendicitis than in the elderly who are also more likely to be perforated [25]. Further confounding epidemiologic analysis is the role of heredity, as having a family history of appendicitis increases the relative risk of the disease by almost threefold [26].

Pathophysiology

Despite its frequency and our ability to diagnose and effectively treat appendicitis for nearly two centuries, our understanding of its etiology is relatively poor. Historically, appendicitis was attributed to obstruction of the lumen and resultant increased luminal pressure leading to distention. This process if left unfettered ultimately can lead to progressive tissue ischemia due to appendiceal wall venule occlusion and stasis of lymphatic flow, leading to gangrene and perforation [27–33]. Appendiceal obstruction may be caused by fecaliths, lymphoid hyperplasia, benign or malignant tumors, and infectious processes. The relative frequency of these processes may be related to the patient's age at presentation. Lymphoid follicular hyperplasia as a sequela of infection may be suspected in the young. In contrast, luminal obstruction in older patients is believed to be from fibrosis, fecaliths, and neoplasia. More recent research suggests there may be a difference between the pathophysiology of perforated and nonperforated acute appendicitis [34]. A review of the National Hospital Discharge Survey identified an increase in the rate of perforated appendicitis starting in 1995 after a quarter century of steady decline. In the same time frame, the rate of both negative appendectomy and incidental appendectomy was declining as the diagnostic accuracy of imaging was enhanced [28].

When perforation occurs, the flora varies based on the chronicity of symptoms. Aerobic organisms predominate early in the course, while mixed flora is more common in late perforated appendicitis. Common organisms include *Bacteroides fragilis* and *Escherichia* [35–37]. Other bacteria are often found and are typical of colonic flora [38]. Known physiologic changes associated with aging may hasten the clinical course of appendicitis in elderly patients [30, 39, 40]. Anatomic variations have been noted in the appendices of elderly patients which may cumulatively result in decreased appendicular wall strength. These variations include smaller-caliber lumens or even obliterated, thinned mucosa, attenuated levels of lymphoid tissue, and fibrous or fatty infiltration of the wall [12]. Other age-related medical comorbidities like atherosclerosis can predispose to ischemia. Any one or combination of these changes may require significantly less endoluminal pressure, as is more common in early appendicitis, to cause prompt rupture in elderly patients. Older patients can have immunosenescence, a predictably diminished inflammatory response [41]. This can lead to blunted signs and symptoms of appendicitis as compared to younger patients.

Presentation

Abdominal pain is the most common clinical symptom of appendicitis and is found in nearly all confirmed cases [42]. Unfortunately, abdominal pain is one of the most common presenting complaints for physician visits. For every 100 people in the USA, there are 35 physician visits for abdominal pain annually [43]. The classic clinical presentation of acute appendicitis is right lower quadrant abdominal pain, anorexia, nausea, and vomiting. The epitomic patient will relate more generalized periumbilical pain that later localizes to the right lower quadrant. This constellation of symptoms can be identified in more than half of patients with appendicitis [42, 44, 45]. Other signs and symptoms usually trail the onset of pain and include nausea, vomiting, fever, and leukocytosis. Fevers, when present, are typically minimal, up to 101.0 °F (38.3 °C) [42, 46–49].

Commonly, the clinical presentation of appendicitis in the elderly mirrors that of younger patients [15, 39, 50].

However, comorbidities and other potential diagnoses confound the diagnosis of appendicitis in elderly patients. Older patients (age >50) are more likely to have diagnostic errors as compared to their younger counterparts (30 % vs 8 %) despite similar presenting signs and symptoms [50, 51].

The greatest diagnostic challenge of appendicitis remains its atypical and nonspecific presentation in many patients irrespective of age. As initial signs and symptoms of appendicitis are often subtle, patients and clinicians may downplay their importance. By estimation, 25 % of patients with appendicitis do not have a classic presentation. Symptoms can be dependent upon the location of the appendix, as it is not anatomically fixed in position. The appendix may be found in the pelvis, retrocecal, adjacent to the terminal ileum or the right colon (paracolic). Unusual presentations have been implicated as a factor leading to a delayed diagnosis. Delays in diagnosis permit time for progression of inflammation increasing the possibility of perforation. Atypical presentation is associated with extremes of age and other medical conditions which also may interfere with establishing the diagnosis. The higher rates of perforation consistently reported in the literature for elderly patients may be from delay in seeking evaluation, physiological differences, or other factors [52–55].

Diagnosis

Scoring systems have been developed to objectively guide clinicians in the diagnosis of appendicitis. Of these, the Alvarado score is the most widely used [56, 57]. Alvarado identified seven signs and symptoms and assigned each a point value: migratory right iliac fossa pain (1 point), anorexia (1 point), nausea/vomiting (1 point), right lower quadrant tenderness (2 points), rebound tenderness in the right lower quadrant (1 point), temperature >37.5 °C (1 point), and leukocytosis (2 points). The sum of these points yields the total score used to guide management. Scores below 3 are considered low risk of having appendicitis and need no further workup [56, 58, 59]. Scores higher than 3 may have appendicitis and should prompt further evaluation. The system was devised in the era prior to routine cross-sectional imaging. More recently, the Alvarado score has been employed as a screening tool to limit unnecessary imaging studies [61]. Elderly men with very high scores (>7) are highly likely to have appendicitis and should undergo appendectomy [59]. Women, particularly those who are premenopausal, may benefit from a confirmatory test prior to appendectomy [56, 57, 59].

There has been an exponential increase in the use of imaging for the identification of acute appendicitis. Although the growing reliance on confirmatory imaging has greatly reduced the negative appendectomy rate, unnecessary diagnostic imaging has associated costs and risks that could otherwise be avoided when the diagnosis can be made based on other clinical signs and symptoms [60–62].

Imaging should be performed when the diagnosis of appendicitis is suspected or unclear, which is often the case in elderly patients. Either ultrasound or cross-sectional imaging, with computed tomography or magnetic resonance imaging, can be used. Ultrasound is generally considered reliable for identifying acute appendicitis, but its sensitivity is suboptimal and dependent on many variables. It has little added value when the clinical presentation is clear [63]. Ultrasonographic findings of appendicitis include:

1. Blind-ended, tubular, noncompressible, aperistaltic structure
2. Diameter > 6 mm, laminated wall
3. Increased periappendiceal echogenicity
4. Appendicolith: echogenic with distal shadowing
5. Doppler: increased circumferential flow
6. Perforation/abscess: thickening of adjacent bowel wall, fluid collections, and hypoechoic mass

The overall diagnostic accuracy of ultrasound is 85 % (Fig. 13.1) [42, 63–65].

Sonography is increasingly available, does not require ionizing radiation, the results are immediately available, and does not require delays for administration of contrast agents. The accuracy of ultrasound is, however, dependent on the skill of the operator. Furthermore, patient factors related to body habitus or the presence of significant bowel gas can limit its utility in some patients. Currently, there are no studies focusing on the use of ultrasound in elderly patients [42, 64–66]. Increased use of ultrasound could reduce the growing reliance on CT scanning for the diagnosis of appendicitis by as much as 25 % [67]. There is increasing evidence to support the use of ultrasound as the initial screening modality, reserving cross-sectional imaging for nondiagnostic or equivocal results. However, the false-positive rate may be higher with this approach [68].

Computed tomography of the abdomen and pelvis is the most sensitive and specific modality for the diagnosis of appendicitis. The campaign against unnecessary operations, the negative appendectomy rate, has driven clinicians to

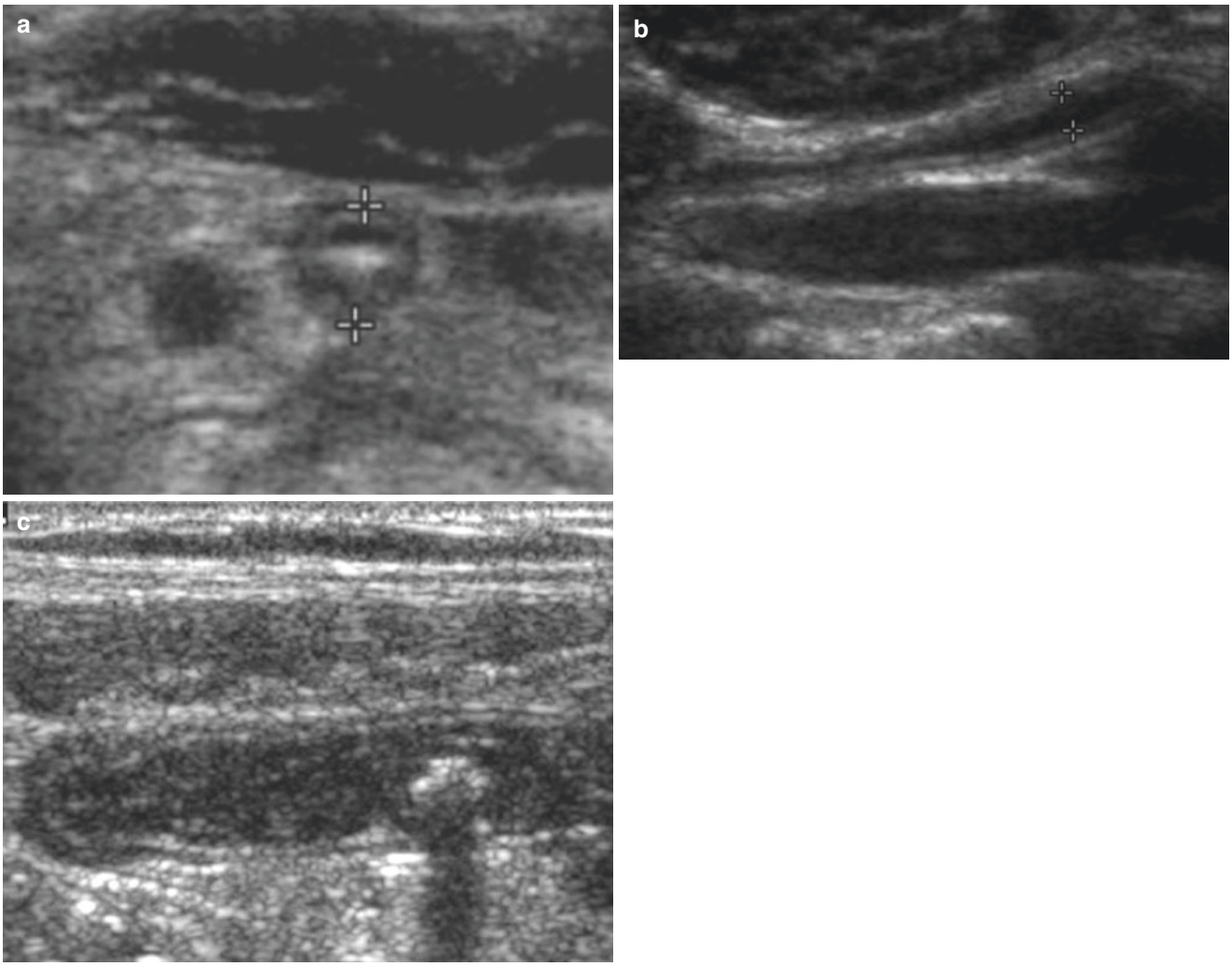

Fig. 13.1 (**a**) Ultrasound demonstrating a noncompressible tubular structure on ultrasound, with a transverse diameter of >6 mm, consistent with acute appendicitis. (**b**) Ultrasound demonstrating a longitudinal view of a noncompressible tubular structure with thickened laminated walls consistent with acute appendicitis. (**c**) Endolumenal fecolith on ultrasound with distal shadowing

become increasingly reliant on CT. CT findings of appendicitis include:

1. Enlarged, inflamed appendix (>6 mm)
2. Appendicolith (20–40 %)
3. Absence of luminal oral contrast
4. Appendiceal wall thickening
5. Periappendiceal fat stranding
6. Abscess or phlegmon
7. Focal cecal thickening (arrowhead sign)
8. Target sign

It is well accepted that CT has a high sensitivity and specificity in all patient populations. Older patients with suspected appendicitis can be diagnosed by CT with an accuracy of >99 %. Despite a lower overall rate of acute appendicitis when compared to younger patients, the sensitivity and specificity of CT in elderly patients with clinically suspected appendicitis are statistically comparable to that of younger patients (Fig. 13.2) [69, 70].

Efforts to reduce unnecessary risk of radiation exposure and radiocontrast nephropathy have led to the suggestion that magnetic resonance imaging (MRI) may be used as an alternative to CT scanning [71, 72]. Most studies of MRI in appendicitis have focused on pregnant women, where the risk of radiation to the fetus is paramount [73, 74]. A Dutch group evaluated this modality for all adult patients and found it to be comparable to CT scan as a second-line study after inconclusive or nondiagnostic sonograms [72]. In the elderly patient, radiation exposure is less of a concern, but underlying renal insufficiency may make potential renal toxicity more concerning. There are no studies to evaluate MRI for appendicitis in the elderly.

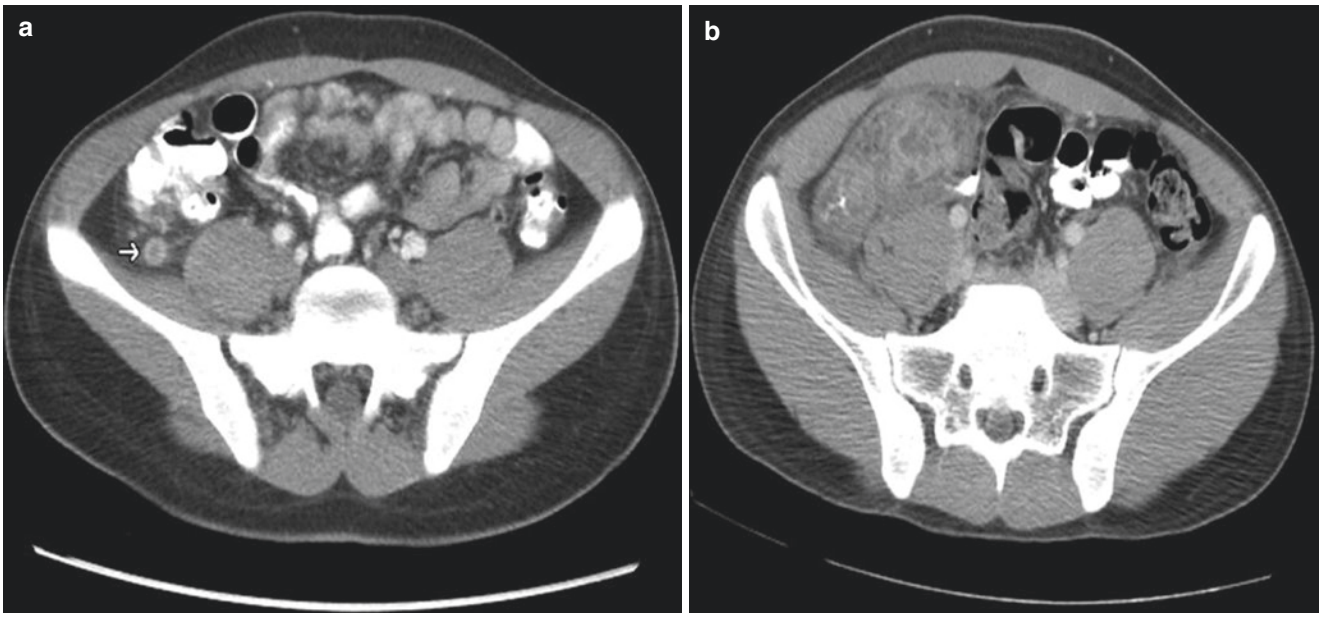

Fig. 13.2 (**a**) A target sign on CT scan of the abdomen and pelvis consistent with acute appendicitis. (**b**) Periappendiceal inflammation suspicious for perforated appendicitis

Treatment

The goals of therapy for acute appendicitis have historically been timely diagnosis followed by prompt surgical intervention. Advanced imaging technology has decreased negative appendectomy rates to roughly 10 %. The evaluation of abdominal pain and the diagnosis of appendicitis are more complex with longer intervals between the onset of symptoms and initial medical visit, especially in elderly patients [42, 51, 53–55, 59–62, 64–66, 75].

Surgical intervention remains the standard of care for elderly patients for uncomplicated appendicitis as well as patients with early perforation without defined phlegmon or abscess. For open appendectomy, a McBurney's incision in the right lower quadrant is the standard choice. Alternative incisions, namely, paramedian and vertical midline, are associated with higher postoperative infectious complications [55, 76]. Laparoscopic appendectomy has been proven safe and effective in the aged population with benefits of decreased length of stay, postoperative complications, and mortality. This holds true for older patients with both perforated and nonperforated appendicitis [77–79].

There are some uncommon clinical scenarios when appendectomy should be delayed. Patients with delayed presentation or longer duration of symptoms (>72 h) are more likely to have complicated appendicitis. Diagnostic imaging may confirm a phlegmon or abscess. Early operative intervention in such cases is correlated with increased morbidity, due to the technical challenges of dense adhesions and inflammation. Additionally, when there is extensive inflammation, appendectomy may not be a safe surgical option, and an ileocecectomy may be required to avoid postoperative complications such as appendiceal stump leak. In patients with a defined phlegmon or abscess without severe sepsis physiology, a nonoperative approach can be considered to avoid these potential complications. Nonoperative management includes antibiotics, intravenous fluids, and bowel rest [80–83]. Many patients will respond to nonoperative management since the inflammatory process has already been sequestered by natural host defenses. Repeat imaging may be necessary to document resolution of the phlegmon, or progression to abscess formation.

If initial or follow-up imaging identifies a defined abscess cavity, percutaneous image-guided drainage can be performed if the patient's clinical condition permits [83–85]. Patients who have an abscess are ideal candidates for percutaneous drainage and nonoperative management, with success rates of 80 %. This approach to appendiceal abscesses results in a decrease in morbidity and shorter lengths of stay [82, 86, 87]. Inpatient admission and close monitoring for signs of treatment failure are warranted. Failure of this approach includes bowel obstruction, ongoing or worsening sepsis, persistent pain, fever, or leukocytosis. In the majority of patients, nonoperative management is successful. However, in the patients who fail nonoperative management, the next step should be prompt operative intervention for source control of the sepsis.

Traditionally, an interval appendectomy has been recommended for patients managed nonoperatively at 6–8 weeks after treatment [88]. The rationale for this has been to prevent recurrent appendicitis [89, 90] and to exclude neoplasms (such as carcinoid, adenocarcinoma, mucinous cystadenoma, and cystadenocarcinomas) [91, 92]. Recent studies suggest that interval appendectomy is unnecessary [93–95]. Recurrent appendicitis is uncommon and appendectomy can be performed at the time of recurrence [94, 95].

In the general population, the risk of malignancy is quite low but increases with advanced age [94, 96]. As with all surgical decisions, and especially in the case of elderly patients, clinicians must be circumspect. The benefit of interval appendectomy should be weighed against the risks of surgical intervention. Colonoscopy should be considered prior to appendectomy in patients over 50 years old who have not had a recent colonoscopy to rule out concurrent colonic pathology necessitating resection.

Antimicrobial management of complicated appendicitis is varied. Traditionally, antibiotics would be continued for 10–14 days in hopes of reducing the likelihood of postoperative abscesses with little evidence. Some have advocated for using clinical markers such as fever and leukocytosis to guide the duration of therapy [97]. The most recent evidence shows no benefit to continuing antibiotics beyond 4 days after appendectomy regardless of systemic inflammatory signs [98, 99]. The appropriate length of antibiotics has not been studied in the elderly but the average of patients in the STOP-IT trial was over 50 [98]. Whether significant immunosenescence should be factored into determining the appropriate length of antibiotics is not clear. There is also limited data to suggest that uncomplicated cases of appendicitis be treated with antibiotics alone, reserving surgical intervention for those who fail nonoperative management [100–102].

Outcomes

Despite improvements in the diagnosis and management of geriatric surgical patients, morbidity and mortality for appendicitis remain high. Morbidity rates (28–60 %) and mortality rates (up to 10 %) are all significantly higher than younger patients. In 2004, deaths from appendicitis were rare, but nearly 70 % of patients who died from appendicitis were ≥65 years old [103]. This is typically attributed to delays in diagnosis and higher rates of perforation. Perforated appendicitis portends to longer hospital stays, an increased risk of wound, and other nosocomial infections. Intra-abdominal sepsis is seen almost exclusively in patients with perforation. The additive burden of disease in elderly patients where cardiac, pulmonary, and malignant comorbidities are far more common not surprisingly yields a higher mortality rate [50–53, 55, 75, 76].

Malignancy and Mucocele

Malignancy of the appendix is uncommon, occurring in approximately 1 % of appendectomy specimens, and accounts for roughly 0.5 % of intestinal neoplasms. Carcinoid tumors are the most common, comprising over 50 percent of appendiceal neoplasms. As is the case with other carcinoid tumors arising in the intestines, appendiceal carcinoids can secrete serotonin and other vasoactive substances. These substances are responsible for the carcinoid syndrome, which is characterized by episodic flushing, diarrhea, wheezing, and right-sided valvular heart disease. Nearly all appendiceal carcinoids are found incidentally during an operation for acute appendicitis, and the majority of those are located at the tip of the appendix [104, 105]. This incidence in patients over 40 is higher than their younger cohorts [96].

Additional surgical management for appendiceal carcinoids is a subject of some debate. Tumor size is an important determinant of the need for further surgery [106]. Very small carcinoid tumors of the appendix (<1 cm) are generally considered benign. However, slightly larger (1–2 cm) tumors have rarely been reported to metastasize regionally and have deep invasion. Appendiceal carcinoid tumors ≥2 cm have a 5-year mortality of approximately 30 %. In contrast, 1 cm appendiceal tumors have a 5 % mortality at 5 years [107]. Whether colectomy should be performed in patients with smaller tumors is unclear, but the latest recommendations do not support formal colectomy for small (<2 cm) tumors [108].

Oncologic right colon resection should be performed for patients with tumors >2 cm, tumors at the base of the appendix, and incompletely resected tumors. Other debated indications for right hemicolectomy include tumors <2 cm, mesoappendiceal invasion, lymphovascular invasion, intermediate- to high-grade pathologic features, mixed histology (goblet cell carcinoid, adenocarcinoid), or obvious mesenteric nodal involvement. Some dissenting authors consider appendectomy alone adequate for tumors <2 cm, regardless of mesoappendiceal invasion. Most agree that for carcinoids <2 cm in size without evidence of mesoappendiceal invasion or nodal involvement, simple appendectomy alone is adequate [107, 109–112].

In contrast to other appendiceal neoplasms, the majority of patients with adenocarcinomas present with symptoms consistent with acute appendicitis. Patients can also present with ascites, generalized abdominal pain, or abdominal mass. Appendiceal adenocarcinomas fall into one of three separate histologic types: the most common is the mucinous type, intestinal or colonic type (which closely mimics adenocarcinomas found in the colon), and, the least common, signet-ring cell adenocarcinoma [113–115].

In general, the optimal treatment for most appendiceal adenocarcinomas is a right colectomy. Some authors advocate a simple appendectomy for adenocarcinomas that are confined to the mucosa or well-differentiated lesions that invade no deeper than the submucosa. Although this distinction can be difficult to make intraoperatively, a more common scenario is the unexpected finding of an adenocarcinoma when the surgical report of an appendectomy specimen is finalized. In such cases, a right colectomy need not be pursued for appendiceal adenocarcinomas that are confined to the mucosa or well-differentiated lesions that invade no deeper than the submucosa [116]. The role of adjuvant chemotherapy for adenocarcinoma of the appendix remains unknown. The low incidence of this disease has precluded the performance of randomized studies, and few institutions see sufficient numbers of patients to report series of homogeneously treated patients.

The term appendiceal mucocele refers to any lesion that is characterized by a distended, mucus-filled appendix. It may be either a benign or malignant condition. The course and prognosis of appendiceal mucoceles are related to their histologic subtypes which include mucosal hyperplasia, simple or retention cysts, mucinous cystadenomas, and mucinous cystadenocarcinomas. Mucoceles that are due to hyperplasia, or that arise from an accumulation of mucus distal to an obstruction in the appendiceal lumen, even if they rupture, are asymptomatic, are benign, and do not recur. They may be diagnosed incidentally on a CT scan done for another purpose. In contrast, mucoceles that develop from true neoplasms (cystadenomas or cystadenocarcinomas) when ruptured can lead to intraperitoneal spread and the clinical picture of pseudomyxoma peritonei.

Surgical resection should be pursued, even for a benign-appearing appendiceal mucocele, since it may harbor an underlying cystadenocarcinoma [117–120]. An oncologic right hemicolectomy is advocated for patients with complicated mucoceles involving the terminal ileum or cecum. If there is no evidence of peritoneal disease and the final pathology after traditional appendectomy shows a cystadenocarcinoma, a right colectomy could be considered to remove lymph nodes; however, the chance of nodal spread is quite small. An acceptable approach (assuming negative resection margins) is observation alone. If, on the other hand, there is evidence of peritoneal disease at laparoscopy, then the procedure should be converted to an open laparotomy for debulking.

It is important to remember the association between appendiceal mucoceles and other tumors involving the GI tract, ovary, breast, and kidney [121, 122]. This possibility should be evaluated either preoperatively or intraoperatively.

Conclusions

Appendicitis is uncommon in elderly patients. However, when it does occur, elderly patients have poorer outcomes. Delayed presentation, preexisting medical conditions, and more rapid progression of disease contribute to increased morbidity and mortality. Elderly patients with significant comorbidities do not tolerate complications that are associated with advanced appendicitis well. It is critical that clinicians have appendicitis in their differential diagnosis when an elderly patient presents to the hospital with abdominal pain. Expeditious evaluation and treatment are imperative.

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Biliary

14

Marko Bukur and Ali Salim

Introduction

As our Western population continues to age and life expectancy continues to increase, the elderly population will account for an escalating amount of health-care expenditure. As health-care providers, we must find ways to contain costs while simultaneously optimizing care of this special patient population. The most common causes of abdominal pain that requires surgical evaluation and treatment in the elderly are symptomatic biliary disease [1]. This is largely due to the fact that the incidence of cholelithiasis, particularly the symptomatic variant, increases with age [2] varying from 20 to 80 % [3, 4]. Early recognition is important due to the fact that elderly patients often present with a more complicated form of disease than their younger counterparts [5, 6]. Delays in treatment can often be precarious, leading to poor outcomes and subsequent increased use of resources. This chapter aims to review the epidemiology of biliary disease, physiologic changes associated with age progression, and the diagnostic work-up and management that will lead to optimal clinical care of elderly patients.

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Biliary Physiology and Age-Related Pathophysiologic Changes

Normal biliary secretion is an intricate, multi-step process that serves several homeostatic functions. Bile is necessary for nutrient absorption of dietary cholesterol and fats, including the soluble vitamins, as well as the mechanism for endogenous cholesterol excretion and drug and heavy metal metabolism. Bile secretion is initiated by hepatocytes into the canalicular spaces that eventually coalesce to form the complex intrahepatic biliary tree before exiting the liver as the right and left hepatic ducts. The average rate of secretion in humans is approximately 600 ml/day [7]. Bile is isoosmolar with plasma and is largely composed of water (97 %) and bile acids (2 %) with the remainder of constituents being phospholipids, cholesterol, and bile pigments [8]. Cholesterol is insoluble in water and requires a fine balance of bile acids and phospholipids to allow formation of mixed micelles that are non-lithogenic. After bile exits the liver via the hepatic ducts, they join together to form the common hepatic duct. The entrance of the cystic duct then forms the common bile duct. Communication with the cystic duct allows for bile to be stored between meals in the gallbladder. In the gallbladder, bile is concentrated through water reabsorption resulting in significantly higher concentrations of bile salts, cholesterol, and phospholipids [9]. After eating, during the gastric phase of digestion, the gallbladder normally empties 75 % of the stored bile into the duodenum prior to refilling with recycled bile acids through enterohepatic circulation.

In the elderly population, there is an age-dependent increase in the incidence of gallstones. By the age of 70 years, 15 % of men and 24 % of women have gallstones with an increase in the incidence to 24 % and 35 %, respectively, in the ninth decade of life [10]. There are three major factors that lead to the increased formation of gallstones including: altered composition of hepatic bile, increased cholesterol nucleation, and decreased gallbladder motility [11]. Several

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age-related changes occur that lead to changes in bile salt composition. With aging, there is a corresponding decrease in bile salt synthesis [12]. This decrease can alter the fine balance in the mixed micelles that will lead to nucleation of cholesterol crystals and possible stone formation. There is also an increased incidence of bactobilia in the elderly largely due to decreased biliary duct motility. These bacteria can produce enzymes that will lead to deconjugation of bile salts and promote sludge and stone formation [11]. Finally, senescent alterations in biliary protein concentration can lead to increased bile lithogenicity.

Changes in cholesterol metabolism are also responsible for stone formation in the elderly. There is an increased relative amount of cholesterol present in the bile of older patients. This leads to nucleation of cholesterol crystal as they become insoluble in the aqueous bile and serve as a nidus for salt precipitation and subsequent stone formation [11]. Additionally, there are multiple factors that lead to altered gallbladder motility as age increases such as decreased physical activity, decreased responsiveness to cholecystokinin, and the presence of comorbidities such as diabetes mellitus [11–13]. Taken together, all of these age-related pathophysiologic changes lead to an increased propensity for gallstone formation and their subsequent pathologic sequelae.

Perioperative Considerations

The expected mortality for elective cholecystectomy in the general population is less than 0.1 %; however this risk rises in the elderly population particularly in the presence of coexisting comorbidities, decreased physiologic reserve, and delays in therapy resulting in emergent operative intervention. In elderly patients that undergo appropriate perioperative evaluation and elective operation have outcomes that are similar to younger patients. In a recent population-based study utilizing a national Medicare database, Fry et al. [14] examined the 90-day outcomes in patients over 65 years of age undergoing elective laparoscopic cholecystectomy. They found that the in-hospital mortality in this patient cohort was 0.7 % with another 1.3 % of patients expiring in the 90-day interval post discharge. Therefore, elderly patients should be appropriately risk stratified in conjunction with the patient's primary physician and anesthesiologist. Recently, a helpful nomogram created by examining Medicare claims data was published by Parmar [15] and colleagues that may aid in identifying elderly patients with symptomatic cholelithiasis that are at the greatest risk for ongoing biliary complications. The nomogram known as the PREOP-Gallstones (Predicting Risks of Complications in Older Patients with Gallstones) model takes into account several demographic factors, preexisting comorbidities, and etiology of gallstone complications to identify two patient cohorts: one that has a "low risk" of subsequent biliary-related complications (<10 % over 2 years) and the other "high-risk" group with a >40 % risk of recurrent symptoms. Though this nomogram was created from a retrospective database, it may provide an individualized assessment of risk in patients presenting with symptomatic biliary disease that allows for an objective discussion between the patient and surgeon regarding the risks and benefits of operative intervention. Further prospective studies examining the PREOP algorithm need to be undertaken.

Major risk factors for cardiopulmonary-related morbidity can be quickly assessed with minimal ancillary testing by assessing the patient's pre-illness level of activity through METs or metabolic equivalents [16], ASA score [17], or Goldman cardiac risk profile [18]. For those patients that require more intensive cardiac evaluation, well-established guidelines are available [16].

Careful perioperative management can reduce the risk for major postoperative complications and can often be accomplished through simple interventions. A detailed review of the patient's pre-illness medications should be carried out and assessed for polypharmacy or drug interactions. It is also important to take note of pre-existing cardiac medication, particularly beta-blockers as withdrawal of these medications has been tied to adverse cardiac outcomes [19, 20]. Intraoperative maintenance of normothermia is important as the elderly have impaired thermoregulation [21], and hypothermia has been linked to an increased incidence of adverse cardiac events [22] and wound complications [23].

Elderly patients are also at increased risk for early postoperative delirium that leads to increased morbidity, prolonged hospital stays, and delayed recovery of functional status [17]. Early recognition is important to halt progression. A vigilant search for common inciting factors such as sepsis, electrolyte disorders, or adverse medications should be undertaken. It is also important to note that inadequate analgesia can exacerbate delirium and lead to increased cardiopulmonary complications [17]. Judicious use of a multimodal analgesic approach can lead to enhanced recovery and decreased morbidity [24] and should be an integral part of the perioperative plan.

Diagnostic Investigation

As previously stated, biliary diseases are the most common cause of surgical pathology in the elderly population [25]. However, unlike their younger counterparts, the clinical presentation is often more subtle. Failure to identify and treat surgical conditions can lead to increased mortality even in patients that are admitted to the hospital for observation [5]. There are several physiologic reasons that are responsible

for the diagnostic challenge in the elderly. Decreased immune function is seen with increasing age [26] which can alter the typical inflammatory response seen with acute intra-abdominal processes [5, 27]. This leads to impaired ability to fight infection and altered pain perception [26] which often delays clinical presentation. The presence of medications or comorbid conditions can also alter physical exam findings. Nonsteroidal anti-inflammatory drugs can mask fever, and steroids can alter the leukocyte count and immune response, while patients that present with "normal" blood pressure and a history of hypertension may have significant occult hypoperfusion. Additionally, it is important to note that the presence of beta-blockers may blunt the tachycardic response seen with serious intra-abdominal pathology. The above pitfalls should all be carefully taken into account when evaluating elderly patients with suspected biliary disease as these patients can present with frank gallbladder perforation, gangrene, emphysematous cholecystitis, or ascending cholangitis with minimal symptomatology [28]. There should be a low threshold for ordering ancillary lab work and imaging investigations.

Laboratory Testing

The most commonly ordered laboratory tests used in the evaluation of biliary disease are complete blood count (CBC), metabolic panel, aminotransferases, alkaline phosphatase, bilirubin, and coagulation panel. Each of these can provide clinically useful information but should not be relied upon exclusively to eliminate pathology.

Often the most scrutinized value on the CBC is the white blood cell count. It can be helpful when elevated but should be noted that unlike in younger patients can be normal in 30-40 % of patients with acute gallbladder pathology [26]. The hemoglobin and hematocrit should also be carefully examined, as microcytic anemia can be indicative of a possible occult malignancy. The metabolic panel should be reviewed as the elderly patient often has electrolyte abnormalities that will need to be addressed prior to operative intervention. This is especially true when the patient is on antihypertensive medications such as diuretics, beta-blockers, ACE inhibitors or angiotensin receptor blockers, and digitalis as these are all well known to cause metabolic abnormalities.

The liver function panel may also be helpful in establishing a working diagnosis prior to diagnostic imaging. Aminotransferase elevations are indicative of liver injury. There may be modest elevations (<500 IU/L) seen with acute/chronic cholecystitis, but the absence of elevation should not exclude this diagnosis as a significant proportion of elderly patients can have normal liver function tests [26]. Markedly elevated aminotransferase levels (>500 IU/L) are seen with acute biliary obstruction such as in choledocholithiasis or biliary pancreatitis.

Markers of cholestasis include serum bilirubin and alkaline phosphatase. Measuring fractionated bilirubin is helpful because it allows discrimination of the predominant source of bilirubin elevation (i.e., conjugated vs. unconjugated). Normally the total bilirubin is predominantly unconjugated and less than 1.2 mg/dl. Elevations in the conjugated form of bilirubin are indicative of biliary tract obstruction, particularly when combined with an elevation in alkaline phosphatase. Total bilirubin levels have also been shown to be predictive of benign versus malignant obstruction depending on the level of elevation [29] and may assist in performing the appropriate diagnostic work-up. Isolated elevation of the alkaline phosphatase level should also not be ignored as it can be elevated with partial or incomplete biliary obstruction.

It is important to also take note of the coagulation panel in elderly patients presenting with suspected biliary disease. Biliary obstruction can cause elevation in the PT/INR due to malabsorption of vitamin K. This fat-soluble vitamin requires bile to aid in its digestion and absorption in the terminal ileum. Malnutrition is also common in the elderly and can also lead to coagulation derangements [30]. Marked elevation in these parameters is indicative of severe hepatocellular dysfunction or chronic long-standing disease with progression to liver failure.

Noninvasive Imaging

Plain Radiographs

Often one of the earliest tests ordered during the evaluation of acute abdominal pain are an upright chest x-ray and flat plate of the abdomen. Though these are often ordered by the emergency department prior to surgical consultation, they should not be neglected if available. In the Western hemisphere, cholesterol is the main component present in gallstones (>75 %) with the remainder being composed of calcium bilirubinate [31]. Because of the lack of calcification, only 15–20 % of stones will be visualized on plain films [32]. Though the sensitivity for stones is clearly not acceptable for diagnosis, there are other features that should be sought. The presence of pneumobilia in a patient that has not been instrumented is indicative of not only gallstones but also biliary-enteric fistula. When pneumobilia is combined with evidence of small bowel obstruction (see Fig. 14.1) on plain films in a patient that has never had abdominal surgery, this is virtually diagnostic of gallstone ileus. Lastly, although a rare entity (0.06–0.8 %), complete calcification of the gallbladder wall ("porcelain gallbladder") may also be seen on plain radiography [33].

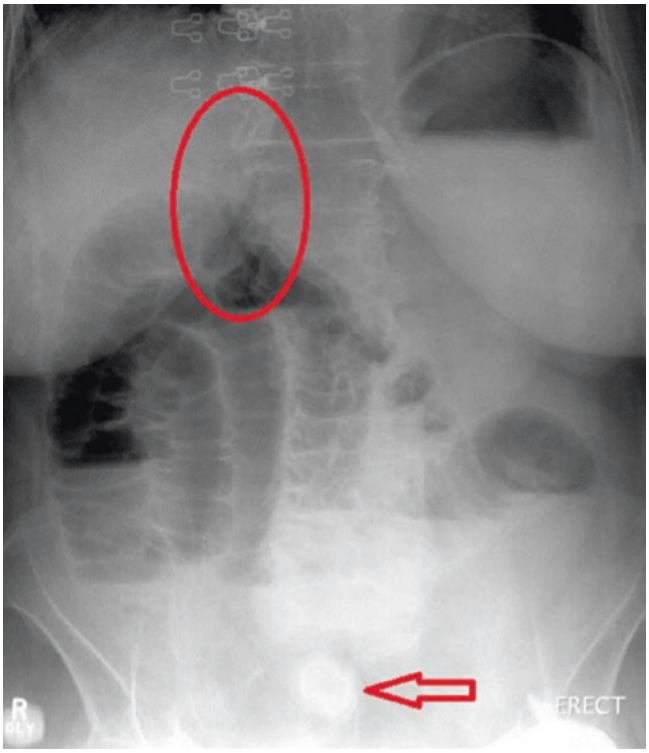

Fig. 14.1 Plain abdominal radiograph of a patient with gallstone ileus. Note the presence of pneumobilia depicted in the circled area. Gallstones may not be present due to lack of calcium composition

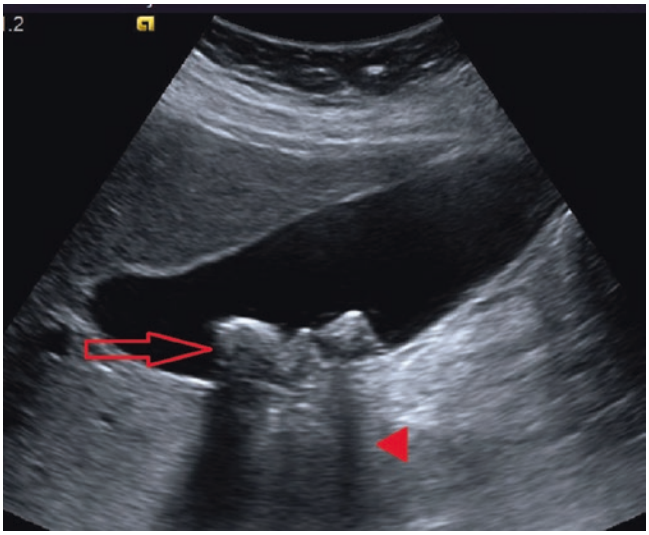

Fig. 14.2 Abdominal ultrasound documenting cholelithiasis. Note the hyperechoic stones (*arrow*) and posterior acoustic shadowing (*arrowhead*)

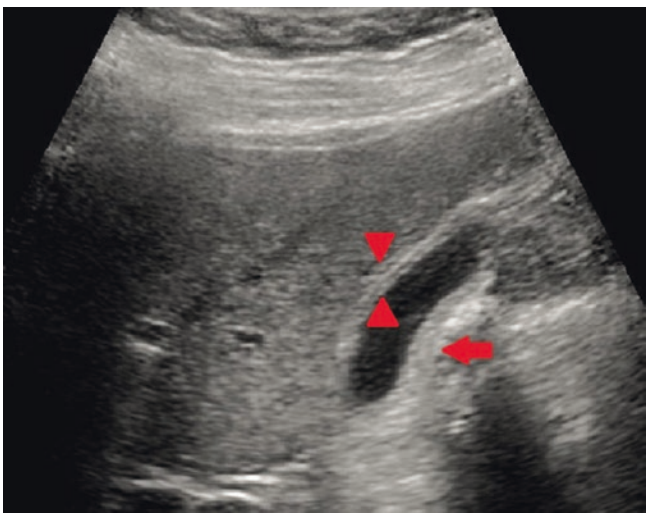

Fig. 14.3 Ultrasound depicting the findings of acute cholecystitis. Note the presence of gallbladder wall thickening (*double arrowhead*) and pericholecystic fluid (*single arrow*)

Ultrasound

Ultrasound has become the initial diagnostic test of choice in patients with suspected biliary disease. The test can be rapidly performed at the patient's bedside and does not require the use of radiation. Ultrasound is highly accurate for identifying stones that are ≥5 mm in size (>96 %) [32]. In order to detect stones, they must be echogenic, have posterior acoustic shadowing, and be mobile (see Fig. 14.2). False-negative results may be seen with decreased sonographer experience, large amounts of bowel gas, small stone size (<3 mm), or with soft pigmented stones ("brown stones") [32–34]. Examining the gallbladder with the patient in multiple different scanning positions can lower the rate of false negative exams.

Ultrasonography is also helpful in establishing the diagnosis of acute and chronic cholecystitis. In the setting of acute cholecystitis, the most reliable finding is a sonographic Murphy's sign or tenderness over the gallbladder with transducer pressure. This finding is 87 % specific for the diagnosis of acute cholecystitis and has a positive predictive value of 92 % when stones are also visualized [35]. False-negative sonographic Murphy's sign may occur in patients that are immunosuppressed, obtunded, recently medicated, or have denervated gallbladders (i.e., diabetics or gangrene of the gallbladder) [32]. Other findings that are indicative of acute cholecystitis include gallbladder wall thickening (>3 mm), which is present in 50 % of cases, as well as the presence of pericholecystic fluid (see Fig. 14.3) [32, 35]. It should be noted, however, that these findings are nonspecific and may occur with adjacent right upper quadrant pathology. The ultrasonographic diagnosis of chronic cholecystitis can also be suggested by nonspecific gallbladder wall thickening due to fibrosis with resultant contraction and near obliteration of the gallbladder lumen producing the "double arc" sign [36].

It should also be noted that right upper quadrant ultrasound is also the initial imaging study of choice to screen for choledocholithiasis. It allows for quick assessment of the bile duct size and continuity. The extrahepatic common bile duct should be measured at the level of the right hepatic artery and

not exceed 6 mm, while the intrahepatic bile ducts should not exceed 2 mm in size [34]. With adequate sonographer experience, the level of biliary obstruction can be identified in 92 % of patients, and overall sensitivity for choledocholithiasis can reach 75 % [34]. It is important to emphasize that choledocholithiasis can also be present in the absence of biliary ductal dilation in 25–33 % of cases [37]. When this occurs or when stones are less than 5 mm in diameter combined with overshadowing by bowel gas, the sensitivity of ultrasound drops considerably. Endoscopic ultrasonography has considerably better sensitivity at detecting choledocholithiasis (96 %) and should be considered in select cases of presumptive biliary obstruction (i.e., low or intermediate probability of retained common duct stones) [38]. Endoscopic ultrasound has been shown to have equivalent sensitivity and specificity to endoscopic retrograde cholangiopancreatography (ERCP) and avoids not only radiation exposure but also potential complications (i.e., bleeding, perforation, and pancreatitis). In a large review of patients undergoing both endoscopic ultrasound and ERCP, Petrov and Savides [39] found that 67 % of patients could be spared ERCP with a negative ultrasound examination without any documented recurrence of common bile duct stones. Additionally, the safety of endoscopic ultrasound in elderly patients with comorbidities was demonstrated in a group of 1000 patients, which revealed that there were no age-related differences in procedure-related complications [40].

Biliary Scintigraphy (HIDA)

Biliary scintigraphy involves the administration of radiolabeled technetium iminodiacetic acid, which is taken up by the hepatic parenchyma and excreted into the bile with eventual flow into the gallbladder. The use of HIDA has largely declined into a second-line test for calculous biliary disease due to its increased expense, amount of time needed to complete the study, and the use of ionizing radiation. HIDA is considered positive for acute cholecystitis when there is the absence of gallbladder visualization within 60 min (see Fig. 14.4). This test can be carried out in a delayed fashion for up to 4 h; nonvisualization during this extended time frame is considered consistent with chronic cholecystitis [41]. Scintigraphy has excellent diagnostic sensitivity (>95 %), particularly in nonhospitalized patients that are much less likely to have false-positive imaging studies [41]. False-positive studies may be seen in up to 30–40 % of patients that are hospitalized for a reason other than abdominal pain, which is a common scenario in the elderly population [42]. Reasons for false-positive exams include: prolonged fasting, cholestasis secondary to hepatic disease, or prolonged parenteral nutrition [32]. HIDA can also play a role in diagnosing postoperative biliary complications (i.e., diagnosing postoperative bile leak) as well as in those patients with suspected biliary motility disorders such as biliary dyskinesia. However, due to the previously mentioned limitations, differences in cost and radiation exposure ultrasonography should be considered as the initial diagnostic imaging test of choice for most biliary diseases.

Computerized Tomography

Computerized tomography (CT) has variable sensitivity in detecting gallstones secondary to the variable amount of calcification present and thus is also a second-line imaging study in the work-up of biliary disease. Those stones that are predominantly composed of cholesterol (>60 %) will be more difficult to identify due to their similar radiographic density as the surrounding bile. CT has lower sensitivity as compared to ultrasonography in identifying choledocholithiasis (75–80 %) (see Fig. 14.5) [32, 43] but can provide

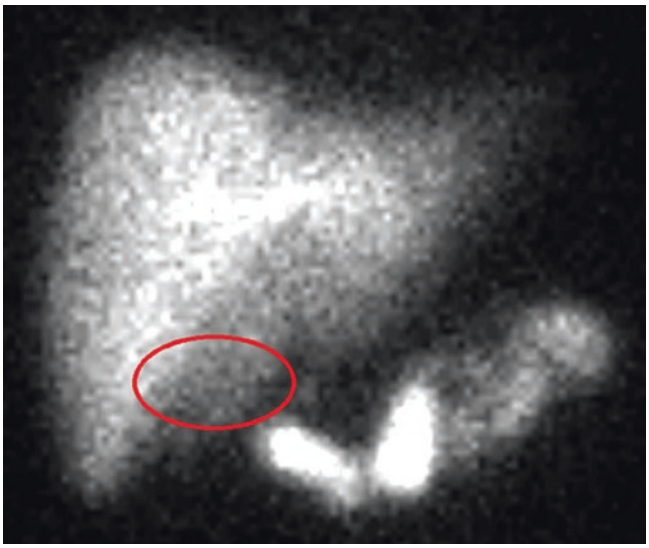

Fig. 14.4 Example of a positive HIDA scan. Note the absence of radioactivity in the area of the gallbladder fossa (*highlighted oval*)

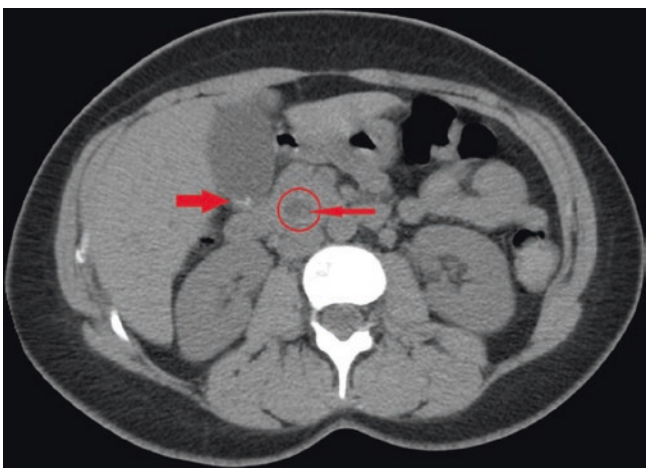

Fig. 14.5 CAT scan of the abdomen showing a stone (*thin arrow*) in a dilated common bile duct (*circled*) along with cholelithiasis (*thick arrow*)

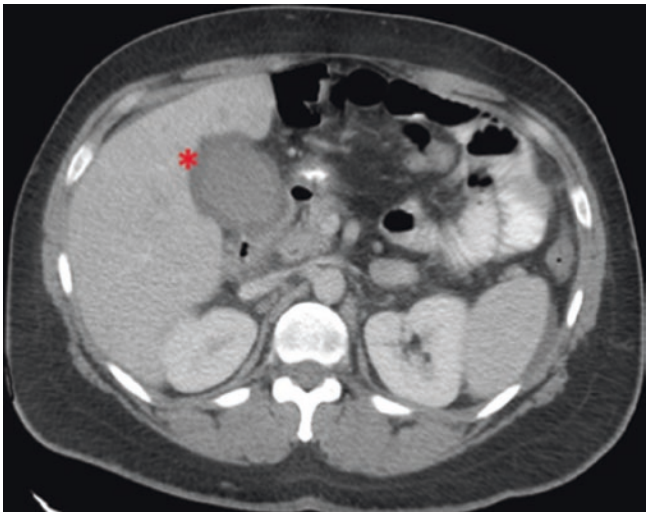

Fig. 14.6 CAT scan of the abdomen showing evidence of acute cholecystitis. Notice distention of the gallbladder (*asterisk*) with surrounding pericholecystic fluid

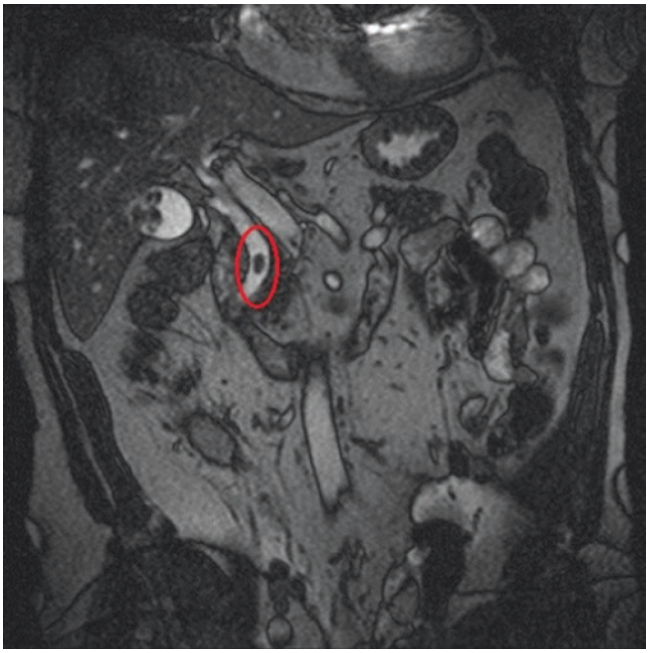

Fig. 14.7 T2-weighted MRCP showing a large stone in the common bile duct (*highlighted oval*)

information regarding ductal anatomy. CT imaging is most useful in demonstrating gallbladder size, wall thickness, and surrounding inflammatory changes associated with acute cholecystitis making it highly specific (99 %) for this particular diagnosis (see Fig. 14.6) [44]. In the setting of suspected malignancy, CT is the diagnostic image of choice because it allows assessment of not only the gallbladder but also surrounding structures such as the liver, porta hepatis, identification of lymphadenopathy, or pancreaticoduodenal pathology [45]. In the elderly patient with pre-existing renal disease, diabetes, or certain medications (i.e., ACE inhibitors, NSAIDs, or metformin), caution should be taken with the administration of intravenous contrast as this can precipitate or worsen renal failure. Gentle intravenous fluid administration, sodium bicarbonate, and/or Mucomyst prophylaxis should be considered in these patients as well as ensuring that iso-osmolar contrast is administered [46]. Because of the increased cost and associated radiation exposure, CT scanning should only be considered when there is diagnostic uncertainty and other abdominal pathology is suspected [47].

Magnetic Resonance Imaging and Cholangiopancreatography (MRI/MRCP)

MRI, though not frequently used as an initial imaging test, has excellent ability to identify gallstones due to the sharp contrast in signal intensity between bile and stones on T2-weighted images [48]. This excellent resolution of stones which are as small as 2 mm in size has made MRCP the diagnostic test of choice for identifying choledocholithiasis (see Fig. 14.7) in asymptomatic patients with moderate to high probability based upon clinical examination and laboratory studies. MRCP has excellent sensitivity (81–100 %) and specificity (85–99 %) for choledocholithiasis and is comparable to ERCP in diagnostic accuracy without the invasive risk [49]. MRCP becomes less sensitive in studies with microlithiasis, pneumobilia, motion artifact, or stones in the peri-ampullary region [50]. MRI can also be useful in those with malignant disease as it images the gallbladder wall, liver parenchyma, and biliary tree with high resolution. MRI may be difficult to obtain in elderly patients with dementia or claustrophobia due to the tight confines of the imaging magnet. Also those with pacemaker or defibrillator devices may also not be candidates for MRI, though certain devices have been prospectively observed after imaging without any adverse effects [51].

Invasive Imaging

Endoscopic Retrograde Cholangiopancreatography

Advancements in endoscopy techniques and increased experience have made ERCP widely available, and it remains the gold standard for the diagnosis of the majority of biliary pathology. However, due to its invasive nature and improvements in the aforementioned noninvasive imaging techniques, ERCP has largely become a planned therapeutic procedure. Those patients presenting with symptomatic choledocholithiasis (i.e., pain, jaundice, fever) or with documented common duct stones on imaging are clearly potential candidates for ERCP (see Fig. 14.8). Predicting which asymptomatic patients will ultimately require ERCP is more difficult, but advanced age (>55 years), hyperbilirubinemia

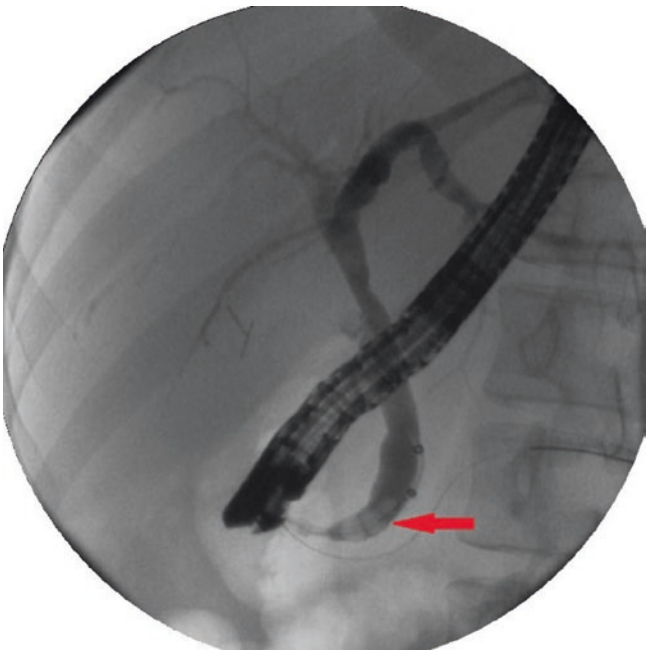

Fig. 14.8 An ERCP demonstrating a dilated common bile duct with multiple stones (*arrow*)

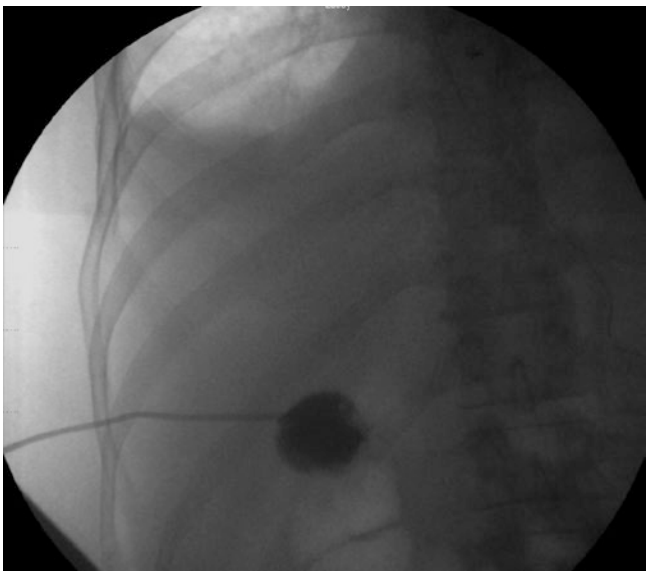

Fig. 14.9 PTC done under fluoroscopy for acute cholecystitis

(>1.8 mg/dl), and common duct dilation have all been shown to increase the likelihood of a therapeutic ERCP [52]. As previously mentioned, endoscopic ultrasound prior to ERCP may eliminate a number of nontherapeutic studies. The success rate for ERCP for common bile duct procedures is near 98 % in experienced hands [53]. ERCP is associated with a number of well-described complications, with the most common being post ERCP pancreatitis, with a reported incidence ranging from 5 to 10 %. Despite the possibility of post ERCP complications, elderly patients appear to tolerate the procedure as well as their younger counterparts [54].

Percutaneous Transhepatic Cholangiography (PTC)

PTC involves the percutaneous passage of a needle into the liver parenchyma under fluoroscopic or ultrasound guidance and then either into the gallbladder or biliary tree for diagnostic and/or therapeutic purposes (Fig. 14.9). This technique was initially introduced in 1979 and remains a valuable option for treating biliary pathology when ERCP is either unavailable or unsuccessful, particularly in the critically ill population [55, 56]. This less invasive technique can be used to successfully treat cholangitis or surgery-related biliary complications in elderly critically ill patients with a high success rate (>95 % [57]). Alternatively, the gallbladder can be cannulated to allow decompression for high-risk patients presenting with acute cholecystitis which is known as a percutaneous cholecystostomy tube. It should be noted that PTC carries a greater complication risk than ERCP because the catheter is passed through the liver into the biliary tree. This procedure can result in post-procedure hemorrhage, septic shock from bacterial translocation, or bile peritonitis.

Benign Calculous Diseases

Acute Calculous Cholecystitis

Clinical Presentation and Diagnosis

In the overwhelming majority of patients with acute cholecystitis, there is cystic duct obstruction by an impacted acalculous. This classically causes severe, persistent epigastric and right upper quadrant pain (especially with a positive Murphy's sign) that may radiate to the patient's back and be associated with nausea or vomiting. In most cases, the patient will recall more "minor" previous episodes that are in fact biliary colic, but acute cholecystitis can be the initial presentation of symptomatic gallstone disease in 15–20 % of patients [58]. In addition to the abdominal findings, there are also typically signs of systemic inflammation such as fever, tachycardia, and leukocytosis. In addition to leukocytosis, other laboratory tests that may be abnormal include: elevation of C-reactive protein and mild elevation of serum bilirubin and transaminases (<500 IU/L). Worse outcomes have been demonstrated in elderly patients presenting with LFT elevation in the setting of acute cholecystitis [59]. If the serum bilirubin is greater than 2 mg/dL, particularly the conjugated form, or serum transaminases are > 500 IU/L, choledocholithiasis should be suspected as the incidence of coexisting common bile duct stones in the elderly is high (10–20 %) [53]. It is important to emphasize, however, that the "classic" presentation in the elderly patient is often the exception rather than the rule as a significant percentage will

have no fever, abdominal pain, nausea/vomiting, or normal laboratory investigation [5, 60, 61]. In the debilitated noncommunicative patient, the only presenting symptoms of acute cholecystitis will be a change in mental status or poor oral intake [61, 62].

When the diagnosis of acute cholecystitis is suspected, abdominal ultrasonography is the initial imaging test of choice. A sonographic Murphy's sign combined with the presence of stones, gallbladder wall thickening, and pericholecystic fluid essential clinch the diagnosis. In cases where the diagnosis is less clear, or when there are no stones visualized, a HIDA scan may be useful. The CT findings of acute cholecystitis or potential gallbladder malignancy could also be assessed in patients that have this imaging test ordered for abdominal pain of unknown etiology.

Treatment of Acute Calculous Cholecystitis

Ongoing cystic duct obstruction causes inflammation and can lead to bacterial infection in the bile as well as ischemia of the gallbladder wall. Initial supportive measures such as bowel rest, intravenous fluid hydration, and analgesics are appropriate. The Infectious Diseases Society of America guidelines recommend empiric antimicrobial therapy in cases of clinically suspected infection [63]. Initial therapy should include coverage against microorganisms in the *Enterobacteriaceae* family. Appropriate initial antibiotic choices for noncomplicated cases include second- or third-generation cephalosporins or a combination of fluoroquinolones combined with metronidazole [63]. For patients presenting with severe sepsis or those that are considered high risk (i.e., elderly, diabetics, or the immunocompromised), broad-spectrum antibiotics such as piperacillin/tazobactam or aminoglycosides should be used [63].

The timing and choice of surgical intervention for acute cholecystitis has undergone considerable debate and change over the past several decades. Laparoscopic cholecystectomy has become the initial operative intervention of choice due to its superior outcomes compared with open surgery [64, 65]. The techniques of laparoscopic cholecystectomy are beyond the scope of this chapter and can be found elsewhere [66]. The traditional treatment approach involved initial nonoperative management with supportive measures and antibiotics in the acute inflammatory period followed by delayed surgical cholecystectomy. The perceived advantage of this approach was that the operation would be technically easier due to lack of acute inflammation. Besides the additional cost incurred with this approach, the recurrence rate of acute cholecystitis can be as high as 30 % over a 3-month waiting period [67–69]. It is important to note that in one third of these recurrences, patients presented with biliary obstruction (i.e., cholangitis and biliary pancreatitis that were more severe than the initial presentation) [67]. Elderly patients are also known to be more likely to present with complicated acute cholecystitis (i.e., gangrene, perforation, or emphysematous cholecystitis), all of which are more likely to require emergent surgical intervention with subsequently increased morbidity and mortality [26, 70].

Two recent systematic reviews of the literature compared early laparoscopic cholecystectomy (within 24–72 h) versus late operation (6–12 weeks after initial presentation) [71, 72]. Both meta-analyses found that there were no significant differences in conversion rates to open procedures, incidence of common bile duct injuries, or postoperative complications. Early laparoscopic cholecystectomy was also shown to be associated with decreased hospital lengths of stay as well as total costs [71]. However, it should be noted that in one of the meta-analysis, the incidence of bile leaks was higher in the early cholecystectomy group (3 % vs. 0 %) [71]. Also due to the small number of total patient in these pooled randomized trials (n = 451), the incidence of common duct injury could easily be over- or underrepresented in either group due to the low overall incidence of this complication (0.4–0.6 %) [73]. Despite these limitations, the consensus of both meta-analyses is that early laparoscopic surgery is safe in the hands of experienced surgeons and should be considered the preferred management strategy in patients with acute cholecystitis.

Even with these evidence-based recommendations, elderly patients have been shown to be more likely to be managed differently than younger patients. Previous studies have documented that up to 30 % of elderly patients do not have any therapeutic intervention for acute gallstone disease [74, 75]. These delays in treatment are also well documented to result in another symptomatic biliary admission (i.e., cholecystitis, cholangitis, or biliary pancreatitis) in up to 38 % of patients [76, 77]. This finding was perceived to be secondary to increased comorbidities or presentation with acute complicated disease [6, 75]. Recently, in a single-institution review, Bergman and colleagues showed that this might not be the case [70]. They found that increasing age was independently associated with a lower likelihood of surgical intervention after adjusting for severity of biliary disease as well as pre-existing medical comorbidities. Additionally, the group at Los Angeles County retrospectively compared the outcomes of elderly patients (age greater than 65) presenting with acute cholecystitis undergoing early (within 24 h of admission) vs. delayed cholecystectomy (>24 h) [78]. They found no significant differences in postoperative complications, open conversion rates, or in-hospital mortality between the two groups, while anesthesia time and hospital stays were significantly shorter in those patients that had early cholecystectomy. These findings should give surgeons pause to delaying intervention in elderly patients. Furthermore, operative delays also increase the incidence of emergency surgical intervention [74, 75]

with mortality rates as high as 6–15 % [53]. This contrasts with appropriately selected elderly patients that have electively scheduled cholecystectomy and outcomes that are similar to younger patients. Conversely, patients that have a score of more than 3 on the Charlson comorbidity index have been shown to have a 2-year mortality rate of 40.4 % [15], and the PREOP-Gallstone may be helpful in the decision-making process in this patient cohort. Thus, the take-home message should be that age alone should not exclude early operative management in elderly patients presenting with acute cholecystitis.

Some elderly patients with acute cholecystitis will present with severe sepsis and septic shock or have comorbidities that are not optimized which would preclude from undergoing surgical cholecystectomy safely. These patients need to be aggressively treated with admission to the intensive care unit (ICU) and early broad-spectrum antibiotics. Obtaining source control in these patients obviously presents a clinical challenge. Two less invasive procedures, PCT and ERCP, should be considered in these patients once underlying physiologic derangements have been corrected by resuscitation.

PCT can either be done at the patient's bedside under ultrasound guidance or in the fluoroscopy suite. After initial aspiration, a pigtail drainage catheter can be left in place for removal of further infected bile. Cultures of the bile should be sent to tailor empiric antibiotic therapy, particularly if the elderly patient has come from a nursing facility or has received recent antibiotic exposure as this is associated with a higher incidence of resistant organisms that traditional antibiotics may not cover adequately. PTC has excellent efficacy and results in the resolution of sepsis in up to 87 % of critically ill patients, with acceptable 30-day mortality rates [79]. This temporizing measure can allow optimization of the patient's critical illness as well as any other underlying comorbidities. The drainage catheter should be left in place for 6 weeks to allow for establishment of a fibrous fistula tract prior to removal. In certain patients that are a prohibitive surgical risk due to their underlying medical problems, conservative management with PTC cholangiography with stone extraction and catheter removal can be accomplished successfully often without recurrence [61, 80]. In a long-term follow-up study with a mean duration of 3 years, 183 critically ill patients undergoing only PTC for acute cholecystitis had a recurrence rate of only 12 % [57].

ERCP with selective cannulation of the cystic duct and stent placement is another treatment modality that may be particularly useful in critically ill patients that are unable to undergo PCT particularly in the setting of coagulopathy or uncontrolled ascites [81].This procedure is more technically challenging than ERCP and requires advanced endoscopy skills. In experienced hands, this procedure is successful in over 90 % of cases with a reported clinical efficacy of 80–90 % [81].

It should be stressed to the reader that PCT should only be used as a treatment modality in those patients that are too critically ill or medically unfit to undergo a surgical operation as this procedure is associated with increased hospital lengths of stay and up to a 25 % rate of readmission for biliary-related complications. A detailed Cochrane review comparing PCT versus cholecystectomy as initial treatment for severe acute cholecystitis found no evidence to support the use of PCT over surgical intervention [82]. A recent large retrospective single-institution review reached similar conclusions even when accounting for patients that underwent conversion to open cholecystectomy [55]. Those patients that were treated surgically had shorter lengths of stay, as well as a lower number of complications and readmissions compared with those that underwent PCT as treatment for acute cholecystitis. Only those patients that presented with increased comorbidities and medical risk for surgery as defined by the Charlson comorbidity index appeared to benefit from PCT over surgical intervention for acute cholecystitis [55]. Despite this preponderance of evidence, a recent national review by Duszak and Behrman documents a 67 % increase in the use of PCT over the last two decades [83].

Chronic Calculous Cholecystitis

Clinical Presentation and Diagnosis

Chronic cholecystitis is typically the most common manifestation of symptomatic calculous disease and occurs in the setting of multiple (and often insidious) episodes of biliary colic. This scenario is typical in the elderly due to the alterations in pain perception and immune response to inflammation that have been described (see section "Diagnostic Investigation"). The patient often presents with symptoms similar to those of acute cholecystitis without systemic signs of inflammation. Typically the pain is located in the epigastrium/right upper quadrant and is dull or of less intensity due to the absence of acute peritoneal irritation. The patient's temperature, white blood cell count, and liver function tests are most commonly within normal limits. The metabolic panel should also be checked, particularly in the elderly patient, as they often are on medications that can cause fluid and electrolyte derangement. Ultrasonography again should be the initial imaging test of choice that often demonstrates stones within a thickened contracted gallbladder wall. The "double arc" sign is pathognomonic for this condition when seen on ultrasonography [32]. Occasionally chronic cholecystitis will be associated with mural calcification of the gallbladder wall. This may involve a portion of the wall or the entire gallbladder otherwise known as a "porcelain" gallbladder (Fig. 14.10). The significance of this finding has been controversial due to the potential association with

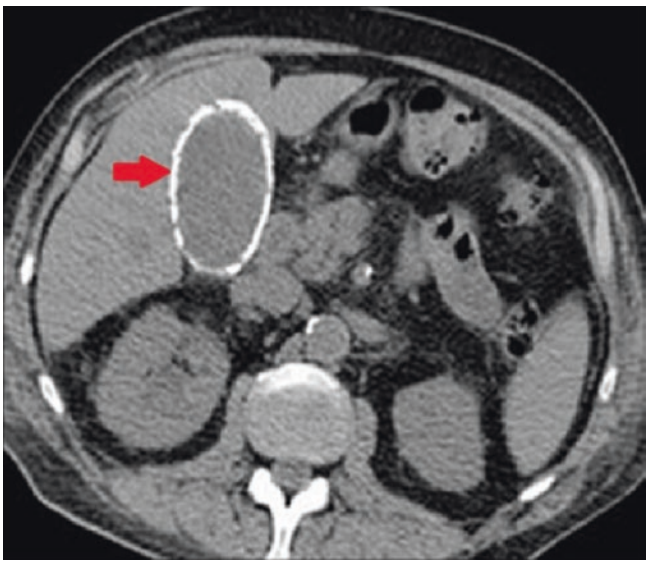

Fig. 14.10 CAT scan of the abdomen showing complete calcification of the gallbladder wall (*arrow*) consistent with a "porcelain" gallbladder

gallbladder carcinoma particularly in the elderly patient [84–86]. Ultrasound findings that are suggestive of this pattern and that show loss of delineation between the gallbladder wall and liver parenchyma where there is no serosal layer should lead one to consider additional diagnostic imaging such as CT or MRI [87].

Treatment of Chronic Calculous Cholecystitis

Once chronic cholecystitis has been diagnosed, initial treatment should be directed at relieving pain symptoms with the judicious use of narcotics. Intravenous fluids should be given as the patient often will be dehydrated from diminished oral intake and may need electrolyte correction. After acute symptoms have resolved, the patient should be risk stratified for surgery. If patients are acceptable candidates, elective laparoscopic cholecystectomy should be undertaken as the natural history of chronic cholecystitis is to recur (40 % chance over 2 years) [88]. Delaying operation because of age and waiting for an episode of recurrence of disease in the elderly are hazardous as they often present in a delayed fashion and with a higher incidence of complicated calculous disease that may require urgent as opposed to elective surgical intervention that is associated with higher morbidity and mortality [26, 53, 70, 88]. Elderly patients may also be considered candidates for same-day discharge or ambulatory cholecystectomy in certain instances, with success rates of 70 %, or more documented in the literature [89].

A special form of chronic cholecystitis that deserves mention is the "porcelain gallbladder." Though the incidence of porcelain gallbladder remains low (0.2 % in a recent large series) [61], there is concern of the potential for malignancy, particularly in those over 50 years of age (incidence of 0.08 %/year of symptoms) [88]. The management of the porcelain gallbladder has undergone considerable change over the past several decades. Early reports suggested a high association between porcelain gallbladder and gallbladder carcinoma (up to 60 %) [90] which led to recommendation of open cholecystectomy once the diagnosis was made. Recently, several large clinical series have questioned the significance of the porcelain gallbladder after finding a much lower incidence of malignancy (0–5 %) [85, 86, 90]. The reasons for this dramatic shift are felt to be due to advances and increased usage of abdominal imaging as most cases of porcelain gallbladder were only diagnosed on plain films of the abdomen, geographic variation of study, and wider usage of laparoscopic cholecystectomy [90].

The overwhelming majority of elderly patients that have a porcelain gallbladder identified on imaging have symptomatic disease which would make them surgical candidates unless their preoperative estimated risk was found to be prohibitive [85, 86, 90]. The asymptomatic patient with incidental findings of a porcelain gallbladder represents a clinical impasse on whether to proceed with operative intervention or observe the patient. The risk of surgical intervention, particularly in the patient with comorbidities, should be balanced against the low potential risk of gallbladder carcinoma and discussed with the patient in order to establish a course of action. Laparoscopic cholecystectomy has been found to be technically feasible in patients with a porcelain gallbladder and should be the initial procedure of choice with more aggressive intervention being reserved for those patients that are found to have cancer on their final pathology or intraoperative findings that are suggestive of carcinoma [90, 91].

Choledocholithiasis

Clinical Presentation and Diagnosis

The majority of common bile duct stones that lead to symptoms originate from the gallbladder itself and can lead to a wide array of clinical symptoms. The elderly population also has a higher incidence of common bile duct stones (range 15–20 %) that present with symptomatic calculous disease compared to younger patients [53]. Up to a third of common duct stones will spontaneously pass into the duodenum [92], while others may lead to common duct obstruction resulting in biliary pancreatitis or cholangitis.

Right upper quadrant pain with abnormal liver function tests is present in over 75 % of patients [93]. The liver panel usually shows a cholestatic (elevated serum bilirubin) pattern, and transaminases may be >500 IU/L along with elevation of alkaline phosphatase or serum gamma-glutamyl transferase (90 % of cases) [94]. Leukocytosis may also be present in the acute phase, and coagulation parameters should be routinely checked as biliary obstruction can lead to transient vitamin K

deficiency and subsequent coagulopathy. It should be noted that around 10 % of patients will be asymptomatic with only mildly elevated liver function tests and common duct stones that are found incidentally on imaging for a reason other than biliary symptoms [93, 95]. In the elderly, malaise, altered mental status, or acute deconditioning may be the only presenting symptoms [62].

Abdominal ultrasonography should be the initial imaging test of choice and has excellent sensitivity for detecting biliary ductal dilation (see Imaging section) and may directly visualize common duct stones. If the ultrasound is normal but clinical and laboratory testing is suggestive of choledocholithiasis, then MRCP should be considered as this has higher sensitivity than sonography. ERCP should generally be reserved for therapeutic purposes due to its invasive risks and technical complications.

Treatment of Choledocholithiasis

Once the diagnosis of choledocholithiasis is made, there are a variety of treatment options available, and these should be tailored based upon local expertise and resource availability. Initial treatment should be directed at alleviating pain, fluid resuscitation, and correction of any electrolyte or coagulation disorders that may be present. Complete removal of common duct stones should be the objective regardless of the intervention chosen because up to 50 % of patients will have recurrence of symptoms if left untreated, and 25 % of these recurrent cases will result in potentially serious complications (i.e., biliary pancreatitis or cholangitis) [94].

Endoscopic therapy with ERCP or percutaneous intervention (PTC) are both acceptable methods of ductal clearance according to the Society for Surgery of the Alimentary Tract (SAGES) and British Society of Gastroenterology guidelines [39, 52] and should be chosen based upon local availability and expertise. As elderly patients are often on anticoagulants or antiplatelet medications, these should be withheld in anticipation of therapeutic intervention. Antibiotics are also typically given periprocedurally and should again be directed primarily against the *Enterobacteriaceae* family. ERCP with balloon dilation of the sphincter has an excellent clinical success rate and appears to be safe even in the elderly population with known comorbidities [40, 53].

Once ductal clearance has been achieved, elderly patients should be offered cholecystectomy if they are acceptable surgical candidates because of the potential for recurrent biliary symptoms. In a 2-year prospective investigation, Lee et al. found that the age and the presence of comorbid conditions were risk factors for recurrence of choledocholithiasis [96]. Additionally, these patients were felt to be at higher surgical risk at the time of recurrent presentation than if they had cholecystectomy at the time of initial presentation. Similar findings were seen in a large systematic review done by the Cochrane group which found a decreased recurrence rate and increased survival advantage even in patients deemed "high risk" were managed with early cholecystectomy as opposed to a "wait and see" approach [97].

The timing of cholecystectomy after ERCP and sphincterotomy has also been investigated prospectively. In a randomized trial comparing "early" laparoscopic cholecystectomy (within 72 h) versus delayed cholecystectomy (6–8 weeks after ERCP), there were no differences in operative duration or rate of conversion to open procedures, while 36 % of patients in the delayed group developed recurrent biliary symptoms [98]. The authors concluded that early cholecystectomy prevented future symptoms related to common duct stones without an increase in morbidity in those undergoing early operation. Patients that undergo ERCP with sphincterotomy and ductal clearance are still at risk for residual choledocholithiasis. Clinical studies assessing this risk in prospective series have found it to be as high as 13 % [99, 100]. Therefore, the authors recommend routine intraoperative cholangiography in patients that had a preoperative ERCP with ductal clearance to reduce the chance of having retained common duct stones (Fig. 14.11). For those surgeons with advanced laparoscopic skills and institutions that have the instrumentation and imaging capability, single-stage procedures to treat choledocholithiasis include laparoscopic cholecystectomy with intraoperative cholangiogram followed by common bile duct exploration have gained

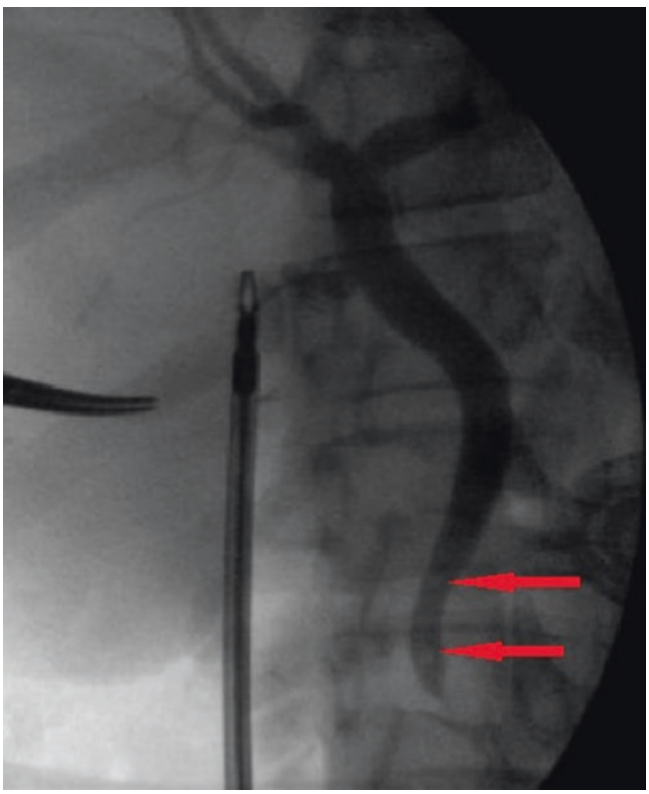

Fig. 14.11 An intraoperative cholangiogram demonstrating two filling defects consistent with common bile duct stones (*arrows*)

popularity. This leads to decreased hospital lengths of stay and total charges without an increase in associated morbidity or mortality [101–103]. This operative approach has also been validated in the elderly and high-risk patients [104]. The benefits of one-stage treatment of choledocholithiasis have only been observed in uncomplicated cases (i.e., no cirrhosis, cholangitis, or biliary sepsis) [101] and with adequate laparoscopic experience [105].

Cholangitis

Clinical Presentation and Diagnosis

Cholangitis can follow a wide spectrum of disease in the elderly patient, from a mild infection to fulminant septic shock with multiple organ dysfunction. Early recognition of which form of disease is present is imperative to achieve good clinical outcomes. An obstructing common duct stone is the most common etiology of cholangitis but may also occur in the presence of benign or malignant biliary strictures. Stasis of bile leads to bacterial overgrowth from the duodenum with *Escherichia coli* being the most common offending organism followed by other members of the family *Enterobacteriaceae*. Increased amounts of pressure in the biliary tree lead to translocation of bacteria into the bloodstream with resultant toxemia [94]. The classic clinical picture of Charcot's triad (fever, right upper quadrant pain, and jaundice) is present in 70 % of patients [94]. The addition of altered mental status changes and hypotension to Charcot's triad form Reynold's pentad and are indicative of suppurative cholangitis, a surgical emergency. In addition to clinical exam findings, laboratory studies often reveal leukocytosis with elevated liver transaminases and cholestasis. Thrombocytopenia, decreased serum bicarbonate (reflective of metabolic acidosis), and elevation of creatinine are diagnostic of more severe cholangitis [106]. Coagulation studies should also be checked in preparation for ductal decompression as biliary obstruction with superimposed sepsis can lead to coagulopathy. Diagnostic imaging is frequently done with ultrasonography that typically reveals dilation of the biliary tree.

Treatment of Cholangitis

Initial therapy should be to establish intravenous access and begin fluid resuscitation followed by early administration of broad-spectrum antibiotics. Appropriate initial antibiotics include third-generation cephalosporins, fluoroquinolones combined with metronidazole, or beta-lactamase inhibitor combinations (i.e., piperacillin/tazobactam) [63]. Blood cultures should be obtained but not delay antibiotic therapy. Since most patients present with mild-moderate cholangitis (nonsuppurative), this will lead to clinical improvement in anticipation of ductal decompression within the next 24 h [52]. Even with initial improvement, elderly patients should be closely monitored for decompensation since age (>50 years) has been shown to be a predictor of poor outcomes [107]. Once sepsis has resolved and the patient is otherwise medically fit, laparoscopic cholecystectomy should be offered to the patient.

For those patients that present with florid sepsis and organ dysfunction, they should be aggressively resuscitated and transferred to the intensive care unit for invasive monitoring. Hemodynamic support with vasopressors may be required in cases of septic shock, and optimization of physiologic parameters should be undertaken to allow for source control through biliary decompression through the least invasive means available. Endoscopic decompression with ERCP has become the initial procedure of choice for most elderly patients [94]. The aim of the procedure is to relieve biliary pressure through minimal manipulation to prevent exacerbation of endotoxemia. Sphincterotomy with biliary stent placement is the most frequently utilized technique. Should ERCP be technically difficult and unsuccessful, external decompression using PTC is a good second-line option. Even with successful decompression, there is still mortality of 5–10 % [108]. In situations where ERCP/PTC is unsuccessful or unavailable, drainage can be accomplished surgically with open common bile duct exploration and T-tube placement. The mortality for this intervention is much higher than the preferred nonsurgical techniques (16–40 %) [93]. After successful biliary decompression and stabilization of the patient, antibiotic therapy should be continued for 14 days and the patient risk stratified for cholecystectomy once optimized from the medical point of view.

Biliary Pancreatitis

Clinical Presentation and Diagnosis

In some cases of choledocholithiasis, the stone transiently lodges at the ampulla and causes an obstruction of the pancreatic duct. This leads to intraductal activation of enzymes and pancreatic glandular damage with a generalized inflammatory response that leads to subsequent symptoms. Risk factors for the development of biliary pancreatitis include advanced age (>60) and female gender [109]. Most cases of biliary pancreatitis are moderate and will resolve with supportive care. However, severe cases of pancreatitis can lead to sepsis and multiple organ dysfunction with mortality rates that exceed 20 % [110] and require a multidisciplinary approach with critical care support.

Clinical symptoms of acute biliary pancreatitis include sharp epigastric pain with radiation to the back that can be confused with aortic dissection or myocardial ischemia in the elderly. Nausea and vomiting are also typically present. Signs of systemic inflammation such as tachycardia and

fever may also be present. In severe cases, the patient can also have hypotension and altered mental status. Helpful laboratory investigations include CBC, serum chemistry with a serum calcium level, liver function tests, and serum amylase and lipase. Leukocytosis is often present secondary to inflammatory response, and the hematocrit is often elevated from hemoconcentration. Serum chemistry can also depict signs of impaired tissue perfusion if the serum bicarbonate is low or renal parameters are indicative of acute renal impairment. Transaminases are often greater than 500 IU/L in the acute phase with a moderate elevation of serum bilirubin. Typically both the serum amylase and lipase will be elevated, but serum amylase declines earlier in the time course of pancreatitis and may be normal in cases of delayed presentation.

Once the diagnosis of biliary pancreatitis is suspected, the initial imaging test should be an abdominal ultrasound. This test can be done even in unstable patients as it can be done at the patient's bedside. Ultrasound is diagnostic of biliary pancreatitis if it reveals calculi or sludge in the gallbladder. Dilation of the biliary tree may also be noted. In patients that are clinically unstable or that do not improve with resuscitation, CT imaging can be helpful in assessing the severity of pancreatitis [111]. The initial study should be non-contrast as it is still clinically useful and avoids exposing a hypovolemic elderly patient to a potentially nephrotoxic contrast load. A CT scan with IV contrast can be obtained at a later time when the patient is clinically stable to delineate areas of potential pancreatic necrosis.

Treatment of Biliary Pancreatitis

Initial therapy is directed at alleviating pain with judicious use of narcotics and nasogastric decompression for those patients presenting with symptoms of ileus. Generous fluid resuscitation should also be undertaken due to the amount of fluid sequestration that can occur in the retroperitoneum. There should be a low threshold to admit elderly patients to the ICU even in moderate cases due to their limited physiologic reserve. Many different scoring systems for determining the severity of pancreatitis have been developed [112–115], but the Ranson score has been shown to have the highest predictive accuracy [113]. A Ranson score of 3 or more is indicative of severe disease. Well-established evidence-based guidelines have been developed for treatment [116, 117].

There are three areas of current debate regarding the optimal therapy of biliary pancreatitis. The first area of controversy in the treatment of severe pancreatitis is the use of prophylactic antibiotics. Several systematic reviews examining the utility of antibiotic prophylaxis in severe acute pancreatitis have been undertaken and have failed to demonstrate any protective benefit on mortality or the risk of developing infected pancreatic necrosis [118–120]. Due to problems with emerging bacterial resistance, the authors recommend against the routine use of antibiotic administration in sterile cases of severe pancreatitis. In instances when superimposed cholangitis is suspected with biliary pancreatitis, appropriate antibiotic therapy is warranted.

Another topic of debate in the management of severe biliary pancreatitis involves the use of early (within 24–48 h) ERCP with sphincterotomy. In the past there has been some literature to support early ERCP in patients with biliary pancreatitis that present with severe disease as or patients with moderate disease that do not exhibit clinical improvement or experience persistent pain [94]. Recently, a meta-analysis reexamined this topic utilizing seven randomized prospective trials (ERCP vs. conservative treatment) in patients that presented with severe biliary pancreatitis without evidence of cholangitis [39]. The authors found that there was no significant benefit or difference in outcome in those patients that underwent early ERCP even when stratifying for disease severity. Therefore, early ductal decompression with ERCP in cases of severe biliary pancreatitis should not be carried out routinely as it provides no significant advantage over general supportive care.

The final area of discussion involves the timing of cholecystectomy after an episode of biliary pancreatitis. As mentioned in the section on choledocholithiasis, the natural history of biliary pancreatitis is recurrence (up to a third of all patients) if the gallbladder is not removed [121]. Each recurrent episode places the patient at risk of life threatening pancreatitis or cholangitis. Recently, the group from Harbor-UCLA investigated the feasibility of early cholecystectomy (within 48 h of admission) in patients presenting with moderate biliary pancreatitis (Ranson <3) and found no apparent increase in perioperative complications and a decreased hospital length of stay compared to those that had an operation after resolution of abdominal pain or improved enzymatic parameters [122]. Other investigations have also found similar findings with the consensus being that laparoscopic cholecystectomy should be performed during the same admission for acute biliary pancreatitis in those patients with acceptable surgical risk [121, 123, 124]. Despite the overwhelming evidence favoring cholecystectomy for biliary pancreatitis, a recent appraisal of this approach in elderly patients showed that over 40 % of patients admitted with a diagnosis of gallstone pancreatitis in a large Medicare sample were not treated surgically with high recurrence rate (33 %) [125]. This clearly leaves room for considerable improvement in caring for elderly patients with symptomatic biliary disease. For patients that are a prohibitive surgical risk due to comorbid illness, ERCP with endoscopic sphincterotomy does provide some protection against recurrence of acute biliary pancreatitis and should be offered to patients that are not surgical candidates [96, 124].

Gallstone Ileus

Clinical Presentation and Diagnosis

Gallstone ileus is classically a disease of the elderly and is an uncommon cause of bowel obstruction (0.1 % in the most recent population-based study [126]) despite its deceptive name. The onset of symptoms is often subtle but may be preceded by symptoms of biliary colic or chronic cholecystitis in approximately 25–75 % of patients [126, 127]. The patient is typically an elderly female (age >70 years) that experiences nausea and vomiting associated with colicky abdominal pain [126]. These symptoms may be fleeting due to transient episodes of obstruction where the stone intermittently lodges and dislodges in narrowed areas of the intestinal tract. This is characteristically known as the "tumbling" phenomenon [128]. The origin of the stones causing the small bowel obstruction is most commonly secondary to the development of a fistula between the gallbladder and duodenum. Other organs involved with development of a fistulous connection are the stomach (cholecystogastric fistula) and transverse colon (cholecystocolonic fistula). Typically the stone causing the obstruction has to be greater than 2.5 cm in size, and the most common site of obstruction is the terminal ileum followed by duodenal-jejunal junction, the duodenal bulb, pyloric region, or sigmoid colon [93]. The classic radiological findings of pneumobilia, ectopic gallstone, and intestinal obstruction observed on plain films of the abdomen (Rigler's triad) are only seen in approximately 50 % of patients (Fig. 14.1) [129]. CT scan is much more sensitive in identifying the diagnosis (93 % sensitivity and 99 % specificity) when obtained [130]. Only 70 % of patients are correctly diagnosed preoperatively with the remainder being diagnosed at the time of operation [127].

Treatment of Gallstone Ileus

As patients that present with this condition are often elderly and debilitated, initial therapy should be directed at fluid resuscitation for dehydration and the correction of any electrolyte abnormalities in preparation for laparotomy. The optimal surgical procedure for this condition continues to be contested. The easiest technical approach involves relief of the obstruction with enterolithotomy, stone removal, examination of the intestine to ensure multiple stones are not present, and closure of the enterotomy. The cholecystoenteric fistula is left in situ to be treated at a later date once the patient is optimized medically or symptoms recur. The second and more aggressive line of treatment involves a one-stage procedure combining enterolithotomy with takedown and closure of the fistula along with cholecystectomy. Lastly, in some cases where there is bowel necrosis, resection is required.

A recent assessment of the operative management of this disease is provided by Halabi, et al. and utilizes the National Inpatient Sample [126]. The authors examined three million cases of bowel obstruction over a four-year period with 0.095 % having gallstone ileus as the source. Three methods of operative therapy were compared: enterolithotomy with stone extraction, enterotomy with stone extraction plus cholecystectomy and fistula closure in one stage, and finally bowel resection alone without fistula closure. Several demographic, hospital, and comorbid factors were taken into consideration when analyzing outcomes, which included hospital lengths of stay, total charges, postoperative morbidities, and in-hospital mortality. Overall mortality was 4.9 % for stone extraction alone compared to 7–13 % for other interventions. Compared to patients undergoing stone extraction alone, more complicated procedures were associated with almost a threefold higher mortality and had twice the risk of complications. Regardless of which surgical approach is considered, it is important to ensure that the entire bowel is checked for multiple stones, which is common in over 25 % of patients [126]. While enterolithotomy is generally associated with less perioperative morbidity and mortality, recurrence of gallstone ileus (5–17 %) and symptomatic biliary disease (5–10 %) [129] remain potential problems. Autopsy findings of patients that have undergone enterolithotomy alone have demonstrated that the fistulous connection between the biliary tree and GI tract can close spontaneously in the absence of cholelithiasis [131]. Additionally, elective resection is associated with a lower incidence of complications and postoperative mortality [126]. While enterolithotomy is the preferred procedure by most experts, this condition is relatively rare, and no large randomized studies are available to compare the superiority of one procedure over another [129]. No Level I data exists regarding the treatment of this condition; thus surgical therapy should be tailored individually based upon the patient's global condition as well as intraoperative findings.

Benign Acalculous Diseases

Acute Acalculous Cholecystitis

Clinical Presentation and Diagnosis

Acalculous cholecystitis represents 5–10 % of acute gallbladder pathology in adults [93]. Predisposing risk factors include advanced age, presence of comorbidities, and critical illness. This illness generally occurs in patients over 60 years of age and within the second to fifth week of critical illness [132]. Common predisposing conditions include postoperative complex cardiac and vascular patients as well as those whom have suffered major burns, trauma, or cardiac arrest [133]. The etiology is multifactorial but thought to be related to biliary stasis [133] and systemic hypoperfusion leading to gallbladder ischemia with bacterial overgrowth. Despite

increased awareness of this disease entity, mortality rates continue to be as high as 30 % [133].

A high index of suspicion is necessary to diagnose acute acalculous cholecystitis; due to the patient's often debilitated state, they are unable to communicate pain, and the presence of sepsis and with leukocytosis and liver function abnormalities is common in many critically ill patients. Abdominal ultrasound is the most useful imaging test with gallbladder wall thickening being the most common diagnostic finding. The sensitivity of ultrasound for diagnosis can vary widely from 29 to 92 % [132] due to false-positive exams that can occur with ascites or other inflammatory conditions. HIDA can also be used for the diagnosis in cases of high suspicion when the ultrasound is equivocal with sensitivity that ranges from 67 to 100 % [132]. The downside of this diagnostic test is that it often requires patients to be transported from the ICU for an extended period of time although some centers have portable units that are capable of performing this test at the patient's bedside.

Treatment of Acalculous Cholecystitis

Once the diagnosis has been made or clinical suspicion is high enough, PCT is the treatment of choice due to the debilitated state of the patient. Typically patients are already on empiric antibiotics for their critical illness, and coverage should include the same organisms that are responsible for acute cholecystitis. Cholecystostomy tube placement can either be performed at the patient's bedside under ultrasonography or under fluoroscopy with either procedure being clinically effective for resolution of sepsis [79]. Surgical intervention is reserved only for those patients that do not respond to percutaneous intervention. In a study comparing outcomes, using bridging cholecystostomy followed by elective cholecystectomy vs. open cholecystectomy showed decreased mortality and shorter recovery times in those patients treated by initial PTC [134]. Once drainage has been accomplished, the cholecystostomy tube can be left in place for 4–6 weeks to allow a tract to establish and patient to convalesce. A repeat cholangiogram can then be performed (Fig. 14.12) to document gallbladder drainage through the cystic duct. If this is the case, the cholecystostomy tube can often be removed without worry of recurrence once the patient recovers from their critical illness and elective cholecystectomy considered.

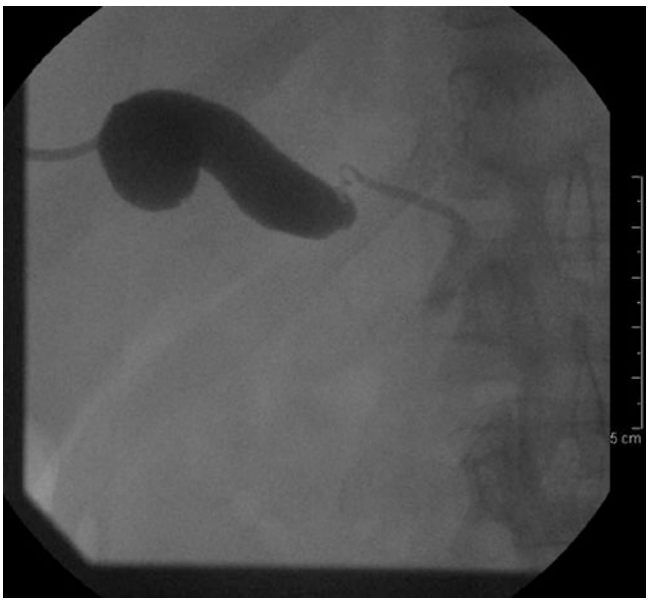

Fig. 14.12 PTC cholangiogram done after convalescence from critical illness secondary to acalculous cholecystitis. Notice the patency of the cystic duct with passage of contrast into the common bile duct

Motility Disorders of the Biliary Tree

Clinical Presentation and Diagnosis

Motility disorders of the biliary tree include biliary dyskinesia as well as sphincter of Oddi dysfunction. The hallmark of both disorders is a constellation of classically biliary type symptoms: epigastric or right upper quadrant pain that is episodic and severe enough to interrupt the patient's daily life as defined by the Rome committee [135].

In biliary dyskinesia laboratory investigations and imaging studies are normal and no other etiology for the patient's pain can be discovered. The diagnosis of biliary dyskinesia is made exclusively with the use of biliary scintigraphy with cholecystokinin infusion in order to determine the patient's gallbladder ejection fraction (EF). Normal gallbladder EF is around 70 %, while studies are considered abnormal when the EF is less than 50 % or the infusion of cholecystokinin reproduces the patient's pain symptoms [136]. It should be noted that certain medications that are common in elderly patients (i.e., calcium channel blockers and opiates) could also cause impaired gallbladder ejection fraction and cause an abnormal scintigraphy scan [136].

Sphincter of Oddi dysfunction can present as either recurrent attacks of abdominal pain that mimic biliary colic, as recurrent idiopathic pancreatitis, or as postcholecystectomy pain. The most classic form of sphincter of Oddi dysfunction is a triad of biliary colic, abnormal liver function tests, and documentation of a dilated common bile duct on imaging without any evidence of gallstones [137]. The diagnostic work-up [138] should consist of endoscopy with ultrasonography as this may document stones that are not seen on traditional ultrasonography or other imaging modalities. If this is negative, then ERCP should be done to rule out microlithiasis and sphincter manometry performed. Elevated basal sphincter pressures or paradoxical spasm noted with cholecystokinin infusion are suggestive of the diagnosis.

Treatment of Biliary Motility Disorders

Biliary dyskinesia is treated by laparoscopic cholecystectomy in acceptable risk patients with some specimens revealing microlithiasis or stones that were missed by sonography. Symptom relief after cholecystectomy ranges from 70 to 90 % of patients [139, 140]. Patients that have typical biliary symptoms, an abnormal gallbladder EF, or occult cholelithiasis have the best postoperative results [136].

Sphincter of Oddi dysfunction is treated by endoscopic sphincterotomy of both the biliary and pancreatic ducts [141] although a trial of medical management may be undertaken first with medications such as calcium channel blockers or anticholinergics [138, 142]. For patients that have an inaccessible papilla or a recurrence of symptoms after sphincterotomy, open transduodenal sphincterotomy is an option [143]. The efficacy of sphincterotomy varies widely from 20 to 91 %, with those patients that have elevated basal pressures on manometry with classic biliary colic pain achieving the best results [137, 138].

Neoplasms of the Gallbladder

Gallbladder Polyps

Clinical Presentation and Diagnosis

Polyps of the gallbladder are observed in about 5 % of patients that undergo abdominal ultrasound [144] with most patients being asymptomatic (77 %) [145] and imaged for another reason. The majority of these documented polyps are pseudopolyps with the majority being cholesterol polyps or adenomyomatosis (85 %) followed by inflammatory polyps (10 %) with the remainder being true polyps that are predominantly either adenomas or adenocarcinomas [146].

True polyps are the only form of polyps with malignant potential. Polyp size, vascularity, rate of growth, Asian descent, and patient age have been linked to malignant potential [146, 147]. Cholelithiasis was originally thought to be associated with polyp development and malignancy; however several authors have documented that this is not the case [145, 148]. The most commonly cited size that is associated with a risk for malignancy is 10 mm. Using this size cutoff, Koga analyzed polyps found in cholecystectomy specimens and observed that 88 % of malignant polyps were greater than 10 mm in size [149]. This size criterion has been challenged due to malignancy being found in polyps of smaller size. A Mayo Clinic study showed that polyps under 10 mm carried a 7.4 % chance of malignancy and that a size greater than 6 mm was a risk factor for malignancy [150]. Using this reduced size cutoff on ultrasound resulted in 100 % negative predictive value. It should be noted that sonography has been shown to overestimate lesion size by 4 cm or more and that may have a false-positive rate as high as 22 % [147]. Also, more recent data examining cholecystectomy specimens have found that no cancers have arisen in polyps that are less than 2 cm in size [151] and that in the US population the progression from adenoma is exceedingly rare and routine imaging is not warranted for polyps less than 10 mm [147].

As previously mentioned, age is also a risk factor for polyp malignancy. Two separate studies have shown that patient age over 50 has a significantly higher chance of being associated with a malignant polyp [152, 153]. Based upon the patient's age and size of polyp, the patient can be risk stratified into low or high risk for neoplasm. Endoscopic ultrasound may provide assistance in intermediate cases based upon clinical scoring features of the polyp due to the superior imaging provided as well as opportunity for biopsy by some endoscopists [43, 154, 155].

Treatment of Gallbladder Polyps

In patients that are symptomatic (i.e., biliary colic) without another identifiable etiology for the pain, laparoscopic cholecystectomy should be offered [146]. Polyps that are greater than 10 mm in size without symptoms should also be treated with laparoscopic cholecystectomy unless the polyp is greater than 1.8 cm in size [146]. Two different series have shown that polyps above this size are often associated with an invasive cancer, and an open cholecystectomy should be considered with partial liver resection and lymphadenectomy if necessary based upon the depth of invasion (see section "Gallbladder Carcinoma") [96, 156, 157]. For asymptomatic lesions that are 6–10 mm, watchful waiting along with serial abdominal ultrasound examinations has been proven to be a safe treatment strategy keeping in mind that there may be a high false-positive rate [145, 148]. Polyp growth has been observed in 6 % of patients according to one 11-year retrospective study (*Ito*). Though there are not any well-established guidelines regarding the interval of screening, most experts favor imaging every 6–12 months [148, 158]. Lesions that are of intermediate size (6–10 mm) represent a treatment challenge given evidence that neoplastic growth may occur at polyp sizes in this range and conflicting data regarding the malignant potential of gallbladder polyps. In these cases endoscopic ultrasonography may be helpful to determine which lesions are suspicious enough to warrant cholecystectomy [146].

Gallbladder Carcinoma

Clinical Presentation and Diagnosis

Although uncommon, gallbladder carcinoma is the most common cancer of the biliary tree with the overwhelming majority of cases being adenocarcinoma (80 %) [159]. Approximately 10 % of these malignancies are diagnosed in cholecystectomy specimens [159]. The incidence in the

United States is 1.2/100,000 with the malignancy occurring more frequently in other countries. Risk factors include advanced age (>65), female gender, obesity, and those of Asian descent [160]. As previously mentioned, cholelithiasis was previously thought to be a causal factor in the development of gallbladder carcinoma, but recent data suggests otherwise.

Unfortunately most cases are asymptomatic or have nonspecific complaints leading to delayed presentation at an inoperable stage (50 %) [161]. Other patients may present with typical biliary symptoms and have undergone cholecystectomy with incidentally discovered cancer in the removed specimen (10 %) or have undergone abdominal imaging for another indication revealing gallbladder findings that are concerning for malignancy (i.e., large polyps or mass with liver involvement) [159].

In the patients where gallbladder cancer is suspected preoperatively, a CT of the abdomen should be obtained to assess for tumor invasion into the liver or other organs as well as lymph node involvement [161]. Findings on CT that preclude curative resection include: invasion of the common hepatic artery or main portal vein, lymph node involvement outside the hepatic hilum, or obvious evidence of metastasis [159]. Assessing the thickness of the gallbladder wall is also important, as this is the most common imaging finding in gallbladder carcinoma. A wall thickness of greater than 10 mm with strong mucosal enhancement strongly suggests the presence of cancer [147]. A recent report assessing the diagnostic ability of PET imaging in patients with suspected gallbladder carcinoma showed an accuracy of 96 % for identifying the primary lesion and 86 % percent for identifying nodal involvement [162]. This can allow for accurate preoperative staging, as lesions that have portal vascular involvement or nodal metastasis away from the hepatic hilum are considered non-resectable. Most patients with the diagnosis are often elderly with comorbidities, and a reasonable assessment of functional liver reserve should be done to ensure that a large liver resection would not lead to acute fulminant hepatic failure.

Treatment of Gallbladder Carcinoma

In cases where the diagnosis of gallbladder cancer is known or suspected preoperatively, an open cholecystectomy with wedge resection of the liver as well as portal lymphadenectomy should be the planned procedure [163]. Diagnostic laparoscopy may be considered prior to laparotomy as this can identify peritoneal disease or noncontiguous hepatic involvement not seen on preoperative imaging that would preclude curative resection in almost 50 % of patients [164]. Once the specimen is excised, the cystic duct margin should also be sent and if positive be followed by an excision of the common bile duct with hepatico-jejunostomy reconstruction [161]. Margins of the liver wedge resection should also be checked and if positive be extended surgically until negative margins are obtained [163]. Some tumors require formal anatomic liver resection (Couinaud segments IV and V), but this is usually known preoperatively.

Commonly patients that have undergone cholecystectomy for presumed benign disease will have the tumor identified on final pathology. Tumors that are found to be in situ or only invade the lamina propria (T1a) are considered cured with 5-year survival rates of greater than 90 % [159]. All other tumors with more extensive invasion should undergo reoperation with wedge resection of the liver, lymphadenectomy, and possible common bile duct excision [163]. Laparoscopic port site excision was once considered mandatory; however, while port site metastasis is common (19 %), routine excision does not increase the 5-year survival [165]. Once the tumor extends into the peri-muscular connective tissue of the gallbladder or there is lymph node involvement, the 5-year survival decreases dramatically even with attempts at curative resection as adjuvant chemotherapy and radiation remain ineffective [163, 166]. This should be kept in mind when considering extensive resections in the elderly patient. In patients that present with unresectable disease and biliary obstruction, endoscopic or percutaneous interventions with biliary stenting are often successful at providing palliation [53, 163].

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Diverticulitis

15

Chasen Croft and Frederick Moore

Anatomy of the Colon

The colon is a continuous tube extending from the ileocecal valve to the rectum. It is composed of four segments: the ascending colon, transverse colon, descending colon, and sigmoid colon. The first section, the ascending colon, extends along the retroperitoneum for approximately 20 cm from the ileocecal valve upward toward the transverse colon. The anterior and lateral segments of the ascending colon are completely intraperitoneal, whereas the posterior segment is completely retroperitoneal. The transverse colon extends from two fixed positions, the hepatic and splenic flexures. It measures about 45 cm in length. As the transverse colon is completely invested in peritoneum, it is completely mobile. Superiorly, the transverse colon is attached to the stomach by the greater omentum, a wide band of stored fat. Posteriorly, it is connected to the posterior abdominal wall by the transverse mesocolon. The descending colon extends downward from the splenic flexure toward the sigmoid colon, with a distance of approximately 25 cm. Like the ascending colon, the descending colon is fixed within the retroperitoneum. The descending colon is relatively thin-walled and transitions to the thicker, mobile sigmoid colon at the pelvic brim. In contrast to other segments of the colon, the sigmoid colon is a small-diameter, thick-walled tube which varies in length from 15 to 50 cm (average 40 cm). It is covered by peritoneum and, like the transverse colon, is very mobile. The sigmoid colon forms a characteristic S-shape as it descends into the pelvis where it transitions into the rectum.

The colon receives arterial blood flow via two main arterial trunks, the superior mesenteric artery (SMA) and the inferior mesenteric artery (IMA). The SMA and IMA are direct branches off of the aorta, with the SMA supplying blood flow to the entire small bowel. The ileocolic artery, a branch of the SMA, supplies the terminal ileum, cecum, and appendix. The right colic artery usually arises directly from the SMA and supplies the ascending colon and the hepatic flexure; however, it is absent in up to 20 % of the population. The middle colic artery is a proximal branch of the SMA, and divides into the right and left branches, which supply the proximal and distal transverse colon, respectively. The IMA originates just above the aortic bifurcation. The most proximal branch, the left colic artery, supplies the distal transverse colon, the splenic flexure, and the descending colon. However, the area of the splenic flexure has inconsistent collateral circulation and is vulnerable to ischemia during even brief periods of hypotension. This is commonly referred to as a "watershed" area. The sigmoid colon is supplied via an arcade, formed between two to six sigmoid branches which collateralize with the left colic artery. This arcade proceeds proximally and connects the SMA and IMA, forming a continuous marginal artery arcade. Additional collateral flow is formed from the arc of Riolan, or meandering mesenteric artery. This is a collateral artery which directly connects the SMA to the IMA, forming a vital collateral circulation should one of these arteries become occluded.

The venous and lymphatic drainage of the colon mirrors the arterial supply. The drainage from the ascending and proximal transverse colon empties into the superior mesenteric vein (SMV). The SMV then joins the splenic vein to become the portal vein. The distal transverse colon, descending colon, and sigmoid colon drain into the inferior mesenteric vein, which coalesces with the splenic vein. The lymphatics follow a similar pattern, draining into the para-aortic lymph basin which, in turn, drains into the cisterna chyli.

Effects of Aging on Colon Motility and Function

The primary function of the colon is to provide a site for bacteria-induced fermentation, storage of waste, and maintenance of water balance. Like all organs of the body, the colon is subject

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to the effects of aging. However, the exact effects are poorly understood. Within the gastrointestinal tract, there is a continuously regulated balance of intestinal epithelial proliferation and apoptosis. Alterations in this balance have been proven to be a causative factor in the development of colorectal cancer [1]. Sipos et al. reported that, on average, 4–5 days are required for colonic mucosa renewal [2]. While it seems intuitive that as the colon ages the rate of colon mucosal regeneration slows, this, in fact, seems to not be the case. Recent data suggests that the rate of colon epithelial proliferation may increase with age, while the rate of apoptosis decreases [3]. This corroborates the "two-hit" hypothesis of carcinogenesis proposed by Knudson [4].

A frequent problem in the aging population is slow-transit constipation. Studies of transit times in the aged show either a slower rate of passage through the colon or no differences with aging [5–7]. As the transit time slows, the transluminal pressure within the colon increases. Stewart et al. studied nearly 3200 patients aged 65 and older, 26 % of women and 16 % of men reported recurrent constipation, finding a significant increase in reported constipation with increasing age [8]. Of the 13 factors identified as significantly contributing to constipation, the most important were age, sex, total number of medications consumed, pain in the abdomen, and the presence of hemorrhoids. In addition to select demographic factors contributing to slow-transit constipation, immunocytochemistry studies have demonstrated decreased levels of interstitial cells of Cajal, the gastrointestinal pacemakers [9].

Epidemiology and Pathology of Diverticular Disease

Colonic diverticula are herniations of the colonic mucosa and submucosa through defects in the muscular layer resulting in the formation of pulsion or pseudodiverticula. Pseudodiverticula emerge through the muscularis propria along the antimesenteric tenia at points of penetration of vasa recta, which supply the mucosa and submucosa, creating weak areas within the muscular layer. Although the terminologies used to describe the conditions associated with *diverticular disease* are often used interchangeably, the meanings are quite different. Diverticulosis is simply the presence of colonic diverticula, without associated inflammation. Symptomatic diverticular disease is diverticulosis associated with pain or alterations in bowel habits in the absence of radiologic evidence of diverticular inflammation. In contrast, diverticulitis refers to inflammation of one or more diverticula, generally implying perforation of a diverticulum. This term is actually a misnomer, as the disease is actually a perforation of one or more diverticulum with resultant extraluminal extravasation of feces. The term *peridiverticulitis* has been proposed to more accurately describe the infectious process.

Diverticular disease is a common disease which affects 20 % of men and women older than 40 years of age, 50 % of those older than 60, and more than 60 % of those over the age of 80. In the United States, diverticular disease accounts for greater than 300,000 hospitalizations yearly, with estimated direct healthcare costs in excess of $2.4 billion annually [10–13]. One quarter of all patients will develop complicated diverticular disease, defined as diverticulitis associated with phlegmon, abscess, fistula, free perforation, or stricture. The disease is known as the *disease of the industrial revolution*, since there are no reports or pathologic specimens documenting evidence of diverticular disease prior to this period [14]. During the end of the nineteenth century, the process of roller milling wheat was introduced in Europe and the United States, a technique which removes two thirds of the fiber content of wheat. Coincident with the implementation of this new technique, diverticulosis was observed in the first decade of the twentieth century. It was initially regarded as a pathologic curiosity. It is now known that a diet low in fiber is a contributing factor in the development of diverticular disease [14, 15]. In a study of nearly 48,000 US men, a low-fiber diet increased the risk of symptomatic diverticular disease by two- to threefold over a 4-year period [16]. In addition to low dietary fiber, alterations in colonic intraluminal pressures have been shown in patients with diverticular disease. Although resting intraluminal pressures between diverticular disease patients and controls do not differ significantly, higher pressures have been demonstrated in segments of colon with diverticula [17]. In addition, later studies indicate increased colonic motility, as assessed by the number and amplitude of bowel wall contractions, in the sigmoid colon of patients with diverticular disease [18–20]. Therefore, both a low-fiber diet and colonic dysmotility have been implicated in the pathogenesis of diverticular disease.

Another cardinal feature of diverticular disease is abnormalities of the muscularis propria. Whiteway et al. demonstrated that the colonic muscle cells in diverticular disease specimens are normal compared to controls; however, the elastin content of the taeniae coli increases by 200 % [21]. The elastin is laid in a contracted form and may be responsible for the shortening or "contracture" of the taeniae, which in turn leads to the concertina-like corrugation of the circular muscle [21]. This abnormality can be seen on barium enema radiographs, a pathognomonic sign. Other studies have demonstrated an alteration in the collagen deposition of the aging colon. Thomson et al. showed that as the colon ages, the collagen fibrils of the left colon increase in size and become more tightly packed than those of the right colon [22]. They further showed that these changes are accentuated in diverticular disease patients. Furthermore, the ratio of type I collagen to type III collagen appears to be altered. In diseased segments of the colon, there are decreased mature type I collagen and increased type III collagen, with a resulting lower collagen ratio I/III indicative of scarring [23].

Treatment of Diverticular Disease

Uncomplicated (Simple) Diverticulitis

The treatment of diverticular disease can be divided into two simple categories: medical management and surgical therapy. The decision of which algorithm to follow is determined by the acuity of disease (complicated vs. uncomplicated), patient comorbidities, and patient compliance. Uncomplicated diverticulitis, defined as acute diverticulitis without associated abscess, fistula, obstruction, or free perforation, can be diagnosed on the basis of clinical criteria alone. Most patients will present with left lower quadrant pain, fever, and leukocytosis. Other associated findings may include nausea and vomiting, constipation or diarrhea, dysuria, and urinary frequency. If the clinical picture is unclear, further diagnostic studies should be performed. The two most commonly performed radiologic studies used to aid in the diagnosis of diverticular disease are water-soluble contrast enema and computed tomography scan; however, ultrasonography and magnetic resonance imaging can also be used. Due to the risks of extravasation of barium from the perforation in a patient with acute diverticulitis, barium enema should be avoided in the acute setting. The American College of Radiology currently recommends computed tomography (CT) as the preferred imaging modality in patients with clinically suspected acute diverticulitis [24, 25]. Once the diagnosis of uncomplicated diverticulitis is made, it should be treated with bowel rest, analgesics, and antibiotics, although some authors now suggest the use of clear liquids is acceptable [26]. Conservative management has been shown to induce resolution of acute, uncomplicated diverticulitis in 70 to 100 % of patients [26–29].

The selection of antibiotic for medical management of acute, uncomplicated diverticulitis should cover the spectrum of bacteria commonly found in the colonic flora. This includes gram-negative rods and anaerobes [30]. The most commonly isolated aerobic gram-negative species is *Escherichia coli* and the predominant anaerobe is *Bacteroides fragilis*, present in up to 94 % of patients with intra-abdominal infections [30, 31]. Combination therapy (such as clindamycin and gentamicin) or monotherapy (such as cefoxitin) has been shown to be equally effective in the treatment of uncomplicated diverticulitis [29]. In select patients, particularly those with only minimal tenderness and who are otherwise healthy, ambulatory treatment with oral broad-spectrum antibiotics (trimethoprim-sulfamethoxazole, double-strength twice daily, plus metronidazole, 500 mg every 6 h for 10 days to 2 weeks) may be utilized. However, this regimen should not be offered to immunocompromised patients, including those receiving chronic steroids, as their clinical exam cannot be reliably followed and overwhelming sepsis can ensue with alarming rapidity. Following successful nonoperative treatment of uncomplicated diverticulitis, patients should be placed on a high-fiber diet (30–40 g of soluble fiber per day) once the acute inflammation has resolved.

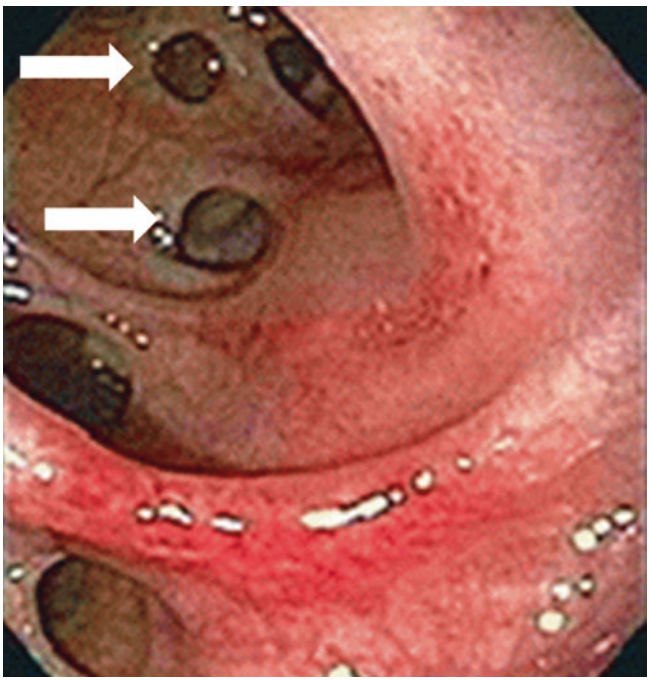

Fig. 15.1 Colonoscopy showing multiple diverticula (*white arrows*) without evidence of diverticulitis

After recovery of an initial episode of diverticulitis, patients should be evaluated with a complete colonic examination. Appropriate studies include a combination of flexible sigmoidoscopy and single-contrast or double-contrast barium enema or complete colonoscopy [26]. The preferred test is a colonoscopic examination, which can directly visualize the colonic mucosa and evaluate for underlying sigmoid cancer, a condition which may be missed with barium enema alone (Fig. 15.1). More than 75 % of patients respond to conservative management, and a recurrence rate of 20–25 % can be expected, mostly within the first 5 years after an initial attack [32–34].

Complicated Diverticulitis

In contrast to uncomplicated diverticulitis, patients with acute, complicated diverticulitis typically present with localized or generalized peritonitis, fever, and leukocytosis. The diagnosis should be confirmed radiographically, with either computed tomography or magnetic resonance imaging. In 1978, Hinchey et al. published the first classification system to standardize the nomenclature describing the breadth of perforated diverticular disease [35]. This classification has been used since the 1970s, before the advent of computed tomography. It describes four stages of perforated disease. Stage I disease includes pericolic abscess or phlegmon.

Table 15.1 Western Trauma Association Complicated Diverticulitis Score

Western Trauma Association Complicated Diverticulitis Score	
Grade IA	• Phlegmon with no abscess
Grade IB	• Phlegmon with abscess <4 cm
Grade II	• Phlegmon with abscess >4 cm
Grade III	• Purulent Peritonitis
Grade IV	• Feculent Peritonitis

Adapted from Western Trauma Association Critical Decisions on Trauma: Management of Complicated Diverticulitis

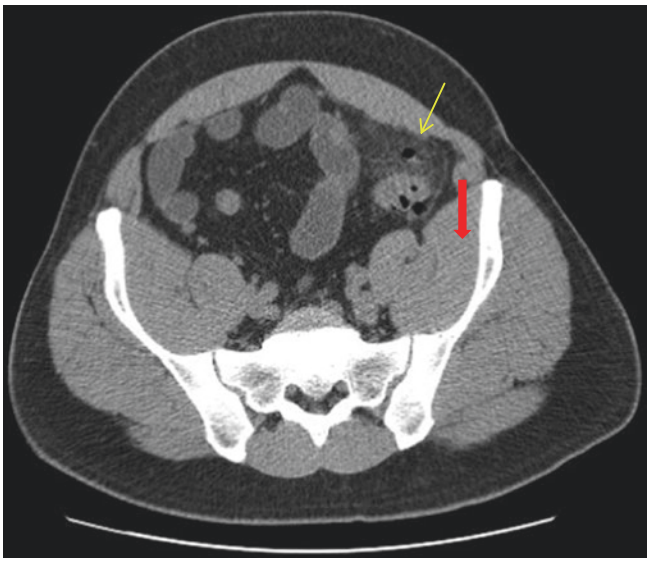

Fig. 15.2 Western Trauma Association grade IA complicated diverticulitis. Computed tomography shows sigmoid diverticulitis (*red arrow*) with pericolonic phlegmon and small focus of extraluminal air (*yellow arrow*)

Stage II disease is a walled-off pelvic, intra-abdominal, or retroperitoneal abscess. Stage III disease describes generalized purulent peritonitis and stage IV disease is generalized feculent peritonitis. Since the advent of this classification system, few modifications have been introduced. The Western Trauma Association (WTA) consensus has modified this system to reflect contemporary management of complicated diverticular disease (Table 15.1).

The optimal treatment of patients with complicated diverticulitis has undergone significant changes with the evolution of surgical techniques and nonoperative therapies. As late as the 1990s, the standard treatment for complicated diverticulitis was surgical resection and colostomy often performed in a multistage procedure, a technique described in the 1920s [36]. A paradigm shift has occurred mostly as the result of advances in antibiotics, interventional radiology, and critical care medicine.

Patients with WTA grade IA (phlegmon with no abscess (Fig. 15.2)) and grade IB (phlegmon with abscess <4 cm) should be treated with hospitalization, bowel rest, and intravenous antibiotics. Those who respond with resolution of pain, fever, and leukocytosis should be started on an oral diet and converted to oral antibiotics. Antibiotics should be continued for 14 days, from the initiation of intravenous antibiotics. Patients should undergo colonoscopy and be placed on a high-fiber diet following resolution of the acute inflammatory process. Those who fail conservative management should undergo definitive resection, described later in this chapter.

Patients with WTA grade II disease (phlegmon with abscess >4 cm), or those with abscesses not responding to conservative therapy, should undergo CT-guided percutaneous drainage (PCD) [26, 37]. Seventy to ninety-three percent of patients amenable to CT-guided PCD can be successfully drained [38]. The preferred approach is transabdominal, either anterior or lateral. Other approaches include transgluteal, transperitoneal, transvaginal, or transanal. The potential advantage to performing CT-guided PCD is that it may avoid the need for urgent operation, allowing defervescence with resolution of some inflammation prior to a definitive operation. These admitted patients should be treated with intravenous antibiotics, while following their clinical exam for possible failure, such as increased abdominal pain, increasing leukocytosis, or hemodynamic instability. The reported failure rates for CT-guided PCD range from 15 to 30 %. Complications, including bleeding, perforation of a hollow viscus, and fistula formation, occur in up to 5 % of patients. Although some authors suggest CT-guided PCD may avoid the need for definitive resection altogether, the American Society of Colon and Rectal Surgeons does not endorse this concept currently.

In patients whom CT-guided PCD is not feasible, laparoscopic lavage and drainage may be an acceptable alternative. To perform the operation, pneumoperitoneum is established and a 12 mm umbilical trocar is placed. Two 5 mm operating trocars are then placed in the right lower quadrant and suprapubic positions to assist with manipulation and lavage (Fig. 15.3). The patient should be positioned in Trendelenburg with a left tilt, and the surgeon and assistant should be on the patient's right side. The abdomen should be thoroughly inspected, and all omental, small bowel, pelvic structures, and abdominal wall attachments should be mobilized away from the inflamed sigmoid colon. However, vigorous manipulation of the diseased segment of colon should be avoided. If there is no evidence of free perforation of the colon, the four quadrants of the abdomen are lavaged until the effluent

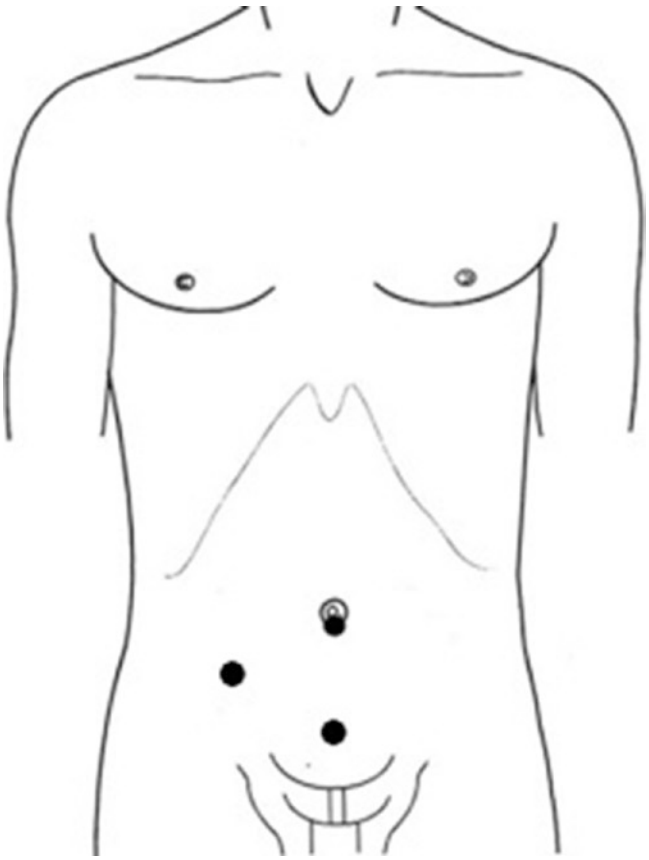

Fig. 15.3 Trocar placement for laparoscopic lavage. A 12 mm trocar is inserted at the umbilicus and two 5 mm trocars are placed in the right lower quadrant and suprapubic positions

is clear. Should free perforation be identified, the diseased colon should be resected. A closed-suction drain is placed in the pelvis and externalized through the right lower quadrant trocar site. Multiple studies have reported the use of laparoscopic lavage in patients with Hinchey II–IV diverticulitis with low complication rates (<8 %) and without the need to convert to an open procedure [39–41]. Successful laparoscopic lavage may control sepsis and allow patients to be bridged for an elective one-stage operation. However, more recently two large multicenter, randomized trials have questioned the utility of laparoscopic lavage in perforated diverticulitis associated with purulent and feculent peritonitis. The laparoscopic lavage group of the Ladies trial sought to prove laparoscopic lavage for perforated diverticulitis would lead to a reduction in major morbidity and mortality [42]. During the 12-month follow-up, no significant difference was reported in the incidence of morbidity, including need for surgical re-intervention, abscess requiring drainage, facial dehiscence, or death. However, the combined 30-day morbidity and mortality rates were higher among the patients who underwent laparoscopic lavage (39 %) versus those who received a Hartmann's procedure (HP) (19 %). This study, which was terminated early due to non-superiority, did not show a reduction of combined morbidity and mortality in patients who underwent laparoscopic lavage for perforated diverticulitis when compared with sigmoidectomy. The authors concluded that laparoscopic lavage for the treatment of diverticulitis is not superior to sigmoidectomy. The SCANDIV randomized clinical trial postulated that laparoscopic lavage was superior to colon resection in patients with perforated diverticulitis [43]. Primary outcomes included any complication that required re-intervention, life-threatening organ dysfunction, or death within 90 days. 101 patients were randomized to the lavage group, while 96 were randomized to the resection group. No statistically significant difference was found between the two groups. Among patients with fecal peritonitis, statistically significant differences were observed in the secondary outcomes. Considerably more patients in the lavage group required a secondary surgical procedure because of complications, including secondary peritonitis and intra-abdominal abscess formation. These findings led the authors to conclude that laparoscopic lavage should not be used in the treatment of perforated diverticulitis. The current role of laparoscopic lavage for perforated diverticulitis continues to evolve. Further studies are needed to determine the patient population in which this intervention may pose the most therapeutic benefit.

Diverticulitis Associated with Free Perforation

Free perforation associated with acute diverticulitis is classified as WTA grade III (purulent/Hinchey III) or grade IV (feculent/Hinchey IV) peritonitis. Lidor et al. demonstrated that of more than 53,000 elderly patients studied, patients that underwent emergency surgery for complicated diverticulitis were older (76.8 vs. 73.9 years of age), had increased inhospital mortality, had a larger rate of intestinal diversion, and had higher 30-day readmission rates [44]. This population presents unique challenges, but the surgical management remains unchanged. Patients who present with florid sepsis, hypotension, and significant metabolic derangements represent a surgical emergency that requires rapid resuscitation, broad-spectrum antibiotics, and prompt operative therapy. Depending on the hemodynamic stability, a truncated or *damage control* laparotomy may be performed. In the unstable patient, a limited resection of the inflamed colon and temporary abdominal closure should be performed. The patient is then returned to the intensive care unit for further resuscitation. Once the physiologic abnormalities are corrected, the patient is returned to the operating room for peritoneal lavage, completion sigmoid colectomy, and end colostomy formation.

In patients who present with perforation, but whom are otherwise hemodynamically stable, a definitive resection may be undertaken. Ureteral stents should be used selectively in

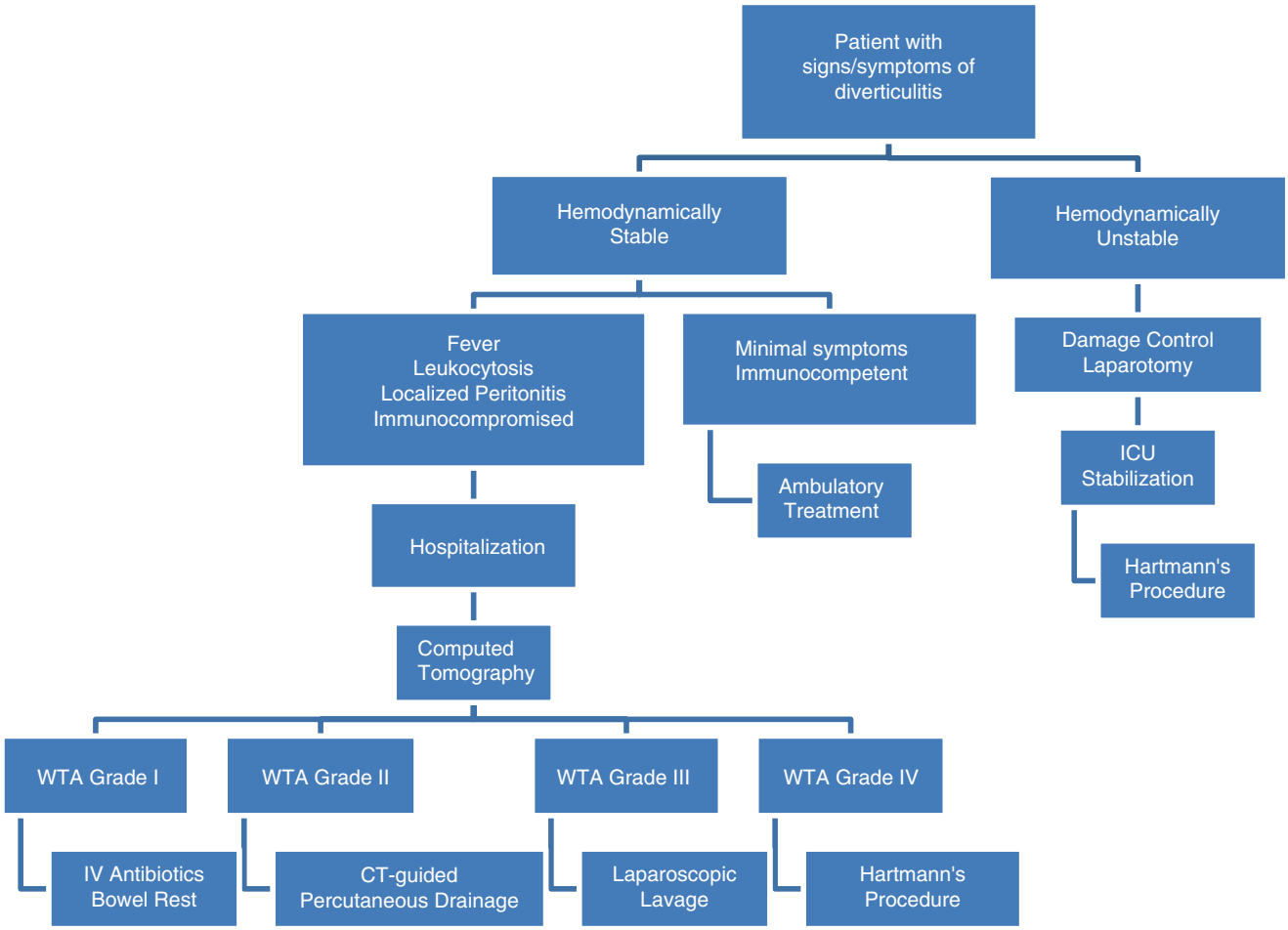

Fig. 15.4 Diverticulitis management algorithm. *Abbreviations*: *WTA* Western Trauma Association, *CT* computed tomography

those patients with abscesses or excessive inflammation in the pelvis, which may aid in the identification of the ureters and protection from injury. The sigmoid colon is then mobilized, extending proximally to an area of noninflamed descending colon. The distal dissection should extend to the upper rectum. It should be noted that it is not necessary to resect all diverticula. The current *standard of care* therapy is Hartmann's procedure, whereby the diseased colon is resected and a temporary end colostomy is performed. This procedure requires a second operation for reversal of the colostomy. However, there is currently much debate as whether to perform a primary resection with anastomosis (PRA) or a Hartmann's procedure (HP). Primary resection and anastomosis of the affected colon segment has been used in an attempt to minimize the morbidity and mortality associated with the reversal of Hartmann's procedure, which has a documented morbidity as high as 50 %. Therefore, the choice of operation should be influenced by factors such as patient age, comorbidities, degree of contamination, and mode of presentation. In a meta-analysis of 15 studies comparing PRA to HP, PRA was shown to have reduced morbidity and mortality, even when used in an emergency setting [45]. However, all studies were limited by significant patient selection bias, where patients with less comorbidities underwent PRA. Currently PRA should be reserved for patients with more favorable comorbid criteria, a lesser degree of contamination, and no preoperative hemodynamic instability.

Summary

Diverticular disease is commonly seen in the elderly population. Thorough history and physical examination combined with computer tomography will diagnose and grade nearly all patients. Treatment algorithms (see Fig. 15.4) will be based upon the patient's preexisting medical comorbidities, physiologic status, and grade of diverticulitis. Newer concepts, including laparoscopic lavage and single-stage operations, are gaining acceptance and may become more routine as more data becomes available.

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Intestinal Obstruction

16

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Background

The elderly comprise the fastest-growing segment of the United States' population; thus, surgeons will be faced with increasing numbers of older patients particularly those with intestinal obstruction. These patients will be more challenging to care for since they will have more complex medical comorbidities than younger patients. This challenge will be compounded by the fact that many of these patients will have undergone previous abdominal surgery and a small but growing minority might have undergone multiple abdominal procedures. Since intestinal obstruction is one of the more common surgical diseases in the elderly, it is imperative that surgeons sharpen their understanding of the evaluation and treatment of patients with bowel obstruction.

Intestinal obstruction is a common cause of pain and disability in the elderly, and this disease places a large economic and resource burden on the healthcare system. A review of US healthcare data revealed an annual estimated cost of well over one billion dollars to treat adhesion-related bowel obstruction, and many of these patients were noted to be of advanced age [1]. Unlike younger patients, where a vast array of nonobstructive surgical disease states cause the patient to seek medical care, intestinal obstruction is a far more frequent cause of abdominal pain in the elderly. The obstruction is due to a much broader range of etiologies. Although adhesive bowel obstruction is common in the elderly, additional etiologies include gallstone ileus, obturator or rare hernias, bezoars, cecal and sigmoid volvulus, as well as more common problems such as inguinal or incisional hernias, inflammatory bowel disease, and neoplasms.

Intestinal obstruction is truly a "surgical disease" which has been affirmed by a recent investigation that showed decreased mortality, length of stay, and costs when patients were admitted to the care of a surgeon rather than the medical service, even though the majority of patients were managed nonoperatively. In fact, only a very small percentage of patients with intestinal obstruction require immediate or urgent operation upon presentation [2, 3]. Identifying which patients require immediate operative intervention is critical since delays in therapy typically result in bad outcomes for elderly patients due to their associated comorbidities and limited physiological reserve. Timely intervention in these patients can limit progression to intestinal ischemia and perforation or the need for significant bowel resection that may result in short gut, especially if the patient has already undergone prior operation with bowel resection. However, determining when to intervene in these patients is complicated due to the presence of confounding variables such as altered mental status, dementia, medications, comorbidities, as well as a blunted pain response in the elderly. Additionally, the immune system in the elderly may be less robust than that of younger patients, and the typical signs of inflammation or infection may be diminished or absent. It is these comorbidities and physiologic limitations that make timely management decisions regarding operative intervention even more critical in the elderly. These decisions are further complicated by the disastrous complications that may occur with inappropriate operative intervention making the decision to operate on the elderly obstructed patient one of the most challenging in all of general surgery. In order to assist clinicians with this decision process, some novel diagnostic technologies and clinical strategies have emerged. The success of clinical pathways in other surgical specialties and disease states is spilling over into the management of bowel obstruction in the elderly. Emerging evidence supports protocol-based management of elderly patients with intestinal

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obstruction, particularly in identifying which patients require exploration versus those that are best managed nonoperatively. These protocols are of particular interest to acute care surgeons since they typically are the surgeons caring for these challenging patients; thus staying abreast of recent developments is a crucial aspect of caring for these patients.

Causes

More than 20 % of emergency abdominal operations are performed for intestinal obstruction, and small bowel causes outnumber large bowel ones by a 3 to 1 ratio [4]. In elderly patients the predominant cause of intestinal obstruction is postoperative adhesions with the highest prevalence occurring in patients with previous colorectal or pelvic procedures. Incarcerated hernias and neoplasms are the next most common cause of obstruction, and it is noteworthy that adhesions and hernias remain the two most common causes of small bowel obstruction across all age groups [4]. The demographics of patients undergoing operation for intestinal obstruction continues to evolve and mirrors the aging of the US population with the peak incidence of operative obstructions occurring during the seventh decade of life [5]. In light of recent projections that over 30 % of the population will be over the age of 65 by the year 2030, it is likely that the elderly will make up the majority of patients requiring admission and operative intervention for intestinal obstruction.

Although much more rare, other causes of small bowel obstruction in the elderly include primary small bowel tumors, small bowel metastases from melanoma or direct invasion from colon cancers, Crohn's disease, volvulus, intussusception, internal hernias, bezoars, strictures, and gallstone ileus. Primary small bowel tumors make up approximately 5 % of all gastrointestinal neoplasms, but their most common presenting sign is obstruction. This is also true for other neoplasms such as lymphoma, stromal tumors, carcinoid tumors, adenocarcinoma, and metastases [6]. Gallstone ileus occurs when a gallstone passes through a fistula between the gallbladder and duodenum and subsequently transits the small bowel ultimately impacting in the terminal ileum. This entity is rare, accounting for only 1–4 % of cases of small bowel obstruction, but when it does occur it is almost exclusively in elderly patients [7]. The typical patient suffering from gallstone ileus tends to be debilitated and have significant comorbidities which complicate their care, but the diagnosis is straightforward with the proper imaging studies and appropriate index of suspicion.

Colonic obstructions are much more prevalent in the elderly compared to younger patients. In developing nations, colonic volvulus, specifically sigmoid volvulus, is a major cause of large bowel obstructions. Many years ago this was also true in the United States, but now colonic tumors are the most common cause of large bowel obstruction as the American diet has changed from a high residual diet of roughage to a high-fat diet low in fiber. Other causes of large bowel obstruction include primary colonic tumors and inflammation or late stricture from diverticulitis, ischemic strictures, and incarcerated hernias. The sigmoid colon is the most frequent location of obstructing colon cancer, and in general cancers distal to the splenic flexure more commonly cause obstruction due to the narrower lumen of the left colon compared to the right. It is also important to consider the functional, nonmechanical etiologies of large bowel obstruction that are commonplace in patients of advanced age, especially those who are debilitated or have a history of laxative dependency. The syndrome of colonic pseudo-obstruction, or Ogilvie's syndrome, typically occurs in elderly patients hospitalized for other reasons, and the treatment of colonic dysfunction is very different from that of mechanical causes of obstruction. Lastly, constipation and stool impaction are often causes of colonic obstruction that occurs almost exclusively in the elderly and should be considered in the differential diagnosis of obstruction.

Signs and Symptoms

The diagnosis of intestinal obstruction in the elderly can be challenging due to the varied nature of their chief complaints; thus it is advisable that the clinician adopt a systematic approach to the patient considering each sign and symptom separately. The most common symptom of bowel obstruction is obstipation, a prolonged period without the passage of flatus or stool. When obtaining the history of present illness from the patient or caregiver, it is important to determine when the last signs of bowel function occurred and whether this is a significant change from their baseline function. This may be difficult if the patient has a history of constipation, since new onset obstipation may be hard to differentiate in a background of slow transit time. Other commonly reported symptoms include crampy or colicky periumbilical abdominal pain that can progress to diffuse and unrelenting pain as the obstruction becomes established. This visceral pain is nearly always associated with nausea and sometimes emesis, but the lack of emesis does not rule out the presence of intestinal obstruction. Reviews of large series of patients with bowel obstruction have shown obstipation, emesis, and abdominal pain are the most commonly noted symptoms [5, 8, 9]. Generally, the more proximal the site of intestinal obstruction, the less voluminous the patient's emesis will be, and in the case of gastric volvulus, the patient may retch but produce very little vomitus at all. More distal obstructions can lead to copious emesis since in addition to whatever food or fluid has been ingested, the gastrointestinal tract makes several liters of secretions adding to the volume of the vomitus. Feculent emesis is observed in long-standing intestinal

obstruction and is the result of bacterial overgrowth proximal to the site of obstruction. Less specific symptoms such as fatigue, general malaise, and weakness are likely related to dehydration and possibly lack of nutritional intake. Patients with intestinal obstruction lose significant amounts of fluids from sensible sources such as emesis as well as insensible sources such as sequestration of edema fluid in the bowel wall and lumen. Patients with a relapsing and remitting course of symptoms that vary with oral intake likely have a partial intestinal obstruction. These patients often report a decrease in their stool production or frequency. Conversely they may complain of intermittent loose stools and may not report obstipation at all. Many of these patients will have learned to alter their diet to protect themselves from developing abdominal pain that they associate with taking certain solids, particularly roughage.

All patients with a suspected intestinal obstruction should undergo a thorough history and physical examination. It is particularly important to inquire about medical comorbidities, past surgical history, endoscopic history, and whether there have been similar prior episodes or hospital admissions for intestinal obstruction. Physical examination should be done in a comprehensive fashion with particular focus on the patient's general appearance, behavior, and abdominal findings. *Cope's Early Diagnosis of the Acute Abdomen* advocates that "one should always take the time to watch the patient quietly for several minutes" to gauge if there is an abdominal emergency [15]. Patients writhing in pain, trying to find a comforting position, or suffering bouts of emesis indicate colicky pain from distention of a hollow viscus in contrast to the ominous sign of those lying very still who may have peritonitis. The abdominal exam should be done systematically starting with inspection, followed by auscultation and palpation. Inspection allows for assessment of the degree of distention and the presence of surgical scars, a sign that the patient may have adhesive bowel disease. Distention tends to be less noticeable in more proximal obstructions such as gastric volvulus, gastric outlet obstruction, or duodenal obstructions. More distal obstructions of the small bowel due to adhesions, incarcerated hernias, cecal or sigmoid volvulus, colonic masses, and colonic pseudo-obstruction lead to marked and impressive distention due to large volumes of air and fluid that accumulate proximal to the point of obstruction. This is also why tympany upon percussion tends to present on physical examination with more distal obstructions. Auscultation can be revealing if there are classic high-pitched tinkling bowel sounds of an early obstruction but tends to be fairly insensitive and nonspecific, particularly if there are diminished sounds as seen in long-standing obstructions.

Palpation is performed to evaluate for tenderness, signs of peritoneal irritation, and guarding, and a thorough exam looking for abdominal wall or groin hernias is mandatory. Abdominal tenderness implies irritation of the peritoneal surfaces and in the early stages of obstruction is due to the apposition of a dilated viscus against the peritoneum. Involuntary guarding or signs of peritoneal irritation are worrisome and imply peritonitis. Lastly a rectal examination should be done to evaluate for impacted stool, bleeding, and masses. Patients with strangulated intestinal obstruction and bowel ischemia often have abdominal pain out of proportion to physical exam findings and warrant prompt operative exploration. Unfortunately, signs of peritonitis including abdominal guarding and rebound tenderness are of limited sensitivity and specificity and have been shown to be present in less than 50 % of patients with small bowel obstruction and strangulation [9, 10]. While nonspecific, the general appearance of patients is important to note, and very toxic-appearing patients often have peritonitis, septic shock, or advanced bowel ischemia.

The patient's vital signs can be very helpful as the clinician formulates a differential diagnosis. Tachycardia is common and may be due to dehydration and hypovolemia, pain, or marked systemic inflammation from ischemic bowl or peritonitis. Fever may be present, and like tachycardia it has been shown in multiple reviews to have no significant correlation to the presence of dead bowel. A hallmark study in the past reviewed the records of 238 patients with small bowel obstruction focusing on the presence of the four "classical" findings of leukocytosis, tachycardia, fever, and localized tenderness. When patients had none of these present, a period of nonoperative management was appropriate and not associated with added morbidity or mortality [11]. This approach has been supported by more recent investigation and ongoing clinical experience, but there remains no formal set of symptoms or signs in intestinal obstruction that can be utilized to determine whether urgent surgery is needed. Indeed, one review of small bowel obstruction stated "identification of those at risk for bowel ischemia and bowel death is an art as much as it is a science" [13].

Workup and Evaluation

One of the primary decisions in the evaluation of elderly patients with suspected intestinal obstruction is to determine the urgency of the condition and whether there is a closed loop obstruction or ischemic intestine requiring immediate operation. Unfortunately retrospective analyses of elderly patients with operative findings of strangulated or compromised intestine have shown that classic clinical signs such as peritonitis or abnormal vital signs are only present in the minority of patients [12]. Accordingly, it is important to add elements of laboratory and radiologic testing to enable the clinician to increase their diagnostic acumen.

A complete blood count with differential and a basic metabolic panel should be obtained on all patients with suspected intestinal obstruction. Leukocytosis is often suggestive of

generalized inflammation or infection but is too nonspecific to indicate compromised intestine. Generally, the degree of leukocytosis often correlates with the severity of the intra-abdominal process, but this is not the case in the elderly who may have mild leukocytosis or even a normal white cell count in the presence of necrotic bowel. The presence of bandemia is a worrisome sign, but this too has a low sensitivity for compromised or necrotic bowel; however, the combination of leukocytosis with significant bandemia ought to increase the index of suspicion for strangulation. Lactic acidosis may suggest ischemic bowel but can also be elevated due to dehydration. Dehydration is a common finding in patients with intestinal obstruction and is the result of fluid losses from emesis, bowel edema, and intraluminal fluid accumulation as well as decreased oral intake. Mild dehydration may result in hemoconcentration and prerenal azotemia, while the classically described hypokalemic, hypochloremic alkalosis is seen with long-standing obstruction. This results from loss of potassium followed by hydrogen ions as the kidney attempts to preserve sodium and water via the renal tubular mechanisms. This finding is seen with proximal obstructions, while distal obstructions tend to have a more unpredictable electrolyte profile. In fact patients may exhibit marked hypernatremia or hyponatremia depending on what compensatory physiologic mechanism has predominated.

Following laboratory analysis, radiologic evaluation should start with an upright chest x-ray to evaluate for free intraperitoneal air and the need for urgent exploration. Plain abdominal films obtained in the supine and upright positions assess for dilated loops of bowel, "step laddering" indicating fluid collections in the dependent portions of intestinal loops with air in the superior portion, and most importantly for the presence of air in the descending colon and rectum indicating a distal (colonic) obstruction. Air in the distal colon on radiographic studies indicates that a complete bowel obstruction is very unlikely and that a period of nonoperative management is warranted. Overall, the sensitivity and specificity of plain x-rays for diagnosing obstruction are between 50 and 80 %, while CT scan with oral and intravenous contrast has been shown to have greater than 90 % sensitivity [16]. Recent meta-analysis reveals that the CT findings indicative of bowel obstruction include proximal dilated intestine, transition point, and fecalized intestinal contents [17]. CT scan without oral or intravenous contrast has been shown to have equal sensitivity and specificity for bowel obstruction compared to contrast studies avoiding many of the complications associated with contrast administration [17]. CT scan evaluation for ischemic intestine is not quite as reliable; however sensitivity and specificity have been shown to be greater than 80 % and 90 %, respectively, with the key findings being reduced intestinal wall contrast enhancement and mesenteric attenuation [16, 17]. Not all patients need a CT scan and in some cases avoiding a scan is desirable since having a patient with intestinal obstruction lay flat may predispose them to massive aspiration and respiratory complications including death. Patients with a history of prior abdominal surgery and likely adhesive bowel obstructions can be admitted with a workup of plain x-rays since the information from a CT scan often does not change management. Interestingly, some advocate scans as potentially therapeutic for cases of partial obstruction as hyperosmolar water-soluble contrast agents may draw fluid into the bowel lumen and promote intestinal motility. The role of water-soluble contrast remains controversial in the setting of bowel obstruction since some studies have shown faster resolution of adhesive obstruction and lower rates of need for surgery, while others have shown no benefit [20–22]. Follow-up plain radiographs may be useful in patients that have undergone CT scan evaluation to assess progression of the contrast. The presence of such contrast in the colon within 24 h of administration has been shown to be 97 % sensitive and 96 % specific for resolution of adhesion-related obstruction in meta-analysis [22].

Ultrasound and MRI are additional imaging adjuncts that have some utility in the diagnosis of bowel obstruction. Ultrasound is classically used to evaluate gallbladder pathology; however there is increasing enthusiasm for its usefulness to assess obstruction. It has been shown in a few series to be as sensitive and more specific for diagnosis of obstruction when compared to plain x-rays [23–25]. The major advantages of ultrasound are its ability to be done quickly in a point of care fashion, its repeatability, and the lack of ionizing radiation exposure to the patient. Key findings suggestive of intestinal obstruction on ultrasound are bowel dilation, bowel wall thickening, presence of hypo- or hyperperistalsis, and free intra-abdominal fluid. Bowel wall thickening and free fluid may be more indicative of ischemia or perforation, but further study is needed to confirm the reliability of these findings. Ultrasound can also be used to assess inferior vena cava diameter to assess the volume status in patients with obstruction and may have a role in guiding fluid resuscitation. MRI is expensive and time consuming, and it is unwise to place an elderly patient with potential obstruction in the supine position for a prolonged period due to risk of vomiting, aspiration, and atelectasis. Other advanced imaging options to diagnose obstruction are MR fluoroscopy, CT enterography, enteroclysis, and capsule endoscopy but are beyond the scope of this discussion and are more investigational in nature at this point in time. No matter what imaging study is contemplated, it must be restated that patients with signs of peritonitis or septic shock do not require any radiologic evaluation, and in this setting radiographic imaging only delays definitive care.

Treatment and Intervention

Patients with signs and symptoms of intestinal strangulation, intestinal ischemia, or closed loop obstruction should be promptly fluid resuscitated and brought to the operating room for abdominal exploration. Patients appropriate for nonoperative management of bowel obstruction are those with early postoperative obstruction, obstruction due to inflammatory bowel disease such as Crohn's, partial obstruction due to adhesions from prior operations, and metastatic disease or carcinomatosis. A peculiar but challenging scenario encountered in elderly patients is signs of bowel obstruction but with no history of prior operation or findings of incarcerated or strangulated hernias on examination. In this patient population, there is a significant probability of neoplastic disease, and if the patient is fit enough for surgery, they should undergo abdominal exploration.

After the initial workup and evaluation have been completed, the elderly patient with intestinal obstruction needs a multifaceted approach to their care whether they are to undergo urgent operation or a trial of nonoperative management. Patients are often hypovolemic with prerenal acute kidney injury and require prompt resuscitation with isotonic intravenous fluid. In retrospective analysis, patients with intestinal obstruction and acute renal failure have been shown to have increased mortality and more likely require bowel resection [2]. The choice of lactated Ringer's or normal saline as the resuscitative fluid is based on the patient's initial electrolyte profile. Prompt fluid resuscitation is imperative if the progression from a prerenal state to acute tubular necrosis is to be prevented since elderly patients with acute kidney injury, renal loss, or need for renal replacement therapy have very poor outcomes. A Foley catheter should be placed and urine output monitored on an hourly basis to guide the fluid resuscitation. It is not possible to adequately monitor urine output and resuscitation without a urinary catheter since relying on a sick or debilitated elderly patient to save all urine in a collection chamber is unlikely to be successful. Since surgeons are more familiar with the pathophysiology of bowel obstruction and have experienced firsthand in the operating room the appearance of dilated, thickened, or ischemic bowel and the effects of this on fluid volume shifts and resuscitation needs, all elderly patients with intestinal obstruction should be admitted to the surgical service as previously noted. Even patients with significant cardiac comorbidities including congestive heart failure require fluid resuscitation in the setting of bowel obstruction, and this fact is often overlooked by well-meaning but ill-informed medical providers.

All patients with intestinal obstruction should receive nasogastric tube (NGT) decompression in order to decompress the stomach and lessen the risk of aspiration. NGTs also reduce the continued salivary, gastric, and possibly some duodenal, hepatic, and pancreatic fluid contributions to the intestine proximal to the obstruction and may be beneficial in improving the success of nonoperative management of obstruction. Patients also swallow several liters of air per day that can worsen distention and abdominal pain which is also effectively prevented with a NGT. Small-caliber NGTs are prone to clogging from food particles or fecalized gastric contents, predisposing the patient to emesis and aspiration; thus large-bore NGTs are preferable. Special attention should be paid to observing proper NGT insertion technique with radiographic confirmation of tube location since literature reviews note significant error rates ranging from 1.9 % to 89.5% [27]. Insertion technique is especially important in the elderly since they are more prone to aspiration during the insertion. Injecting 5 mL of 2 % lidocaine gel nasally 5 min prior to NGT placement results in less procedural discomfort and gagging, particularly in elderly patients, and having the patient sit upright is mandatory. Injecting air and auscultating are inadequate for confirmation of NGT placement, and CXR should be performed. Recently, bedsides ultrasound has emerged as a quick, reliable, and radiation-free method to confirm NGT placement [28]. NGTs should be placed to continuous low wall suction, and their patency confirmed from time to time. Bilious liquid backing up in the sump port of an NGT signifies incorrect location of the tube and is a risk factor for gastric aspiration and pulmonary complications.

All patients with intestinal obstruction, particularly the elderly, should be evaluated by a surgeon on presentation and admitted to the surgical service. Serial examinations and continued vigilance are the most important aspects of the plan to gauge whether the patient is improving and regaining bowel function or worsening and in need of operation. Significant clinical experience is required to appreciate the subtleties of the physical exam in patients with obstruction, especially elderly patients who may be stoic, and have a variable mental status or confounding comorbidities. For example, the elderly often are unable to mount a tachycardic response to inflammation due to the presence of cardiovascular comorbidities or adrenergic blocking agents. In large retrospective analysis of patients with intestinal obstruction, greater than 50 % of patients over the age of 75 were shown to have a significant medical comorbidity with cardiovascular disease being the most common [29]. It is not surprising that increasing age has been shown to markedly increased risk of strangulated, nonviable intestine and mortality from obstruction [29]. Patients requiring operative intervention may require bowel resection, repair of hernias, and even damage control approaches due to patient instability. The technical details of the operative management of these

patients are beyond the scope of this chapter as the breadth of disease processes that cause obstruction requires a variety of different surgical approaches, including laparoscopic approaches previously believed to be contraindicated [31].

Special Considerations

Formerly, it was a surgical maxim that clinicians should "never let the sun rise or set on a small bowel obstruction" indicating the risk of nonoperative management and the complexities of managing these patients. However, over time, postoperative obstruction and adhesive obstructions have evolved to nonoperative management. Today, obstructions occurring in the early postoperative period can be successfully managed after waiting as long as 7–14 days following an operation. As evidence amasses that bowel obstructions can be managed expectantly, efforts are now focused on identifying which patients are likely to need early surgical intervention. The goal of these efforts is to improve patient care by performing operations in a more timely fashion when they are needed while avoiding prolonged hospital stays and unnecessary laparotomies. Protocolizing care and creating predictive models for patients with obstruction is emerging as a beneficial way to approach these patients, and it is anticipated that positive results will be realized similar to that observed in colorectal, bariatric, transplant, and pancreatic surgical patients. A 2014 series of greater than 200 patients with bowel obstruction identified persistent abdominal pain, abdominal distention, fever at 48 h, and high-grade obstruction on CT scan as predictors of surgical intervention. In this series, the combination of persistent abdominal pain and distention was most predictive of need for surgery, and the authors concluded that a major benefit of protocolized care was decreased length of stay and costs [32]. Similarly, a group of investigators at the University of Florida gave water-soluble contrast to all patients not requiring surgery at the time of admission and followed contrast progression radiographically. They found that this approach led to early identification of patients with complete obstruction requiring exploration and possibly helped to resolve partial obstructions due to the hyperosmolar action of the water-soluble contrast [22] Table 16.1.

Although radiographic studies can be very helpful in the management of patients with bowel obstruction, it must be noted that overreliance on imaging studies can complicate clinical decision making. CT scans are thought by some to overestimate or "overcall" the degree of intestinal obstruction and should not be the sole reason a patient is explored. It is now accepted that patients that present without signs of peritonitis but with a CT scan showing near complete or high-grade obstruction may be managed without operation. This is especially true in patients with adhesive-related obstructive disease, and more than half of patients with high-grade obstruction on CT may be successfully managed nonoperatively. Surprisingly, patients managed in this fashion had shorter lengths of stay compared to those undergoing exploration for CT scan findings alone [34] Patients presenting with obstruction and history of malignancy including primary gastrointestinal cancers

Table 16.1 Use of water-soluble contrast studies for bowel obstruction

Authors/Journal	Year	Study design	Diagnostic utility	Therapeutic utility
Biondo et al. *Br J Surg*	2003	Randomized Adhesive SBO patients	Contrast in colon at 24 h considered PSBO and fed orally	Shorter LOS in contrast group but no reduction in need for OR
Feigin et al. *Am J Surg*	1996	Randomized Postoperative SBO patients	No difference in identifying those that need OR	No difference in time to resolution of symptoms
Onoue et al. *Hepatogastroent*	2002	Observational Adhesive SBO patients	With contrast 96.9 % accuracy at predicting successful nonoperative management	Did not assess
Burge et al. *ANZ J Surg*	2003	Randomized Adhesive SBO	Did not assess	Patients with Gastrografin® with lower LOS, 3 vs. 4 days($p = 0.03$)
Di Saverio et al. *World J Surg*	2008	Randomized Adhesive SBO	Did not assess	Gastrografin® reduced operative rate, time to resolution, LOS
Farid et al. *J Surg Res*	2010	Randomized Adhesive SBO	Gastrografin® a better predictor of need for OR	Gastrografin® reduced operative rate, time to resolution, LOS
Galardi *Am Surg*	2013	Retrospective review Adhesive SBO	Gastrografin® SBFT to OR in 1.0 days versus 3.7 days in those without Gastrografin® SBFT	Gastrografin® with resolution in nonoperative cases at 1.8d versus 4.7d

or possible metastatic disease should be approached with extreme caution. Operations in these patients can be quite perilous and can result in significant morbidity such as enterotomies and enterocutaneous fistulas but can also be highly therapeutic as well. There is a paucity of literature guiding the care of these patients, but a strategy of conservative management with nasogastric decompression, judicious use of narcotics, antiemetics, and antisecretory agents often is successful [35]. It may be desirable to consult palliative care services in order to define goals of care early in the management of these patients to best determine how to maximize quality of life and limit pain and suffering. Generally, patients with recurrent or metastatic malignancy are best managed with resection and primary anastomosis rather than the creation of bypasses or stomas. Patients with diffuse carcinomatosis and malignant obstructions that cannot be resected or opened up surgically should have a gastrostomy tube inserted to decompress the gastrointestinal tract followed by hospice care, but this plan of care needs to be highly individualized.

The advent of acute care surgery services has led to a reduction in time to operative intervention, complication rates, and length of stay for a number of emergency abdominal conditions [36, 37]. Typically, acute care surgeons have added certification in critical care; thus they have a good working knowledge of caring for medically complex and elderly patients which renders them well suited to care for patients with intestinal obstruction. Indeed, the institution of the acute care model has been associated with a reduction in mortality for patients over the age of 80 years requiring emergency abdominal surgery [38]. The reasons for this mortality benefit are likely multifactorial, but prompt exploration for patients with worsening abdominal exams or physiology coupled with enhanced skills when caring for the sickest patients is likely at play. The establishment of acute care surgery registries, especially for vulnerable elderly patients, should help define and refine the optimal care of patients with urgent abdominal conditions.

One final aspect of management that deserves mention is whether narcotic pain medication should be administered or withheld from the elderly patient with intestinal obstruction. While some surgeons think it may obscure physical examination and lead to delays in recognizing the patient with ischemic or strangulated intestine, there is some limited randomized data indicating that this is not the case. Perhaps no one has stated it as eloquently as in the classic text, *Cope's Early Diagnosis of the Acute Abdomen*, which describes the practice of withholding narcotic pain medication as a "cruel practice [that] is to be condemned" [15]. In light of the multitude of nurses, house officers, and now acute care surgeons, caring for these patients coupled with serial examination should allay concerns regarding the use of narcotic pain medication in these patients.

Conclusions

Elderly patients with intestinal obstruction present unique challenges to the surgeon. The breadth of etiologies of obstruction is far greater in the elderly population including common ones such as adhesive bowel disease ranging to distinct entities such as gallstone ileus, colonic volvulus, and colonic pseudo-obstruction. The comorbidities and more limited physiologic reserve of elderly patients should make providers more vigilant for subtle signs of physiologic deterioration; however, the decision for surgical intervention is still largely based on honed clinical acumen. The use of protocols and the emergence of acute care surgery services should continue to be evaluated in a scientific manner, especially in light of the growing numbers of elderly patients presenting with intestinal obstruction.

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Intestinal Hemorrhage in the Elderly

17

Leslie Kobayashi, Todd W. Costantini, and Raul Coimbra

Introduction

- Overall the incidence of intestinal hemorrhage is decreasing.
- The reduction in the incidence of intestinal hemorrhage is primarily due to a decrease in upper gastrointestinal bleeding.
- Elderly patients, particularly those on anticoagulants, are at increased risk of intestinal hemorrhage.
- Mortality due to intestinal hemorrhage is increased among the elderly patients, but has decreased significantly over time.

GI bleeding is a common clinical problem with an overall incidence of approximately 100 cases per 100,000 of the general population [1]. Hospitalization for GI bleeding is a frequent occurrence in the United States. Hospitalization due to upper GI bleeding is more common than lower GI bleeding with an incidence of 60.6/100,000 for upper GI bleeding compared to an incidence of 35.7/100,000 for lower GI bleeding. However over the past decade, the incidence of hospitalizations for upper GI bleeding has been decreasing, while admissions for lower GI bleeding have remained relatively stable [2, 3]. Mortality from GI bleeding is approximately 3 % and has decreased over time [3]. Mortality due to upper GI bleeding tends to be higher than mortality for lower GI bleeding.

The combination of advancing age, comorbid disease, and polypharmacy places the elderly patient at increased risk for GI hemorrhage. Rates of both upper GI bleeding and lower GI bleeding increase significantly with age. The incidence of hospitalization for bleeding from the upper and lower GI tract in patients age > 75 years is 425.2/100,000 and 380.1/100,000, respectively. In addition, older patients are commonly prescribed various medications which may decrease the integrity of their gastrointestinal tract or cause coagulopathy predisposing them to GI bleeding [4]. The widespread use of aspirin for prevention of coronary events has caused an increase in major gastrointestinal bleeding episodes [5]. Elderly patients are also frequently treated with other anticoagulant and antiplatelet medications for several conditions including stroke, atrial fibrillation, and prevention of in-stent thrombosis [6]. Hemorrhage is a major concern in patients who are prescribed these medications, with an incidence of 13.1 episodes of major hemorrhage per 100 patient years during the first year of anticoagulation in individuals older than 80 years. This is compared to an incidence of major hemorrhage of 4.7 per 100 patient years in individuals younger than 80 years [7]. Of particular concern are patients taking the novel oral anticoagulants (NOAs) including thrombin and Factor Xa inhibitors. A meta-analysis of the largest randomized controlled trials of NOAs demonstrated a 25 % increase in GI bleeds compared to warfarin (OR 1.25, CI 1.01–1.55) [8]. This increased risk was confirmed in several other population-based studies [9, 10] and a further meta-analysis of elderly patients (age ≥75 years) on NOAs [11]. The increased risk of GI bleeding appears most pronounced among those older than 75 years and in patients on dabigatran [9, 11].

Mortality due to GI bleeding also increases with age, but remains low overall with a mortality of just over 3 % in patients age 65–84 and 5.2 % in patients over age 85 [12]. Notably, a recent study demonstrated significant reductions in mortality (4.8–3.1 %, $p < 0.001$) due to upper GI bleeding over the past three decades, with the most significant improvements (6.6–3.8 %, $p < 0.001$) occurring in patients over the age of 60 [3]. Pre-hospitalization functional status alters outcomes in elderly patients admitted to the hospital with GI bleeding and may alter treatment strategies in patients who have significant functional impairments. A study by Inouye et al. found that measures of physical and

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cognitive function are strong predictors of 90-day and 2-year mortality in patients age 70 years or older [13]. In addition, among geriatric patients who present with GI bleeding and do not undergo definitive therapy with either angiography or surgery, only a quarter will experience another significant acute GI bleeding event at 4-year follow-up [14, 15]. Therefore, weighing the risks and benefits of aggressive treatment of elderly patients with GI bleeding must take into account comorbid conditions and functional status with low overall mortality and risk of recurrence.

Causes of Gastrointestinal Bleeding

- The differential diagnosis of GI bleeding is broad and requires an organized approach to ensure the prompt diagnosis of the bleeding source (Table 17.1).
- Upper GI bleeding is more common than lower GI bleeding, with the most common causes including peptic ulcers and gastropathy.
- Lower GI bleeding is comparatively more common among the elderly with the most common source being diverticulosis.

Table 17.1 Common causes of gastrointestinal bleeding in the elderly

Upper GI bleeding
Peptic ulcer disease
Gastritis
Esophageal/gastric varices
Mallory-Weiss tear
Boerhaave's syndrome
Malignancy
Lower GI bleeding
Diverticulosis
Angiodysplasia
Malignancy
Inflammatory bowel disease
Ischemic colitis
Infectious colitis
Hemorrhoids
Anal fissure
Solitary rectal ulcer

Upper Gastrointestinal Bleeding

Case Vignette

A 78-year-old female is admitted to the intensive care unit after a motor vehicle collision. She is diagnosed with a subdural hematoma and is intubated due to a low Glasgow Coma Score (GCS). On hospital day 3 she acutely develops bright red, bloody output from her nasogastric tube that is associated with hypotension and tachycardia.

Upper GI bleeding is characterized as bleeding proximal to the ligament of Treitz including the stomach, duodenum, and esophagus. Patients with upper GI bleeding may present with symptoms such as hematemesis (vomiting of fresh, bright red blood, coffee ground emesis) or melena (passage of black or tarry stools). It may also be occult and present with hemoccult positive stools or as a microcytic anemia. Symptoms of upper GI bleeding may include lightheadedness, orthostatic hypotension, and syncope related to blood loss and hypovolemia. Upper GI bleeding is estimated to be five times more common than lower GI bleeding [16]. Mortality from upper GI bleeding has also been shown to increase with age [3, 15].

The most common causes of upper GI bleeding in the elderly are peptic ulcer disease and gastropathy accounting for between 55–80 % of cases [17]. Esophagitis and esophageal/gastric varices account for the majority of the remaining cases of upper GI bleeding in the elderly population. Other causes of upper GI bleeding include esophageal tears due to Boerhaave's syndrome or Mallory-Weiss syndrome, duodenal diverticula, Dieulafoy's ulcers, angiodysplasia, hemobilia, aortoenteric fistulae, and neoplasms. History should focus on prior episodes of peptic ulcer disease, diagnosis or treatment for *Helicobacter pylori*, smoking, alcohol use, previous abdominal surgeries, and steroid use. Liver disease is another key risk factor and may suggest variceal bleeding. Critically ill patients are also prone to upper GI bleeding due to stress gastritis, with patients receiving mechanical ventilation, and those admitted with traumatic brain injury, severe burn, or trauma at significantly increased risk. Medication history including anticoagulants, antiplatelet agents, and recent use of nonsteroidal anti-inflammatory drugs (NSAIDs) should be obtained.

Lower Gastrointestinal Bleeding

Case Vignette

An 84-year-old male on Plavix presents after a syncopal fall. He is found to have sinus tachycardia during your initial evaluation. On exam, he is noted to have guaiac positive stool.

Lower GI bleeding is defined as bleeding from a location distal to the ligament of Treitz. While lower GI bleeding is

less common than upper GI bleeding, there remains a high incidence of lower GI hemorrhage among the elderly. It is important to remember that one of the most common sources of blood per rectum is from the upper GI tract, and therefore, upper GI bleeding should always be considered and ruled out. Obtaining a detailed history of bleeding events is crucial and should include the color and quantity of the blood passed per the rectum. Patients should be queried regarding any previous history of colon malignancy, diverticulosis, and personal or family history of inflammatory bowel disease. Nearly 80 % of patients presenting with lower GI hemorrhage will stop bleeding without intervention; however, the recurrence rate can be as high as 25 % [18]. Similar to upper GI bleeding, mortality in patients with lower GI bleeding has been shown to increase with age [19].

The most common cause of lower GI bleeding is diverticulosis of the colon which is usually characterized by abrupt onset and usually painless hematochezia. Lower GI bleeding is also frequently caused by colonic neoplasms where ulceration of the mucosal surface by the tumor results in bleeding. Bleeding from colonic neoplasms is often more subtle than diverticular bleeding and may lead to slow blood loss over a prolonged period of time. Colitis from infection or ischemia may also lead to lower GI bleeding. Patients with inflammatory bowel disease also frequently experience lower GI bleeding which is associated with bloody diarrhea and crampy abdominal pain. Lastly, angiodysplasia is a common cause of lower GI bleeding, especially in the elderly, accounting for up to 30 % of lower GI bleeding in patients over the age of 65 [20]. Anorectal bleeding should also be considered and may be characterized by bright red bleeding from hemorrhoids, solitary rectal ulcer, or anal fissures.

Obscure Gastrointestinal Bleeding

GI bleeding from a source that is not identified by either colonoscopy or esophagogastroduodenoscopy (EGD) is referred to as obscure GI bleeding. In these cases bleeding may be from a small bowel source or may originate from a source in the upper GI tract or colon that was not visualized during prior diagnostic attempts. While obscure GI bleeding is less common than a defined upper or lower GI source, this cause of bleeding is often challenging to diagnose and treat and may lead to ongoing blood loss with prolonged hospital stays. The most common sources of obscure GI bleeding among the elderly are angioectasias and tumors [21, 22].

Diagnosis

- Endoscopy is the diagnostic and therapeutic intervention of choice for intestinal hemorrhage.
- Angiography is a good alternative to endoscopy for both diagnostic and therapeutic intervention in patients with relatively brisk GI bleeding and is a good, less invasive alternative to surgery in older patients.
- Nuclear scintigraphy, CT enterography, and capsule endoscopy are preferred diagnostic modalities for obscure and slow GI bleeding.

Endoscopy

GI endoscopy, including EGD and colonoscopy, is the diagnostic, as well as therapeutic, procedure of choice for diagnosing GI bleeding. EGD is safe and effective in the elderly population and has been shown to deliver important diagnostic information in over 90 % of patients [4]. Colonoscopy is also effective with similar rates of completion and higher diagnostic yield compared to younger patients. However there is a higher rate of exams limited by poor preparation and a higher rate of complications and perforations in patients ≥80 years [21, 23]. Because the elderly are less likely to tolerate large volume preps and are at higher risk of serious adverse effects such as life-threatening electrolyte abnormalities, severe dehydration, and acute kidney injury, the American Society for Gastrointestinal Endoscopy (ASGE) recommends against the use of sodium phosphate and magnesium-based preps and for the use of a split-dosage balanced polyethylene glycol-based preparation solution [21]. Colonoscopy and EGD generally require conscious sedation to ensure patient comfort and to allow for the technical completion of the study. Although elderly patients tolerate unsedated EGD better than their younger counterparts particularly if using a small caliber scope, sedation is generally well tolerated in the elderly patient and significantly increases test completion [21, 24]. The elderly can be more sensitive to the effects of periprocedural medications, and studies have demonstrated a significantly higher incidence of desaturations in geriatric patients during sedation for endoscopy when compared to younger patients [21, 25]. Because of this the ASGE recommends lower initial doses and slower titration of procedural medications for endoscopy in elderly patients [21]. Elderly patients may also be at increased risk of aspiration during invasive procedures and tolerate such events poorly due to underlying lack of physiologic reserve.

Angiography

Angiography is another useful modality in the diagnosis of GI bleeding. Angiography allows for localization of the bleeding source when the rate of bleeding is as low as 0.5 ml/min.

Diagnostic angiography is available in most medical centers and can be performed via arterial puncture and catheter placement, usually via the femoral artery. Diagnostic angiography is safe and well tolerated with risks including puncture site complications including bleeding, hematoma, and pseudoaneurysm formation. There is also risk of acute kidney injury associated with the administration of iodinated intravenous contrast [26]. In addition to its diagnostic capabilities, angiography also possesses the added benefit of potential therapeutic intervention. Catheter-based interventions including vasopressin injection and angioembolization will be discussed later in this chapter.

Nuclear Medicine

Nuclear scintigraphy can be used to identify the source of GI bleeding and involves Tc-99 m-labeled red blood cells or technetium-99 m (Tc-99 m) sulfur colloid. Radiolabeled red blood cells maintain their activity for longer periods of time compared to injection of Tc-99 m sulfur colloid, allowing for serial imaging, and may give better results when used to diagnose lower GI bleeding. Nuclear scintigraphy is safe, noninvasive, and an accurate method of identifying GI bleeding from any source in the GI tract [27]. The benefits of this imaging technique for detecting GI bleeding include its sensitivity for very slow bleeding, with the ability to detect bleeding rates as low as 0.1 ml/min. Additionally, it is noninvasive [28].

Computed Tomographic Scanning

Contrast-enhanced multidetector-row helical computed tomography (MDCT) scanning is a newer technology which can be used to identify GI bleeding by using the images obtained during the arterial phase to identify extravasation of contrast into the GI tract (Fig. 17.1). Areas concerning on the arterial phase can be further investigated using delayed images to assess for residual contrast, or pooling of contrast, which further supports the presence of active arterial bleeding. Like angiography MDCT appears to be most effective in detecting active or symptomatic GI bleeding; however unlike angiography, MDCT has been reported to detect bleeding rates as low as 0.1 ml/min, similar to that for nuclear scintigraphy [6]. It also has the advantage of being noninvasive, is widely available, avoids the risks associated with arterial puncture required for angiography, and has the added benefit of identifying extraluminal pathology or causes of hemorrhage. However MDCT is associated with risks of IV contrast administration and radiation exposure [27]. Using MDCT to diagnose the source of bleeding may be an efficient method to facilitate directed interventions via either endoscopy or angiography and may improve the ability to localize bleeding and increase the diagnostic and therapeutic yield of angiography [29, 30].

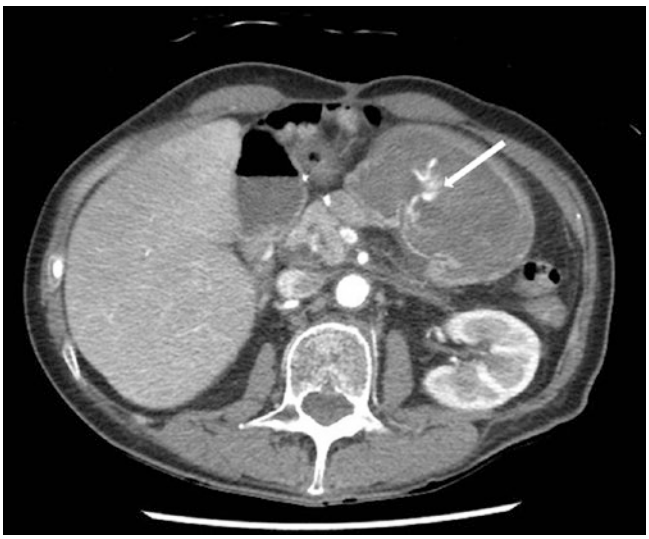

Fig. 17.1 Upper GI bleeding diagnosed by contrast-enhanced computed tomographic (CT) scan. The *arrow* indicates an area of active arterial extravasation seen in the stomach

CT Enterography

As the technology of CT scanning improves, the sensitivity of imaging with the advent of multidetector imaging systems with 64 channels has improved image resolution and introduced more applications for the use of CT scans in the diagnosis of GI bleeding. CT enterography utilizes orally delivered, neutral contrast material that improves the visualization of mucosal pathology. In most CT enterography protocols, oral contrast is given in several doses in 20 min intervals in order to distend the lumen of the intestine. With the neutral background provided by the enterally delivered contrast material, active hemorrhage can be visualized and localized more easily than traditional CT scanning protocols. The delivery of the volume of oral contrast required to perform CT enterography does place elderly patients at risk of aspiration. CT enteroclysis is another option which delivers contrast enterally at a continuous rate via a nasojejunal tube which is placed under fluoroscopic guidance, potentially decreasing the risk of vomiting, reflux, and aspiration [31].

Magnetic Resonance Imaging

The use of magnetic resonance imaging (MRI) in the diagnosis of GI bleeding continues to evolve; however, it is not currently a mainstay of diagnosis for bleeding localization. The

use of MRI for localization of bleeding in occult GI bleeding has shown a diagnostic yield of 40 % with improved localization of pathology in the distal small bowel compared to the proximal small bowel [32]. MRI enterography has low diagnostic yield for identifying intraluminal small bowel bleeding sources causing occult GI bleed; however, this imaging modality has been shown to identify extraintestinal pathology which may aid in the diagnosis of the cause of hemorrhage [33]. Further studies are needed to define the role of MRI in the diagnosis of occult GI bleeding; however, it may be a useful imaging adjunct to consider in patient with bleeding sources not localized by other, more traditional imaging techniques.

Capsule Endoscopy

Improvements in technology have allowed for the more widespread use of capsule endoscopy for the diagnosis of GI bleeding. The capsule, which is the size of a large pill, is swallowed and travels the entire length of the GI tract through peristalsis. Capsule endoscopy is especially useful in identifying obscure sources of GI bleeding and can allow visualization of the small intestine with imaging completed to the cecum in nearly 75 % of cases [34]. Capsule endoscopy is a purely diagnostic test with a yield near 50 % but does not allow for intervention [35–37]. Clinical studies evaluating the effectiveness of capsule endoscopy for obscure GI bleeding have shown a diagnostic yield between 30 and 69 %; however diagnostic yield increases with increasing age and is highest in patients ≥85 years [22, 38–40]. Most likely the higher diagnostic yield is due to a higher incidence of pathology in elderly patients, with the most common lesion found being angioectasia [21, 22]. The test is well tolerated and safe, with retained capsule representing the most significant risk associated with this procedure [41, 42].

Management

- Management of the elderly patient with GI bleeding should include appropriate invasive and noninvasive hemodynamic monitoring and fluid resuscitation.
- Aspiration precautions should be enacted and consideration given to early and/or prophylactic intubation.
- Careful medication history should be taken with attention paid to antiplatelet and anticoagulant medications.
- Assessment of coagulopathy should be performed, and any abnormalities corrected with platelet and plasma transfusions, adjuncts such as prothrombin complex concentrates, and tranexamic acid can be considered.
- Endoscopy is the preferred diagnostic and treatment modality for intestinal hemorrhage in the elderly, with excellent efficacy and safety.

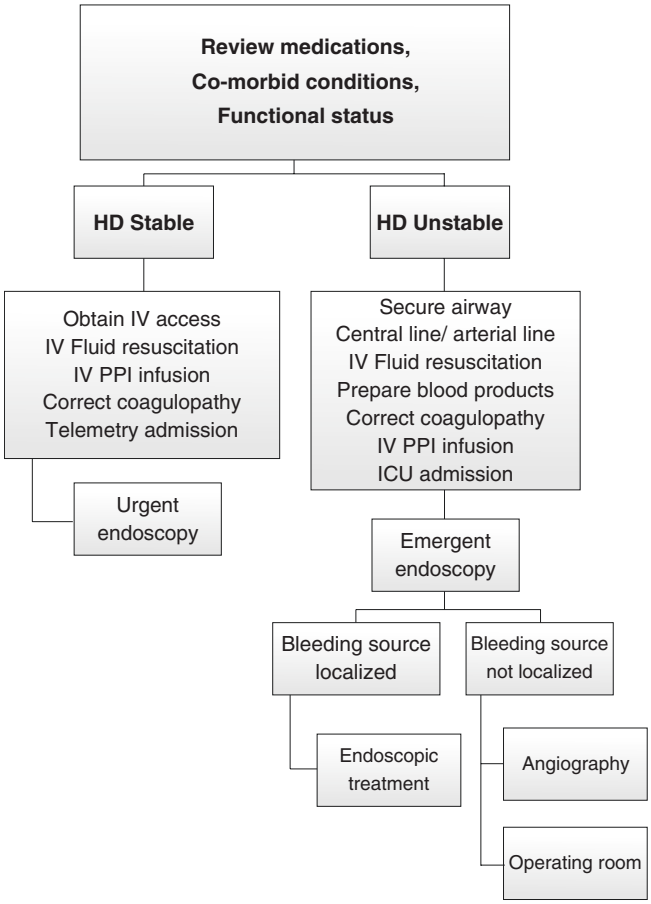

Fig. 17.2 Algorithm for the management of upper GI bleeding

- Complications, in particular perforation during colonoscopy, are more common in elderly patients and should be kept in mind during procedures and during post-procedural monitoring.
- In patients where endoscopy has failed to control hemorrhage, angiography and surgery can be considered. Angiography is less invasive and associated with lower rates of complications and so may be more attractive for frail elderly patients; however it is also associated with higher rates of rebleeding.
- Treatment algorithms for the diagnosis and treatment of patients with upper and lower GI bleeds are shown in Figs. 17.2 and 17.3.

Initial Evaluation

As with any acute illness associated with blood loss, the initial assessment of GI bleeding should include evaluation of the airway, breathing, and circulation. The patient should be evaluated in the appropriate level of care with frequent monitoring of vital signs. Patients should have two large bore IVs placed for transfusion of blood or IV fluids as needed. The

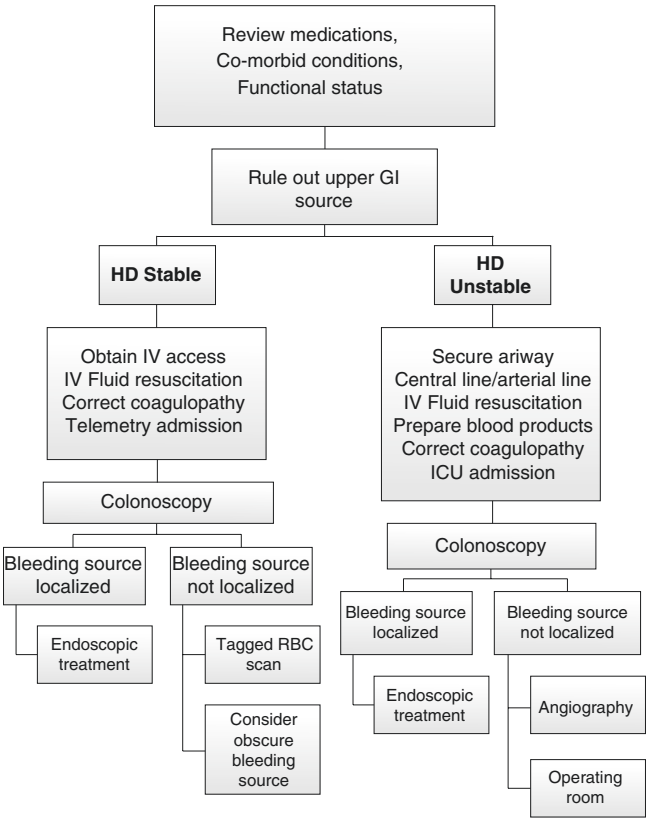

Fig. 17.3 Algorithm for the management of lower GI bleeding

primary treatment goals in patients with suspected GI bleeding include adequate resuscitation, diagnosis of the cause of GI bleeding, localization of bleeding, and treatment of the bleeding source with endoscopy, angiography, or surgery. A nasogastric tube may be placed and saline lavage performed to give some insight as to whether the bleeding is originating from an upper GI source. A Foley catheter should be placed to monitor urine output and assess the response to fluid resuscitation. If the index of suspicion is high for an upper GI source of bleeding, high-dose proton pump inhibitor infusion therapy should be initiated.

Aspiration Risk in Elderly

Elderly patients who are hospitalized with GI bleeding have been shown to experience complications early in their hospital course, frequently within 96 h of admission [43]. Among the most frequent complications in the elderly are pneumonia and aspiration [17]. Therefore, airway protection and pulmonary toilet are of significant importance during the resuscitation and hospitalization of patients with GI bleeding.

All patients should be administered supplemental oxygen and the head of bed should remain elevated at all times. Supplemental oxygen by nasal cannula is an important adjunct at the time of endoscopy as it has been shown to prevent hypoxemia, oxygen desaturation, and cardiac arrhythmias [44]. Consideration should be given to early, prophylactic intubation in order to secure the airway and limit the risk of aspiration. This is especially true in patients undergoing endoscopy who will be receiving conscious sedation. Elderly patients generally require lower doses of benzodiazepine sedative medications than their younger counterparts [21, 45]. Elderly patients may experience unexpected respiratory arrest that may necessitate emergent endotracheal intubation further increasing the risk of aspiration. Elderly patients may also experience paradoxic reactions to conscious sedation which may result in altered mental status making endoscopic interventions difficult [15]. Current guidelines from the ASGE recommend heightened attention to the dose and effects of standard sedatives used during endoscopy on the elderly and emphasize the importance of lower initial doses of sedatives with more gradual titration [21].

Fluid Resuscitation

Normal saline and lactated Ringer's are the most common resuscitation fluids used in the treatment of hypovolemic shock. Studies comparing the use of normal saline and lactated Ringer's in patients with acute hemorrhage show equivalent outcomes [23, 46]. There is a theoretical risk of hyperkalemia with the use of lactated Ringer's which may be exacerbated in patients with acute kidney injury or chronic renal insufficiency seen in many elderly patients. Resuscitation with colloids has theoretical benefits over crystalloid resuscitation due to its ability to restore intravascular volume more efficiently due to the higher oncotic pressure resulting in decreased losses into the extravascular space. This may be beneficial in elderly patients as colloid resuscitation may allow for lower total infusion volume required to restore perfusion pressure. Unfortunately several studies have been performed to compare crystalloid versus colloid resuscitation showing no clear statistical benefit in patients receiving colloid resuscitation [47, 48]. A large randomized controlled trial compared 3497 patients who received 4 % albumin to 3500 patients receiving normal saline [24]. This study found no significant difference in mortality, need for renal replacement therapy, or hospital length of stay suggesting no benefit in the use of colloid resuscitation compared to crystalloid resuscitation.

Recent research from the trauma population suggests that early transfusion of blood products may be beneficial in patients with acute hemorrhage. Not only does early transfusion of packed red blood cells (PRBCs) appear to be superior to crystalloid resuscitation in patients with hemorrhage, but the transfusion of other blood components may be beneficial

as well. Studies suggest that transfusion of fresh frozen plasma (FFP) and platelets in addition to PRBCs may decrease mortality [18]. The optimal transfusion strategy appears to be a 1:1 ratio of FFP to PRBCs [27]. Studies also suggest that increasing the ratio of platelets to PRBCs may be beneficial as well [49].

Medications

Elderly patients who are diagnosed with GI bleeding should be queried regarding their current medication regimen with particular focus on antiplatelet and anticoagulant medications. Laboratory studies including complete blood count, PT/INR, and PTT should be measured to diagnose any derangements in the clotting cascade. Classical measures of coagulopathy may not address all coagulation abnormalities and thus may fail to correctly diagnose coagulopathy. The classical measures fail to measure platelet dysfunction due to medications or fibrinolysis. Limitations of these traditional laboratory measures of coagulopathy have led to increased interest in the use of alternative measures of coagulation, clot strength, and fibrinolysis. Thromboelastography (TEG) and thromboelastometry (ROTEM) are an established method for measuring the viscoelastic properties of blood for hemostasis testing [12, 20, 32]. TEG/ROTEM has the benefit of providing detailed information on clot formation and clot strength and provides results more rapidly than conventional measures of coagulation.

Treatment with fresh frozen plasma (FFP) is a common method used to reverse anticoagulation in patients taking Coumadin. FFP is effective; however it takes time to transfuse and may require the infusion of large volumes of fluid in order to correct the INR. In elderly patients who are actively bleeding, strategies need to be considered that more rapidly correct the coagulopathy and prevent large volume infusions that may be problematic in patients with comorbid disease such as congestive heart failure. Pharmacologic agents such as Factor VIIa and prothrombin complex concentrates (PCC) should be considered as they result in rapid correction of the clotting abnormality and require minimal volume infusion.

Recombinant Factor VIIa has traditionally been used as a treatment for uncontrolled bleeding in patients with hemophilia. It has been used to treat GI bleeding in patients with liver disease and in the treatment of trauma-induced coagulopathy [31, 33]. Randomized control trials have failed to show improvements in mortality in cirrhotic patients with acute upper GI bleeding compared with placebo [50, 51]. There are case reports which suggest that recombinant Factor VIIa may be a useful strategy in elderly patients with GI bleeding who are poor candidates for aggressive intervention; however, there are concerns regarding increased thromboembolic complications, particularly those affecting the arterial circulation; further randomized controlled trials are needed to further define its role in treating acute GI bleeding in the elderly [52]. Several studies have compared the use of PCC to FFP and vitamin K for reversal of coagulopathy following injury or in anticipation invasive procedures. These studies have concluded that PCC corrected the INR more quickly and effectively than the combination of FFP and vitamin K. Because of these studies, several guidelines advocating the use of PCCs to reverse coagulopathy in cases of acute bleeding have been published. A study of patients with life-threatening hemorrhage, including GI bleeding (32 %), studied adherence to these guidelines and found that adherence to guidelines for PCC reversal (PCC ≥20 IU/kg +vitamin K dose ≥5 mg within 8 hrs) resulted in a two-fold decrease in 7-day mortality [53]. A further study comparing PCC to FFP for reversal of warfarin in patients with GI bleeding found a greater reduction in INR, reduced active bleeding, and a decrease in the need for invasive procedures in the PCC group [54]. Further studies are needed assess safety and to better define the role of PCC in the treatment of elderly patients with GI bleeding, but it should be part of the armamentarium in the treatment of bleeding patients.

Patients on antiplatelet medications such as clopidogrel (Plavix), and to a lesser degree aspirin, experience alterations in the platelet function that may cause coagulopathy in the acutely bleeding patients. Point of care testing is available to determine the degree of platelet inhibition caused by clopidogrel, which can vary significantly among patients [43]. Treatment with platelet transfusion can be considered in bleeding patients with pharmacologically induced platelet inhibition despite normal platelet counts.

While Coumadin therapy increases the INR, which allows for a quantification of the clotting abnormality, newer antithrombotic medications may not cause any changes in basic laboratory measures even when fully therapeutically anticoagulated. Medications such as dabigatran (Pradaxa) and other new direct thrombin inhibitors have effects that cannot be measured by conventional clinical laboratory assays, and TEG/ROTEM are required to detect their effects. These agents also do not have any means of reversal, making management of patients with GI bleeding taking these agents difficult. Patients with significant bleeding may require hemodialysis to remove the medications and restore normal coagulation [44].

Endoscopy

Endoscopy is the primary diagnostic and treatment modality for both upper and lower GI bleeding. Endoscopy is generally a safe and well-tolerated procedure; however, mortality associated with EGD is increased when performed for hemorrhage with a mortality rate of 0.1 % [55]. Once the bleeding

source is diagnosed, therapeutic maneuvers can be immediately implemented including placement of hemoclips, thermocoagulation, argon beam coagulation, injection of epinephrine, or placement of rubber bands across varices. Certain endoscopic findings are associated with increased risk of rebleeding including active pulsatile bleeding or the presence of a visible vessel within the base of an ulcer. Timing of upper GI endoscopy for non-variceal bleeding has been investigated; evidence suggests that EGD should be performed in an urgent though not emergent fashion. Multiple studies demonstrate that endoscopy within the first 24 h of admission is safe and more urgent endoscopy within the first 6 h of admission offers no additional benefit [56, 57].

Complication rates associated with colonoscopy are generally less than 3 %, and it has high diagnostic utility in identifying a source of LGIB. There is no consensus on the optimal timing for colonoscopic examination; however, recent studies suggest that early intervention may be beneficial. Colonoscopy performed within the first 24 h of admission has been shown to provide a definitive diagnosis in up to 96 % of patients [58]. Adequate visualization during colonoscopy requires adequate bowel preparation which has been shown to be safe and effective during acute GI bleeding [55, 59]. Similar to upper GI endoscopy, colonoscopy allows the opportunity to treat bleeding sites using mechanical clipping, electrical coagulation, or injection of epinephrine. Even if bleeding cannot be treated endoscopically, the bleeding site can be localized and marked to facilitate other intervention. Clips left at the time of endoscopy may help localize the bleeding site during angiographic intervention. Placement of an ink tattoo at the time of colonoscopy can also be used to localize the site of bleeding if operative intervention is required.

While colonoscopy is a safe procedure, elderly patients are at increased risk of complications. A systematic review of adverse events in elderly patients undergoing colonoscopy found that octogenarians have a high risk of complications with 28.9 cardiovascular and pulmonary complications per 1000 scopes compared to 19.1 cardiovascular and pulmonary complication per 1000 scopes in patients 65 years of age and older [60].

Angiography

Once bleeding is localized using digital subtraction angiography, treatment can be performed using transcatheter arterial embolization. Arterial embolization for acute GI bleeding is highly effective with bleeding controlled in 80–90 % of patients [61, 62]. Recurrent hemorrhage after angiographic embolization is infrequent, with higher rates of rebleeding in patients with angiodysplasia and arteriovenous malformation. Recurrent bleeding episodes can be evaluated with repeat angiography and further embolization if needed. Risks of arterial embolization include bowel ischemia which may result in ulceration, necrosis, or perforation. Bowel ischemia is a rare event after embolization with an incidence of less than 5 % in most series [60, 63]. Contrast-induced nephropathy causing acute kidney injury (AKI) is also a concern after diagnostic and therapeutic angiography with rates ranging between 2 and 25 % [64]. Risk factors for contrast-induced AKI include diabetes mellitus, congestive heart failure, and dehydration prior to the procedure which is a frequent occurrence among patients with acute hemorrhage [65]. Interventions to reduce contrast-induced nephropathy have been investigated including acetylcysteine and bicarbonate fluid hydration. Acetylcysteine has been shown to provide minimal protection from acute kidney injury after contrast administration in multiple randomized control trials [66–68]. Bolus infusion of sodium bicarbonate in addition to standard hydration may decrease contrast-induced nephropathy compared to standard hydration alone [37, 69]. Clearly, aggressive fluid rehydration should be performed prior to angiographic intervention and the delivery of contrast in order to limit the risk of contrast-induced acute kidney injury.

Catheter-directed infusion therapy may be used to treat bleeding in locations where arterial embolization is not ideal. Vasopressin causes constriction of the arterial wall and reduces blood flow at the site of bleeding which may provide more beneficial conditions to allow clot formation. While catheter-directed vasopressin infusion is effective in controlling bleeding, rebleeding rates reach 50 % [70, 71]. Vasopressin is often not an ideal treatment in the elderly as it is generally discouraged in patients with severe coronary artery disease or cardiac arrhythmias and may also cause bowel ischemia.

Surgery

Attempts to stop hemorrhage from an upper GI source using endoscopy or angiography may be unsuccessful, or bleeding rapid enough, that surgery is required. Surgical interventions for upper GI bleeding are met with high morbidity and mortality, especially in the elderly [67]. If bleeding is suspected from a gastric source, an anterior gastrotomy can be performed with identification and ligation of the bleeding source. Rarely, in cases of unlocalized hemorrhage, gastric devascularization can be performed. In this procedure, the blood supply to the stomach is ligated with the exception of the short gastric vessels.

Upper GI bleeding from a duodenal source is most commonly due to posterior ulcers in the first portion of the duodenum. Surgical treatment options for these lesions include anterior duodenotomy with oversewing of the bleeding vessel versus oversewing of the bleeding vessel with definitive antiulcer operation, most commonly truncal vagotomy with

pyloroplasty. Simple oversewing of the bleeding ulcer is recommended in the hemodynamically unstable or those with multiple medical comorbidities.

If nonsurgical means of stopping lower GI bleeding fail, surgery may be needed to control hemorrhage and remove the involved segment. Criteria for emergent bowel resection for bleeding include 4–6 units of blood transfusion in a 24 h period, ongoing hemodynamic instability, and/or the inability to stop bleeding by endoscopic or angiographic means. For lower GI bleeds, subtotal colectomy may be required if the location of bleeding cannot be localized. Mortality rates in patients undergoing subtotal colectomy remain high, ranging from 20 to 35 % [72, 73]. Segmental colon resection is preferred in order to preserve colon length and is associated with decreased mortality compared to subtotal colectomy. Segmental colon resection requires that the bleeding source has been localized thus ensuring that the cause of hemorrhage will be resected. Despite preoperative angiographic localization of the bleeding source, there is a risk for rebleeding after hemicolectomy that requires repeat operation for completion subtotal colectomy [74]. Operative risks are also determined by the preoperative functional status of the patients. A review of a large Medicare database demonstrated that nursing home patients experience substantially higher mortality rates after colectomy, with 32 % mortality in elderly patients who are institutionalized compared with 13 % mortality in their non-institutionalized counterparts [66].

Summary

Gastrointestinal hemorrhage is a common problem in the elderly that results in frequent hospitalization and places this population of patients at risk for significant morbidity and mortality. Clinicians must consider the patient's comorbid conditions, medication usage, and functional status when diagnosing and treating GI bleeding in the geriatric patient. Special attention should be given for the potential coagulopathy that may exist in the elderly patient taking anticoagulant or antiplatelet medications. The management of GI bleeding often requires a multidisciplinary approach including the emergency room physician, acute care surgeon, gastroenterologist, and radiologist. While endoscopy remains a mainstay in the management of GI bleeding, the clinician should be familiar with the various diagnostic and treatment modalities available to diagnose and treat upper, lower, and obscure GI bleeding.

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Acute Abdomen

18

David A. Spain

Acute Abdomen

Abdominal pain is one of the most common chief complaints for patients presenting for emergency medical care, regardless of age [1]. Older patients tend to present to medical attention in a more delayed fashion. For appendicitis and other intra-abdominal infections, the average duration of symptoms prior to presentation is 1–5 days longer in elderly patients compared to younger patients [2, 3].

Perhaps because of the tendency toward later presentation and the presence of comorbidities, older patients tend to have higher acuity of disease compared to younger patients with similar complaints and diagnoses. Up to 60 % of geriatric patients with acute abdominal pain require hospital admission, 10–30 % will require an operation or invasive procedure, and ultimately, the mortality rate is 5–8 %. The rates of admission and invasive intervention are roughly twice as high as those for younger patients with similar presentations, and the mortality rate is as much as five- or tenfold higher [4–7]. Accurately determining the diagnosis and the need for an operation in a timely fashion is both important and challenging in this patient population.

History and Physical Exam

A careful and complete history is fundamental to the evaluation of the acute abdomen. Unfortunately, geriatric patients presenting with acute abdominal symptoms often have nonspecific abdominal pain, leading to diagnostic inaccuracy that increases with age [6, 7]. Memory loss, with or without dementia, affects 3–8 % of the elderly population, which can present a significant obstacle to obtaining an accurate history [8, 9]. Furthermore, 25–45 % of elderly patients have significant hearing loss that can impair speech recognition in noisy settings such as the emergency department [10].

The presence of a family member, caretaker, or close friend can be invaluable in providing the history, clarifying the timeline or sequence of events, and to establish the patient's baseline level of function prior to the onset of acute illness.

Open-ended questions often provide a more accurate story than closed-ended questions, which tends to confirm the preconceived notions of the medical team. The time course, location, quality, and radiation of pain should be established, along with any inciting or exacerbating factors such as positioning, movement, or coughing. Changes in the location or intensity of pain are important clues.

Associated symptoms including fevers, chills, nausea, vomiting, or changes in bowel or bladder habits should be elicited. The onset and quality of the vomitus may indicate the level of obstruction, be it distal or proximal. The frequency, consistency, and color of bowel movements may indicate obstruction, inflammation, or bleeding.

The majority of elderly patients have at least one comorbid condition that complicates their acute abdominal pain, and a careful review of cardiac and respiratory symptoms may help to identify important nonsurgical causes of acute abdominal pain such as pneumonia or myocardial infarction [3, 11]. Urinary symptoms should also be elicited, and postmenopausal bleeding is always significant and concerning for malignancy.

Previous operations and their indications should be well documented. Medications should be reviewed, paying particular attention to anticoagulants, antihypertensives, NSAIDs, steroids, antimicrobials, and immunosuppressants. The majority of elderly patients are taking at least one long-term medication, and the addition of a new medication has the potential to cause adverse drug reactions. Many of these reactions are gastrointestinal in nature and can mimic acute

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intra-abdominal pathology [12, 13]. Age-appropriate cancer screening study results should be reviewed.

Important aspects of the physical exam can be obtained, while the history is taken. The overall appearance of the patient, whether ill-appearing or obvious distressed, is crucial. Observations about the patient's dress, grooming, or hygiene can be proxies for overall care access to medical attention and elder abuse. The patient's habitus and the presence of cachexia are important indicators of nutrition and the ability to withstand a surgical intervention. The quality and rate of the pulse, skin turgor, and capillary refill time can provide important clues about systemic toxicity and overall volume status. The presence of fever is important, as many elderly patients with an acute surgical disease do mount a febrile response [14].

One major contributor to difficulties in diagnosis is the high prevalence of cognitive impairment present in this patient population. Although definitions of cognitive impairment vary, 20 % of elderly patients have some impairment in language, visuospatial awareness, or attention that can impair the examiner's ability to elicit physical examination findings [9, 15]. Nonverbal signs of pain or tenderness such as wincing, grimacing, changes in breathing patterns, or tensing of the abdominal wall musculature take on a greater importance for patients who may not be able to communicate directly.

The sclera should be inspected for jaundice, and detection of conjunctival pallor can be a rapid way to screen for profound anemia. The mucous membranes of the face should be inspected for color and moisture. Neck masses and lymphadenopathy are important findings that can be associated with infection or malignancy.

The lung fields should be auscultated carefully to find signs of pneumonia or pleural effusions that sometimes mimic or accompany intra-abdominal pathology. The heart sounds should be auscultated carefully, as pericarditis and heart failure can both be present with abdominal pain. The flanks should be palpated and percussed for costovertebral angle tenderness as a sign of nephrolithiasis or upper urinary tract infection.

The abdomen is best examined from the patient's right side, with the patient in the supine position and arms down at the sides. Having the patient flex both knees may allow for better relaxation of the abdominal wall and less guarding. The abdomen is inspected for distention and any obvious lesions or hernias. The stigmata of liver disease such as jaundice, spider angiomas, and caput medusae should be noted. The auscultation of high-pitched bowel sounds can occasionally be helpful in cases of suspected bowel obstruction.

When examining a tender abdomen, the goal is to elicit sufficient information without causing undue pain or discomfort. Asking the patient to cough prior to palpation may cause localized abdominal tenderness as a sign of peritoneal irritation. All four quadrants should be palpated, beginning in a quadrant away from the site of pain and starting with gentle palpation and moving to deeper palpation as tolerated by the patient. Exquisite tenderness to percussion or light palpation signifies peritonitis, which does not need to be verified by deeper palpation. Assessing rebound in a patient when localized or generalized peritonitis has already been established is unnecessary, and only serves to distract the patient, thereby decreasing the sensitivity of other aspects of physical examination. Voluntary guarding, involuntary guarding, and "washboard" rigidity signify increasing degrees of visceral and parietal peritonitis. Obvious masses should be noted. Dullness to percussion or a palpable fluid wave signifies ascites that may be associated with liver disease, heart disease, malnutrition, or malignancy.

The digital rectal examination is a fundamental part of the evaluation and should not be omitted. The presence of rectal masses, tenderness, blood, and the presence and quality of stool in the rectal vault are all important clues.

In men, the genitalia and scrotum should be examined for hernias, torsion, and epididymitis. In women, a pelvic examination may be required to evaluate for adnexal masses, tenderness, or signs of a pelvic wall or floor hernia.

The pulse exam including palpation of each extremity and abdominal pulsations is important to detect signs of vascular insufficiency and aneurysm related to mesenteric ischemia or abdominal aortic aneurysm disease as causes of acute abdominal pain. Peripheral edema can be a sign of venous occlusion or fluid overload.

Laboratory Analyses

Although laboratory analyses do not differentiate between surgical and nonsurgical causes of abdominal pain in elderly patients, routine evaluation should include a complete blood count, serum chemistries, liver function tests, serum amylase and/or lipase, and a urinalysis [16]. In general, most laboratory values in healthy elderly patients fall into the same reference ranges as younger patients [17–19].

The presence of leukocytosis can signify inflammation, infection, or malignancy. Hints to the chronicity and cause of anemia detected in the blood count can be found in the mean corpuscular volume, which may be microcytic in anemia of iron deficiency or chronic disease, or macrocytic in the setting of liver disease or malnutrition. Thrombocytopenia is a sensitive marker of portal hypertension.

Assessment of renal function including serum urea nitrogen (BUN) and serum creatinine is important for elderly patients with abdominal complaints. In addition to the azotemia from any fluid losses during acute illness, these patients may have underlying chronic kidney insufficiency.

Furthermore, many patients with abdominal pain will undergo intravenous iodinated contrast injection for CT scanning, and an assessment of renal function is important to stratify risk for contrast nephropathy.

Measurement of electrolytes is important for patients who have had fluid losses from vomiting or diarrhea. Elderly patients taking diuretics also have a tendency to have electrolyte abnormalities even when healthy [19]. Glucose measurement may detect hypoglycemia from lack of oral intake and be compounded by hypoglycemic therapy or hyperglycemia from diabetic ketoacidosis (DKA) or hyperosmolar nonketotic coma (HONC) as causes of nonsurgical abdominal pain. Liver function tests are useful when liver or biliary disease is suspected. The measurement of serum amylase and/or lipase is mandatory if pancreatitis is a possibility.

Although elderly patients have a high incidence of malignancy, the measurement of serum tumor markers to screen for various cancers in patients with acute abdominal pain is costly, untimely, and unlikely to provide any useful information during the initial evaluation.

Diagnostic Imaging

Ideally, an imaging test is ordered to evaluate the diagnostic hypotheses generated by the history, physical exam, and laboratory analyses. Although advances in imaging technology continue to provide greater resolution, no radiographic test provides perfect diagnostic information for abdominal pain. Instead, the clinician's must deal with probabilities and likelihoods, where the pretest probability of having a particular disease is modified by the likelihood ratio of the chosen imaging test result, which gives the posttest probability of having confirmed that particular diagnosis. Accordingly, the choice of imaging for each case depends on the performance of each imaging test to provide a high (or low) likelihood ratio in that particular situation.

The acute abdominal radiograph series is an inexpensive, widely available, and low-risk test for acute abdominal pain. Generally, this test involves acquiring an upright chest radiograph, an upright abdominal radiograph, and a supine abdominal radiograph. If the patient cannot tolerate standing upright, then a lateral decubitus or supine cross-table radiograph may be substituted. The chest radiograph can evaluate for acute cardiopulmonary disease such as pneumonia but, more importantly, is considered the most sensitive plain radiograph for the detection of pneumoperitoneum, i.e., free air. While plain abdominal radiographs may demonstrate foreign bodies and bowel obstruction as well as evidence of volvulus, bowel ischemia, and stones, they are generally insensitive for diagnosing acute abdominal pathology [20].

Abdominal ultrasound continues to be the test of choice for evaluating right upper quadrant pain [21, 22]. Although this modality is somewhat dependent on operator skill and experience, ultrasound is a sensitive test for evaluating for gallstones and acute cholecystitis. While elderly patients do tend to have larger caliber extrahepatic bile ducts on ultrasound, the vast majority of elderly patients without biliary disease have calibers below 6–7 mm, the generally accepted upper range of normal [23, 24]. Abdominal ultrasound can also demonstrate perinephric fluid collections or hydronephrosis associated with urinary tract pathology. The use of abdominal ultrasonography in the diagnosis of acute appendicitis in adults is controversial, and further study is needed, especially in the elderly population. Ultrasound is very accurate in the diagnosis of abdominal aortic aneurysms [25].

In elderly female patients with pelvic complaints, transvaginal ultrasound is an efficient modality that does not involve contrast injection or ionizing radiation. Although diagnoses such as ectopic pregnancy and pelvic inflammatory disease are not concerns in the elderly population, transvaginal ultrasound is sensitive for the detection of endometrial cancer and adnexal masses, both benign and malignant [26, 27].

Computed tomography (CT) scanning is relatively fast, widely available, and has been shown to be helpful in the diagnosis of a wide variety of diseases in patients with acute abdominal pain [28]. In elderly patients with acute abdominal pain where accurate diagnosis can be challenging, CT has been shown to alter clinical decision-making in a significant portion of cases [29]. CT also provides spatial anatomic information that may be useful to surgeons or other interventionalists. CT does require exposure to ionizing radiation and the risk for the induction of malignancy, although this risk is lower for older patients whose postexposure lifetimes are generally shorter. Although non-contrast CT scans do provide some diagnostic information, the utility of CT is greatly augmented by the administration of intravenous radiocontrast during the examination. Acute kidney injury from contrast administration continues to be an important complication of CT examinations, and advanced age has been associated with increased risk, independent of other known risk factors such as renal insufficiency, diabetes mellitus, and cardiovascular disease [30]. Therefore, before intravenous contrast is given, the potential benefit of the examination should be assessed along with the risk of contrast nephropathy and the possible need for incorporation of prevention strategies.

Although magnetic resonance imaging (MRI) has been found to be accurate in the diagnosis of acute appendicitis, diverticulitis, acute cholecystitis, and acute pancreatitis [31], it is not widely available, and utility of MR in acute abdominal pain is limited by lengthy examination times and higher cost compared to CT.

Differential Diagnosis

When caring for a patient with acute abdominal pain, the most important question is whether or not the patient requires an urgent operation. If hemodynamic instability, generalized peritonitis, or clinical deterioration is present, the safest course of action is often to proceed directly to the operating room or surgical intensive care unit under the care of a surgical team. With few exceptions, if a patient presents in extremis with acute abdominal pain, they suffer from one of a few catastrophes: ruptured abdominal aortic aneurysm, severe pancreatitis, bowel infarction, or sepsis from some uncontrolled source of infection such as cholangitis or urosepsis. In this situation, information is often limited, and the task is to determine rapidly the most likely cause and proceed as quickly as possible with stabilization and definitive treatment. In this situation, further efforts to diagnose the patient more accurately or thoroughly in the emergency department serve only to delay the potentially life-saving intervention that is required.

If the patient with acute abdominal pain is hemodynamically stable and peritonitis is absent, then there is time to review all relevant clinical information and develop a differential diagnosis. Here, the location and nature of pain are particularly helpful. In general, the differential for acute abdominal pain in the elderly patient will not differ significantly from that of a younger patient, although certain diagnoses such as ectopic pregnancy are not encountered in elderly patients.

In comparison to generalized peritonitis where late-stage inflammation is usually related to a perforated hollow viscus, the cardinal presentation of localized pain and tenderness provides some information about which viscera are diseased. Furthermore, observational studies of elderly patients presenting with acute abdominal pain have described the most common diagnoses in this cohort [4, 6, 11, 32–34]. Among causes of right upper quadrant pain and tenderness, biliary colic, acute cholecystitis, and cholangitis are most common. Right lower quadrant findings suggest acute appendicitis or an unusual presentation of diverticulitis. Left lower quadrant pain and tenderness would be a more usual presentation of diverticulitis. Epigastric pain and tenderness invoke peptic ulcer disease or pancreatitis. Suprapubic or flank findings suggest a urinary source such as infection or stone disease, which are both quite common in the elderly population [6].

The cardinal presentation of distention, nausea, and vomiting suggests bowel obstruction. When accompanied by colicky pain, small bowel obstruction would be most common, due to incarcerated hernia, adhesions, or malignancy [32, 33]. When distention is more prominent than pain, large bowel obstruction from diverticular disease, malignancy, volvulus, and constipation are most common [32, 33].

Given the higher rates of malignancy for elderly patients and the significant rates of malignancy in elderly patients presenting with abdominal pain, cancer should always be considered as a possibility [11, 32, 34].

Important nonsurgical causes of abdominal pain include myocardial infarction, pulmonary embolism, pneumonia, toxic ingestion, and drug or alcohol withdrawal.

Pitfalls

The term “nonspecific abdominal pain” should be used with caution. Especially in the elderly patient, the absence of a diagnosis does not indicate that a life-threatening process does not exist. Important causes of abdominal pain tend to progress with time, and a period of observation with careful reexamination is prudent for any elderly patient who presents with acute abdominal pain. The observation period allows for the integration of serial physical examinations and follow-up laboratory or imaging data either to make an accurate diagnosis or to decide that the patient requires an urgent intervention. However, this decision-making period should be time limited (approximately 6–8 h) and not indefinite as delays to operations more than 24 h lead to significant increase in complications [35].

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Necrotizing Soft Tissue Infections

19

D. Dante Yeh and George Velmahos

Epidemiology

History

> Many were attacked by the erysipelas all over the body when the exciting cause was a trivial accident or a very small wound… Flesh, sinews, and bone fell away in large quantities. The flux which formed was not like pus but a different sort of putrefaction…Fever was sometimes present and sometimes absent… there were many deaths. The course of the disease was the same to whatever part of the body it spread… The most dangerous cases of all such cases were when the pubes and genital organs were attacked. [1] – Hippocrates (circa 500 BC)

Since its first description in antiquity, man has been afflicted by aggressive soft tissue infections arising from seemingly trivial wounds or often without any provocation. Centuries later, Ambroise Paré (1510–1590) reported that "there can happen no greater than a Gangreene, as that which may cause the mortification and death of the part, and oft times the whole body… mortification and death of the part, which it feafth upon, dying little by little" [2]. The first descriptions in English are credited to Leonard Gillespie, Sir Gilbert Blane, and Thomas Trotter (a British naval surgeon and two British naval physicians, respectively) in the late eighteenth century [3, 4]. In the United States, Joseph Jones, a Confederate medical officer in the American Civil War, first published in 1871 a report describing "hospital gangrene." [5, 6]. Jones, authorized by the United States Sanitary Commission, described 2,642 cases with a mortality rate of 46 % [5]. Meleney, reporting on 20 cases in China, is credited with establishing streptococcus as the major etiologic agent in 1924. His description of the deadly disease remains relevant almost a century later:

> The disease is characterized by its alarmingly rapid development….the affect member becomes greatly swollen, hot, red and tender, with symptoms and signs of acute inflammation spreading rapidly both proximally and distally from the original focus… As the part swells, the stiffness, pain and increased weight rend it quite useless. In some cases, the pain of onset is replaced by a numbness, which later develops into a complete anesthesia for the affected portion… blisters and bullae begin to form… sometimes the area of skin necrosis is very small, while the subcutaneous gangrene is very extensive… in other cases, the extent of the subcutaneous necrosis is not recognized until an incision is made… the process continues to advance rapidly until several large areas of skin have become gangrenous, and the intoxication renders the patient dull [7].

The term "necrotizing fasciitis" was first coined by Wilson in 1952 and referred to both gas-forming and non-gas-forming infections. In the 1990s, the term "flesh-eating bacteria" was popularized by the media. Various names have been used to describe this deadly disease: hospital gangrene, necrotizing erysipelas, necrotizing myositis, acute necrotizing cellulitis, streptococcal gangrene, suppurative fasciitis, gas gangrene, clostridial gangrene, clostridial cellulitis, clostridial myositis, malignant ulcer, gangrenous ulcer, Cullen ulcer, putrid ulcer, phagedena ("eating away"), phagedenic ulcer, phagedena gangrenosa, progressive synergistic bacterial gangrene, acute synergistic gangrene, acute dermal gangrene, etc. [4, 8, 9]. The numerous monikers used to describe this cluster of disease in the literature have created much confusion and may contribute to misdiagnosis and delay in treatment. All forms of this disease include necrotic or devitalized tissue which encourages the rapid growth of bacteria and also precludes delivery of antibiotics and host defenses [8]. Because the treatment is the same regardless of location or depth, the all-encompassing term *necrotizing soft tissue infection* (*NSTI*) is now preferred.

Incidence

According to the United States Center for Disease Control and Prevention, the estimated incidence of NSTI in the

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United States is between 500 and 1500 cases per year and most cases are community-acquired [9, 10]. Recent epidemiologic studies suggest that the incidence of NSTI may be increasing over the past several decades, potentially due to increasing use of immunosuppression and rising incidence of obesity and diabetes [11–13]. This disease affects men slightly more than women [14–18]. Although NSTI has been described in all ages, the mean age is between 50 and 60 years in most series [14–16, 19, 20]. Infants and children are rarely affected. The incidence of NSTI increases with increasing age, being three times higher in those over age 65 (0.55 per 100,000) when compared to those under the age of 45 (0.15 per 100,000) [10, 11]. This is likely related to the prevalence of risk factors for NSTI, almost all are more prevalent in the older population.

The hospitalization rate is approximately 1.3 cases/100,000 population with an average cost of $50,000 to $100,000 per case, not including the costs of rehabilitation and indirect costs [21]. The average length of stay for survivors ranges between 13 and 40 days in most reports [16–19, 21–29]. Only about one-half of surviving patients are discharged home [29]; the remainder are discharged to rehabilitation facilities or nursing homes. Not surprisingly, quality of life is significantly affected, though these changes are not readily discernible using standard outcomes measures [30]. Interestingly, when compared with the general population (controlled for age, sex, and geographic area), the long-term survival of NSTI survivors is markedly decreased [31]. Annual deaths due to infectious causes are significantly higher (14 % vs. 2.9 %) when compared with the general population.

Mortality

Although a wide range of mortality rates (6–76 %) is reported in the literature, modern series mortality rates are approximately 5–10 % [12, 13]. This significant improvement may be secondary to advances in diagnostic modalities, critical care, and regionalization of care. Like other infectious processes, early deaths are due to overwhelming septic shock, while late deaths are usually secondary to progressive multi-organ failure [14]. Much has been written about risk factors for mortality, with delay in surgical excision the most commonly cited [14, 27, 32–35]. Advanced age is another strong predictor of mortality [19, 20, 26, 31, 34, 36, 37] with one series reporting a fivefold greater risk of death occurring in patients age > 60 compared with younger patients [21, 36]. Other reported prognosticators of mortality include the presence of hypotension, [27] tachycardia, [37] hypothermia, [37] thrombocytopenia, [34] bacteremia [10, 19, 20], acidosis, leukocytosis [37, 38], elevated hematocrit [23], bandemia [27], coagulopathy [20], APACHE II score > 20 [23, 28], SOFA score > 8 [35], heart disease, renal failure (acute and chronic), [37] cirrhosis [39], diabetes mellitus (DM), peripheral vascular disease (PVD), immunosuppression [26, 40], number of comorbid medical diseases, malnutrition, cancer, extent of total body surface area (TBSA) involved [33], and obesity [14, 19, 20, 27]. Ethnic race has not been shown to be associated with mortality [36]. Interestingly, female gender has been reported to be a mortality risk factor, although the mechanism is not clear [36].

Recent studies have suggested that outcomes may vary according to hospital volume. In a large review of 1641 patients with perineal NSTI, Sorensen et al. reported that hospitals treating more than one case per year had up to 84 % lower mortality after adjusting for risk factors such as age and comorbidities [41]. In one of the largest single center retrospective studies published to date, Bernal et al. described progressive annual decreases in antibiotic use, number of operations, and length of stay, despite increasing body mass index (BMI) and severity of illness (APACHE II scores) [42]. These and other studies demonstrating variation by hospital center support the argument for regionalization of care to experienced centers for improved outcomes [19, 43].

Etiology

Risk Factors

Predisposing factors to the development of NSTI vary by series and are influenced by geography and patient population. Some series report intravenous (IV) drug abuse as a strong risk factor [18], whereas in others, unintentional trauma and surgical operations are most common [14, 20, 22, 27]. Among all comorbid medical conditions, DM is most strongly associated with NSTI, present in up to 50 % of confirmed cases [15, 16, 27, 31, 33, 44]. Importantly, no predisposing risk factor is present (idiopathic) in a high percentage of patients with NSTI, between 15 and 40 % in most reports [14, 16, 18, 20, 22, 24, 27, 29, 38].

Classification

NSTI are typically classified according to microbiologic causative organisms, though the distinction is of questionable clinical relevance as the initial treatment does not differ.

Type 1 (polymicrobial) – this is the most common type, occurring in approximately 75 % of confirmed cases [15,

22, 33, 45]. There are typically between 2 and 4 organisms cultured per patient [14, 15, 46] and up to eleven organisms in one series [4]. The milieu contains a combination of anaerobic, aerobic, Gram-positive and Gram-negative bacteria [14]. These infections tend to occur on the trunk, particularly postoperatively [4]. Immunocompromised patients are especially at risk of developing type 1 NSTI [45].

Type 2 (Streptococcus pyogenes alone or in combination) – in contrast to type 1 NSTI, type 2 infections tend to occur in younger, immunocompetent patients such as IV drug abusers and athletes [45]. Monomicrobial infections are more common on the extremities [4].

Type 3 (marine vibrios) – this type of NSTI is characterized by a particularly aggressive and fulminant clinical course caused by marine *Vibrio* spp. (*V. vulnificus*, *V. parahaemolyticus*, *V. damsela)* [47–49]. As etiologic agents, *Vibrio* spp. are associated with increased mortality [20, 27]. Cirrhosis (especially from chronic hepatitis B) is a strong risk factor for the development of type 3 NSTI [45], which commonly involves both lower extremities without any obvious entry sites. This type is almost exclusively acquired in the community after exposure to warm seawater [39]. Interesting, the GI tract has been reported to be a possible portal of entry, with case reports describing NSTI after ingestion of raw oysters [50].

Microbiology

Although NSTIs are most frequently polymicrobial, certain organisms appear most commonly, and an understanding of these "usual suspects" is crucial in directing initial empiric antibiotic therapy. Multiple infecting organisms are the rule, and it is believed that these facultative bacteria behave synergistically.

S. pyogenes – *S. pyogenes* is among the most commonly isolated organisms in both monomicrobial and polymicrobial infections [15]. Expression of surface proteins M1 and M3 is believed to increase streptococcal adhesion to tissues, preventing phagocytosis by neutrophils [51, 52]. Release of streptococcal exotoxins A, B, C, and superantigen contributes to host cytokine release (TNF-α, IL-1, IL-6) and platelet/neutrophil aggregate-mediated microvascular occlusion and may occasionally lead to the deadly toxic shock syndrome [4, 45, 51].

MRSA – in recent years, increasing prevalence of MRSA as a causative organism in NSTI has been reported (29–39 %), rivaling *S. pyogenes* in some series [19, 20, 44, 53]. Interestingly, MRSA NSTI occurs most commonly as a monomicrobial infection [44] in patients without coexisting risk factors [8, 53] and is often characterized by a subacute presentation. Several authors have suggested that this form of NSTI may be less virulent than those caused by other agents [44, 53].

Clostridium spp. – Clostridia are saprophytes found widespread in soil, clothing, and as resident flora of the gastrointestinal tract in humans and animals. While *Clostridium* spp. (especially *C. perfringens*) have been historically closely linked to NSTI (previously known as "gas gangrene"); in the modern era, *Clostridium* is a very rare causative agent in NSTI (<5 %), found most commonly in cases involving injection drug abuse [20, 25, 54]. Like *S. pyogenes*, the virulence of *Clostridia* is attributable to the elaboration of exotoxins, alpha-toxin, and theta-toxin in this case [45]. In addition to local tissue effects (myonecrosis and microvascular thrombosis), alpha-toxin also depresses cardiac contractility and activates cytokine expression [5]. These systemic effects may explain the higher mortality rates encountered with clostridial infection [23].

Zygomycete – this ubiquitous fungus is responsible for a rare but devastating form of NSTI known as *mucormycosis*, seen predominantly in diabetics, especially in the presence of uncontrolled hyperglycemia and ketoacidosis [5]. Infection usually begins with minor trauma followed by rapid spread to periorbital structures, the maxillary sinus, the hard palate, and the cranial vault. Mucormycosis has also been reported to result from a new species, *Apophysomyces mexicanus* [55, 56]. This form of NSTI is rare and highly lethal.

Others – dozens of other organisms have been reported to be associated with NSTI in varying degrees of frequency (Table 19.1). Aerobic agents include *E. coli*, *Enterobacter*, *Klebsiella*, *Haemophilus influenzae*, and *Pseudomonas*; common anaerobes include *Bacteroides*, *Peptostreptococcus*, *Prevotella*, and *Fusobacterium*. Atypical pathogens (seen mainly in immunosuppressed patients) include *Mycobacterium kansasii*, *M. cheloneii*, *M. smegmatis*, and various fungal species [56–59].

Location

NSTI can affect any part of the body. For simplicity, the body regions most commonly affected are usually categorized in order of decreasing incidence: the extremities, perineum and buttocks, trunk, and head and neck. The body region affected varies according to the study patient population; for example, IV drug abusers are disproportionately affected in the extremities at the sites of injection [18–20, 22] while Fournier's gangrene is seen most commonly in diabetics [22, 36]. Fournier's gangrene, named after French dermatologist

Table 19.1 Organisms identified in necrotizing fasciitis

Gram-positive aerobic bacteria	*Bacillus* sp.
	Coagulase-negative staphylococci
	Enterococci
	Group A, β-hemolytic streptococcus
	Group B streptococcus
	Staphylococcus aureus
Gram-negative aerobic bacteria	*Acinetobacter* spp.
	Citrobacter spp.
	Enterobacter spp.
	Escherichia coli
	Haemophilus influenzae
	Klebsiella spp.
	Pasteurella multocida
	Proteus spp.
	Pseudomonas aeruginosa
	Serratia spp.
Anaerobic bacteria	*Bacteroides* spp.
	Clostridium spp.
	Fusobacterium spp.
	Peptostreptococcus spp.
	Prevotella spp.
Marine *Vibrio* spp.	*Vibrio alginolyticus*
	Vibrio damsela
	Vibrio parahaemolyticus
	Vibrio vulnificus
Atypical	*Mycobacterium kansasii*
	M. cheloneii
	M. smegmatis
Fungi	*Aspergillus* spp.
	Candida spp.
	Rhizopus

Jean Alfred Fournier who described a series of five male patients in 1883, is the eponymous name used to describe NSTI of the perineum (Figs. 19.1 and 19.2). This form of NSTI affects men up to ten times more commonly than women [60]. This location of NSTI (perineal) is less lethal than other locations and has an overall mortality rate of 16 % [61]. NSTI of the head and neck is most commonly preceded by a dental infection [62, 63].

NSTI can occur following insect bites and muscle strains. Non-recreational drug use needle injection-related NSTI has been reported after tattooing, [11] acupuncture [33, 64], and insulin administration [33] (Figs. 19.3 and 19.4). Case reports of postsurgical NSTI have been reported for appendectomy, mastectomy, hemorrhoidectomy, inguinal hernia, various gynecologic operations, orthopedic fixation, dental procedures, transanal procedures, urologic procedures (including circumcision), angiographic interventions, and laparoscopic procedures [6, 61, 65]. As a general rule, infections adjacent to mucous membranes (oral cavity, rectum, vagina) are caused by the normal resident flora of those mucous membranes, while infections in distant areas are usually caused by resident skin flora [66].

Diagnosis

The distinction between NSTI and non-necrotizing infections is of prime importance, the latter being treated with antibiotics alone. The main differential diagnosis includes simple cellulitis, erysipelas, abscess, clostridial and non-clostridial myonecrosis, toxic epidermal necrolysis (TEN), staphylococcal scalded skin syndrome, and rarely, cutaneous anthrax (Table 19.2).

Clinical Exam

The physical exam findings in NSTI have been known since the first description by Hippocrates: soft tissue edema (71–83.7 %) [14, 20, 27], erythema (52–85.6 %) [14, 16, 20, 27],

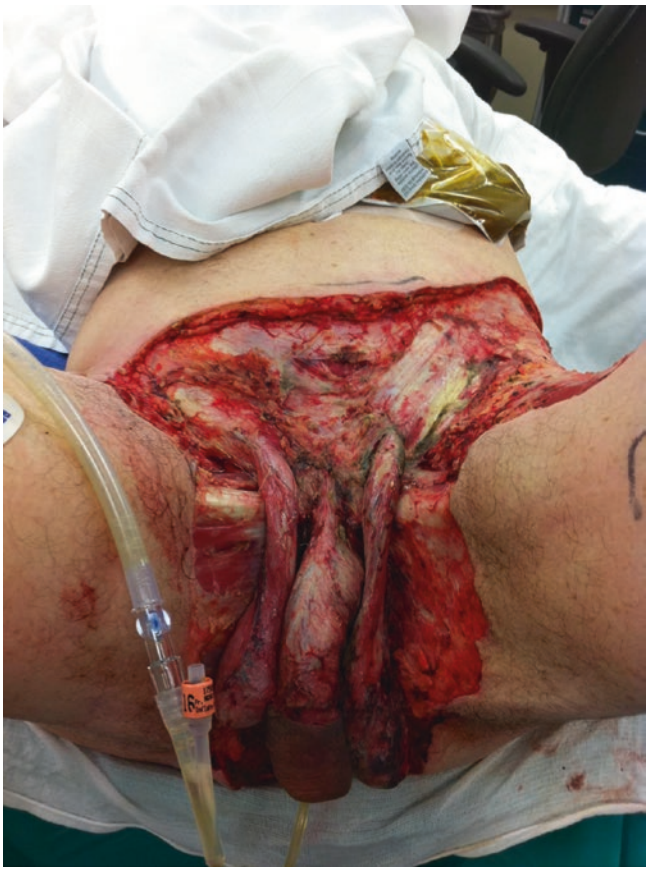

Fig. 19.1 Fournier's gangrene after radical debridement (Dante's personal collection)

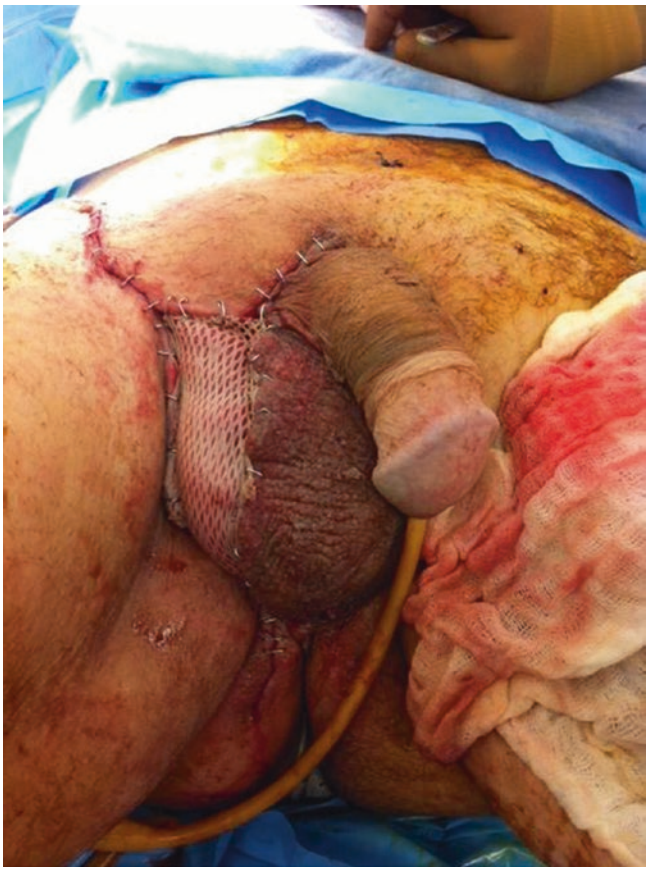

Fig. 19.2 Fournier's gangrene after partial wound closure and skin grafting (Dante's personal collection)

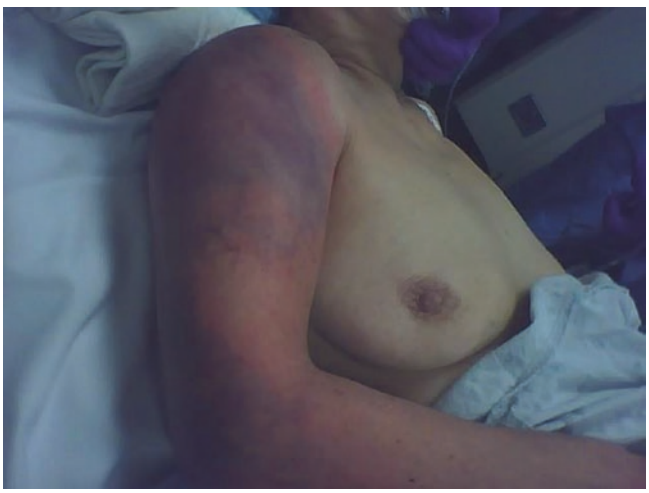

Fig. 19.3 Preoperative appearance of upper extremity NSTI (George Velmahos' collection)

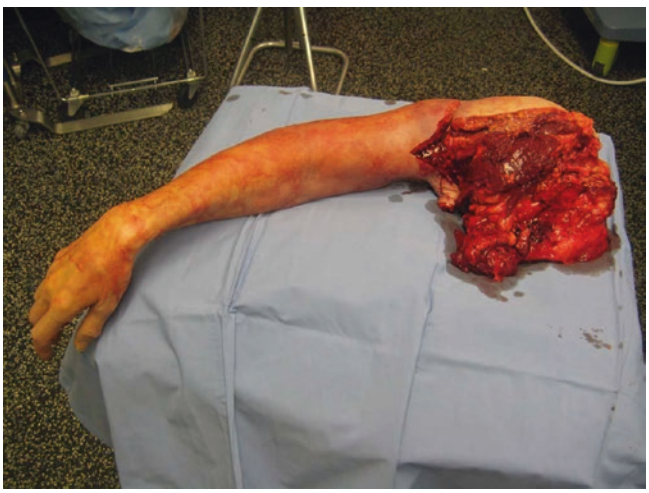

Fig. 19.4 Lifesaving upper extremity amputation required for NSTI (George Velmahos' collection)

and skin blebs and bullae (13.3 and 44.9 %) [14, 16, 18, 20, 25, 27]. Crepitus and skin necrosis, highly specific signs, are present in less than a third of patients [5, 36]. The symptom most characteristic of NSTI is severe pain (often out of proportion to exam) (54.7–86.6 %) [14, 19, 20, 25, 27]. Absence of pain and numbness may result, however, from destruction of cutaneous nerves. Systemic symptoms such as fever (32.5–60 %) and hypotension are variably present [14, 16, 20, 25, 27, 33]. No single physical finding is universally present. Reliance upon the physical exam for diagnosis may

Table 19.2 Differential diagnosis of NSTI

Abscess
Anthrax (cutaneous)
Cellulitis
Erysipelas
Lymphedema
Myonecrosis (Clostridial and non-Clostridial)
Myxedema
Noninfectious fasciitis
Phlegmasia cerulea dolens
Staphylococcal scalded skin syndrome
Toxic epidermal necrolysis (TEN)

result in delayed recognition and treatment [15, 52]. In fact, NSTI is the admitting diagnosis in only a minority of confirmed cases [8, 25].

Radiology

Plain Films

Plain films were once considered essential in the diagnostic work-up of NSTI. In recent series, however, soft tissue gas evident on x-rays is present in only about 30 % of cases of confirmed NSTI [14, 18, 33]. This is likely due to the presence of non-gas forming pathogenic bacteria and variable stages of disease upon presentation. While the presence of subcutaneous emphysema is very specific and can confirm the diagnosis when clinically suspected, the absence of subcutaneous gas is not sufficiently sensitive to rule out the diagnosis of NSTI (Figs. 19.5 and 19.6). Awaiting the results of plain films should not delay surgical consultation or intervention.

Ultrasound

The use of ultrasonography (US) in the diagnosis of NSTI has been described in several single institution studies. US findings characteristic of NSTI include diffuse thickening of the subcutaneous tissue, fascial fluid collections, fascial irregularity, and subcutaneous air [67, 68]. Preliminary work in cadavers suggests that ultrasound is accurate in the detection of subcutaneous air [69].

Using operative and histological findings as the reference standard, Yen et al. report a sensitivity of 88.2 %, specificity of 93.3 %, positive predictive value (PPV) of 83.3 %, negative predictive value of 95.4 %, and an accuracy of 91.9 % [67]. Limitations of this modality include the dependence on operative experience and availability. Until larger, multicenter studies confirm these preliminary results; routine use of US for the diagnosis of NSTI cannot be recommended.

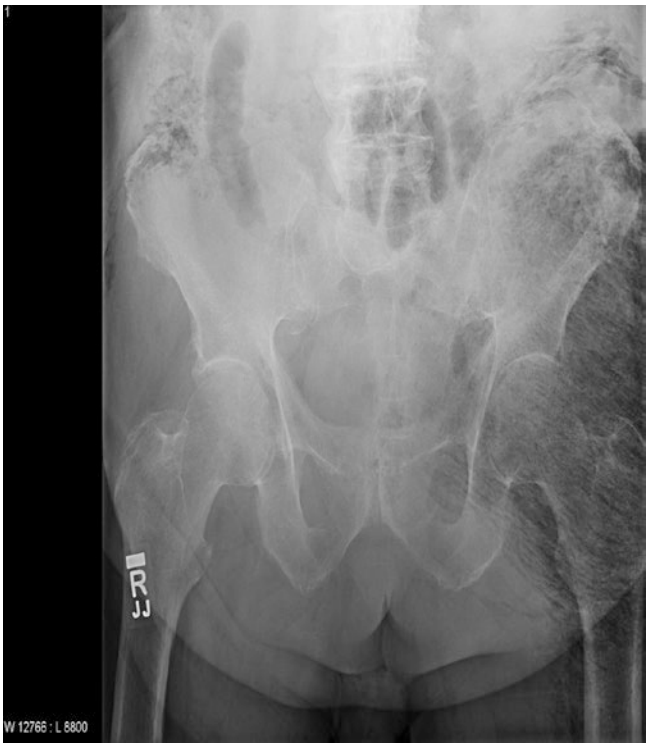

Fig. 19.5 Subcutaneous emphysema evident on plain films (Laura Avery's collection)

Computed Tomography (CT)

The literature on the use of CT to aid in the diagnosis of NSTI is conflicting; earlier studies reporting inaccuracy are limited by older CT technology and small sample sizes. Newer-generation scanners (16 slice and above) have increased sensitivity in detecting pathological changes associated with NSTI: asymmetrical and diffuse areas of soft tissue inflammation and ischemia, muscle necrosis, gas across tissue planes, and fluid collections (Fig. 19.7). Using these four CT criteria, Zacharias et al. report a sensitivity of 100 %, specificity 81 %, PPV 76 %, and NPV 100 % [17]. Thus, the utility of CT seems to be greatest in

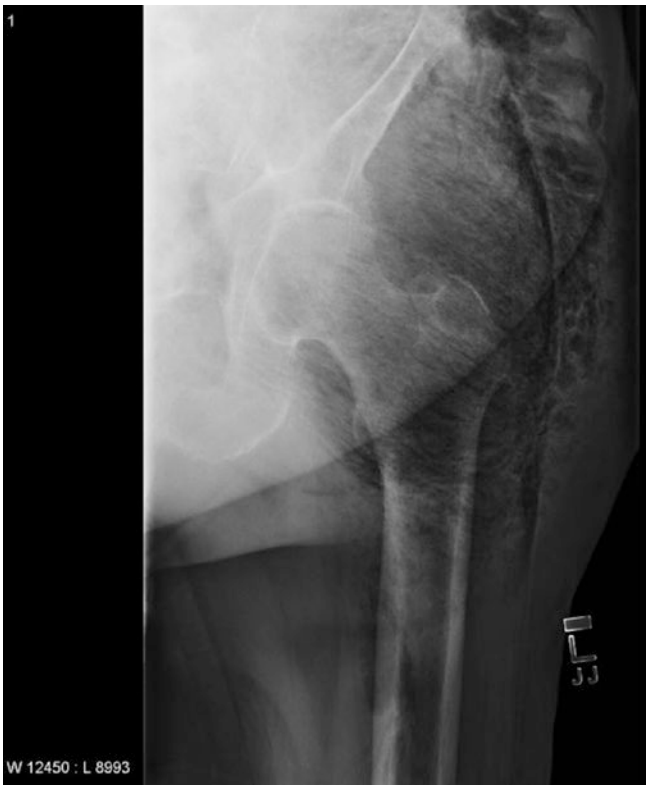

Fig. 19.6 Subcutaneous emphysema evident on plain films (Laura Avery's collection)

ruling out NSTI in clinically equivocal cases, thus avoiding unnecessary operative explorations (Figs. 19.8, 19.9, and 19.10). Others have also reported comparable accuracy of CT in the diagnosis of NSTI using other CT findings such as lack of fascial enhancement, lymphadenopathy, and edema [70, 71].

Magnetic Resonance Imaging (MRI)

Without question, MRI is more sensitive than plain films, US, or CT in the detection of acute inflammation. In general, NSTI manifests as high signal intensity on T2-weighted images and as low signal intensity on T1-weighted images [72, 73]. Absence of Gd-DTPA contrast enhancement is strongly suggestive of tissue necrosis [74]. There are two main drawbacks of MRI. Firstly, this modality may be too sensitive. Falsely positive MRI scans may result in unnecessary surgical explorations for cellulitis. Secondly, MRI may not be immediately available in all institutions. Reliance on this modality for diagnosis may cause therapeutic delay. Routine application cannot be recommended.

Laboratory

No single laboratory value has sufficient accuracy to assist in the diagnosis of NSTI. Bacteremia is present in < 30 % [15, 20, 27] and leukocytosis is nonspecific. In cases with equivocal physical exam and radiologic findings, a constellation of laboratory values may help distinguish the diagnosis of NSTI from cellulitis. Wong et al. have described a Laboratory Risk Indicator for Necrotizing Fasciitis (LRINEC) score to stratify patients into low, moderate, or high risk categories using commonly ordered laboratory tests: C-reactive protein, WBC, hemoglobin, sodium, creatinine, and glucose [75]. According to the authors, at a cutoff LRINEC score of ≥6, their model has a PPV of 92 % and NPV of 96 %. While these results are impressive, one must apply the LRINEC with caution as the LRINEC score may be less accurate in patients with multiple medical comorbidities and/or a blunted inflammatory response, both of which are present in the geriatric population. Since the initial description of the LRINEC score, others have reported lower accuracy [76–78].

A second group, Wall et al., have proposed a simple laboratory model based on two values: WBC >15.4 and serum sodium Na <135 [18]. These authors report that their model can distinguish NSTI from non-NSTI with a NPV of 99 %. Again, one must proceed with caution in the evaluation of the elderly patient as this model has not been validated in this population.

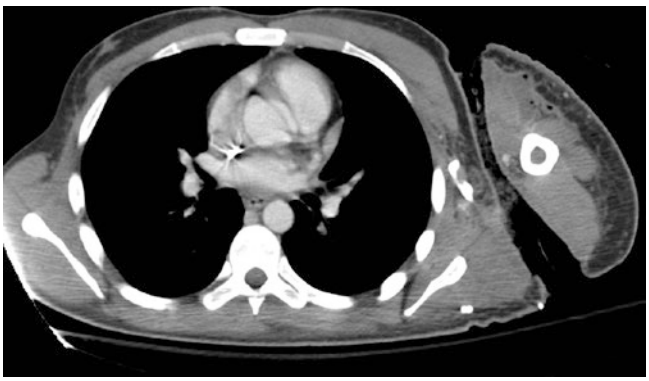

Fig. 19.7 NSTI computed tomography appearance (Laura Avery's collection)

Surgical Exploration

It cannot be overemphasized that wide surgical debridement is the only effective therapy for NSTI and that time is of the utmost essence. Delay in surgical therapy has been repeatedly demonstrated to be associated with increased mortality and increased number of required debridements [32]. Even with severe hemodynamic and metabolic derangement, surgical exploration and debridement must proceed; physiologic resuscitation and correction is futile in the continued presence of infected, necrotic tissue.

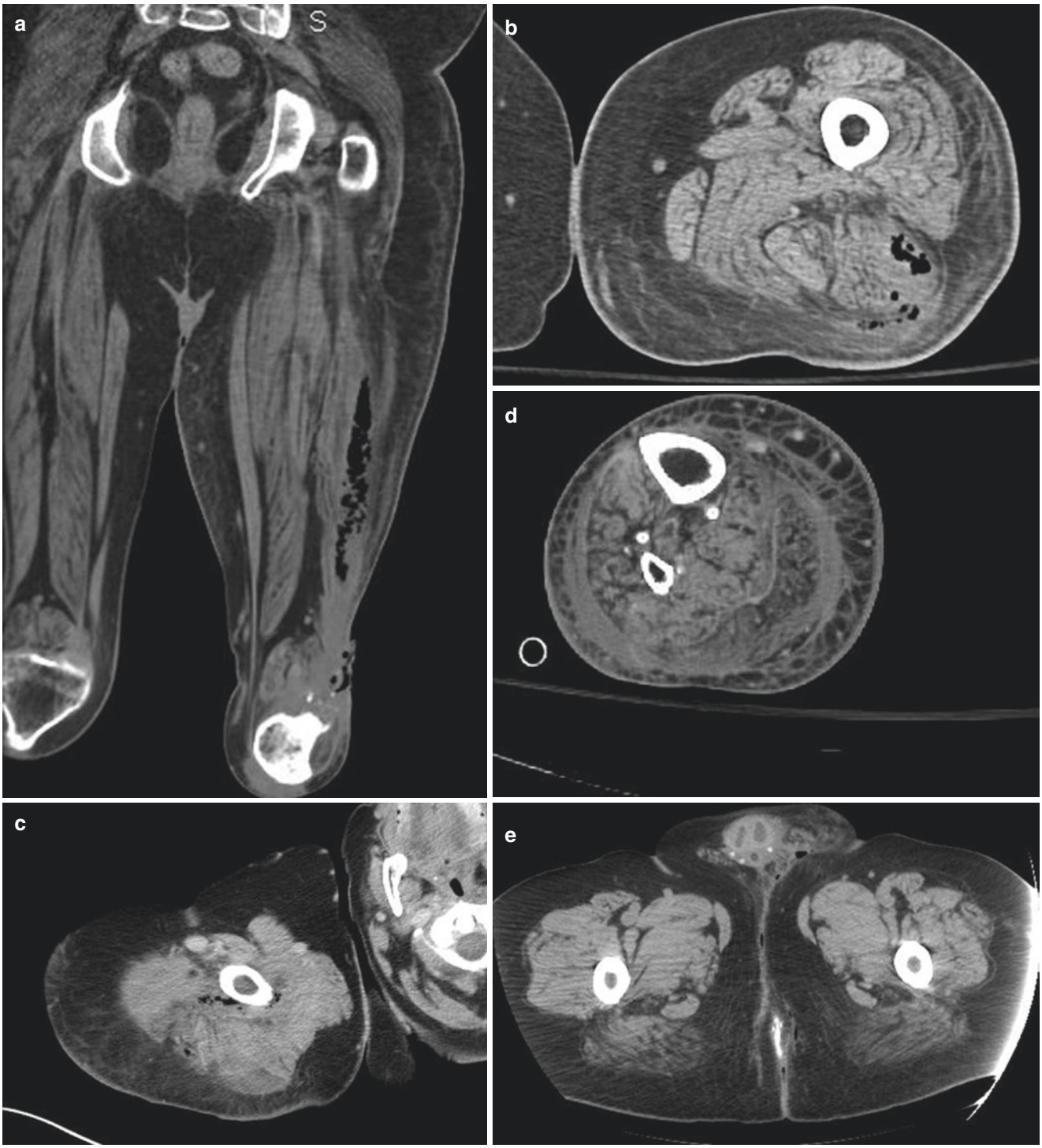

Fig. 19.8 Confirmed NSTI

Because of the difficulty in establishing the diagnosis non-invasively, several authors have described bedside tests, including aspiration with Gram stain [79], frozen section biopsy [80], and "the finger test." The "finger test" is performed by making a small incision (2 cm) through the skin down to the fascia and bluntly probing the wound with a finger. A positive test (indicating NSTI) results if one can dissect the subcutaneous tissue off the fascia with minimal resistance [24]. Because of the possibility of sample bias and the potential delay in diagnosis and therapy, these lesser diagnostic operations are not recommended; in most instances the morbidity associated with delayed treatment

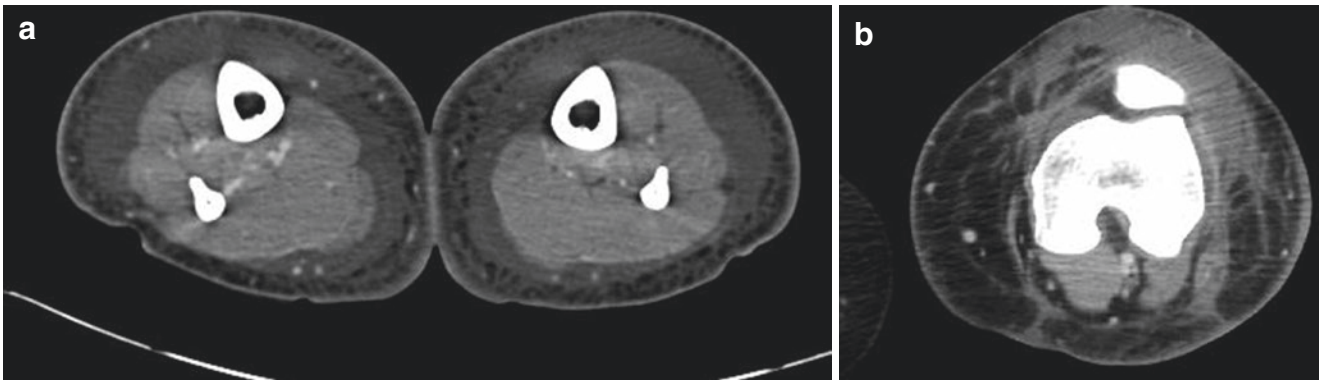

Fig. 19.9 Cellulitis – no NSTI

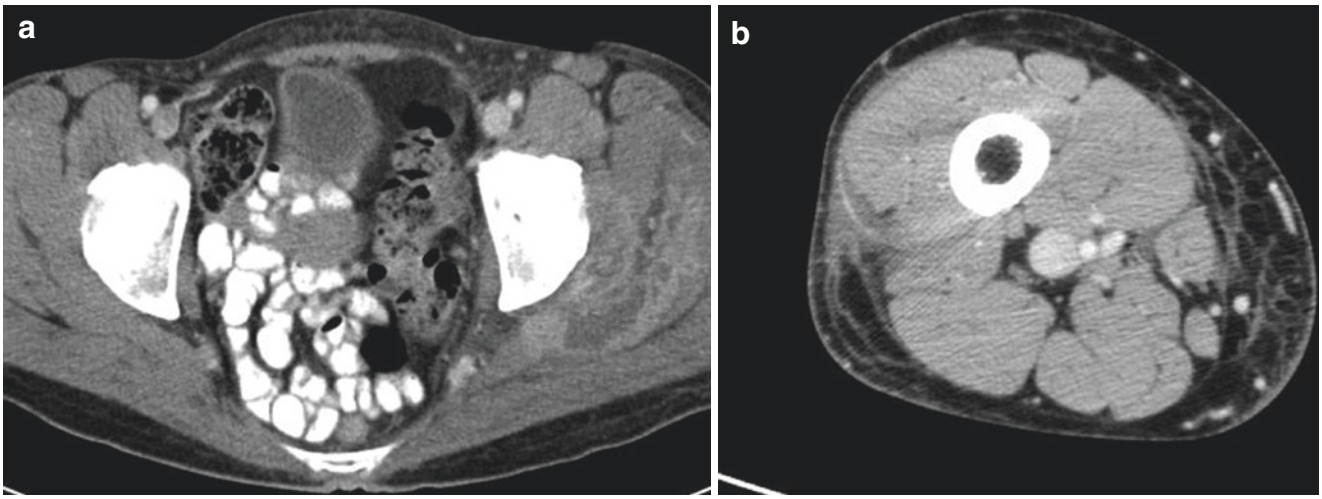

Fig. 19.10 Abscess – no NSTI

of NSTI outweighs the morbidity of an exploratory incision in superficial skin and soft tissue infection.

The surgical approach at the first debridement should resemble a "search and destroy" mission. All frankly necrotic and infected tissue should be excised irrespective of anatomic or functional boundaries (Fig. 19.11). As this disease pays no respect to anatomic planes, the treating surgeon should not hesitate to remove tissue when the patient's life is at stake. At operation, affected tissue is easily recognized by lack of bleeding and lack of normal resistance to blunt dissection. In elderly patients, however, ease of tissue separation alone may not be a reliable indicator of infections.

A clinical caveat: finger dissection should be utilized with care in injection drug abusers as broken needle tips may reside in the subcutaneous tissues (Fig. 19.12). Necrotic fascia is noted to be discolored (grayish) and sometimes surrounded by a thin, foul-smelling "dishwater" liquid distinct from the garden variety creamy thick pus encountered in simple abscesses. Intraoperative aerobic and anaerobic cultures should be taken to aid in future targeted antibiotic therapy; these cultures should be taken from subcutaneous tissues, not from the skin surface or blister fluid. Tissue biopsies should be taken from the interface between necrotic and alive tissue for optimal diagnostic yield [45]. Skin should be debrided until brisk capillary dermal bleeding without epidermal discoloration is encountered. Large skin flaps may impede wound drainage, and it may be prudent to excise skin with extensive underlining to facilitate wound care. Muscle and fascia should be debrided to healthy tissue with normal contractile function (in response to electrocautery).

Attempts to preserve marginal tissue are ill-advised as residual infection only serves as a nidus for further spread. Much like with a wildfire, the goal is to dig a trench beyond the advancing front (in unburned forest) to halt the progression. A scheduled second-look operation is highly recommended, although the appropriate timing is unknown. Common intervals are between 12 and 48 h; however, this may be influenced by changes in clinical condition. Frequently, additional debridement is required and multiple operations are the rule. Strong consideration should be

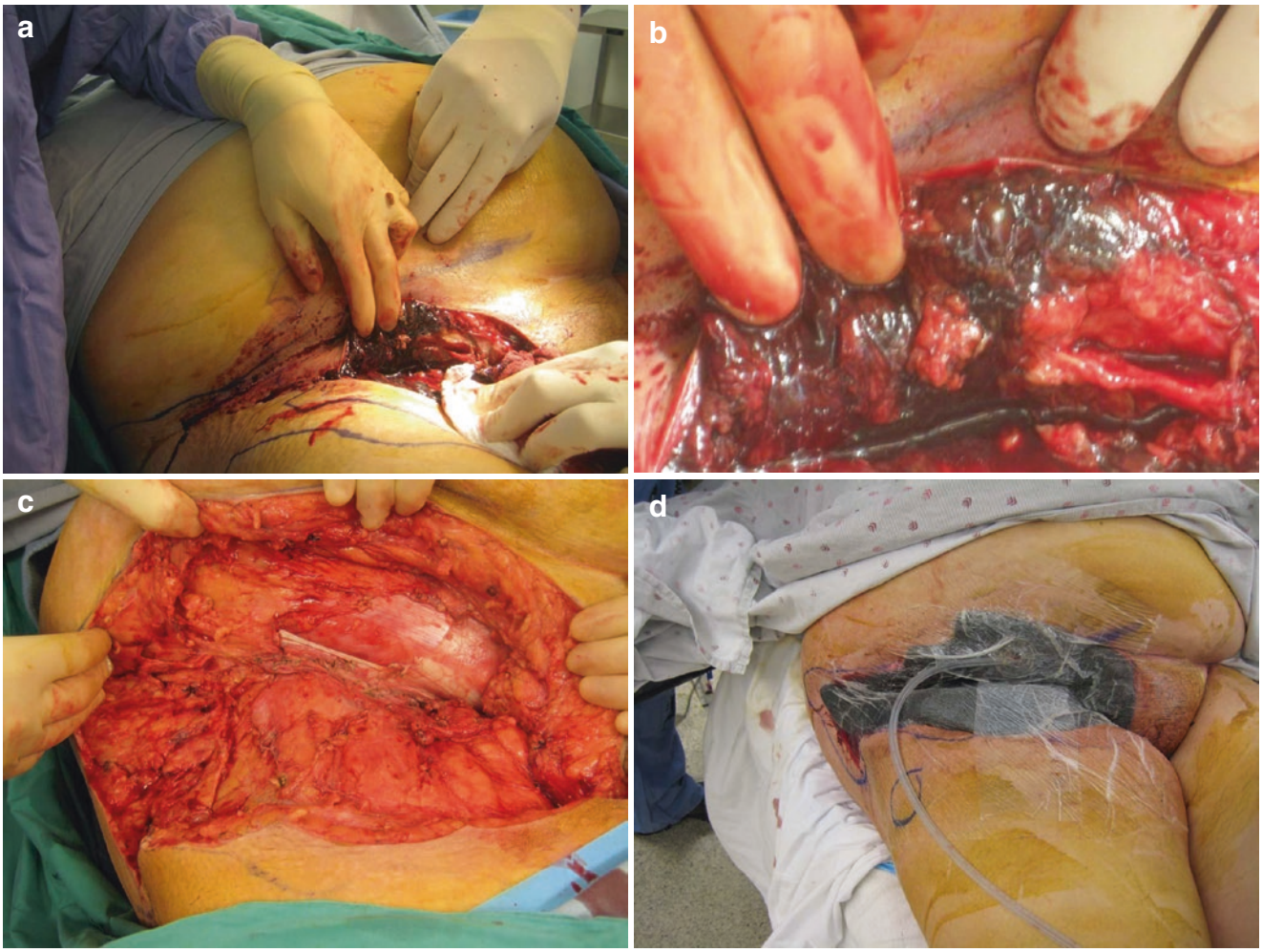

Fig. 19.11 NSTI intraoperative appearance. (**a**) Necrotic muscle and fat is evident. (**b**) Necrotic muscle and fat is evident upon initial exploration. (**c**) Wound debrided to healthy, viable tissue. (**d**) VAC dressing on open wound (George Velmahos personal collection)

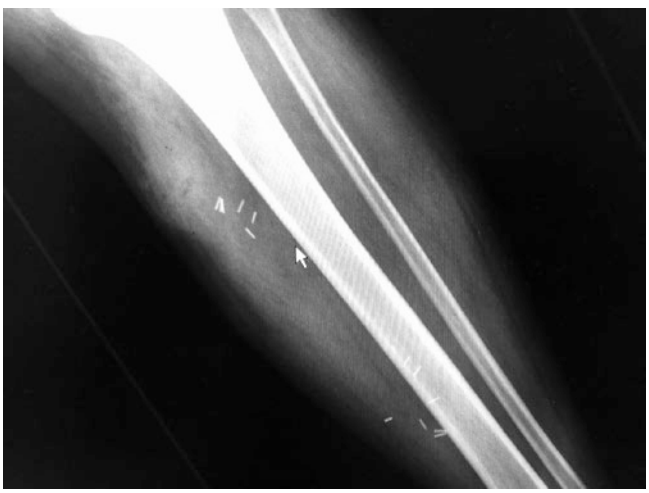

Fig. 19.12 Broken hypodermic needle tips embedded within the tissue (Dante's personal collection)

given to early scheduled reoperation [81]. One recent study suggests that procalcitonin ratio may be a useful indicator of successful surgical eradication [82]. The average number of debridements required has been reported to be between 2.3 and 5.6 [14, 16, 18, 20, 23, 25–27]. Wound closure at the initial operation is strongly discouraged. Adjunctive use of 5 % mafenide acetate solution has been reported to decrease the number of debridements required and increase success of subsequent wound closure [83].

Reported amputation rates range between 11.7 and 26.3 % [10, 14, 16, 23, 25, 27, 34], and risk factors for amputation include PVD, DM [14], and age over 65 years [23]. Even without amputation, 30 % of survivors are left with functional disability at discharge [19].

For perineal NSTI, two pearls are offered. Firstly, the necessity of a temporary diverting colostomy is not usually

apparent in the first few days, and delaying this additional procedure is recommended as many patients will not ultimately require fecal diversion. Additionally, since these infections may spread along the anterior abdominal wall, it is prudent to await the final anterosuperior demarcation before committing to ostomy placement. Secondly, orchiectomy is almost never required even when the entire scrotum has been debrided. Consultation with a urologist is recommended for ultimate testicular disposition; however, in the acute setting, the viable testes may be wrapped in petroleum gauze.

Once no further debridements are required and the infection cleared, the surgeon must deal with the residual defect. Accumulating experience and evidence supports the use of vacuum-assisted closure dressings to hasten the formation of granulation tissue [45]. If primary closure is not feasible, ultimate closure will often require skin grafting or flap coverage.

Adjunctive Treatments

Antibiotics

Once the diagnosis of NSTI is suspected, broad-spectrum antibiotic therapy should be instituted immediately to mitigate the systemic effects of infection; however, without surgical excision, mortality is almost universal despite appropriate microbial coverage. Antifungal therapy is not routinely given unless the clinician suspects invasive mucormycosis. Although numerous combinations of regimens have been described, none have been demonstrated to be superior to any other. Because of the polymicrobial nature of NSTI, initial empiric therapy must adequately cover Gram-positive, Gram-negative, aerobic, and anaerobic organisms, including MRSA. The addition of a protein synthesis inhibitor (such as clindamycin, erythromycin, or linezolid) is also recommended as it is believed to inhibit exotoxin and M protein production [5, 9, 45, 51]. Clindamycin has several other theoretical advantages: it reduces the synthesis of penicillin-binding protein, has a longer post-antibiotic effect than the β-lactams, suppresses TNF-α synthesis, and facilitates phagocytosis of group A streptococcus [79]. The Infectious Disease Society of America (IDSA) recommends that antibiotic therapy should continue until no further debridements are required, the patient has been afebrile for at least 48 h, and the patient's clinical condition has improved [84]. Prolonged treatment is not associated with improved outcomes and may contribute to the selection of resistant microorganisms.

Hyperbaric Oxygen

The use of hyperbaric oxygen (HBO) to inhibit anaerobic infections was first described in the early 1960s [85], and it is believed that increased tissue oxygen tension enhances local defense mechanisms, mitigates reperfusion injury, and moderates the systemic inflammatory response by decreasing proinflammatory cytokine and exotoxin production [45, 85, 86]. Laboratory and animal studies demonstrated that at >1 atmosphere absolute pressure, oxygen enhances bacterial killing (especially *Clostridium*), arrests toxin production [87], and increases collagen formation, fibroblast growth, and superoxide dismutase production [4]. The recommended HBO treatment protocol for NSTI is 2.0–2.5 atm absolute pressure for 90 min twice daily (3.0 atm thrice daily if *Clostridium* is suspected) until no further debridements are required.

Routine application of this treatment modality is much debated and many studies show conflicting results. Supporters report decreased number of debridements, decreased amputation rate, and decreased mortality [88–90]. However, the literature supporting its use comprises mainly animal studies, case series, and retrospective studies. Most are single center and underpowered and none are randomized. Perhaps the strongest evidence to date supporting the use of HBO is an analysis of the Nationwide Inpatient Sample (NIS), an administrative database, in which propensity scoring derived from multivariate logistic regression of known confounders was used to compare outcomes in patients who received HBO with those who did not. The authors report higher cost of hospitalization and longer length of stay, but significantly lower inhospital mortality rates (4.5 % vs. 9.4 %, p=0.001) [91]. Another study examining the University Health Consortium (UHC) database (but limited only to HBO-capable centers) reported a significant survival benefit associated with HBO, particularly in the most severely ill [92]. Opponents report no difference in outcomes in other studies [93–96]. Concerns about recommending its use include limited availability and the transport of a critically ill patient to the dive chamber. All agree that HBO therapy or transfer to an HBO-capable center should not delay surgical debridement. Until a well-controlled, adequately powered prospective study is performed, the use of HBO as adjunctive treatment for NSTI will remain controversial.

IVIG

Rarer still (and even more controversial) is the use of intravenous immunoglobulin (IVIG) as adjunctive therapy for

NSTI. The biologic rational supporting its use is that the administered immunoglobulin antibodies can neutralize circulating exotoxin and superantigen and reduce plasma concentrations of proinflammatory cytokines, thus mitigating the systemic inflammatory response [5, 51]. Clinical evidence supporting its use is scant [97, 98], and most involves treatment of toxic shock syndrome secondary to group A streptococci [99]. IVIG is not currently FDA approved for the treatment of NSTI.

Other

AB103 is a peptide mimetic of CD28, a T-lymphocyte receptor. Because of its potential to dampen the inflammatory response to exotoxin, this agent has been studied as a therapeutic adjunct in the treatment of NSTI. In a multicenter randomized, placebo-controlled, double-blinded study, Bulger et al. demonstrated that a single intravenous dose of AB103, administered within 6 h of NSTI diagnosis, resulted in improved organ failure scores at day 14 [100]. Because of sample size, clinically relevant outcomes such as number of debridements, ICU-free days, or ventilator-free days were similar. In a follow-up multicenter retrospective study, the investigators demonstrated in a larger cohort that the modified SOFA score was correlated with clinically important outcomes and thus was an appropriate surrogate endpoint for future trials [101]. A phase 3 trial is currently planned.

Conclusion

NSTI is a rare and deadly disease primarily affecting middle- and older-aged individuals. Misdiagnosis leading to delay in treatment is common, and a high index of suspicion must be maintained. Pain is the most consistent presenting symptom. The use of laboratory markers and radiologic imaging may assist in ruling in or out the disease. Treatment is expedient surgical excision and should be regarded as a surgical emergency. Amputation rates are high and multiple debridements are the rule. Empiric antibiotic therapy should be broad-spectrum and should include a protein synthesis inhibitor such as clindamycin. The use of adjuvant therapies such as HBO and IVIG is controversial. Mortality remains between 10 and 30 % and long-term disability is common.

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Acute Vascular Insufficiency in the Elderly

20

Michael J. Sise

Educational Objectives

The evolving demographic shift in the United States resulting in increasing numbers of elderly citizens directly impacts all of healthcare. Emergency services now are inundated with geriatric patients who often present with surgical problems complicated by multiple comorbidities. The key to the successful management of surgical emergencies in the elderly is not only early diagnosis and prompt treatment but also aggressive management of multiple pre-existing major health problems. This is especially true in acute ischemia in the elderly. Delay in diagnosis is common in these patients despite the fact that a simple history and physical examination often are sufficient to make the diagnosis. These delays lead to high morbidity and mortality because the elderly frequently have multiple serious comorbidities and limited reserve to tolerate the sequelae of ischemia. The goal of this chapter is to provide a useful approach to the management of acute vascular insufficiency in the elderly for the acute care general surgeon. This review includes extremity and abdominal acute arterial and venous occlusive diseases and presents algorithms and checklists to help organize and direct diagnosis and management. Illustrative case presentations of each major etiology of acute vascular insufficiency conclude this chapter and provide an integration of the key elements of successful early diagnosis and prompt treatment.

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Introduction

The incidence of peripheral arterial disease (PAD), coronary artery disease (CAD), and cardiac arrhythmias among the elderly is extremely high and increasing yearly [1–4]. Combined with the steadily rising life expectancy, the problems of acute limb ischemia and acute mesenteric ischemia are of growing importance to acute care surgeons. More than 25 % of the elderly have clinically significant and active health problems related to PAD, CAD, or atrial fibrillation [3, 5]. Acute vascular insufficiency presents in a variety of settings. Although the emergency department remains the most common location to encounter these patients, the ICU, medical-surgical floors, and the operating room may also be the site of consultation for these emergencies. However, the work-up remains straightforward and is based upon a thorough history, an appropriate examination, adjunctive Doppler pressure measurements or CT imaging studies, and, in a few compelling clinical settings, an immediate operation. The time urgency of diagnosis and effective treatment is based upon the "golden period" of 6–8 h within which adequate blood flow must be restored if limb-threatening tissue loss or life-threatening bowel necrosis is to be prevented. Acute limb ischemia is much more common than acute mesenteric ischemia but shares a number of characteristics including etiology, pathophysiology, and the need for immediate diagnosis and treatment [6, 7].

Acute Limb Ischemia

Acute, nontraumatic limb ischemia is usually due to either cardiac source emboli or thrombotic occlusion of pre-existing occlusive arterial disease. Although less common, iatrogenic arterial occlusion is a growing problem for the acute care surgeon [9]. Most, if not all of these patients, have

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major comorbidities that complicate their management [10]. Prompt diagnosis and treatment are essential to successful management.

Pathophysiology

Extremity ischemia is the result of either acute arterial occlusion or acute worsening of chronic occlusive disease. Infrequently, severe acute venous occlusion results in ischemia secondary to arterial vasoconstriction and venous hypertension (phlegmasia cerulean dolens) [11]. The vascular anatomy of the extremities and the tissue mass perfused give rise to important differences in the presentation of upper and lower extremity acute ischemia.

Both the arms and legs have a single major proximal vessel that traverses the mid-extremity joint and divides into three vessels supplying the distal limb. There are key collateral vessels which determine the severity of ischemia with acute occlusion. However, the embryologic development of that single proximal vessel is distinctly different in the upper and lower extremities. In the arm, the brachial artery traverses medially in a straight course down the upper arm accompanied by the median nerve without passing through any muscular skeletal structures until it passes under the flexor aponeurosis below the antecubital fossa. In the leg, the superficial femoral artery (SFA) develops in the human embryo as an anterior anastomosis between the femoral region and the popliteal artery. The initial embryonic blood supply is via a posterior sciatic artery which involutes [12]. This explains the spiral anterior to posterior-medial course of the SFA as it passes through the adductor magnus muscle at Hunter's canal. It is accompanied by the small sural nerve.

Collateral flow into the most proximal portion of the extremities is typically adequate to prevent limb-threatening ischemia with inflow occlusion in the arm, but this is not true in the leg. Acute subclavian or axillary artery occlusion usually does not result in limb-threatening arm ischemia because of the extensive arterial collaterals around the shoulder [6]. Occlusion of the inflow vessels of the leg (external iliac or common femoral arteries) is associated with limb threat because pelvic collaterals to the upper thigh are not adequate to acutely supply perfusion to the large muscle mass of the leg [11].

The collateral arterial supply in the arm is via the proximal superior contribution of the profunda brachial artery and the distal ulnar and radial collateral branches from the upper forearm. They are usually not sufficient to mitigate the ischemia that results from acute occlusion of the brachial artery. In the leg, which has a much larger muscle mass, the collateral flow from the profunda femoral artery proximally to the branches of the distal popliteal artery is usually not adequate to prevent ischemia in acute SFA occlusion [6].

The chronic and progressive occlusive disease of atherosclerosis in the lower extremities results in the growth of collaterals that prevent ischemia at rest in the early stages of the disease [6]. Progressive disease with obliteration of distal vessels will lead to chronic ischemia at rest. Acute thrombosis of extensively atherosclerotic vessels can result in acute limb-threatening ischemia [13]. In patients with previous extremity angioplasty and stent placement or arterial bypass surgery, acute thrombosis may cause acute limb-threatening ischemia if pre-existing collateral flow is insufficient [5, 7].

The most common etiology of acute extremity arterial occlusion is an emboli originating from a cardiac source. In extremity embolism, the typically lozenge-shaped chronic thrombus that dislodges from a fibrillating left atrium usually lands in the brachial artery or the proximal femoral vessels. If the organized thrombus is large enough, it may land at the aortic bifurcation as a saddle embolism occluding both iliac arteries. If it flows to the upper extremity, it will occlude the subclavian or axillary artery. Less commonly, fresh and less organized thrombus from an acutely ischemic ventricular wall, a ventricular aneurysm with thrombus, or paradoxical embolism of venous thrombus through a patent foramen ovale diffusely distributes itself in multiple levels of the extremity [11, 15, 16] (Table 20.1).

Peripheral arterial aneurysms are an uncommon but important source of distal emboli. At the time of presentation, there is usually evidence of multiple prior episodes of small emboli followed by the current complete thrombosis and acute distal limb ischemia [16]. These aneurysms can be of both an atherosclerotic and, less commonly, a congenital origin. Popliteal artery atherosclerotic aneurysms are the most common peripheral aneurysms and are associated with bilateral lesions in 50 % and abdominal aortic aneurysms in 60 % of patients [17, 18]. Congenital popliteal entrapment and thoracic outlet syndrome with arterial compression can lead to aneurysms with embolic and thrombotic complications [19, 20]. Rupture of peripheral aneurysms is rare [17]. If left untreated, these rare congenital aneurysms are associated with a significant risk of limb loss because of chronic small distal emboli, acute thrombosis, and delay in diagnosis [19–21].

Table 20.1 Sources of arterial emboli by frequency

1. Organized chronic cardiac thrombus from atrial fibrillation
2. Subacute thrombus from ischemia endocardium of acute MI
3. Iatrogenic catheter induced thrombus
4. Paradoxical embolism from DVT, multiple PE with patent foramen ovale
5. Peripheral artery aneurysm – congenital or atherosclerotic origins
6. Atherosclerotic aortic plaque
7. Aortic aneurysm

The increasing use of the extremity arteries for diagnostic and therapeutic endovascular techniques has resulted in a rise in iatrogenic acute limb ischemia [9, 22, 23]. Catheterization site arterial occlusion may result from an intimal dissection, accumulation of thrombus along indwelling catheter sheaths with subsequent thrombosis or distal embolism, and intravascular occlusion from misplaced closure devices. Diagnosis of this source of acute ischemia is also frequently delayed. Similarly, the outcome is dependent upon prompt recognition and treatment.

The ischemic pattern in the extremity with the classic "five Ps" of arterial occlusion occurs in the extremity one level distal to the area of occlusion [5, 13]. If complete, this ischemia results in skeletal muscle and nerve tissue death at approximately 6 h [13]. This has given rise to the concept of a "golden period" of 6 h. This is the period of time between the onset of ischemia and the successful restoration of flow to salvage the limb from permanent loss of muscle and nerve tissue (Table 20.2).

Iatrogenic arterial occlusion is an increasingly common cause of acute limb ischemia [9]. The use of the femoral artery for catheter access for endovascular cardiac and peripheral interventions places a large number of patients at risk for acute ischemia from access site occlusions [22, 23]. Orthopedic surgical procedures in the hip and knee also put the femoral artery and the popliteal artery at risk for acute occlusion [25].

Acute massive venous thrombosis and outflow occlusion can cause acute limb ischemia. This entity is known as phlegmasia cerulean dolens or painful blue edema [26]. The venous obstruction and engorgement with desaturated blood is associated with significant pain and resulting arterial vasoconstriction. Left untreated, limb threatening ischemia results from the accumulation of desaturated venous blood, decreased arterial flow, and compartment syndrome [26].

Table 20.2 Acute and chronic signs and symptoms of extremity arterial occlusive disease

Acute ischemia
Sudden onset of the "5 Ps"
Pain
Pulselessness
Pallor
Paresthesias
Paralysis
Absent or monophasic Doppler tones at the ankle or wrist
Chronic arterial occlusion
Mild:
Diminished distal pulses
Mild claudication of the legs or exercise-induced muscle pain arm relieved by rest
Ankle or wrist pressure index 0.6–0.75
Moderate:
Absent distal pulses
Severe exercise-induced extremity pain
Extremity pressure index <0.6
Severe:
Night pain of the forefoot or numbness of the hand
No exercise tolerance
Extremity pressure index <0.5
Limb threat:
Rest pain in the extremity
Nonhealing ulcer digits, heel, or palm
Dependent rubor
Blanching on elevation
Absent or monophasic distal Doppler tones

Clinical Presentation and Diagnosis

Acute limb ischemia presents with sudden onset pain followed quickly by numbness and weakness. In patients with pre-existing occlusive disease, these symptoms may be less distinct [5, 13]. The most common clinical setting of acute limb ischemia includes a history of atrial fibrillation [5, 16]. Pre-existing lower extremity occlusive arterial disease with thrombosis is the next most common setting. These acute on chronic limb ischemia patients will have a history of claudication or past extremity angioplasty with stent placement or arterial bypass surgery. The third most common clinical setting is a history of either acute or chronic ischemic heart disease with thromboembolism when mural thrombus dislodges from the damaged endocardium [16]. There is rising incidence of catheterization site occlusion in patients undergoing cardiac endovascular procedures [9, 22]. These iatrogenic lesions also occur in the setting of associated cardiac disease.

History and physical examination quickly reveal the most likely source of the acute occlusion in the vast majority of patients. Cardiac source emboli usually occur in the setting of atrial fibrillation or acute myocardial infarction. Less commonly, emboli result from paradoxical embolism of venous thrombus through a patent foramen ovale in patients with lower extremity deep venous thrombosis and multiple pulmonary emboli [15]. The resulting pulmonary hypertension with opening of an incompletely closed foramen ovale allows passage of a venous embolism from the right atrium through the foramen ovale into the left atrium and into the systemic circulation. Rarely, emboli from atherosclerotic arterial plaque or a peripheral aneurysm present as acute limb ischemia [8, 16]. These lesions more commonly cause digital ischemia. Thrombosis of a pre-existing bypass graft or a stent is an important source of acute ischemia in patients with previous surgical or endovascular management of chronic disease [14]. This group

of patients usually has a progression of distal occlusive disease and, less commonly, occlusion of a patent graft in the absence of identifiable progression of disease. These patients must undergo detailed catheter arteriography and often are candidates for thrombolytic therapy [14]. Consultation with a vascular surgeon is usually required in this setting.

Most patients with acute limb ischemia from embolism do not have a history of claudication and have normal pulses in the contralateral, non-affected extremity [5, 8, 16]. Saddle embolism to the aortic bifurcation may result in an absence of palpable pulses in both legs [27]. Acute thrombosis of pre-existing arterial occlusive disease usually occurs in the setting of pre-existing claudication. Physical exam usually reveals diminished pulses in the contralateral extremity and signs of chronic ischemia in the affected extremity. Ankle brachial indices may also reveal contralateral occlusive disease (Table 20.2).

Complete thrombosis of the infrarenal aorta is a rare and usually catastrophic event [28]. Practically all of these patients have significant cardiac disease with poor cardiac output which leads to thrombosis of chronic occlusive disease of the distal aorta and iliac bifurcation. The clinical presentation may include buttock and leg muscle weakness or paraplegia from distal spinal cord and lumbar plexus ischemia. The diagnosis is often delayed because of the baffling constellation of clinical findings despite the fact that physical examination reveals the bilateral absence of pulses from the femoral arteries distally with lower body and leg mottling. The mortality rate in these patients exceeds 50 % [28].

Phlegmasia cerulean dolens presents in the setting of massive lower extremity DVT complicated by arterial vasoconstriction and dehydration [26]. This lower extremity and, rarely, upper extremity syndrome is striking in its appearance with a swollen, blue, and cool to the touch limb [26]. Severe pain is always present. The compelling nature of these findings usually prompts venous duplex studies which confirm the diagnosis.

Doppler assessment of arterial flow in the extremity is an essential adjunctive measure to add to physical examination. Although the experienced examiner can assess flow based on the character of the audible Doppler signals, the best way to use the Doppler device is in conjunction with an extremity systolic blood pressure determination. The manual blood pressure cuff is placed at the wrist or ankle and the probe placed over the distal vessel. The cuff is slowly inflated, and the cessation of signals indicates the systolic blood pressure at the level of the cuff. Normal ankle brachial index (ABI) is 1.1 [6]. Less than 0.8 is abnormal. In general, claudication begins to be significant at that level of reduced flow. Below an ABI 0.5 or an ankle systolic pressure of 60 torr, potentially limb-threatening ischemia begins [6] (Table 20.2).

Once the diagnosis of acute limb ischemia due to a cardiac source embolism is made, there is an important decision to be considered. If the patient with distal limb ischemia has atrial fibrillation, no history of prior claudication or arm exercise intolerance, an otherwise normal peripheral vascular examination with a normal groin or axillary pulse proximal to the ischemic area, and normal contralateral limb pulses, immediate operative exploration for embolectomy is indicated [8]. Prompt CT angiography is indicated if the distribution of emboli is unclear. However, if the patient has pre-existing renal insufficiency, the risk of contrast nephropathy must be carefully considered when considering CT angiography.

Although thrombolytic therapy has been widely advocated in this setting, it does not offer the same prompt removal of the obstructing embolic debris that occurs with immediate embolectomy. Emboli from the left heart usually have a fibrous component that is not fully removed by thrombolysis and suction embolectomy catheters. Fogarty catheter embolectomy may be more effective and expedient. There is a tendency to want to avoid the morbidity of a general anesthetic in elderly patients. This may lead to days of infusing TPA in an ICU setting and, in reality, may involve overall increased morbidity including increased rates of limb loss. The choice of endovascular vs. open revascularization must be carefully made to optimize limb salvage and limit morbidity and mortality [29–34].

Preoperative CT or catheter arteriography is essential in patients who do not have a clearly identifiable cardiac source embolism or an obvious level of arterial occlusion. Acute on chronic occlusion needs to be delineated with detailed arteriography [13]. Although CT angiography may be adequate, catheter arteriography is preferred. In the setting of pre-existing chronic occlusive disease, catheter arteriography also allows for endovascular techniques when appropriate [35, 36].

The most important factor to consider in obtaining arteriography is the time it takes and the potential delay to the operating room. Remembering the "golden period," there must be a rapid workup if arterial flow is to be successfully restored within 6 h. Therefore, if endovascular therapy is not an option, a high-resolution CT angiography should be obtained immediately.

Compartment syndrome should be anticipated in patients with acute limb ischemia [37]. All muscle compartments in the extremities are vulnerable to reperfusion intracompartmental hypertension that can lead to muscle necrosis after revascularization [38]. Compartment syndrome results from post-ischemia swelling of muscle in the confined space created by the muscle fascia in the extremities. This swelling increases the tissue pressure within the compartment compressing the first lymphatic and then venous outflow with eventual occlusion of arteriolar inflow [28]. Ultimately the

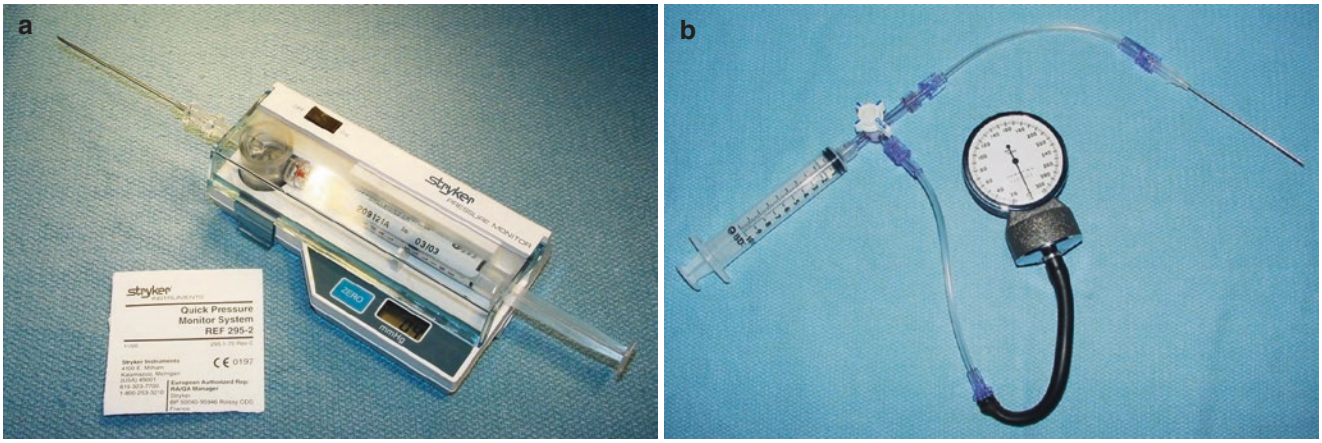

Fig. 20.1 (**a**) Stryker™ pressure-monitoring device for muscle compartment pressure measurement. (**b**) Alternative pressure monitoring device for muscle compartment pressure measurement. The syringe and half of the line to the manometer is filled with saline

tissue perfusion pressure threshold of 25 mm Hg is exceeded, and ischemic neurolysis and myonecrosis occurs. It may take hours to occur after restoration of flow, and therefore serial examinations are essential to prevent delaying diagnosis and treatment. Compartment pressures should be measured with the Stryker device or by other devices (Fig. 20.1). Compartment syndrome occurs most commonly in the muscle compartments of the calf and is relatively uncommon in nontraumatic arterial occlusion in the upper extremity [37].

Endovascular vs. Open Surgical Management

The integrated approach with both endovascular and open vascular surgical technical abilities is essential to the successful management of acute limb ischemia [29, 39]. The decision to choose one over the other method of relieving limb ischemia is dependent not only on the presence of acute vs. chronic vascular occlusive disease but also the status of the ischemic limb. Acute limb-threatening ischemia demands prompt revascularization if amputation is to be avoided. The likelihood and promptness of successful revascularization by either an endovascular or an open approach must guide the decision to go to the angiography suite or the operating room. Although hybrid suites offer both capabilities, decisive action must occur by choosing one or the other modalities and promptly intervening. If endovascular therapy is chosen, the conversion to an open approach must remain an option if further limb-threatening ischemia continues to the point of certain limb loss.

The most common cause of preventable limb loss after successful revascularization in both endovascular and open surgical procedures is failing to perform fasciotomy in the presence of calf compartment syndrome. There is an increased likelihood of failing to diagnose compartment syndrome with endovascular treatment of acute limb ischemia. Careful monitoring of calf compartment pressures and prompt fasciotomy must follow all endovascular procedures for acute limb ischemia.

Open Surgical Management

The performance of emergency vascular surgery should be limited to those surgeons who are capable and qualified. That does not limit these procedures to those who are board certified in vascular surgery. There are many general surgeons who are very skilled in vascular technique by virtue of their interest and experience. There should be a designated call panel for appropriate vascular surgical backup at all times for an acute care surgery service.

The use of checklists to manage acute surgical emergencies is strongly recommended. These are best prepared in advance and should be printed and posted in the operating room. Examples of checklists are provided below, and I recommend each surgeon to create their own version to include their choices for operative management (Figs. 20.2 and 20.3).

The patient should be widely prepped and draped with generous inclusion of the entire upper or lower extremity and the shoulder or lower abdomen. One leg should also be prepped and draped from inguinal region to toes to allow for saphenous vein harvest. Adjunctive measures such as bolus intravenous systemic heparinization, the administration of a continuous infusion of low molecular weight Dextran™, and administration of intravenous antibiotics should be considered and utilized where appropriate. Preparation for surgery should also include appropriate management of associated cardiopulmonary disease by the anesthesiologist.

Surgical exposure requires appropriately placed incisions that provide for exploration and reconstruction. In the

Fig. 20.2 Checklist for femoral thrombectomy for cardiac source embolism and ischemia leg

Checklist – Lower Extremity Thrombectomy Cardiac Source Embolism

1. ***Pull up A-grams on PACS, position patient, EggCrate Feet, TIME OUT, (Start Dextran 40), give antibiotics, choose sutures***
2. ***Decide on early fasciotomy***
3. ***Mark landmarks and sketch incision sites on leg***
3. ***Expose vessels and control with vessel loops***
4. ***Administer heparin bolus 5,000 units***
5. ***Choose transverse vs. longitudinal arterotomy***
6. ***Fogarty catheter thrombectomy proximal and distal vessels***
7. ***Flush with heparinized saline***
8. ***Supplemental dose of 2,500 units of heparin at 50 minutes***
9. ***Close artery (PTFE patch if longitudinal arterotomy)***
10. ***Pulse, Doppler interrogation, on-table agram as indicated***
11. ***If distal occlusion, go to distal popliteal via Medial upper calf incision – repeat steps 5, 6***
12. ***Protamine, hemostasis, close wound, reassess pulses, Doppler if needed***
13. ***Reassess calf muscle compartments, measure pressures, fasciotomy if needed***
14. ***Talk to family, referring MD, and dictate***

Fig. 20.3 Checklist for four-compartment calf fasciotomy

Calf Fasciotomy Checklist

1. ***Mark landmarks and incision lines – note head of fibula and mark 2 finger breadths below for exclusion zone for peroneal nerve safety***
2. ***Skin incisions – full length medial and lateral to create full dermotomy***
3. ***Incise anterior compartment fascia through lateral incision proximally and distally, avoiding peroneal nerve exclusion zone proximally***
4. ***Probe under facia to the tibia to assure in the anterior compartment***
5. ***Release lateral compartment fascia in similar fashion probing under fascia to confirm in proper space posterior to the intermuscular septum***
6. ***Posterior compartment release – generous longitudinal medial incision 2cm behind tibia and avoid the saphenous vein***
7. ***Deep posterior release under direct vision to locate and avoid posterior tibial artery***
8. ***Hemostasis on skin, check muscle contraction with electrocautery in all compartments***
9. ***Place loose moist sponge or kerlex in wounds – wrap leg loosely***
10. ***Recheck perfusion at DP, PT, dictate and complete chart work***
11. ***Reassess wounds for hemorrhage and dressing tension every 4 to 6 hours next 24 hours – avoid recurrent compression from dressings as muscle compartments swell after release***

upper extremity, the axillary artery is exposed by making a transverse infraclavicular incision over the delto-pectoral groove. A muscle-splitting incision is carried down through the pectoralis major muscle. The pectoralis minor muscle is divided close to the coracoid process and the axillary artery and vein exposed where they traverse just below the plane of the muscle. There are cords of the brachial plexus, nerves to the pectoral muscles, and large muscular branches of the artery in this area. Proximal and distal exposure of the artery should be carefully obtained avoiding damage to the brachial plexus and the axillary vein. Silastic vessel loops should be double passed proximally and distally and used to gently occlude the vessel. The artery is relatively fragile, and pulling too vigorously on the vessel loops may fracture the arterial intima causing a dissection. A transverse arteriotomy is performed, and proximal and distal thrombectomy with appropriately sized Fogarty catheters is carried out. A gentle heparinized saline flush (10 units heparin per ml) proximally and distally is performed taking care to not flush air or residual thrombus back up the vertebral arteries or the common carotid artery on the right side which can cause cerebral emboli and stroke.

The brachial artery is best exposed through a longitudinal incision along the medial aspect of the upper arm over the groove between the triceps and biceps muscles. The incision can be extended distally with an "S"-shaped extension across the antecubital fossa from ulnar to radial aspect and onto the forearm to expose the origins of the forearm vessels when the occluding thrombus is located at that level. (See below in Case Presentation 1.)

The location of incisions for acute lower extremity ischemia is determined by the level of the embolic occlusion. If

the acute ischemic episode is due to a thrombosis of severe pre-existing occlusive disease, a bypass graft, or a stented arterial segment, a vascular surgery colleague should be consulted to appropriately manage this complex problem. Iliac or femoral artery occlusion from an embolism is best approached through a longitudinal incision over the common femoral artery in the groin. The common, superficial, and profunda femoral arteries are controlled with Silastic vessel loops. If the common femoral is soft and free of significant atherosclerotic plaque, a transverse arteriotomy is made. If it is not and chronic atherosclerotic changes are present, a longitudinal arteriotomy is the safest approach. Proximal and distal Fogarty catheter thrombectomy/embolectomy is carried out followed by gentle flushing with heparinized saline. The transverse arteriotomy is closed primarily with either a running or interrupted Prolene™ suture. A longitudinal arteriotomy should be closed with a patch angioplasty. Distal flow is assessed by pulse and Doppler examination or, if needed, completion arteriogram. If distal thrombus is present and needs to be removed, a medial longitudinal incision along the posterior aspect of the tibia below the knee provides access to the distal popliteal artery. The exposure of the proximal tibial vessels may be required for distal control and should be carefully performed to avoid injury to the popliteal vein and the tibial nerve (Fig. 20.4). A checklist for management of lower extremity acute ischemia due to an embolism originating from the heart is helpful for even the most experienced surgeon in the management of this problem (Fig. 20.2).

The treatment of phlegmasia cerulean dolens is based on prompt anticoagulation and catheter-directed thrombolytic therapy [26]. Pain management and hydration are also important. An inferior vena cava filter should be placed at the initiation of thrombolysis because of the risk of pulmonary embolism [40]. Open thrombectomy of the common femoral and iliac vein is very infrequently required [40]. At the time of opening the common femoral vein, careful use of a large Fogarty catheter in the iliac vein will retrieve distal thrombus. Wrapping the leg firmly with a sterile elastic bandage will milk out proximal thrombus. Retrograde Fogarty catheter passage down the veins of the leg results in significant damage to the valves and worsens the risk of recurrent thrombosis.

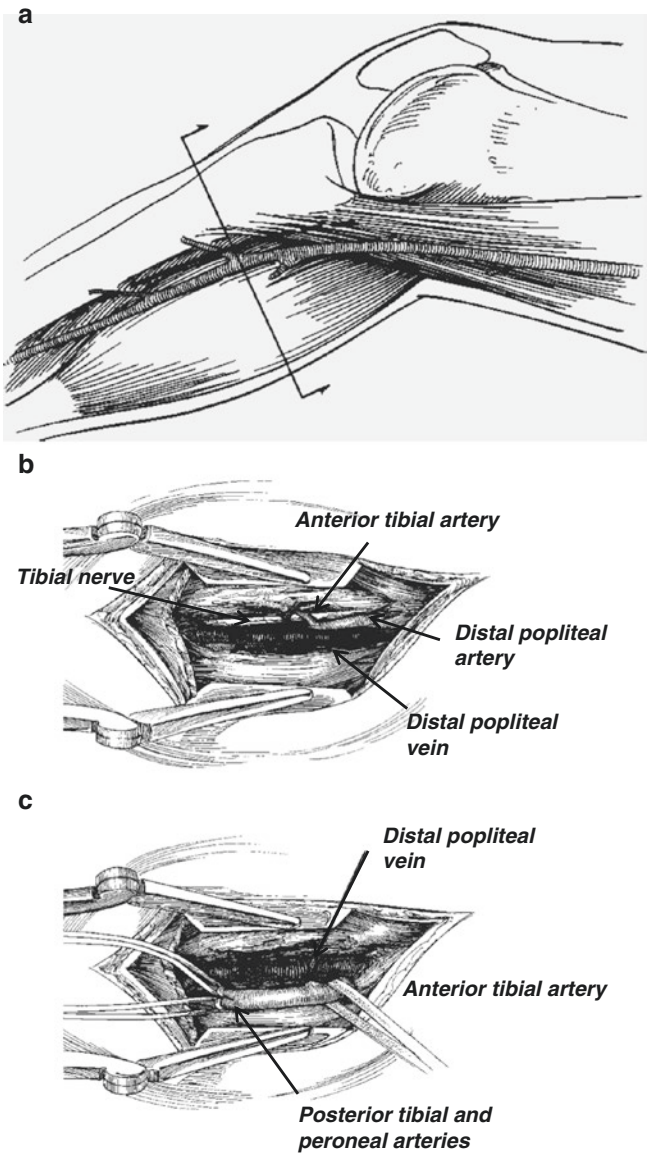

Fig. 20.4 (**a**) Incision for exposure vessels in the upper calf. (**b**) Dissection to expose distal popliteal artery. (**c**). Dissection to expose origins of tibial vessels

Fasciotomy

Failure to perform an adequate fasciotomy when indicated after revascularization of an acutely ischemic limb is the most common cause of preventable limb loss [37, 38]. Calf compartment syndrome is common, and forearm compartment syndrome is relatively rare in nontraumatic acute limb ischemia [37]. Calf fasciotomy, particularly in the setting of prolonged ischemia, must always be considered prior to completion of the operation. Intraoperative compartment pressure measurements may provide decision-making data [37, 38]. However, if normal pressures are initially obtained, eventual reperfusion edema and subsequent swelling may occur with delayed compartment syndrome. Serial postoperative compartment pressure measurements may be required. There are four compartments in the calf that need to be released. These include the anterior and lateral compartments on the anterolateral aspect of the calf and the deep and superficial posterior compartments (Fig. 20.5). The standard approach for release requires two incisions: one on the lateral side and other one on the medial side of the calf [41]

(Fig. 20.6). Although isolated anterior compartment syndrome occurs in some settings, four-compartment release is usually required. A checklist for fasciotomy is strongly recommended and an example is included in Fig. 20.3.

The lateral calf incision should be generous. Start proximally no higher than three to four centimeters below the fibular head in order to avoid the superficial branch of the peroneal nerve. The incision should be taken distally to within three to four centimeters of the lateral malleolus. The fascia of both the anterior and the lateral compartments needs to be incised longitudinally along the muscular septum that separates the two compartments. One must avoid extending the incision beyond the limits of the skin incision proximally to avoid injury to the peroneal nerve. Make certain that the anterior compartment is fully released by palpating the tibia anteriorly under the fascia. Misplacing the incision lateral to the interosseous membrane can lead to not decompressing the anterior compartment with devastating consequences.

The medial incision should be made posterior to the midline of the medial side calf to avoid lacerating the greater saphenous vein. The fascia over the gastrocnemius should be fully incised proximally and distally. The gastrocnemius and soleus muscles are retracted posteriorly in the distal calf to expose the deep posterior fascia. This layer needs to be incised under direct vision to avoid lacerating the posterior tibial artery.

Once all four compartments are adequately released and hemostasis is obtained, a loose dressing is applied. Care should be taken to avoid tight dressings which can recreate the compartment syndrome when muscle swelling occurs. Subsequent wound closure is performed in 2–3 days or when edema has sufficiently resolved. Split-thickness skin graft may be required when a delayed primary closure is not possible.

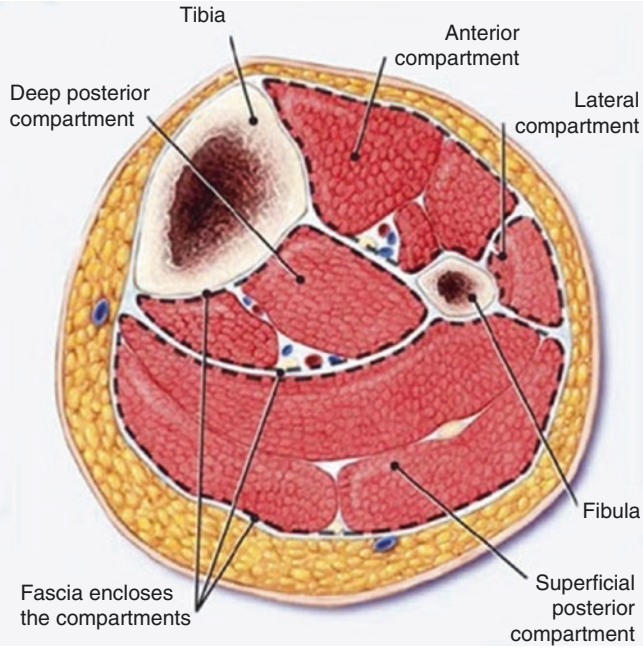

Fig. 20.5 Calf muscle compartments

Postoperative Considerations

Serial examinations after successful restoration of flow are essential to detect re-occlusion or compartment syndrome and promptly treat these limb-threatening complications. These patients usually have significant comorbidities, and postoperative care should include a period of monitoring in the intensive care unit or a specialized telemetry unit. The nursing staff needs to have training and experience in monitoring the perfusion of the distal extremity. Any evidence of recurrent ischemia, operative site hemorrhage, or compartment syndrome should prompt an immediate return to the

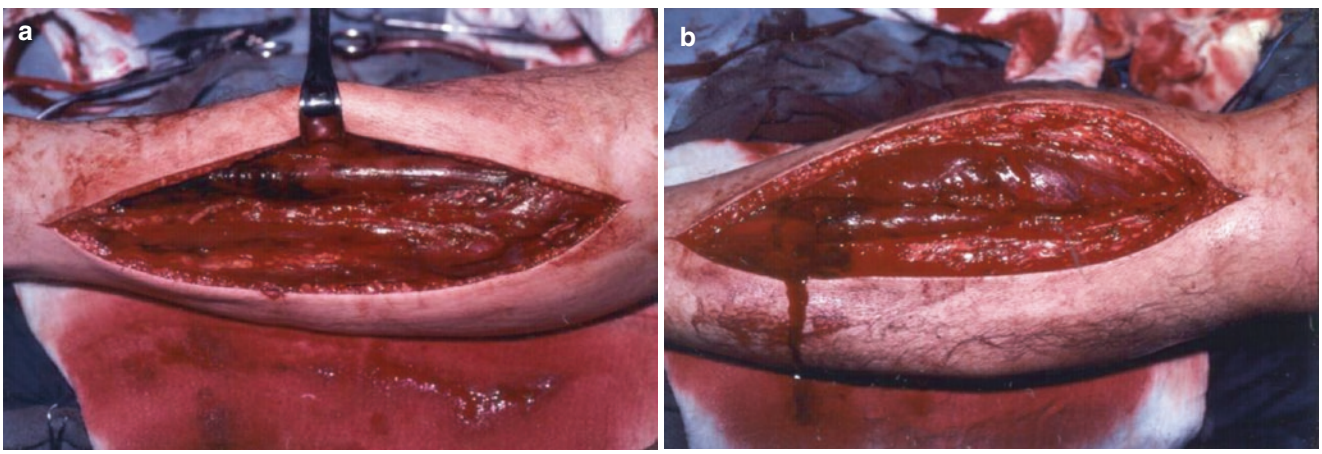

Fig. 20.6 (**a**) Lateral incision for the release of anterior and lateral muscle compartments. (**b**) Medial incision for posterior and deep posterior compartments

operating room. In patients with cardiac source embolism, systemic anticoagulation should be initiated no sooner than 12 h after the operation was finished. The risk of a recurrent embolism outweighs the risk of operative site bleeding. Continuous heparin infusion without a bolus is recommended instead of weight-based subcutaneous fractionated heparin. In the early postoperative period, it is best to preserve the ability to reverse the intravenous infusion of heparin with protamine if needed because of bleeding complications. Once the patient is stable, the subcutaneous fractionated heparin every 12 h and oral warfarin can be administered. Lifelong anticoagulation is recommended in patients with cardiac source embolism.

Acute Mesenteric Ischemia

Acute mesenteric ischemia is a potentially lethal process that requires prompt recognition and treatment for successful management. The mortality rate remains more than 50 %, and there is little room for either delay or errors in management [42, 43]. Symptoms vary from the insidious onset of vague generalized abdominal pain to the sudden onset of severe and constant pain. There are four common causes: cardiac embolism to the superior mesenteric artery, acute thrombosis of a previous partial occlusion from an atherosclerotic lesion, splanchnic vasoconstriction leading to low flow and regional ischemia known also as non-occlusive mesenteric ischemia, and mesenteric venous thrombosis (Table 20.3). Each of these causes is secondary phenomenon which results from other major diseases and occurs in a high-risk setting [44, 45] (Table 20.4).

Pathophysiology

The arterial blood supply of the gut is divided into four areas defined by the arteries which supply them. Collateral perfusion exists for each area (Table 20.5) [46, 47, 53]. In the absence of pre-existing occlusive disease and collateral vessels, the collaterals are not sufficient to provide adequate flow if the superior mesenteric artery is acutely occluded. In chronic mesenteric occlusive disease from atherosclerosis, patients may have total gut perfusion via a single remaining mesenteric artery or the bilateral hypogastric arteries via collateral flow to the other vessels [53]. However, many of these patients have intestinal angina when eating large meals. The venous drainage of the gut is via the portal venous system. Gastric venous drainage is via the splenic vein. The small bowel and the proximal colon through the splenic flexure drain via the superior mesenteric vein. The descending colon drains via the inferior mesenteric vein. Collateral venous vessels are also present and connect each major area.

Cardiac source emboli have a predilection to enter the orifice of the relatively large superior mesenteric artery and then typically lodge distal to the origin of the proximal jejunal branches and the middle colic artery [53]. This gives rise to a pattern of small intestine and colon ischemia with sparing of the proximal jejunum and perfusion of the

Table 20.3 Etiology of mesenteric ischemia

50 %	Arterial embolism
20 %	Arterial thrombosis
20 %	Small vessel occlusion
10 %	Venous thrombosis

Table 20.4 Risk factors for mesenteric ischemia

Arterial embolism or thrombosis
Cardiac disease:
Atrial fibrillation
Recent myocardial infarction
Congestive heart failure
Digitalis therapy
Previous arterial emboli
Hypercoagulable state
Hypovolemia, shock
Venous thrombosis
Portal hypertension
Intra-abdominal inflammation
Trauma or major bowel surgery
Prothrombotic state
Chronic renal failure

Table 20.5 Gut regions, their blood supply, and collateral connections

Region	Blood supply	Collateral connections
Foregut Distal esophagus through the ampulla of Vater in the duodenum	Celiac artery	Pancreaticoduodenal arteries and arc of Buhler distally
Midgut Ampulla of Vater region of the duodenum to splenic flexure of the colon	Superior mesenteric artery	Pancreaticoduodenal arteries and arc of Buhler proximally, marginal artery of Drummond and Arc of Rioland distally
Hindgut Splenic flexure of the colon to distal sigmoid colon	Inferior mesenteric artery	Marginal artery of Drummond and Arc of Rioland proximally Superior hemorrhoidal to middle hemorrhoidal arteries distally
Cloacal derivatives	Branches of the bilateral hypogastric arteries	Middle hemorrhoidal to superior hemorrhoidal arteries proximally

transverse colon and distal colon. Celiac artery emboli are less common as are emboli to the inferior mesenteric artery, and hypogastric artery emboli rarely cause ischemia due to a variety of pelvic collaterals [53].

The clinical manifestations of mesenteric ischemia are the result of insufficient blood flow to meet the metabolic demands of the bowel [46, 47]. The onset of acute ischemia leads to initial hyperperistalsis with gut emptying and vomiting and diarrhea. This is accompanied by intense ischemic pain from gut wall ischemia. This visceral pain is vague and projected across the area of the superficial abdominal wall depending upon the area of visceral innervation [46, 47]. Foregut structures generate pain in the epigastrium, midgut in the periumbilical regions, hindgut in the infraumbilical region, and cloacal derivatives (rectum and genitourinary organs) in the suprapubic region of the abdomen [53]. Visceral ischemia pain is intense and constant and does not increase with palpation nor is it associated with abdominal wall rigidity. This gives rise to the pathognomonic "pain out of proportion to physical findings" attributed to acute mesenteric ischemia [46, 47]. The initial vomiting and diarrhea frequently divert the examining physician's attention to consider other diagnoses 4 [36, 47]. Ultimately, when ischemia leads to necrosis, inflammation of the gut surface leads to abdominal tenderness and associated physical findings of peritonitis. At the point of intestinal infarction, a systemic inflammatory response is initiated with an extremely high associated mortality rate [36, 37]. Elderly patients with this complication typically have cardiopulmonary and other comorbidities which further limit their ability to recover.

Clinical Presentation and Diagnosis

Acute intestinal ischemia from sudden embolic occlusion of the superior mesenteric artery causes the classical findings outlined above. Acute or chronic occlusion of a pre-existing atherosclerotic lesion may lead to a more insidious onset of pain because of pre-existing collateral flow which mitigates the severity of the resulting ischemia [7, 46–48, 51]. There may be a history of intestinal angina (postprandial pain), fear of food, and weight loss. The least common etiology, mesenteric venous thrombosis, causes an insidious onset of initially vague symptoms which worsen progressively over time [54, 55]. Non-occlusive acute mesenteric ischemia from vasoconstriction occurs in the setting of critical illness with reduced cardiac output and is associated with vague symptoms or undetectable symptoms in the intubated patient on a critical care unit.

Atrial fibrillation is the most common etiology of embolism [7, 46, 47]. Patients usually report sudden onset of pain associated with nausea, vomiting, and diarrhea. Mild abdominal distension and hypoactive bowel sounds without abdominal tenderness are the most common initial findings. In patients with acute worsening of chronic mesenteric ischemia, there is frequently a history of postprandial pain, and weight loss occurs in close to 90 % of patients (Table 20.6). Mesenteric venous thrombosis usually is associated with congenital or acquired hypercoagulability and a variety of comorbidities (Table 20.4) [54, 55, 58].

Table 20.6 Common symptoms and findings in patients with chronic mesenteric arterial occlusive disease

1.	Postprandial pain	100 %
2.	Weight loss	85 %
3.	Abdominal bruit	70 %
4.	Nausea, vomiting	60 %

The laboratory studies of patients with acute mesenteric ischemia are initially normal except for an often profound leukocytosis [7, 46]. The white blood cell count is often in excess of 20,000. This finding is an important early indicator and, when present, should prompt the inclusion of acute intestinal ischemia in the differential diagnosis. Metabolic acidosis is a late finding and usually indicates intestinal infarction. Hyperamylasemia and elevated serum lipase may also be seen early in the course of mesenteric ischemia [42, 43, 46, 59].

The best hope for an early diagnosis of acute mesenteric ischemia in patients at risk is a promptly performed CT scan of the abdomen with intravenous contrast. [58, 60, 61] (see Case Presentation 9).This exam definitively rules in the presence of mesenteric arterial and venous occlusion or indicates the presence of one of the other etiologies of these clinical findings. Early discovery with CT scanning allows timely diagnosis before significant bowel compromise occurs [42, 43, 60, 61]. End-stage intestinal necrosis causes severe shock and an overwhelming inflammatory response with an attendant high mortality rate [62, 63]. The outcome of acute mesenteric ischemia has not significantly improved in the last four decades because of the high incidence of both intestinal infarction at the time of diagnosis and the common associated significant comorbidities [42, 43, 46, 64, 65]. The only hope to improve outcome remains prompt recognition, early diagnosis, and successful management prior to the development of bowel necrosis [42, 43, 46].

Management of Mesenteric Ischemia

The overarching principles of management of acute mesenteric ischemia are summarized in Fig. 20.7 [66]. The decision for an immediate open surgical approach versus an endovascular approach is based upon the duration and severity of bowel ischemic, the nature of the occlusive lesion, and the ready availability and the capability of the emergency

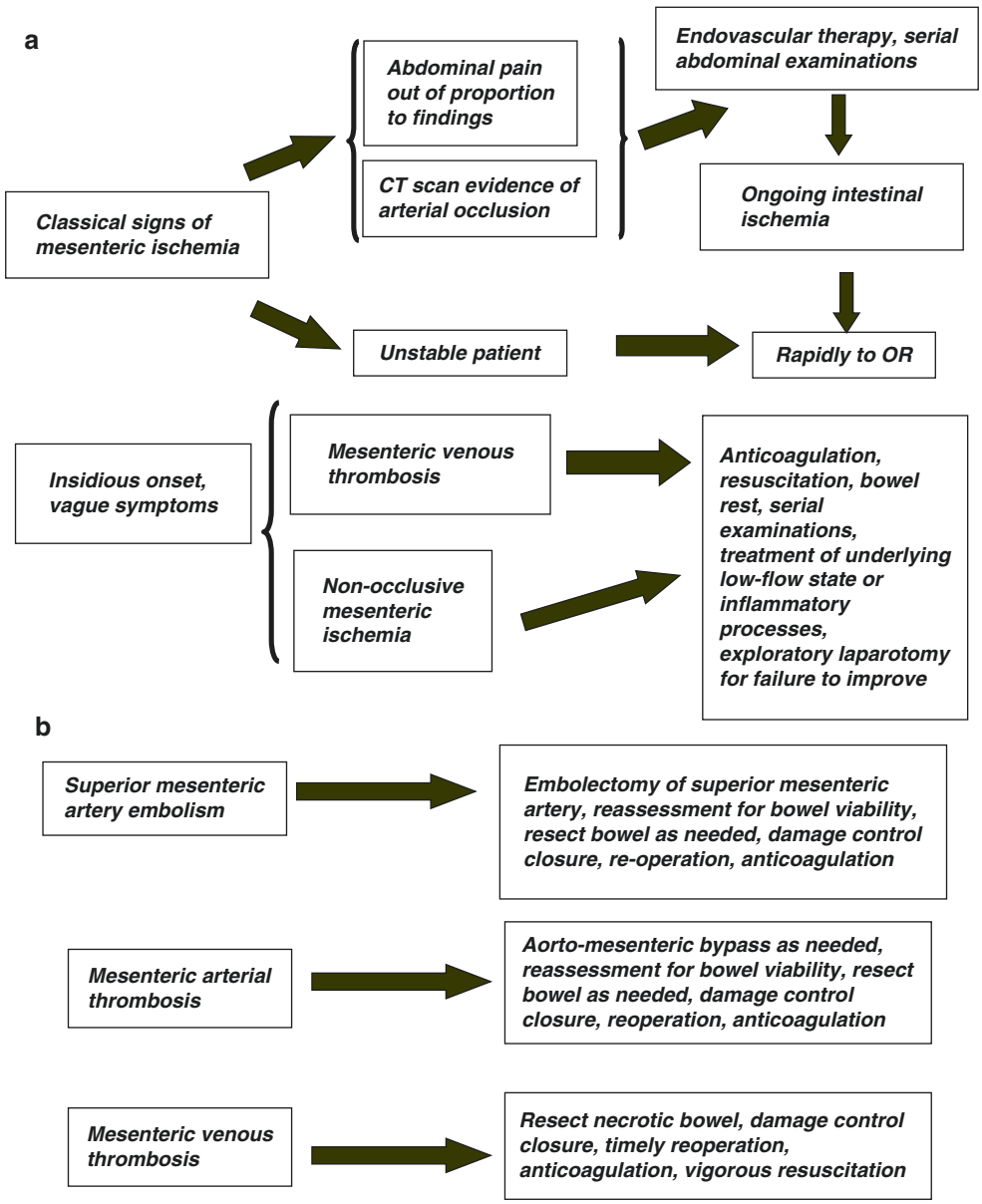

Fig. 20.7 (**a**) Decision-making in the management of mesenteric ischemia. (**b**) Open surgical management of mesenteric ischemia

center's interventional radiology or vascular surgical intervention program [42, 43, 46, 66, 67]. Patients with suspected bowel infarction or impending infarction need to go directly to the operating room for open surgical therapy [43, 67]. Embolic occlusion usually is due to organized cardiac thrombus which is often not amenable to thrombolytic therapy. Prompt operation with superior mesenteric artery embolectomy combined with inspection of the bowel for necrosis is appropriate [43, 68].

Chronic occlusive disease may be managed with endovascular techniques with stenting the mesenteric arterial lesion [46, 47, 69–72]. Thrombolytic therapy has limited application in acute mesenteric ischemia [46, 47, 71, 72]. None of these endovascular techniques should be attempted unless there is an active pre-existing program with adequate personnel, equipment, and timely staffing at the emergency center [73–75]. The risk of bowel necrosis and subsequent peritonitis requires prompt abdominal exploration to assess bowel viability even when arterial flow has been restored by endovascular techniques. Laparoscopy does not have a role in the management of mesenteric ischemia [46, 47, 67, 68].

The celiac and mesenteric arteries originate from the aorta and are closely associated with the renal artery orifices in the upper abdomen. The celiac axis lies just below the aortic hiatus of the diaphragm. The proximal portions of the celiac and superior mesenteric arteries are each covered by a closely applied plexus of lymphatic and neurologic tissue. These vessels are relatively thin walled and must be handled with care. The portal vein and major mesenteric veins are also thin walled and easily torn during exposure.

Intraoperative assessment of intestinal blood flow requires inspection of the entire intestinal tract, assessing color, peristaltic activity, and palpating the mesenteric arteries. The main trunk of the superior mesenteric artery is located by upward retraction of the transverse colon cephalad, downward retraction of the small bowel, and palpation of the root of the mesentery along the inferior margin of the neck of the pancreas. The celiac artery and its branches are palpated through the lesser sac just below the left lobe of the liver. The inferior mesenteric is palpated along the left anterior-lateral area of the infrarenal aorta at the base of the left colon mesentery. Assessment of the mesenteric border of the bowel for Doppler signals aids in the evaluation of questionable perfusion. Angiography with fluorescein and an ultraviolet lamp can be helpful in assessing the return of perfusion [76].

The pattern and appearance of ischemic bowel are essential in determining the cause of mesenteric ischemia if it is first encountered in the operating room [42, 46, 47]. Embolism to the superior mesenteric artery most often lodges in the main vessel distal to the origin of the proximal jejunal branches and the middle colic artery. There is proximal sparing of the jejunum and the transverse colon with ischemia of the remaining small bowel and ascending colon. Superior mesenteric artery occlusion secondary to thrombosis of the origin leads to ischemia throughout its distribution from the duodenum to the splenic flexure of the colon. If the celiac artery and the inferior mesenteric artery are also occluded, more proximal and distal areas of ischemia are encountered. Acute thrombosis of both vessels leads to total intestinal ischemia from the distal esophagus to the rectum.

A transverse incision in the main trunk of the superior mesenteric artery at the mesenteric root below the pancreas is used to remove emboli [47, 77]. This visceral artery is relatively fragile artery and requires careful handling to avoid tears and dissections. Fogarty embolectomy catheters should also be passed gently both proximally and distally to avoid arterial injury. Next, the vessels should be flushed with heparinized saline (10 units of heparin per ml) proximally and distally. Do not flush forcibly proximally in order to avoid dislodging thrombus into the aorta and causing a distal embolism. Closure of the arteriotomy must be done with either running monofilament suture or interrupted sutures. Placing proximal and distal vascular clamps and gently retracting the edges of the vessel wall toward the arteriotomy minimize tension during the closure. Once flow has been reestablished, placing warm laparotomy packs and waiting 10–15 min to reassess are helpful to relieve spasm. Injection of papaverine hydrochloride into the superior mesenteric artery (2 ml of a 30 mg per ml solution) may also reduce vasospasm and improve flow. Planned second-look laparotomy in 24–36 h is prudent unless there is prompt complete restoration of normal intestinal blood flow without questionable areas of perfusion at the initial operation [46, 47].

Proximal mesenteric arterial thrombosis and acute ischemia require experience and skill in advanced vascular surgical technique [46, 47, 69]. It is best to perform an aorto-mesenteric bypass. There are a variety of bypasses described. Although seemingly easier to perform, retrograde iliac artery to mesenteric artery bypass is often more difficult than antegrade supra-celiac aorto-mesenteric bypass and may have inferior results [77–80]. The iliac arteries are often involved with atherosclerotic occlusive disease in this setting. The donor vessel is difficult to sew into, and the bypass is difficult to complete without kinking. This bypass also places synthetic graft in proximity to the duodenum with the risk of eventual erosion and graft infection.

The best choice for restoring flow in acute mesenteric ischemia from proximal mesenteric arterial thrombosis is antegrade aorto-mesenteric bypass from the supra-celiac aorta [78]. This requires exposure of the retro-crural aorta by mobilizing the left lobe of the liver and opening the lesser omentum. The left hepatic lobe is retracted medially and, with the stomach retracted caudally, the crura of the diaphragm divided longitudinally over the aorta to expose the area for the proximal end to side anastomosis. The tunnel for the graft to the superior mesenteric artery at the root of the mesentery is relatively easily made along the left anterior margin of the aorta with gentle blunt dissection behind the pancreas. It is also possible to dissect directly down the superior mesenteric artery behind the pancreas if the stenotic lesion is limited to the ostium. The celiac artery may also be exposed at its bifurcation into the splenic and common hepatic branches for performing a second bypass limb if needed. The patient is systemically heparinized (5,000 unit heparin bolus IV), and proximal and distal occluding aortic clamps are placed. Partial occluding clamps should be avoided since they may damage the aorta or cause distal emboli. The distal anastomoses are performed end to side with careful flushing and, if indicated, balloon catheter thrombectomy. The bowel is inspected for viability once the flow has been reestablished (see description above).

The management of the bowel after restoration of arterial blood flow in acute on chronic occlusive lesions should be conservative [2, 45–47, 68]. Obviously necrotic bowel should be resected by stapling and dividing at healthy margins and anastomosis of bowel segments deferred until reoperation at 24–36 h to make certain further necrosis does not occur. Temporary abdominal wall closure followed by prompt transfer to the intensive care unit for postoperative critical care management should happen expeditiously. Early anticoagulation with intravenous heparin should be added despite the risk of operative site hemorrhage in order to prevent re-thrombosis of mesenteric vessels.

Mesenteric venous thrombosis leading to bowel necrosis is insidious in its onset and much more difficult to manage than arterial sources of mesenteric ischemia [54, 55]. By the

time intestinal infarction occurs from venous engorgement and impeded arterial flow, there are few options that will relieve venous congestion. If early diagnosis and prompt treatment with anticoagulation, bowel rest, and adequate volume resuscitation are achieved, nonoperative management is effective and highly preferred [81]. Mesenteric and portal venous thrombectomy is dangerous and not effective. Systemic anticoagulation, coupled with resection of necrotic bowel, and aggressive resuscitative measures are all essential for optimal management. Multiple reoperations to reassess bowel for viability are often required. Patients who survive extensive bowel resection for mesenteric venous thrombosis are often left with short-gut syndrome [82].

Summary

Successful management of acute limb ischemia and acute mesenteric ischemia requires prompt recognition and timely treatment. There is a period of approximately 6 h of acute ischemia after which permanent nerve and muscle damage in the extremity and bowel necrosis in the abdomen occurs and the threat of limb loss increases as does the risk of an overwhelming intra-abdominal catastrophe. CT or catheter arteriography should be promptly obtained only when necessary but should not delay operative management. Carefully chosen incision sites and proper vascular technique are required. Fasciotomy should be considered in the setting of prolonged extremity ischemia or when compartment pressures compromise venous flow. Planned second-look laparotomy is the mainstay for the successful management of acute mesenteric ischemia. There is a role for the use of checklists to help minimize errors in the management of these critically ill patients.

Illustrative Case Presentations

Case 1

History: An 87-year-old male retired physician with atrial fibrillation on warfarin has sudden onset pain and paralysis on the right forearm 3½ h earlier and presents to the emergency department. Past history hypertension, hyperlipidemia, CABG 12 years ago, open prostatectomy 5 years age. Other meds include beta-blocker, statin, and antihypertensive. No prior events similar to this. Lives a very active life style – hunting, fishing, and volunteering at his church.

Exam: BP 140/70, HR 70 and irregular resp 18, and temp 37 C. Absent pulses, paralysis, and paresthesia on the right forearm, palpable right axillary pulse but not pulse at antecubital fossa. Normal pulses on the left arm and both legs. EKG: atrial fibrillation, no other findings. Chest X-ray is normal. CBC and chemistry panel are normal. INR is 1.5.

Decision-making: This patient has a history and physical examination strongly suggesting brachial artery embolism with limb-threatening arm ischemia. Peripheral pulse examination is otherwise normal. It is now approaching 4 h since the onset of symptoms. Imaging studies are not necessary with this straightforward presentation and may waste time. This patient needs to go promptly to the operating room for expeditious thrombectomy. However, if the distribution of ischemia is not clear or if proximal pulses are absent, CT angiogram of the upper extremity would be appropriate and can be rapidly performed. Preoperative preparation should include administration of an IV bolus of 5,000 units of heparin as soon as possible.

Operative management: Sterile prep and drape right arm and axilla. Draw an S-shaped course for the incision from the distal brachial artery course across the antecubital fossa with a marking pen. Begin with a longitudinal incision over the distal brachial artery above the antecubital fossa (Fig. 20.8).

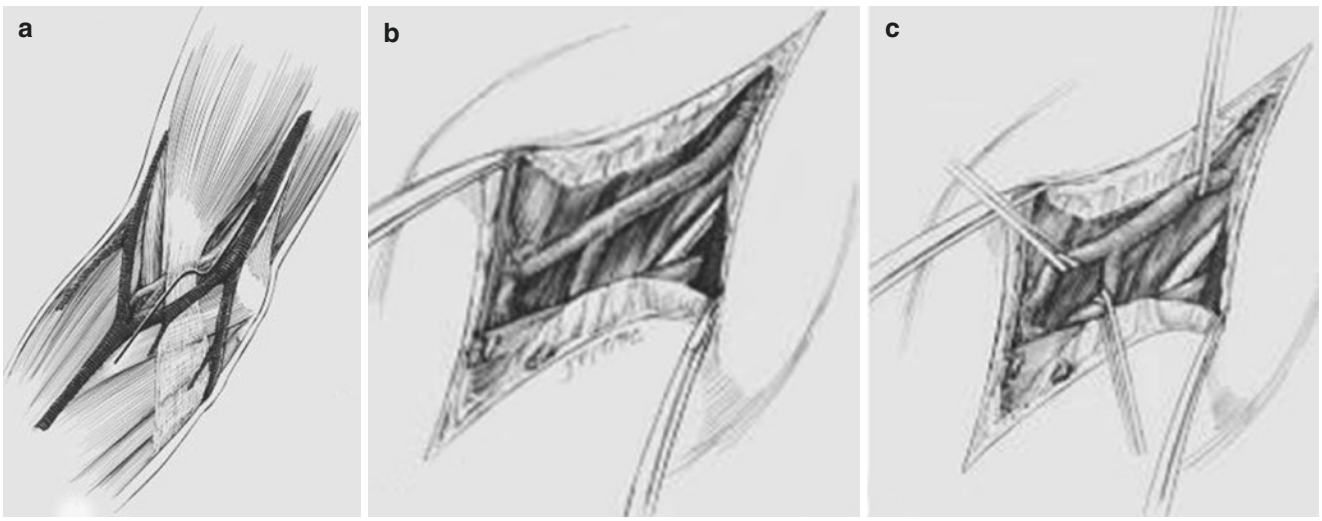

Fig. 20.8 (**a**) Course of incision to expose distal brachial artery. (**b**) Divided flexor aponeurosis and brachial bifurcation. (**c**) Vessel loop control of brachial, ulnar, and radial arteries

A transverse incision is made in the distal brachial artery. Local Fogarty catheter thrombectomy is performed proximally and distally into all vessels with adequate flushing of all embolic material. Heparinized saline (10 u heparin per ml) is flushed taking care to limit infusion volume proximally to avoid air and debris flushing into the origin of vertebral artery with the risk of stroke. Arteriotomy should be closed with a running 5-0 or 6-0 Prolene suture.

Distal pulses and Doppler flow assessed and found to be normal and wound closed primarily.

Postopertive plan: Serial right arm pulse examinations, neurologic examinations, and assessment muscle compartments in addition to inspection of wound site for presence of hematoma. Plan to begin continuous heparin infusion without a bolus at 8–12 h. Begin warfarin at postoperative day 2 if operative site is stable. Consult cardiology and patient's primary physician and discuss concerns that patient be kept in therapeutic range with anticoagulant therapy.

Outcome: Fully recovered without neurologic deficit and with normal upper extremity blood flow.

Case 2

History: A 74-year-old male on the ICU post-op resection diverticular abscess with septic shock and cold right leg with faint Doppler tones. Patient sedated with mechanical ventilation, weaning off pressors. Had work up for claudication with arteriogram 8 months ago. Told to quit smoking, take cilostazol, and walk regularly. Arteriogram from 8 months ago on PACS reveals superficial femoral artery occlusion with traceable collateral flow to the proximal popliteal artery (Fig. 20.9).

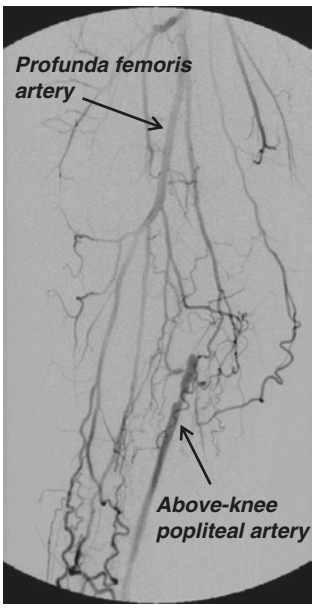

Fig. 20.9 Arteriogram from 8 months earlier with collateral flow to popliteal artery from profunda femoral artery branches

Exam: BP 100/70, HR 110 on SIMV mode ventilation, and temp 38 C. Absent pulses, cool somewhat mottled legs bilateral. Absent pulses below the femoral level bilaterally. Brisk Doppler flow on the left, diminished flow on the right. Ankle brachial index 0.5 on the right and 0.08 on the left.

Decision-making: Patient has history and physical examination strongly suggesting chronic pre-existing occlusive disease on the right leg with vasoconstriction of collateral flow due to critical illness and vasoconstricting drug therapy. This is near limb-threatening ischemia and needs to be promptly addressed with medical management before tissue loss occurs.

Management: Optimize fluid resuscitation and cardiac output. Actively wean from pressor agents as soon as possible. Keep feet well-padded and avoid pressure lesions. Preform serial examinations with Doppler pressures.

Outcome: Slow but steady recovery without tissue loss. After discharge, claudication stable.

Case 3

History: A 67-year-old woman on warfarin for recurrent DVT now has sudden onset 4 h ago of severe pain and marked weakness in both legs. The INR is 2.5.

Exam: BP 120/70, HR 100 and regular resp 28, temp 37 C, O_2 saturation 92 % on mask O_2, absent pulses, paralysis, pallor, and paresthesia on both legs.

Decision-making: Is this aortic dissection, massive cardiac source arterial embolism, or thrombosis of the aorto-iliac segment, or is there some other cause? Patient has history of DVT and now apparent acute limb ischemia. Recurrent DVT can cause pulmonary hypertension which opens a previously physiologically sealed but anatomically patent foramen oval (present in 15 % of adults) leading to a right to left atrial shunt and access to the systemic circulation for the next venous thromboembolic episode. Paradoxical embolism must be ruled out with CT angiogram of the aorta and of the pulmonary vasculature. CT scan reveals the presence of both saddle pulmonary embolism and aorto-iliac embolism (Fig. 20.10).

Operative management: Patient at risk for both fatal pulmonary embolism and limb-threatening ischemia. Immediate operative thrombectomy through bilateral common femoral artery exposures is required. After restoring flow, compartment pressure needs to be measured in both calves to assess for compartment syndrome. Immediately after completion of the operation, an inferior vena cava filter should be placed. Intravenous heparin administration should be promptly.

Postoperative plan: Serial examinations and, if indicated, repeat calf compartment pressures should be performed. The patient will need lifelong anticoagulant therapy. If not already completed, a thorough work-up for underlying hypercoagulation syndrome also needs to be done.

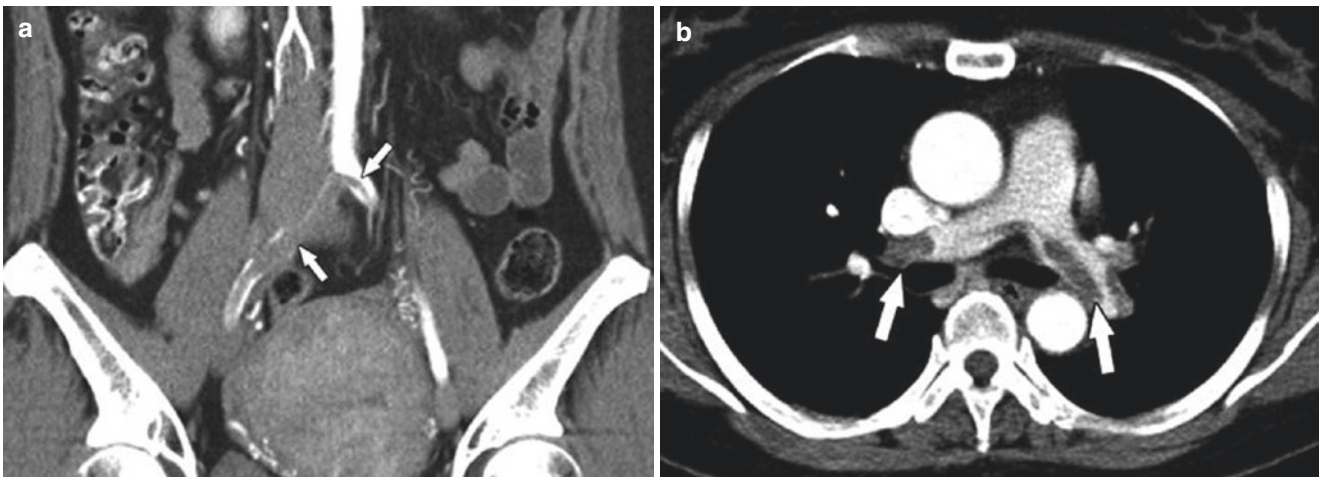

Fig. 20.10 (**a**) CT angiogram reveals a saddle embolism at the aortic bifurcation. (**b**) CT angiogram of the chest reveals large bilateral pulmonary emboli

Outcome: Successful thrombectomy. Discharge on warfarin and bridging enoxaparin 1 mg per Kg q12 h. Long-term follow-up for postphlebitic syndrome legs and disciplined use of support stocking and elevation extremities.

Case 4

History: A 67-year-old retired female teacher who presents to the emergency department with 2-day history of severe left calf claudication at less than a block. History of hypertension, hyperlipidemia, and smoking. Past CABG for three vessel coronary artery disease. She had 2–3 block bilateral calf claudication prior to this event. At rest she had no symptoms.

Exam: BP 150/80 HR 60 and regular. Absent pulses below femoral level left leg and decreased capillary fill left foot. Ankle brachial index is 0.48.

Decision-making: This is a sudden acceleration of symptoms which suggests acute on chronic occlusive disease. The ankle brachial index suggests significant occlusive disease but not limb threatening.

Management: Arteriography will be needed to delineate arterial anatomy and plan therapy. It may be possible to perform an endovascular intervention to relieve this acute event.

Outcome: Successful angioplasty and resolution of left calf claudication (Fig. 20.11). Patient discharge on clopidogrel, cilostazol, and nicotine patches with counseling on smoking cessation. Exercise program initiated and patient followed regularly assess progress.

Case 5

History: A 72-year-old man on warfarin for atrial fibrillation presents to the emergency department with 4 days of right leg pain and paralysis. Wheelchair bound for 5 years from right hemisphere stroke and left hemiparesis. History of coronary artery disease, congestive heart failure, and diabetes. The patient has an advance directive indicating no CPR.

Exam: BP 110/70 HR 100 and irregular. Paralysis, pallor, absent pulses throughout right leg, and absent Doppler signals at popliteal and pedal level. Firm, tender muscle compartments on right calf and paresthesia on both legs. CPK over 50,000 IU/L and myoglobin present in urine. CT angiogram reveals complete occlusion left external iliac, common femoral, superficial femoral, and popliteal arteries with few collaterals. The patient is not communicative and is disoriented.

Decision-making: This is advanced ischemia of many days duration and is not compatible with limb salvage. Left untreated, this patient will die of the systemic efforts of massive muscle necrosis. The only treatment option would be a high above-knee amputation. However, with his advanced cardiac disease, hemiparesis, and limited life expectancy, discussion of goals of therapy with the patient and his family is essential. Comfort care may well be the most appropriate treatment.

Management: You meet at length with the family reviewing the patient's course to this point and the trajectory of his decline explaining that this would have happened sooner or later given the severe nature of his health problems. You query them regarding the patient's wishes, and they state that he did not want care that wouldn't lead to his recovery. You counsel them that the prognosis is extremely poor no matter what medical or surgical choices are pursued and that it is best to begin comfort care.

Outcome: Patient chooses comfort care and is transferred to hospice dying with family in attendance 3 days later.

Case 6

History: You are called to the recovery room by an orthopedic surgery colleague who has completed a redo right hip replacement in a 75-year-old woman with degenerative joint disease 2 ½ h ago. Her right leg is now cool, painful,

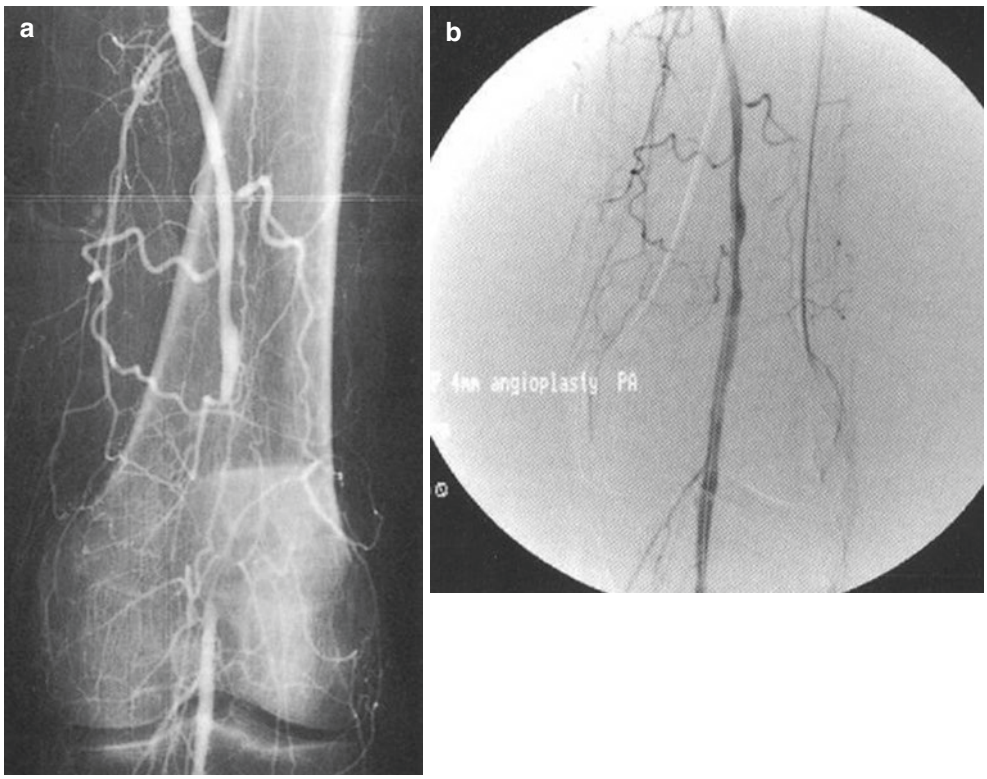

Fig. 20.11 (**a**) Catheter angiogram reveals proximal short-segment popliteal occlusion. (**b**) Short-segment angioplasty and stent placement

paralyzed, and pulseless. The patient has a history of hypertension, hyperlipidemia, and breast cancer. There is no history of calf claudication.

Exam: BP 145/80 HR 75 and regular. Absent pulses at the femoral level and below the right leg and blanched appearing foot. Pulses are present and normal throughout the left leg. There are no Doppler tones at the femoral level and below in the right leg.

Decision-making: This is an apparent total occlusion of the femoral artery caused by the operative procedure. It is now well into the 6 h "golden period," and flow needs to be reestablished ASAP in order to prevent nerve and muscle tissue loss and possible limb loss. The proximity of the acetabulum to the femoral vessels places them at risk for intraoperative trauma. CT or catheter arteriography is not necessary and time consuming. The absence of a history of calf claudication and the presence of normal pulses in the contralateral leg suggest that the vessels were patent with significant chronic occlusive disease prior to this event. Immediate return to the operating room for exploration of the femoral artery and fasciotomy are called for.

Management: The patient is given an intravenous bolus of 5000 units of heparin and promptly returned to the operating room. The patient is prepped from the umbilicus to toes on the right and mid-thigh on the left. The femoral vessels are exposed through a longitudinal incision, and the common femoral artery is found to be thrombosed with a through and through penetration from one of the sharp-ended acetabulum retractors (Fig. 20.12). A longitudinal artery is performed, and there is a moderate-sized posterior atherosclerotic plaque with extensive disruption and thrombosis. Fogarty catheter thrombectomy yields a moderate amount of thrombus from the superficial and profunda femoral arteries. A PTFE interposition graft is placed from the proximal common femoral artery to the bifurcation (Fig. 20.13). Intraoperative Doppler and pulse examination reveal flow throughout the right leg.

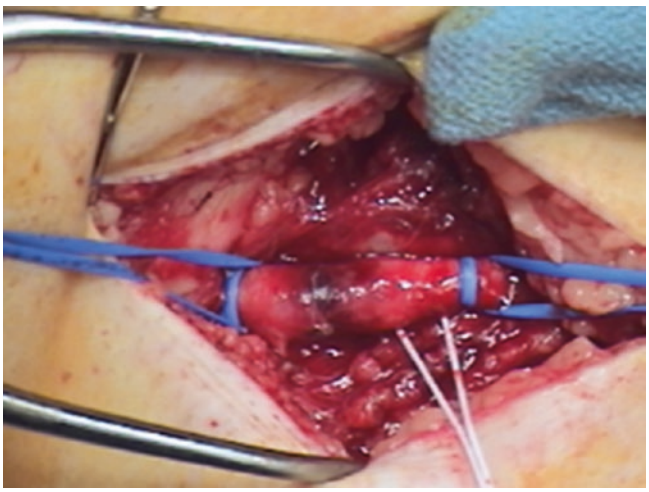

Fig. 20.12 Common femoral artery with perforation and thrombosis from a sharp-ended retractor used in the acetabulum during hip replacement (*Left* is proximal, *right* is distal)

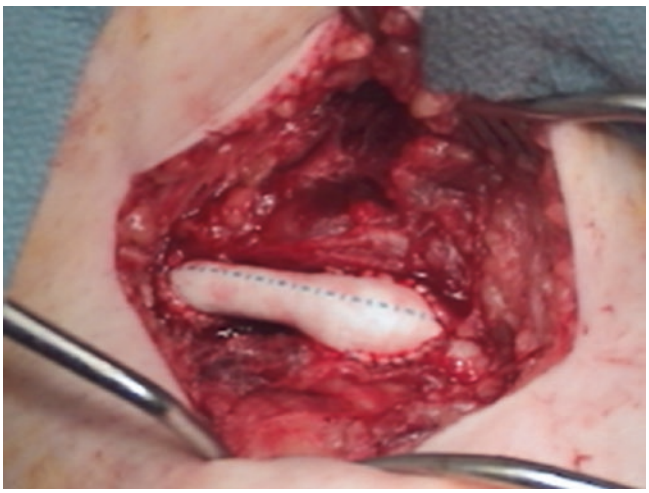

Fig. 20.13 PTFE interposition graft from common femoral (*left*) to the bifurcation at the origins of the superficial femoral and profunda femoral arteries (*right*)

Four-compartment fasciotomy of the calf is performed through generous medial and lateral incisions.

Outcome: The patient recovers after closure of calf fasciotomy wounds with a skin graft over the lateral incision and primary closure of the medical incision at 72 h. You compliment your colleague's prompt recognition of this complication to the patient and her family and follow closely throughout her hospital stay. She is satisfied with her care and continues to be followed by you and your colleague as an outpatient.

Case 7

History: You are called by a cardiologist colleague to evaluate a 66-year-old man who underwent a coronary angioplasty via a right femoral access site for a STEMI 2 h ago. His right leg is now cool, painful, paralyzed, and pulseless. The patient has a history of smoking, hypertension, hyperlipidemia, and non-insulin-dependent type II diabetes. There is also a history of bilateral calf claudication. The patient has been given Plavix and is on an eptifibatide drip.

Exam: BP 140/70 HR 60 and regular. Absent pulses at the femoral level and below the right leg and blanched appearing foot. Pulses are present at the left femoral artery but absent at the popliteal and pedal level in the left leg. There are no Doppler tones at the femoral level and below in the right leg. There are Doppler tones present throughout the left leg and the left ankle-brachial index is 0.65.

Decision-making: This is an apparent total occlusion of the femoral artery caused by the interventional cardiology procedure. It occurred in the setting of pre-existing arterial occlusive disease. It is unclear what the site of occlusion is – at the site of catheter entry or more proximal in the iliac artery. A clear delineation of arterial anatomy is essential to successful management. The patient needs an immediate catheter aorta-iliac and runoff arteriogram. Also, endovascular management is a possibility at the time of arteriography. Operative management, if required, must occur promptly after arteriography to avoid limb-threatening ischemia.

Management: The patient is given an immediate intravenous bolus of 5000 unit heparin and undergoes arteriography at 3 h status postcoronary stent placement. There is an occluded proximal right external iliac artery which appears to have a dissection plane. A wire crosses the occlusion and a covered stent is placed. Distally, there is a patent common femoral artery and a profunda femoral artery. The superficial femoral artery is occluded but collaterals from the profunda femoral artery promptly fill the proximal popliteal artery. There is no distal thrombotic material seen, and you conclude this is due to the powerful antiplatelet agents the patient is receiving as part of the STEMI protocol. After the completion of the arteriogram and covered stent placement, the patient has no pain in the right leg and has a normal right leg neurologic examination. The right ankle-brachial index is 0.75.

Outcome: The patient is discharged home in 2 days, quits smoking, and is placed on a walking program. His walking tolerance improves.

Case 8

History: A 65-year-old male in the emergency department with painful severely swollen left leg with deep bluish discoloration. First noted rapid onset left leg swelling 3 days ago and noted rapid worsening last 12 h. Four weeks earlier, he was riding a horse and had his left leg pinned between the horse and a gate post with a large resulting thigh and calf hematoma. Patient has a history of hypertension, hyperlipidemia, and smoking.

Exam: BP 130/80, HR 90, resp 25. Markedly swollen left leg with bluish discoloration. Foot cool no palpable pedal pulses, markedly diminished arterial Doppler flow signals at foot. Duplex scan reveals extensive popliteal, femoral, and iliac venous thrombosis.

Decision-making: Patient has history and physical examination consistent with massive venous thrombosis, marked entrapment of venous blood, pain, and arterial vasoconstriction – all the elements of phlegmasia cerulean dolens. This uncommon syndrome is the result of untreated lower extremity DVT with extension into the iliac vein. The patient needs immediate anticoagulation, pain management, hydration, and limb elevation. There is also a role for direct intravenous thrombolytic therapy. Failure to respond to thrombolysis in the first 8–12 h should prompt venous thrombectomy at the common femoral vein in the groin. Left untreated, the rate of limb loss and eventual death from the systemic effects of tissue necrosis. Both thrombolytic therapy and operative thrombectomy should be accompanied by inferior vena cava filter placement because of the high risk of pulmonary embolism.

Management: Immediate bolus IV administration of 10,000 units of heparin, infusion of 2 l of normal saline, intravenous pain management with a PCA pump, and elevation of the left leg with admission to the ICU are accomplished. Within 90 min, the patient has placement of an IVC filter an internal jugular vein site and the initiation of thrombolysis via both a popliteal vein access site and a common femoral site.

Outcome: The patient immediately has relief of pain, and the deep bluish discoloration steadily decreases over the first day. Pulses are palpable at the ankle by 2 h. It takes 3 days of thrombolysis to clear all but a persistent area of thrombus in the below-knee popliteal vein. Work-up for thrombophilia fails to identify an underlying cause. The patient begins enoxaparin 1 mg per kg q12 h and warfarin at the end of the thrombolytic therapy. Life-long warfarin is planned and the filter is left in place. On discharge, the patient begins wearing a below-knee support stocking with instructions to use it daily and keep renewing the prescription to keep appropriate compression

Case 9

History: A 73-year-old male first seen in the emergency department with severe abdominal pain of sudden onset first noted 6 h ago. CT scan reveals an abrupt cut off of flow in the main trunk of the superior mesenteric artery (Fig. 20.14).

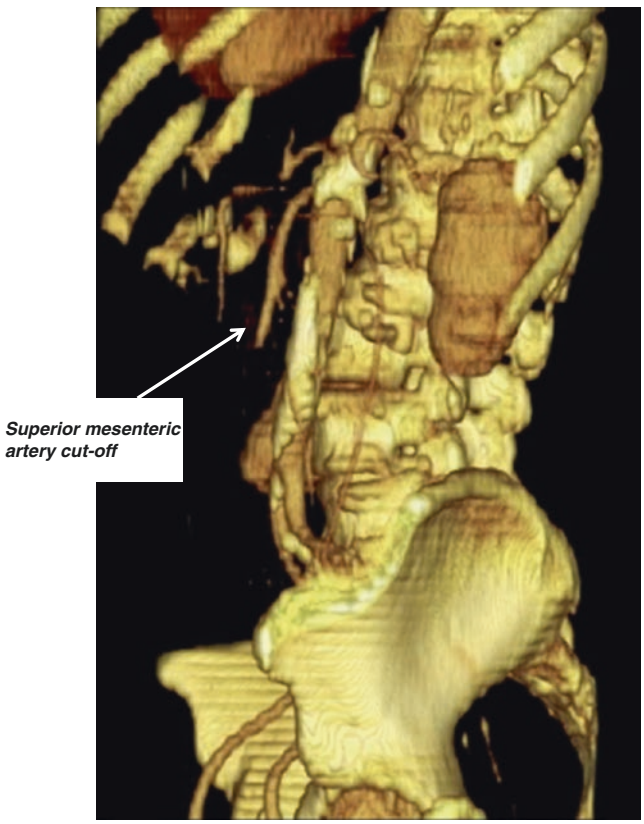

Fig. 20.14 CT angiogram VTR view of abdomen revealing occluded superior mesenteric artery

Patient has a history of hypertension, hyperlipidemia, and smoking. Patient denies chest pain, past history of myocardial infarction, and has no history of cardiac arrhythmias.

Exam: BP 140/80, HR 95 and irregular resp 25. Abdomen mildly distended and diffusely tender to palpation without signs of peritoneal irritation. Peripheral pulses in the extremities are normal. EKG reveals atrial fibrillation.

Decision-making: Patient has history, physical examination findings, and CT scan consistent with cardiac source embolism to the superior mesenteric artery. The time since onset of symptoms and physical examination findings are worrisome for impending bowel infarction. The patient should go directly to the operating room for thrombectomy of the superior mesenteric artery and evaluation of the bowel for viability.

Management: Immediate bolus IV administration of 5,000 units of heparin and transfer to the operating room for expeditious exploratory laparotomy. Superior mesenteric thrombectomy needs to be performed through a transverse incision. The anesthesiologist needs to be prepared to deal with the systemic effects of an introduction of the products of prolonged ischemia from the bowel when it is reperfused. The bowel should be inspected after 15 min of application of warm packs. Necrotic areas should undergo damage control resection without anastomosis. Damage control closure should be performed and a heparin drip stated. Reoperation at 24–36 h will be needed to reassess bowel viability. The patient will require lifelong warfarin.

Outcome: The patient has a brief period of hemodynamic instability after reperfusion of the gut. There are a few questionable areas of bowel perfusion. At 30 h the bowel has all reperfused and no resection is required. The abdomen is closed. The patient has evidence of a non-STEMI myocardial infarction by cardiac enzyme determination after the first operation but remains hemodynamically stable. A cardiac catheterization is performed and a stent placed in the right coronary artery distribution. The patient is discharged to a rehabilitation facility on warfarin at 2 weeks.

Case 10

History: A 67-year-old female in the emergency department with vague abdominal pain and nausea and vomiting for the third time in 3 weeks. She suffered from a bout of apparent viral gastroenteritis approximately 1 month ago. Patient has been healthy in the past. Family history is positive for a brother who died from pulmonary embolism following a femur fracture. WBC 25,000. CT scan reveals a partial occlusion of the superior mesenteric and portal vein with thrombus.

Exam: Vital signs are normal. Abdominal exam is unremarkable.

Decision-making: This patient has mesenteric venous thrombosis. The paucity of abdominal exam findings and leukocytosis with the CT scan findings are typical of this

diagnosis. The prodrome of an inflammatory bowel condition like viral gastroenteritis is also common. The positive family history for venous thromboembolic disease suggests an inherited hypercoagulability. Factor V Leiden is the most likely inherited disease associated with these complications. The late onset is suggestive of the heterozygote state for this patient rather than the homozygote pattern of early thrombotic complications.

Management: This patient needs hospital admission, immediate systemic anticoagulation, hydration, and bowel rest. Serial abdominal examinations are essential to detect intestinal complications related to venous congestion and infarction. The patient should be given an intravenous bolus of 5,000 units of heparin and a continuous heparin infusion. A generous infusion of normal saline should be started and a urinary catheter placed to monitor output. Pain should promptly decrease with anticoagulation and hydration. Continued pain is worrisome for bowel inflammation and impeding infarction. For the first 72 h, the patient should receive nothing by mouth. Serial abdominal examinations are required to make certain that bowel inflammation is not progressing. Any hemodynamic instability or signs of peritoneal irritation would indicate bowel infarction and should prompt immediate exploratory laparotomy. However, with appropriate anticoagulation and bowel rest, intestinal infarction is unlikely in patients who have the diagnosis made in a timely fashion. A work-up for hypercoagulability should be performed on this hospitalization, and the patient should be placed on lifelong warfarin prior to discharge.

Outcome: The patient resumes oral intake with a clear liquid diet at 72 h and is counseled to eat frequent small meal for the next 6–8 weeks. Work-up reveals that she is heterozygous for factor V Leiden. She recovers and continues warfarin. Her surviving siblings are tested, and one is also heterozygous for factor V Leiden. That sister is referred to a hematologist for counseling and treatment.

Case 11

History: A 71-year-old male with severe pneumonia on the ventilator in the medical ICU for 5 days. Patient also has significant coronary artery disease and has required intravenous pressors during septic episodes. The patient has abdominal distension and underwent a CT scan with contrast which shows patent mesenteric arteries but an ischemic pattern in the small bowel.

Exam: BP 90/50, HR 95, resp 18 (ventilator). Abdomen mildly distended and mildly tender to palpation without signs of peritoneal irritation. Peripheral pulses in the extremities are reduced but brisk Doppler tones present with patient on intravenous dopamine drip. WBC is 22,000; the serum amylase is elevated; and arterial blood gases reveal a mild metabolic alkalosis and marginal oxygenation.

Decision-making: Patient has history, physical examination findings, and CT scan consistent with low cardiac output visceral vasoconstriction and "non-occlusive" mesenteric ischemia. The examination and laboratory results suggest low visceral blood flow and the risk of infarction. The optimization of cardiac function and improved visceral perfusion is the best option to prevent the devastating complication of bowel infarction. This patient needs aggressive critical care management. Progression to bowel infarction in a patient with severe pneumonia and compromised cardiac function is almost always lethal.

Management: The medical critical care team boluses intravenous fluids, weans pressors, and begins a heparin infusion at your suggestion. You follow closely for signs of worsening.

Outcome: The patient steadily improves and is weaned, undergoes percutaneous tracheostomy, and eventually weans from mechanical support. He is transferred to a rehabilitation facility 2 weeks later.

Case 12

History: An 83-year-old female first seen in the emergency department with severe diffuse abdominal pain of gradual onset 8 h ago. She has an 18-month history of postprandial pain and has lost 25 pounds of weight. She also had hypertension, hyperlipidemia, past myocardial infarction, and smokes a pack of cigarettes every 2 days. She also has claudication in both calves at two blocks. WBC is 27,000, and CT scan reveals severe aorto-mesenteric calcification with occlusion of the celiac artery and a long severe stenosis of the proximal superior mesenteric artery. There is diffuse distal aorta and iliac artery atherosclerotic plaque and tandem stenoses.

Exam: The patient is a very thin woman with little body fat. BP 140/80, HR 95, resp 25. Abdomen mildly distended and diffusely tender to palpation without signs of peritoneal irritation. Peripheral pulses in the extremities are diminished, but Doppler tones are present. EKG reveals atrial fibrillation.

Decision-making: Patient has history, physical examination findings, and CT scan consistent with acute on chronic mesenteric ischemia. Her history of postprandial pain and weight loss is typical of this disease which is progressive and carries a high mortality because of the associated cardiac disease. She is at a significant risk of intestinal infarction and needs prompt restoration of adequate flow. This presentation does not yet indicate the risk but probably not the presence of infarction, and catheter arteriography allows to delineate arterial anatomy and possible endovascular therapy. Open therapy with mesenteric artery bypass will be required if endovascular therapy is not possible. Exploratory laparotomy may also be required with successful endovascular therapy if there is a suspicion of bowel infarction.

Management: Immediate bolus IV administration of 5,000 units of heparin and transfer to the interventional

radiology suite for arteriography. Superior mesenteric artery stenosis is successfully relieved with a stent, and there is evidence of flow to all major areas. The patient is admitted to the surgical intensive care unit. Three hours later, she is febrile and abdominal pain and tenderness have increased. Exploratory laparotomy is performed because of the suspicion of bowel infarction. A 20-cm segment of distal ileum and the cecum is found to be infarcted and is resected with stapled ends of bowel left, and a damage control closure is performed. The patient is returned to the operating room at 28 h and bowel anastomosis performed with closure of the abdomen.

Outcome: Patient requires a subsequent 2-week hospitalization. Although the patient has cardiac enzyme elevation and evidence of a non-ST segment change myocardial infarction, she recovers and is discharged on clopidogrel and counseled on smoking cessation.

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Thoracic Diseases in the Elderly for Geriatric Trauma and Emergency Care

21

Matthew Benns and J. David Richardson

Introduction

Thoracic diseases in the geriatric patient that require emergency surgery are highly varied and can be quite challenging. They will often present with similar symptom complexes and can easily be confused with medically treated diseases. Unfortunately, many are imminently fatal if prompt diagnosis and management are not initiated. In this chapter, a broad range of thoracic surgical emergencies will be discussed. Specific focus will be given to those etiologies found most commonly in the geriatric population. In most cases, treatment of these conditions does not differ with advancing age.

Respiratory Tract

Airway Obstruction

The causes of acute upper airway obstruction are highly varied and include aspiration of foreign bodies, tumors, strictures, and tracheomalacia. Most conditions other than aspiration will be associated with some chronic symptoms of stridor, cough, or dyspnea. However, they still may present acutely if a chronic lesion progresses past a critical threshold or respiratory secretions cause a sudden obstruction of an already narrowed lumen. The initial assessment and management in the acute setting does not differ between etiologies or with advanced age [1].

Clinical Presentation and Initial Management

Patients with proximal airway obstruction will generally present with choking, cough, and stridor. More distal obstructions may have few or no associated symptoms, other than wheezing on exam. Immediate airway assessment and control, if necessary, is of paramount importance. The preferred method of airway stabilization when required is endotracheal intubation. However, this may not be possible in the setting of proximal obstruction. Repeated unsuccessful attempts may only cause further edema or bleeding within the airway; thus, clinicians should proceed to a surgical airway without delay when intubation fails [1, 2].

Surgical management of acute airway obstruction is usually accomplished via cricothyroidotomy, given the speed with which it can be performed and the limited required supplies. Access to the airway needs to be gained below the level of obstruction; thus, patients with known laryngeal pathology should undergo tracheostomy. If the level of obstruction is unknown when access is required, cricothyroidotomy should be the default point of access. Once the airway is secured, diagnosis of the underlying etiology may proceed. In the case of foreign body aspiration, these can often be extracted or dislodged through the airway incision.

One potential complicating factor that is almost exclusive to older patients is the presence of tracheal calcification. This phenomenon is associated with normal aging and may also occur with long-term warfarin use [3, 4]. It may lead to a distortion of the tracheal anatomy and the calcified trachea may be difficult to incise. Bony fragments may pierce the cuff of a tracheostomy tube on insertion, and the risk of fracturing or tearing the trachea may be higher. If extreme calcification of the trachea is noted on chest radiographs or computed tomography, consideration for performing a surgical airway in the operating room should be given. The patient may be better served by the improved lighting, broader scope of instruments, and anesthesia support of the operating room environment. Patient condition and emergent operating room availability will obviously dictate the feasibility of this approach.

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Diagnosis

After the airway has been assessed and controlled (if necessary), the diagnostic workup for airway obstruction may proceed. Many etiologies will be suggested based on history and physical alone. The gold standard for definitive diagnosis is direct visualization via bronchoscopy, but most patients will undergo some form of radiographic workup first. Plain films of the chest and neck are commonly performed and can be very useful. Positive findings include atelectasis, pneumonia, hyperinflation (in cases of partial obstruction), or aspirated foreign bodies (if radiopaque). Computed tomography is rarely indicated, but may similarly demonstrate the cause or sequelae of obstruction. Patients who have a consistent history, but a negative radiographic workup, should still undergo diagnostic bronchoscopy. The complications of a delay in diagnosis include recurrent pneumonia, hemoptysis, pleural effusion, empyema, and bronchial injury.

Aspiration

The aspiration of foreign bodies is the most common cause of acute airway obstruction in the geriatric population. Dental or medical appliances are the most common objects aspirated. Risk factors include dental procedures, conditions leading to depressed mental status, and dysphagia. Advanced age is not an independent risk factor for foreign body aspiration [5, 6]. However, elderly patients may be more likely to have a delay in diagnosis, with foreign body aspiration most commonly misdiagnosed as pneumonia or lung cancer [7].

The treatment of foreign body aspiration is via bronchoscopy, either rigid or flexible. The choice depends on the comfort level of the treating physician in most cases, but flexible bronchoscopy is more commonly utilized. Prior to inserting the bronchoscope, the patient's airway should either be definitively secured, or preparations for an emergency airway should be in place.

A variety of bronchoscopic instruments can be used to retrieve foreign bodies including forceps, snares, baskets, and balloon catheters. Magnetic probes are available and can be useful for metallic objects. Occasionally, laser coagulation of surrounding granulation tissue is necessary in order to dislodge the object. If the identity of the foreign body is known and can be duplicated, it is often useful to determine what instrument would be most useful for retrieval extracorporeally. Bronchoscopy should be performed through the mouth to prevent loss of the object within the nasal passages. Once grasped, the scope, retrieval instrument, and foreign body should be removed together [6] (Fig. 21.1).

Complications associated with bronchoscopic foreign body removal occur in less than 10 % of patients and include bronchospasm, laryngospasm, pneumonia, pneumothorax, pneumomediastinum, and bleeding. It has an overall success rate of greater than 85 %. Failure of bronchoscopic removal generally requires tracheostomy or thoracotomy for object removal. Surprisingly, location or duration of time in the airway does not seem to predict complications or success [5, 6].

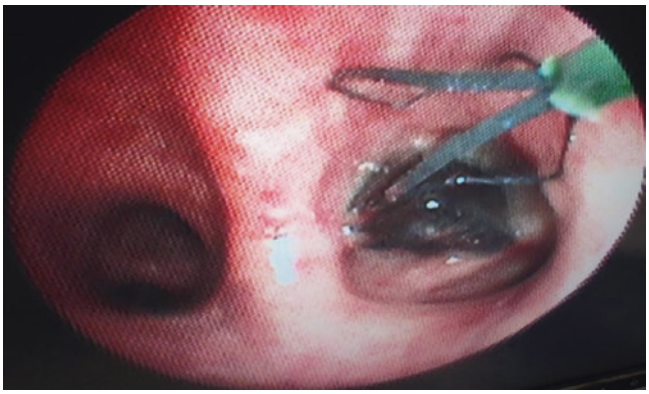

Fig. 21.1 Bronchoscopic removal of aspirated foreign body

Massive Hemoptysis

Hemoptysis may be a common complaint among geriatric patients presenting to the emergency room, but "massive" hemoptysis will frequently prompt acute care surgery consultation. The amount of blood loss to be considered massive is variable, but generally greater than 600 ml/24 h. The actual amount may not be important; however, significant oxygenation and ventilation deficiencies can occur with a much smaller volume of blood. Most patients presenting with massive hemoptysis will develop life-threatening respiratory failure before hemodynamically significant blood loss occurs [8]. This is of particular importance to the geriatric population who may already have diminished pulmonary reserve.

Ninety percent of the bleeding in cases of massive hemoptysis originates in the bronchial arteries. Only 5 % occurs from pulmonary arterial sources and is generally less threatening secondary to the lower pressure. The specific causes of massive hemoptysis are broad, but certain etiologies are more common among the geriatric population. Neoplastic etiologies including both primary and metastatic lesions are the most common. Other causes include infections such as bronchiectasis, tuberculosis, fungal balls, lung abscess, and necrotizing pneumonia. Vascular etiologies are less common, but may still be seen and include AV malformations, thoracic aneurysm, pulmonary embolism/infarction, and mitral stenosis. Medical cases such as Goodpasture syndrome and Behcet's disease are also causes, but are rare among the elderly [8].

Clinical Presentation and Diagnosis

Patients presenting with massive hemoptysis require a prompt assessment that should mirror that of a trauma resuscitation. The airway must be assessed first. Patients with

severe bleeding or signs of respiratory failure should be intubated without delay. The largest possible endotracheal tube should be used to facilitate suctioning as well as bronchoscopy. Double-lumen tubes should generally be avoided, as their smaller lumens may compromise suctioning ability. Physical exam may reveal the side of bleeding in some patients. If this is the case, patients should be placed in the lateral decubitus position toward the side of bleeding in order to diminish the risk of aspirating blood into the contralateral lung. Large-bore IV access should be in place and fluid resuscitation should commence. Patients with unstable vital signs should be transfused with packed red blood cells [8].

The diagnostic evaluation of massive hemoptysis is secondary to the initial stabilization and resuscitation, but can generally proceed in tandem. A sputum examination is recommended for all patients to look for the presence of bacteria. Cultures should be obtained, especially looking for mycobacterium and fungus. Chest x-ray is also a useful initial diagnostic tool. Parenchymal pathologies such as tumors, cavitary lesions, and infiltrates may be readily apparent and help localize the portion of lung responsible for bleeding. It is important to note, however, that greater than 20 % of patients with massive hemoptysis may have a normal chest x-ray. Computed tomography (CT) is also an important tool for evaluation. It may demonstrate small lesions such as tumors or bronchiectasis not readily seen on plain films. When performed with intravenous contrast, it is the preferred method to diagnose thoracic aneurysm or other vascular abnormalities. Caution should be exercised in obtaining CT scans on patients with unstable vital signs or unsecured airways [8, 9].

Bronchoscopy is usually the most effective method for bleeding localization. Both rigid and flexible bronchoscopy can be performed. Rigid bronchoscopy has the benefit of greater suctioning ability and maintenance of airway patency in cases of heavy bleeding, but cannot be used to access peripheral lesions. It also requires general anesthesia in all but the most experienced hands. Flexible bronchoscopy can be performed at the bedside and may easily reach the distal bronchioles, but visualization of heavily bleeding lesions may prove challenging. Occasionally, the installation of dilute epinephrine or other vasoactive agents may reduce bleeding and improve visualization [8, 9].

Therapeutic Options

Therapeutic options for massive hemoptysis are broad and vary depending upon the etiology. Surgical intervention was traditionally the method of choice, but other less invasive options can be effective. In some cases, definitive surgical therapy may be delayed following temporary bleeding control to allow for operative optimization.

Endobronchial methods are commonly first-line therapies, as they can be instituted at the time of bronchoscopic localization. Techniques include the installation of local hemostatic agents, photocoagulation, and endobronchial tamponade using balloon catheters. Endobronchial methods are most often utilized as temporary measures to allow for resuscitation and planning of more definitive intervention, but this depends upon the etiology [8, 9].

Bronchial artery embolization is a highly effective technique with a greater than 90 % success rate at 24 h. Selective angiography is used to identify the bleeding bronchial artery, followed by the instillation of coils or other thrombotic particles. Failure of this technique may occur secondary to nonbronchial collateral circulation [8, 10].

Patients with massive hemoptysis secondary to aspergilloma may be treated with the direct installation of antifungal drugs into the bleeding cavity. This can be accomplished via either percutaneous or transbronchial catheter access. This minimally invasive technique may be particularly useful for patients who are poor surgical candidates. External beam radiation therapy has also been used with success in hemoptysis from fungal balls, but only for those with low rates of bleeding [8].

Surgical intervention includes the full spectrum of pulmonary resection, including pneumonectomy. Patients who have a localized source of bleeding that would be amenable to complete resection and who are otherwise appropriate candidates for surgery should be considered. It is the treatment of choice for patients with malignancies or cavitary diseases in which vascular control alone would not be curative. Surgery is contraindicated in patients with lung carcinoma invading the mediastinum, trachea, heart, great vessels, or parietal pleura. Options must be carefully considered among patients with significant preexisting lung dysfunction, as emergent lobectomy or pneumonectomy will be poorly tolerated with diminished pulmonary reserve [8–10].

Outcome

The mortality rate for patients with massive hemoptysis is difficult to quantify and depends heavily on the underlying etiology. Patients with malignancy or significant bleeding (>1000 ml/24 h) tend to do far worse than those with other presentations. There is no evidence to suggest that age in and of itself is a risk factor for poor outcome [8] (Fig. 21.2).

Lung Abscess

Lung abscess is a well-circumscribed collection of pus within the lung that leads to cavity formation and the presence of an air-fluid level on imaging studies. It is most commonly formed by anaerobic bacteria and follows aspiration. Other etiologies include necrotizing pneumonia, septic emboli, and prior cavitation. Patients with a predisposition to aspiration, underlying immunocompromised state, or

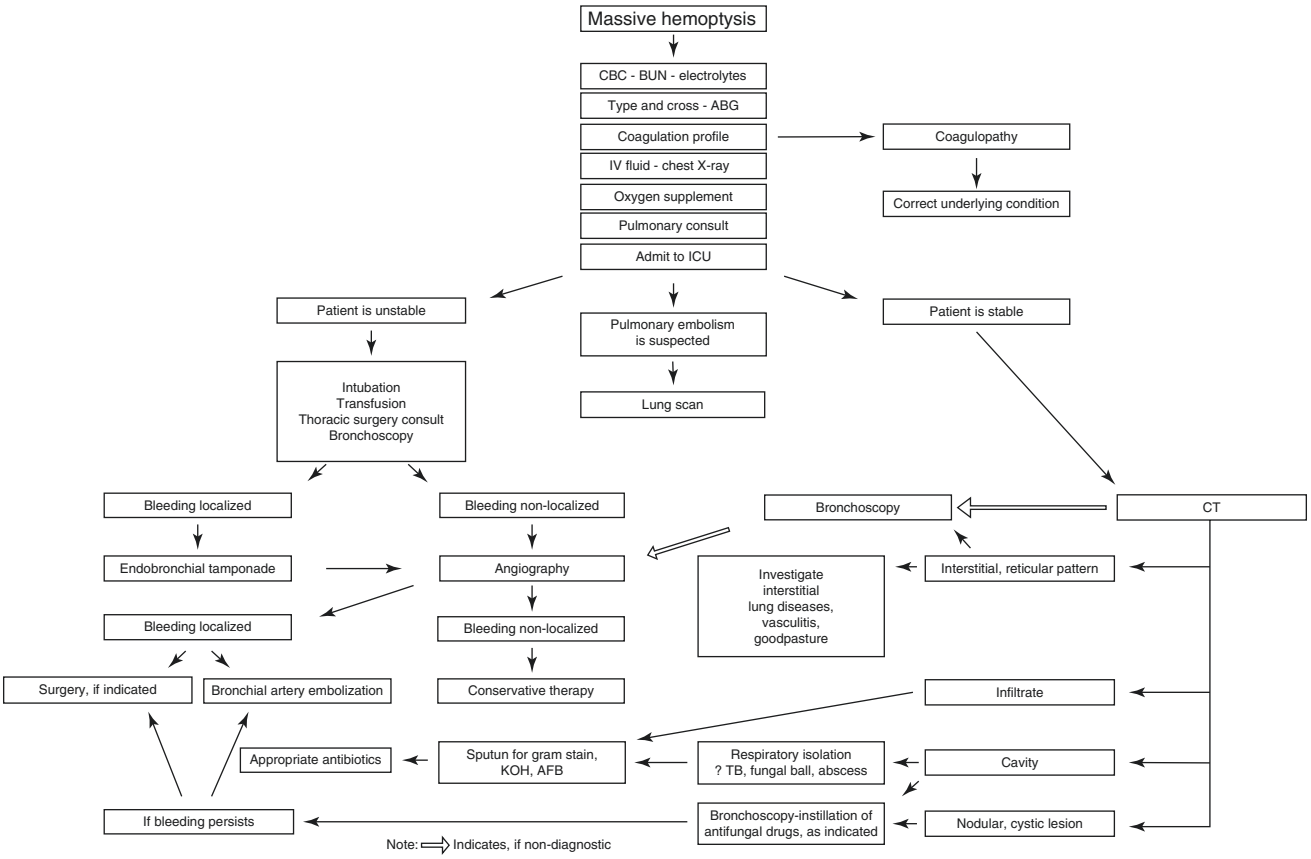

Fig. 21.2 Management of massive hemoptysis [8]

bronchial obstruction are at increased risk. Advanced age in and of itself is not a risk factor for lung abscess development, but has been associated with poor outcome when present [11–14].

Clinical Presentation and Diagnosis

Lung abscess typically presents with cough, pleuritic chest pain, fevers, weight loss, hemoptysis, or dyspnea. Patients will typically have one or more underlying risk factors by history and usually describe a prolonged course of symptoms prior to presentation. Diagnosis is usually straightforward and can be accomplished with plain chest radiography or computed tomography.

Management

The majority of lung abscess cavities will communicate with the bronchial tree and drain spontaneously; thus, antibiotic therapy alone is the primary treatment. Antibiotics are usually chosen empirically because accurate culture data from within the abscess cannot be obtained noninvasively. Traditional therapy was targeted against anaerobic bacteria common in aspiration and utilized penicillin and clindamycin. More recently, there has been the development of resistance to these agents among the common anaerobic isolates. There is also an increasing incidence of gram-negative pathogens among community-acquired cases. Current regimens use a β-lactam with a β-lactamase inhibitor or combination therapy with an advanced-generation cephalosporin and clindamycin or metronidazole. Unusual organisms such as gram-positive aerobes are rarely found to be the etiology of lung abscess and are more common in nosocomial cases [11].

Prolonged antibiotic therapy is successful in greater than 85 % of cases. Unfortunately, the geriatric population is at increased risk for conservative treatment failure. Other risk factors for failure include immunocompromised states, large abscess cavities, and unresolved bronchial obstruction. Antibiotic treatment failure requires improved drainage of the abscess. This can usually be accomplished percutaneously with radiographic guidance and represents definitive therapy for the majority of patients. A small minority of patients will require surgery for clearance. Surgical intervention for lung abscess includes varying degrees of pulmonary resection, including complete pneumonectomy in rare cases. Both traditional and minimally invasive techniques can be utilized. As surgery is taking place in an infected field, there is an increased risk of bronchial stump breakdown and bronchopleural fistula. Tissue coverage over the bronchial stump is recommended if possible [11, 13].

Outcome

Despite improvements in antibiotics and supportive care, the mortality of lung abscess remains at 15–20 %. Patients who do survive typically have a prolonged hospital course with significant morbidity. The risk of death is greater with an increasing number of predisposing conditions [11, 13, 14].

Empyema

Empyema refers to the presence of infected fluid within the pleural space. The most common etiology is infection arising in the ipsilateral lung from pneumonia, lung abscess, or bronchiectasis. Other causes include trauma, post-surgery, esophageal perforation, and spread of intra-abdominal infection across the diaphragm. Primary empyema may rarely occur and is most often due to hematogenous spread of bacteria from gingival and upper respiratory tract infections or tuberculosis. Empyema is seen in about 60,000 patients annually and is of particular importance to the geriatric population because it is more common at the extremes of age [12, 15].

Clinical Presentation and Diagnosis

Patients with empyema typically present with pleuritic chest pain, fever, and nonspecific symptoms such as malaise. Chest radiographs are commonly the first-line diagnostic study and can demonstrate pleural effusion and sometimes loculations, but cannot confirm bacterial infection. Similarly, ultrasound can easily demonstrate pleural fluid collections, but does not confirm empyema. Computed tomography is the most useful diagnostic tool. It can demonstrate and quantify pleural fluid collections, loculations, and pleural enhancement or thickening. Though CT findings can be highly suggestive, definitive diagnosis requires aspiration of purulent fluid or gram stain/culture results [12, 15] (Fig. 21.3).

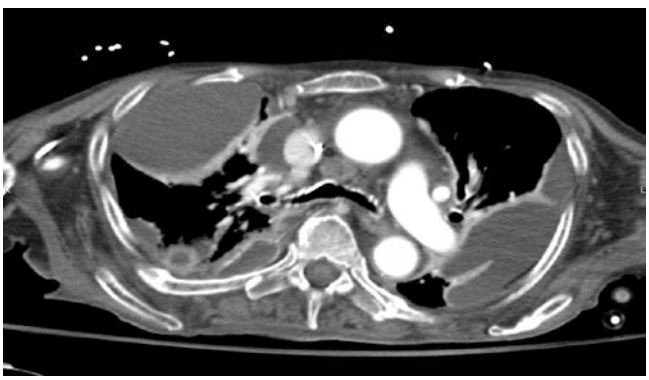

Fig. 21.3 CT scan demonstrating loculated fluid collections suggestive of empyema

Management

The treatment of empyema involves drainage of infected fluid, lung decortication/re-expansion, and antibiotic therapy. The choice of drainage method depends on the phase of the underlying empyema: exudative, fibrinopurulent, or organized. The first two phases can often be managed successfully without surgery [15].

The exudative phase of empyema is characterized by free-flowing fluid with minimal to no loculations. Tube thoracostomy alone is generally sufficient to achieve complete drainage of the empyema. In the fibrinopurulent phase, the fluid is thicker and loculations are common. Sufficient drainage by thoracostomy tube is difficult and may require multiple drains in specific locations. The bedside installation of lytic agents, particularly streptokinase, has been shown to be an effective method to assist the drainage of loculated collections. In many patients, drainage tubes may be required for a prolonged amount of time to prevent re-accumulation. Closed suction drains can be converted to open drains once the lung becomes adherent to the chest wall and gradually backed out over time. If adequate drainage of an early phase empyema is unsuccessful by percutaneous methods, surgical intervention should be considered [11, 15, 16].

The organized phase of empyema occurs over a period of 4–6 weeks and is characterized by the development of a fibrous "peel" of visceral pleura that prevents lung expansion. Surgical intervention is required to decorticate the lung and remove all infected material. Access to the pleural space can be achieved using VATS or traditional thoracotomy, but minimally invasive approaches are less successful in more advanced cases. Incomplete decortication will not allow full expansion of the lung and obliteration of the infected cavity; thus, re-accumulation will occur. In rare cases in which the pleural cavity cannot be obliterated, an open drainage procedure or muscle rotational flap may be necessary to control the empyema. Patients who cannot tolerate thoracotomy and proper decortication may also be candidates for an open drainage procedure under local anesthetic (assuming the presence of a mature empyema and adherent lung) [11, 12, 15].

Outcome

The mortality rate for empyema depends largely on the underlying etiology and associated comorbidities, but is around 15 % overall. Advanced age has not been shown to be an independent risk factor for increased mortality [13, 15].

Spontaneous Pneumothorax

Spontaneous pneumothorax is classified as either primary or secondary, depending upon the presence of underlying lung disease. Primary pneumothorax generally occurs in tall, thin

persons between the ages of 10 and 30 years and rarely occurs in individuals over the age of 40. Secondary spontaneous pneumothorax (SSP), however, has a peak incidence between 60 and 65 years of age and is frequently seen among the geriatric population. It is of particular importance because it can frequently be life-threatening, largely due to the underlying lung disease and low cardiopulmonary reserve. The most common cause of SSP among the geriatric population is underlying chronic obstructive pulmonary disease (COPD), representing greater than 70 % of cases. The probability of pneumothorax increases as the severity of COPD worsens. Other etiologies of SSP in the geriatric population include pulmonary fibrosis, autoimmune diseases, and infectious etiologies [17, 18].

Clinical Presentation and Diagnosis

Patients with SSP will present with dyspnea and frequent unilateral chest pain. Severe hypoxemia or hypotension can occur, even with smaller-sized pneumothoraces. Hypercapnia is also extremely common. The diagnosis should always be suspected among patients with known underlying COPD and new-onset dyspnea or chest pain. A high index of suspicion is essential, as rapid diagnosis and treatment may be lifesaving [17].

The diagnosis of SSP is usually made with chest x-ray, but can be challenging in patients with large bullous lesions. Radiographically, a pneumothorax should appear as a visceral pleural line that runs parallel to the chest wall. Large bullous lesions that abut the chest wall generally have a concave appearance. If the diagnosis is unclear, computed tomography of the chest can be used for differentiation [17] (Fig. 21.4).

Management

Patients with symptomatic SSP should be treated urgently with chest drainage using a small-bore chest tube or drainage catheter connected to water seal. The chest tube apparatus can be placed to suction for patients with large air leaks or incomplete re-expansion of the lung. Chest tube drainage alone will resolve most SSP, but may require a prolonged time course if there is a persistent air leak [17, 19]. Further intervention beyond drainage requires an individualized approach, particularly in the elderly patient who may have significant comorbidities.

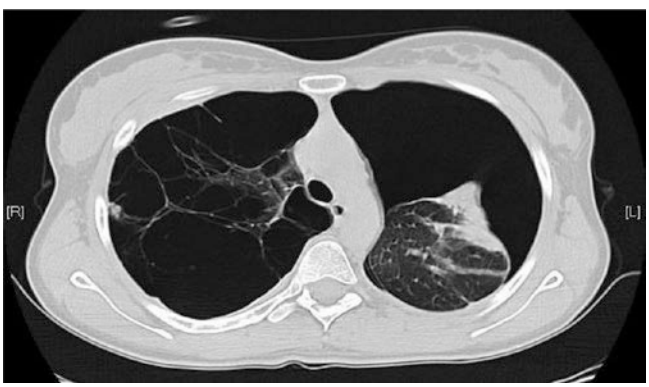

Fig. 21.4 Spontaneous pneumothorax in the presence of significant bleb disease

A blood patch represents one of the simplest and least invasive methods for treating a SSP with persistent air leak. Small leaks may be closed after the instillation of 1–2 ml/kg of blood through the chest tube [20]. This will not impact recurrence, however. The least invasive treatment to prevent recurrence is the instillation of sclerosing agents through the chest tube for pleurodesis, but this also carries the highest rate of long-term failure (up to 25 %). It is even less effective in the presence of an air leak, which is common among SSP. Some patients with SSP may be poor surgical candidates, particularly among the geriatric population. In these patients, bedside chemical pleurodesis may be the only viable option to prevent recurrence [17, 19].

Surgical intervention for SSP involves resection of the ruptured bleb and surrounding bullous disease with or without pleurodesis. Options for the geriatric patient include standard posterolateral thoracotomy, limited thoracotomy, median sternotomy, and video-assisted thoracoscopic surgery (VATS) approaches. Each approach carries specific advantages and disadvantages, and the decision should be made on an individual basis. Thoracotomy offers the best exposure and has the lowest recurrence rate, but is associated with significant postoperative pain and morbidity. VATS may be less invasive, but has a higher recurrence rate among published series. In addition, VATS generally requires single-lung ventilation with full de-sufflation of the affected lung for visualization. Many patients with SSP will not be able to tolerate single-lung ventilation secondary to their underlying pulmonary disease [17–19, 21].

Outcome

The outcome for patients with SSP depends largely on the severity of the underlying lung disease and comorbidities. Overall mortality rates are generally low (<6 %) among geriatric patients with a COPD etiology. Patients with recurrence or who require invasive operative intervention may have prolonged hospital stays and significant morbidity, however.

Aorta

Acute aortic pathology is an important consideration among the elderly, as the major disease processes have an increasing incidence with age. The conditions discussed generally require subspecialized care for definitive management, but initial diagnosis and stabilization may be frequently required of the acute care surgeon.

Acute Aortic Syndrome

Acute aortic syndrome (AAS) is a term used to describe a group of conditions with the common and primary presenting symptom of aortic pain. The conditions that comprise AAS include acute aortic dissection, penetrating aortic ulcer, and intramural hematoma of the aorta. Thoracic aortic aneurysm is a distinct entity, but acute presentations (rupture, expansion, etc.) behave similarly in terms of symptoms and diagnostic workup.

Clinical Presentation and Diagnosis

Patients with AAS typically present with pain that is usually of sudden onset and with maximal initial intensity. It is generally in the substernal area and is classically described as having a "sharp," "tearing," or "ripping" character. The most sensitive description of the pain appears to be the abruptness of onset, as this is present in over 90 % of cases. A careful and thoughtful history is of paramount importance, as up to 30 % of patients ultimately found to have AAS will be initially misdiagnosed [22, 23].

The currently available diagnostic modalities for AAS include computed tomography (CT), transesophageal echocardiography (TEE), magnetic resonance imaging (MRI), and aortic angiography. Contrast-enhanced CT is the most commonly employed as it is highly available and noninvasive. Chest x-ray (CXR) can be suggestive of AAS in up to 85 % of cases, showing a widened mediastinum, pleural effusion, or subtle cardiac contour changes. Electrocardiogram (EKG) tracings in AAS may be abnormal, but are generally nonspecific [22, 23].

AAS is an important consideration among the elderly population because it is predominantly a disease of older people, with at least a third occurring over the age of 70. It is more common among males and is associated with the common comorbidities for atherosclerotic disease such as hypertension and smoking [22, 23].

Acute Aortic Dissection (AAD)

AAD arises from a tear within the intima of the aorta, leading to a flow of blood within the media layer of the aorta. A second or "false" lumen is created as a consequence and can rapidly propagate secondary to the high underlying pressures within the aorta. The diversion of blood flow within the false lumen can lead to ischemia or thrombosis of involved aortic branches. A careful pulse exam is an essential component of the early evaluation, as it may reveal selective deficits that suggest AAD. Dissections of the ascending aorta can have involvement of the coronary ostia and produce cardiac ischemia with associated electrocardiogram changes and enzyme elevations. Consideration of AAD among patients with the appropriate history is important, as confusion with acute coronary syndromes may lead to the premature and potentially disastrous administration of anticoagulation or thrombolytics. Approximately 5 % of AAD is iatrogenic following open cardiac procedures or catheter-based interventions. The iatrogenic AAD population tends to be older and with a higher incidence of underlying vascular disease [22, 24, 25].

Management

The mainstay of medical therapy for AAD is immediate blood pressure control if hypertension is present to try to limit propagation of the dissection. A combination of B-blockers and vasodilators should be employed to reduce the force of ventricular contraction. The goal is systolic blood pressure should be less than 120 mmHg, as long as cerebral and end-organ perfusion is maintained. Opiate pain control during the initial presentation should also be considered, as the catecholamine response to pain can lead to tachycardia and hypertension.

Surgical interventions vary depending on the type of dissection present. There have been several classification schemes used to describe AAS, but among the most common is the Stanford classification. It describes AAD in terms of its involvement with the ascending aorta (type A) or the descending aorta (type B). This division is important, because type A dissections are considered true surgical emergencies. The mortality rate for type A dissections increases significantly with delays to surgical intervention. Factors contributing to mortality include rupture into the pericardium leading to tamponade, coronary vessel involvement and myocardial ischemia, distal organ malperfusion, rupture into the pleural space, or valvular involvement leading to acute cardiac failure [22, 23].

Surgical intervention generally involves resuspension or replacement of the aortic valve with aortic arch replacement and is commonly performed under hypothermic circulatory arrest. Surgery for type A AADs has a mortality rate of 10–35 %, even at the most experienced centers. Most type B dissections can be managed medically with blood pressure control alone. Aortic branch vessel involvement with subsequent end-organ ischemia is the most common reason for surgical intervention among type B dissections. Traditional intervention involves segmental aortic replacement, but endovascular stenting methods have been used successfully [22, 24, 25] (Figs. 21.5 and 21.6).

Penetrating Aortic Ulcer (PAU)

PAU is an atherosclerotic plaque that erodes through the intimal layer of the aorta. It may form a pseudoaneurysm, give rise to intramural hematoma, form the initial focus for aortic dissection, erode into adjacent structures, or lead to

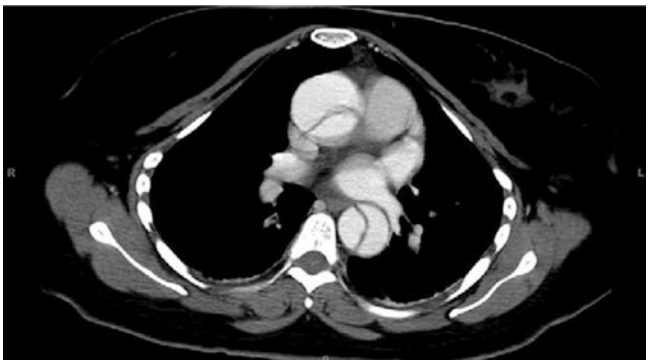

Fig. 21.5 Type A (ascending arch) aortic dissection [25]

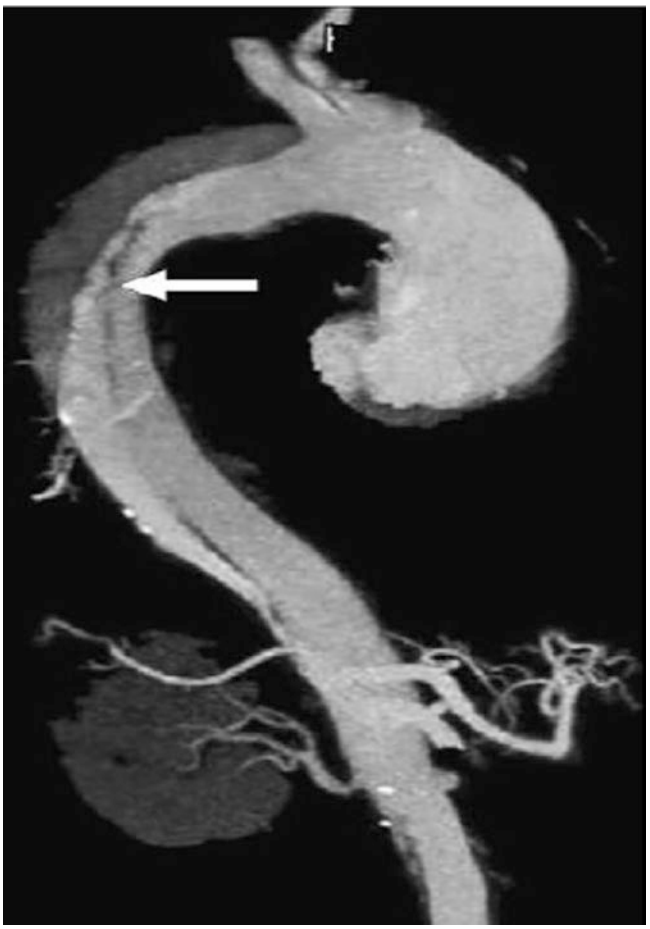

Fig. 21.6 Type B (descending arch) aortic dissection [25]

free rupture. Of the acute aortic syndromes, it has the greatest average age at presentation (> 70 years). It is most commonly diagnosed using contrast-enhanced computed tomography (CT) or angiography. It appears as a contrast-filled outpouching of the aorta with irregular margins and usually in the background of severe atherosclerotic disease [22, 23].

Management

Definitive management of PAU is surgical and involves either open aortic replacement or endovascular stenting. Patient selection for interventional therapy remains somewhat controversial, particularly since the population of PAU patients tends to be of advanced age and with significant comorbidities. Patients with complications such as erosion or rupture should certainly undergo immediate surgical intervention, but more stable presentations may be managed more conservatively. There are reports of patients undergoing successful medical management of PAU with some even demonstrating radiographic improvement or resolution on follow-up imaging. In general however, patients presenting with symptomatic PAU should undergo surgical correction if possible. The current preferred approach is via endovascular stent grafting, but specific ulcer location and aortic anatomy may dictate an open approach [22, 23].

Intramural Hematoma (IMH)

IMH is a dissection of blood within the media or subadventitial layers of the aorta. It is distinguished from aortic dissection in that it does not have an associated intimal tear. However, 30–40 % of IMHs convert to classic aortic dissection with highly variable timing ranging from a few hours to several months after the onset of symptoms. The etiology of IMH formation is thought to be hemorrhage from the vasa vasorum or fracture of an atherosclerotic plaque. Its association with underlying atherosclerotic disease may explain the older average age of individuals with IMH as compared to aortic dissection. IMH is best diagnosed using contrasted-enhanced computed tomography. Due to the lack of intimal involvement, it may not be appreciated on angiography [22, 23].

Management

The treatment of acute IMH is primarily dictated according to the Stanford classification, with 50–60 % of IMHs occurring in the descending aorta (type B). The current consensus is that uncomplicated type B IMHs may be treated medically with blood pressure control and repeat imaging to ensure stabilization. Spontaneous regression and complete resolution of IMH have been reported with medical therapy alone. The optimal treatment of type A IMH is more controversial, as there are no large reported prospective trials. Type A IMH patients with complications such as pericardial tamponade, cardiac valvular dysfunction, or hemodynamic instability should undergo urgent surgical intervention. Supra-coronary ascending aortic replacement is the most common surgical procedure performed. Stable patients may undergo surgical intervention or medical management with timed surgical

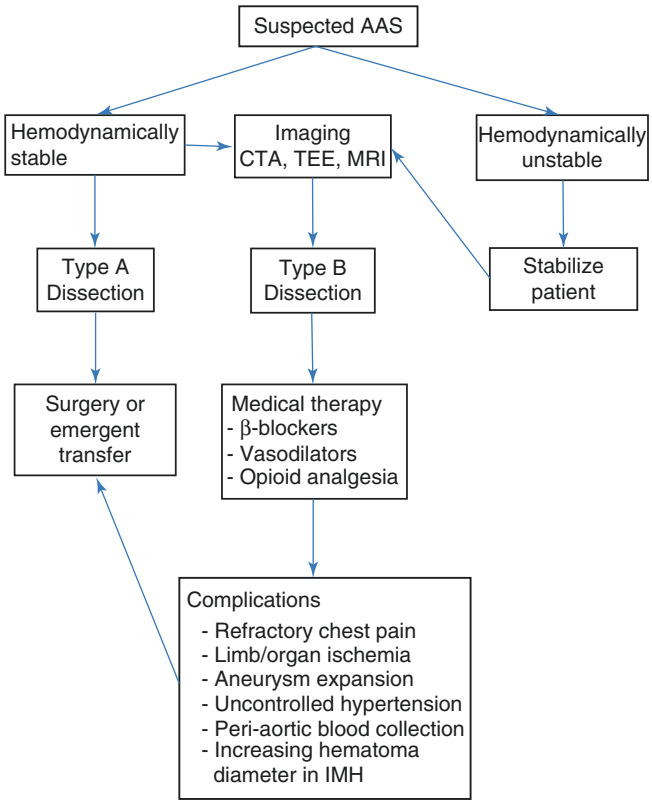

Fig. 21.7 Management algorithm for AAS [26]

intervention based on the development of complications. The overall in-hospital mortality of either approach is less than 20 %. Current work seeks to better characterize those patients at higher risk for progression of stable type A IMH, but progress is hindered by the small overall number of patients with this condition [22, 23] (Fig. 21.7).

Thoracic Aortic Aneurysm (TAA)

TAA is a relatively uncommon disease, occurring at a rate of approximately 10.4 per 100,000 person years. However, it is an important diagnostic consideration in the elderly population because the incidence of TAA increases with age. The average age at the time of diagnosis is 69 years. Advancing age is one of the few independent risk factors for TAA rupture. Other risk factors for rupture include aneurysm size (>5 cm), rate of aneurysm expansion, smoking, hypertension, and chronic obstructive pulmonary disease [23, 27].

Management

Patients presenting with symptomatic TAAs should undergo immediate surgical intervention. Traditional open repair involves resection of the aneurysm and replacement with an appropriately sized prosthetic graft. Reimplantation of branch vessels may be necessary depending upon aneurysm location. Involvement of the arch generally requires at least a short period of hypothermic circulatory arrest [23, 28].

Endovascular techniques have been utilized with success in the treatment of TAAs in the elective setting with suggested benefits including decreased early mortality, spinal cord ischemia, and respiratory failure. Specific vascular anatomy, including peripheral access vessels, plays a significant role in defining appropriate candidates for an endovascular approach. Experience in endovascular repair for symptomatic or ruptured TAA is currently limited [23].

Outcome

Most patients with a ruptured TAA do not make it to the hospital alive. The 5-year survival rate for patients undergoing emergent surgery is <40 %. The prognosis is worse for aneurysms that involve aortic dissections, as this increases the operative complexity [23].

Esophagus/GI Tract

Esophageal Dysmotility/Impaction

Failure of esophageal peristalsis in elderly patients presenting with dysphagia was termed “presbyesophagus” over 40 years ago. It was thought that normal aging leads to

changes in esophageal motility in all patients, with some becoming more symptomatic than others. The introduction of modern esophageal manometry techniques has made the concept of presbyesophagus more controversial. The majority of geriatric patients with dysphagia are now diagnosed with one of the established esophageal dysmotility disorders, although some will still be labeled as "nonspecific." Regardless of the etiology, approximately 10 % of people over the age of 50 and 15 % of people over the age of 85 will have dysphagia. This has important implications in terms of acute care surgery because these patients are at risk for esophageal impaction and foreign body aspiration [29].

Esophageal impaction may occur as a result of a variety of ingestions, both accidental and intentional. Impaction of foodstuffs, particularly meat or bones, is the most common etiology among the geriatric population. The presence of a dental appliance is strongly associated with esophageal food impaction in patients over the age of 60. Foreign body impactions of all types may also be seen in the elderly patient, but this phenomenon is more common among children. Among the more common foreign bodies seen in the geriatric population is the accidental ingestion of oral/dental prostheses [30, 31].

Clinical Presentation and Diagnosis

Patients with esophageal impaction will generally present with pain and vomiting with attempted oral intake and a history of recent ingestion. History alone is generally sufficient to suggest the diagnosis. Radiopaque foreign bodies are readily seen on plain x-ray, but food impactions will remain occult. An esophagram may be obtained and will often demonstrate esophageal obstruction, but the diagnosis is usually made via endoscopy. Once an esophageal impaction is diagnosed, it should be cleared as soon as possible. Delay in therapy can lead to inflammatory changes at the point of impaction and increase the risk of perforation.

Management

Esophagoscopy is the usual method of treatment for most esophageal impactions. It can be performed using either a rigid or a flexible scope. Rigid esophagoscopy may be more effective for cervical or very proximal esophageal impactions, but flexible endoscopy is more commonly utilized. Once the impaction is visualized, a variety of techniques may be utilized for clearance. For solitary objects, forceps or graspers may be used to dislodge the object and then remove it. Meat impactions can similarly be removed, but may require a piecemeal approach. The use of an esophageal over-tube may facilitate the frequent repassage of the endoscope in these cases. For food impactions that do not contain bones, the "push" technique may be employed. The endoscope is advanced into the center of the impaction and gently pushed forward until the food bolus is cleared. Regardless of the endoscopic technique used, extreme care must be employed to avoid injury to the esophagus. This is of particular concern for foreign bodies or bone impactions that have sharp edges, as the esophagus may be lacerated during attempted removal. Other techniques to relieve esophageal impaction have been described, but are generally less effective and less commonly utilized than endoscopy [30, 31].

Although rare, surgery may be required to relieve some esophageal impactions. Foreign bodies with significant delays in diagnosis may be difficult or impossible to remove endoscopically in the setting of significant inflammation. Foreign body impactions with sharp edges may be unsuitable for endoscopic removal secondary to a high risk of esophageal laceration. In these cases, surgical exposure of the esophagus with esophagotomy may be necessary for removal of the impaction [30, 31].

Esophageal Perforation

Perforation of the esophagus is an uncommon, but potentially a lethal condition. Excluding trauma, the most common causes for esophageal perforation are iatrogenic, spontaneous, and foreign body/ingestion related. The presentation and management for esophageal perforations varies widely depending upon the location and circumstances surrounding the perforation. It is certainly not a disease limited to the geriatric population, but older patients with underlying comorbidities and esophageal disease are at risk. Age in and of itself has not been shown to be an independent risk factor for poor outcome. As such, the evaluation and management of esophageal perforation in the geriatric population does not differ from that of the standard adult population.

Etiologies

Iatrogenic perforation from endoscopy or other instrumentation is the most common overall cause of esophageal perforation, accounting for nearly 60 % of cases. The approximate rate of perforation during routine flexible endoscopy is 0.03 %. Perforations during diagnostic endoscopy most commonly occur at the locations of anatomic narrowing of the esophagus, particularly in the cervical esophagus. The risk of perforation increases when considering therapeutic procedures during endoscopy. Sclerotherapy for varices or bleeding carries a 1–3 % risk of perforation at the site of intervention. Pneumatic dilation for stricture or achalasia carries a risk of perforation of 2–6 %, most commonly in the distal esophagus. Of particular concern for the geriatric population is the risk associated with transesophageal echocardiography, which has an incidence of perforation of 0.18 % [32–34].

Spontaneous esophageal perforation represents approximately 15 % of cases. The purported mechanism for many cases is the Boerhaave's syndrome, in which a rapid increase in intraluminal esophageal pressure through a patent lower esophageal sphincter causes transmural rupture of the esophagus. Described inciting events include forceful vomiting, prolonged coughing or laughing, childbirth, seizures, and weight lifting. Anatomically, this most commonly occurs in the left posterolateral location 2–3 centimeters proximal to the GE junction. This area is inherently weakened as the longitudinal muscle fibers taper out and pass onto the stomach wall. The geriatric population is certainly susceptible to this etiology, with reported cases occurring in individuals over 90 years of age [33, 34].

Foreign body ingestions account for approximately 12 % of cases. Sharp or jagged materials such as fish or chicken bones, partial dentures, and plastic eating utensils are the most common offender among accidentally ingested items. Esophageal perforation usually occurs at points of anatomic narrowing such as the cricopharyngeus, upper esophageal sphincter, aortic arch, left mainstem bronchus, or lower esophageal sphincter. Geriatric patients with underlying esophageal dysmotility such as the previously described presbyesophagus may be at particular risk [31, 32].

The remaining etiologies include eroding carcinoma, reflux ulceration, surrounding infection, and immunodeficiency. Carcinoma of the esophagus is of particular importance in the geriatric population, as greater than 50 % of patients with esophageal cancer are diagnosed beyond the age of 65 [33–35].

Clinical Presentation

The signs and symptoms of esophageal perforation will vary depending upon the anatomic location, the size of the perforation, the degree of contamination, and the time elapsed to presentation. The most common presenting symptoms (in order) are pain, fever, dyspnea, and crepitus. Perforations in the cervical esophagus commonly present with neck pain and stiffness. Thoracic perforations may progress to rupture of the mediastinal pleura and associated pleural effusion. Proximal thoracic perforations are more commonly associated with right-sided effusions, while distal esophageal perforations will present with left-sided effusions. With time delay, thoracic perforations may lead to contamination of the mediastinum and subsequent mediastinitis. This may lead to a systemic inflammatory response with associated tachycardia, fluid sequestration, and distributive shock. Perforations near the gastroesophageal (GE) junction may lead to contamination within the abdomen and are associated with epigastric abdominal pain that may progress to diffuse peritonitis [33, 34].

Diagnosis

A variety of studies may aid in the diagnosis of esophageal perforation. Diagnostic algorithms will vary depending on the history and presentation. Iatrogenic perforations commonly present with symptoms shortly following the procedure, and thus the suspicion of esophageal perforation will be high at the outset. Other presentations of esophageal perforation may be more subtle, and patients will undergo a broader workup until suspicion is raised.

Contrast esophagography is the gold standard test for suspected esophageal perforation. The study can be performed with either Gastrografin or barium sulfate. Barium has a higher density and better mucosal adherence, thus allowing it to detect smaller perforations when compared to Gastrografin. However, extravasation of barium may lead to an inflammatory reaction within the mediastinum or peritoneum. As such, it is relatively common to use Gastrografin as the initial contrast agent. This may be followed up with barium if a leak is not demonstrated. It should be taken into account that aspiration of Gastrografin is associated with pneumonitis and pulmonary edema. Patients at significant risk for aspiration may be best served using barium as the initial contrast agent. Overall, contrast esophagography has a false-negative rate of approximately 10 %. For patients with a high suspicion of esophageal perforation, the study may be repeated serially, as initial mucosal inflammation may preclude a positive study [33, 34, 36] (Fig. 21.8).

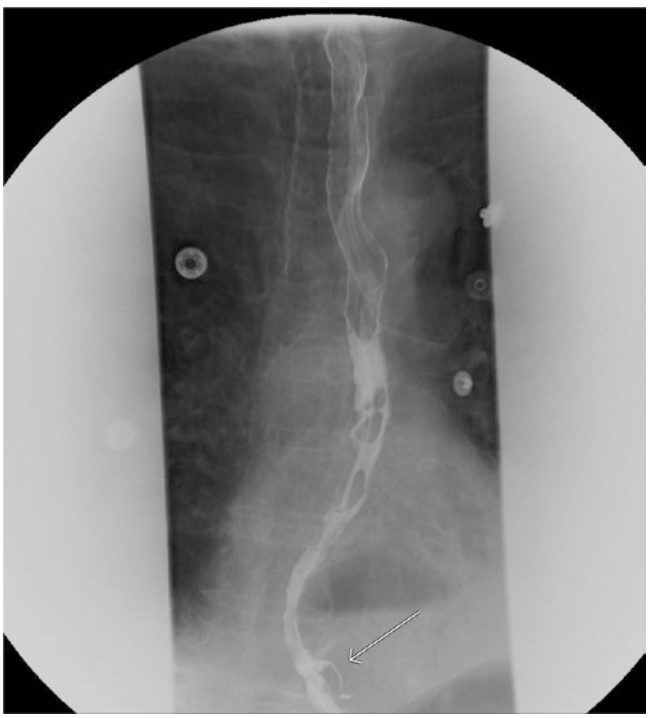

Fig. 21.8 Esophagram showing a small area of extravasation in the distal esophagus

CT scanning has become an important tool in the diagnosis of esophageal perforation. Suggestive findings on CT scan are extraluminal air, esophageal thickening, abscess cavity, or pleural effusions. Small, contained extravasations of contrast not readily visible on esophagography may be seen on CT. Suggestive CT findings, in particular extraluminal air, will be seen in greater than 90 % of cases. For patients with spontaneous perforations, CT findings often raise the initial suspicion for esophageal perforation and lead to esophagography. Conversely, patients undergoing a negative esophagram with continued high suspicion of esophageal perforation (i.e., iatrogenic presentations) may undergo CT scan as an adjunct to identify occult leaks. CT scan is also preferred among patients unable to undergo esophagography [33].

Plain films are less commonly utilized in the workup of esophageal perforation, but may be useful to suggest the diagnosis. Plain films of the lateral neck may show prevertebral air in cervical esophageal perforations. Chest x-ray may demonstrate pneumomediastinum or pleural effusion and suggest thoracic perforation. Abdominal films may show pneumoperitoneum in distal esophageal or GE junction perforation. Importantly, it may take several hours for any associated findings to appear on plain films. Suggestive findings should be confirmed with esophagography or CT scan as appropriate [33].

Flexible endoscopy is generally not recommended in the evaluation of suspected esophageal perforation, but may have a limited role for suspected cases involving foreign bodies, ingestions, or underlying malignancy. The significant drawbacks of endoscopy are that small injuries may be easily missed within the folds of the esophagus and the potential for worsening of the underlying injury through scope trauma or air insufflation [33].

Nonoperative Management

Selected patients may be successfully managed nonoperatively. Proposed criteria include the presence of a contained disruption in the neck or chest, minimal signs of systemic sepsis, early diagnosis, a nonneoplastic etiology, and the lack of underlying obstruction. Nonoperative management includes NPO status, antibiotics covering gastrointestinal flora, and parental nutritional support. The appropriate duration of therapy may vary depending upon specific circumstances of the perforation, but is usually 7–10 days. Importantly, up to 20 % of patients managed nonoperatively will have complications or worsening clinical condition in the first 24 h leading to surgical intervention. Careful and diligent monitoring is essential, as rapid declines in clinical condition are possible. Nonoperative management is most successfully utilized for perforations in the cervical esophagus and in small and early recognized iatrogenic perforations [33, 34, 36].

Surgical Management

The preferred method of surgical treatment is debridement of devitalized tissue, primary closure with or without tissue reinforcement, and wide drainage. Perforations in the neck can be approached via an incision along the anterior border of the sternocleidomastoid muscle (SCM) with lateral retraction of the carotid sheath. High thoracic perforations are approached via a right-sided posterolateral thoracotomy. Low thoracic perforations are approached via a left-sided thoracotomy. Perforations within the abdomen are best approached via a standard laparotomy incision [33] (Fig. 21.9).

Once the esophagus is isolated, the full extent of the mucosal defect is generally exposed via a longitudinal esophagomyotomy. The mucosal defect is then closed and the muscular layer re-approximated. When possible, a vascularized pedicle graft is then sutured to buttress the repair. A variety of buttress options have been described depending on the location of the perforation and include muscular flaps (SCM, intercostals, etc.), pleural flaps, pericardial flaps, and diaphragmatic pedicle grafts. Distal esophageal perforations can be buttressed with a gastric fundoplication. The repair should be widely drained using closed suction drains or chest tubes. Following repair, consideration should be given to the placement of distal enteral feeding access [33, 34, 36] (Fig. 21.10).

Patients presenting with esophageal perforation secondary to significant underlying esophageal pathology may not be appropriate candidates for primary surgical repair. The underlying pathology should be addressed or considered at the time of operation. Patients with perforations secondary to malignancy, megaesophagus, caustic ingestions, or chronic stricture should undergo esophagectomy if feasible. Reconstruction can commence immediately or in a delayed fashion, depending upon the clinical condition of the patient [33, 37].

A number of patients will present with significant mediastinal contamination or devitalization of the esophagus associated with hemodynamic instability. In these patients, standard repair techniques may not be feasible, and they may be too

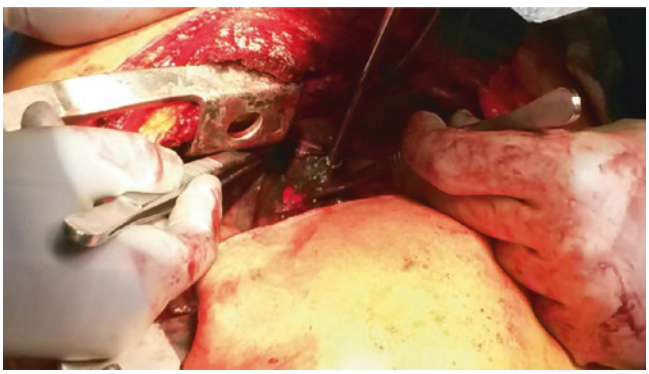

Fig. 21.9 Operative exposure of esophageal perforation via a left thoracotomy (note the hole in the mucosa and surrounding contamination)

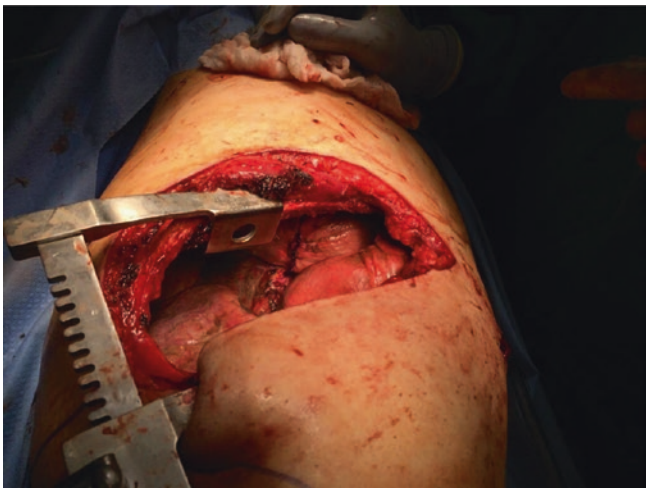

Fig. 21.10 Operative repair of esophageal perforation with diaphragm flap (superior)

unstable for definitive operation. Traditional management of these patients has included cervical esophagostomy, exclusion of the perforated esophageal segment, gastrostomy, jejunostomy, and wide drainage. This approach has significant drawbacks in terms of its morbidity and requirement for extensive reconstruction. A variety of other methods that seek to maintain continuity of the esophagus have been described, including drainage alone or the creation of a controlled fistula through the use of a T-tube. It is important to note that the use of these non-definitive interventions should be based solely on operative findings and overall patient condition and not on time to presentation. Drainage and diversion techniques have previously been emphasized for patients based on significant time delays in diagnosis. However, good results may still be achieved with definitive repair regardless of the amount of delay in diagnosis [33, 38].

Recent series have documented the use of minimally invasive surgery to successfully manage esophageal perforation. Access to the chest is obtained via video-assisted thoracoscopic surgery techniques. Perforations of the distal esophagus within the abdomen may be managed using laparoscopy. The standard principles of debridement, repair, and drainage remain constant when compared to open surgical techniques. These options may be particularly attractive among the elderly patient population, as the significant morbidity of a thoracotomy or laparotomy may be avoided. However, familiarity and technical proficiency with minimally invasive surgery techniques are required [33].

Endoscopic Management

Endoluminal stenting of the esophagus has evolved into a viable treatment option for esophageal perforation, and its use has been documented for a variety of etiologies. Stents utilized for this purpose are generally self-expanding and have a covered central portion that acts to seal the perforation. The stents may then be removed after the perforation has healed. Stenting is an attractive option among patients presenting with terminal disease, such as esophageal cancer. Endoscopic stenting does not allow debridement or drainage and is therefore best suited to those perforations that are diagnosed before there is significant contamination of surrounding tissue. If contamination has already occurred, stenting may be combined with a minimally invasive drainage procedure, such as a VATS decortication. The most common complication of esophageal stenting is stent migration, with incidence varying depending on the type of stent used. Plastic stents tend to have a higher rate of migration (up to 27 %). The rate of endoscopic re-intervention following stenting approaches 20 %. The rate of surgical re-intervention approaches 10 % [39, 40].

Endoscopic clipping is a technique that has had great success in the control of bleeding, but may also be used to treat small perforations of the esophagus. It was originally described to treat a small injury suffered during pneumatic dilation, but has since been used with success in instrumentation, foreign body, and spontaneous etiologies. Suggested indications include small (<1.5 cm), clean perforations with minimal to no contamination or signs of systemic illness [33]. It may also be combined with a minimally invasive drainage procedure if needed. Overall, the reported experience in the literature remains limited, especially when compared to endoluminal stenting.

Endoscopic techniques may be well suited for particularly frail members of the geriatric population, as it potentially avoids the morbidity of major surgery. Advanced age in and of itself is not an indication for endoscopic therapy compared to operative intervention, however. Patients selected for endoscopic management require close observation and diligence, as the possibility of treatment failure and the need for operative intervention always exist (Fig. 21.11).

Outcome

Patients successfully undergoing primary repair have a mortality rate of around 12 %. The mortality rate increases to 17 % for patients requiring esophagectomy and 24 % for the various exclusion and drainage procedures. Reported mortality rates for patients undergoing stenting vary and may depend on the addition of a drainage procedure, but overall are comparable to that of primary repair. There are no sufficient randomized trials comparing the two techniques; however, selection bias must be considered in the current evidence. Patients undergoing drainage alone have an associated mortality of 37 %, though this likely represents a much sicker population of patients. Nonoperative therapy has a published mortality rate of around 18 %, but may be significantly lower with strict adherence to established guidelines [33, 34, 39].

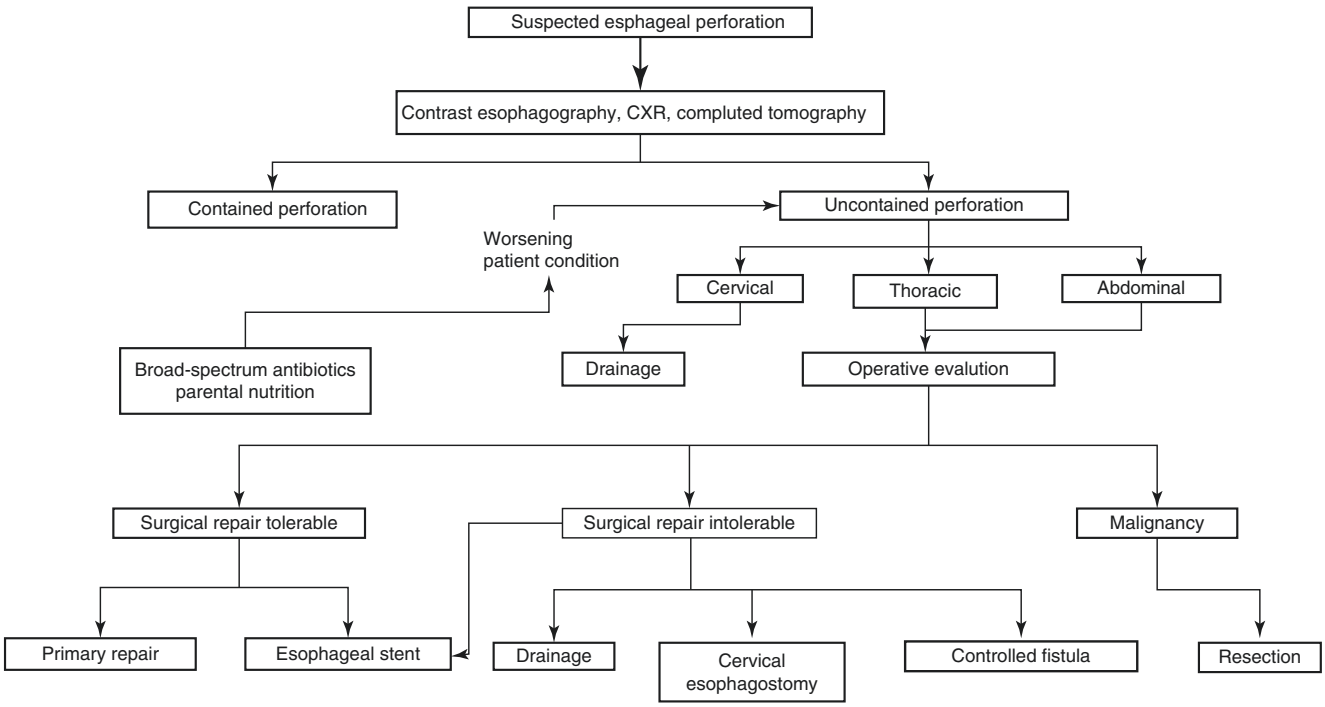

Fig. 21.11 Management of esophageal perforation

Paraesophageal Hernia

Paraesophageal hernia (PEH) is an important consideration in thoracic acute care surgery, particularly in the geriatric population. Long-standing and previously undiagnosed PEH may present acutely with obstruction and often volvulus/strangulation of herniated abdominal viscera such as the stomach, small bowel, or esophagus. Patients with PEH are prone to reflux disease and may therefore also present acutely with complications such as bleeding or perforated ulcerations. Herniated contents may cause direct compression within the thorax leading to acute heart failure or respiratory embarrassment. Tension gastrothorax is a well-described such example [41].

Increasing age may be a risk factor for increased morbidity and mortality in elective paraesophageal hernia repair [42, 43]. Many surgeons may therefore defer elective repair among the elderly, thus increasing the risks for emergent presentations.

Clinical Presentation and Diagnosis

Patients presenting with acute complications of PEH will most often present with upper abdominal or chest pain, often associated with vomiting. Certain complications may additionally present with extreme hemodynamic instability and respiratory compromise. These symptoms may initially be confused for a variety of other more common thoracic pathologies; thus, a high index of suspicion must be maintained during the initial workup.

Plain chest or abdominal radiographs can be highly suggestive of the diagnosis of PEH. Intra-abdominal contents can often be readily seen above the diaphragm, particularly in cases of incarceration and obstruction when there may be significant proximal dilatation. CT scan is also extremely useful to visualize a large PEH, particularly on coronal or sagittal image series. CT may also be highly suggestive of more severe complications such as strangulation or perforation. The presence of pneumatosis intestinalis, extraluminal air, or surrounding fluid may be seen on CT and suggest increased severity. Upper gastrointestinal contrast series is a standard test utilized to diagnose PEH with minimal or no symptoms, but may be difficult or impossible to perform in the setting of an acute complication. In cases involving incarceration of the stomach, flexible endoscopy can be a useful diagnostic aid to assess bowel viability [41].

Management

After addressing potential airway issues, the initial therapeutic intervention in nearly all cases of acute PEH complications is the attempted placement of a nasogastric (NG) tube for decompression. In some cases, decompression may completely resolve the incarceration and lead to a rapid alleviation of symptoms. In cases of tension gastrothorax, decompression is immediately lifesaving. The inability to pass an NG tube generally prompts more urgent surgical intervention to provide decompression.

All patients presenting with a complication of a PEH should undergo consideration for surgical intervention. While

there is ongoing debate regarding the optimal treatment and natural history of asymptomatic PEH, patients presenting with acute complications require intervention. Patients with a high suspicion for strangulation and bowel compromise should proceed to the operating room expeditiously. Those that can be initially stabilized with NG decompression may be candidates for delayed intervention in order to undergo a more thorough preoperative evaluation [44–46].

Repair of the acutely incarcerated PEH has traditionally been accomplished via an abdominal or thoracic approach. Selection depends largely on the comfort level of the operating surgeon. The standard approach involves reduction and assessment of herniated contents, restoration of physiologic and gastric esophageal anatomy, dissection of the hernia sac, closure of the hiatal defect, and often an anti-reflux procedure. Most elective repairs of PEH are currently performed using a laparoscopic abdominal approach with good results. This approach can also be utilized for acute presentations if the operating surgeon is proficient in advanced laparoscopic techniques [41, 45].

An important consideration among the geriatric population is those individuals with symptomatic PEH who are poor candidates for the operating room. In these cases, endoscopic de-rotation and gastric fixation may be considered. This technique is more commonly employed for the treatment of primary gastric volvulus without an associated diaphragmatic defect. Nonetheless, it may be possible to reduce the stomach endoscopically and then fixate it to the abdominal wall, usually with percutaneous gastrostomy (PEG) tubes. It is important to note that more than one PEG tube must be utilized, as the stomach may still rotate if only fixed in a single location [47]. For individuals who are poor candidates for a prolonged operation, but may still tolerate general anesthesia and brief pneumoperitoneum, this technique may be performed with the assistance of laparoscopy.

Outcome

Early series of patients undergoing emergent surgery for PEH showed a mortality rate of greater than 25 %. This prompted the traditional surgical teaching that all PEH should be fixed following diagnosis to prevent future complications and mortality. More modern series have demonstrated a mortality rate less than 10 %, including a significant number of geriatric patients [44]. Mortality is significantly higher if gastrectomy or another bowel resection is required; therefore, a high index of suspicion and prompt intervention are required in acute presentations.

Summary

Thoracic surgical emergencies in the elderly represent a complex and diverse group of disease processes. Advanced age in and of itself does not alter the preferred management of these conditions as compared to the general population, but the elderly patient may have significant comorbidities that add to the complexity of treatment. Some etiologies and characteristics also become much more prevalent with or are unique to advancing age. An understanding of these conditions helps clinicians more readily identify them, as confusion and initial misdiagnoses are common. Although definitive management for many of the conditions described requires subspecialist consultation, the acute care general surgeon will commonly be called upon to participate in the care of these patients.

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Prehospital Care

22

Eric Campion and Lance Stuke

"The fate of the wounded rests in the hands of the one who applies the first dressing."

Col. Nicholas Senn (1844–1908)
Founder, Association of Military Surgeons of the United States

Critically injured trauma patients must receive the highest quality of care from the earliest moments following injury. Rapid and effective prehospital trauma care can often mean the difference between life and death for many patients. In the United States, most prehospital care is provided by the emergency medical technician (EMT) or paramedic. In many countries throughout the world, prehospital care is provided by nurses or physicians. The prehospital environment is difficult, with weather conditions, poor lighting, unruly crowds, and lack of additional support staff all contributing to the challenges faced by the emergency medical service (EMS) provider. EMS members must do their job alone in the back of an ambulance or helicopter without the conveniences or comforts found in the trauma bay. Trauma team members should familiarize themselves with their local EMS providers and actively support their participation within the trauma system.

History of EMS

As with many developments in trauma care, the growth of prehospital medicine can be traced to wartime advances. The Napoleonic Wars of the early nineteenth century saw the first conceptual development of early ambulances. Jean Larrey, one of Napoleon's chief surgeons, formed the *ambulance volante* ("flying ambulance"), with the goal of providing trauma care as close to the battlefield as possible. While little more than a horse-drawn cart, Larrey is credited with developing the first prehospital triage and transport system.

In the United States, an attempt was made to provide for evacuation of injured soldiers during the Revolutionary War. In April 1777, the Continental Congress passed a bill "devising ways and means for preserving the health of the troops," also stating "that a suitable number of covered and other wagons, litters, and other necessaries for removing the sick and wounded, shall be supplied by the Quartermaster or Deputy Quartermaster General" [1]. No records exist showing these vehicles were ever built or utilized. During the Civil War, the Rucker ambulance, developed by Brigadier General Daniel Rucker, was created following the poorly executed evacuation of injured soldiers during the Battle of Bull Run in Manassas, Virginia. Patients could sit or be placed on stretchers, and it also had the capability of carrying water and supplies.

Civilian ambulance services were started shortly after the Civil War and were often associated with a hospital. Charity Hospital in New Orleans, Grady Hospital in Atlanta, Bellevue Hospital in New York, and Cincinnati General Hospital are all credited with early development of horse-drawn ambulances, usually staffed at that time by physicians in training.

While military trauma care continued to advance during the First and Second World Wars and the Korean War, civilian EMS in the United States remained relatively stagnant. No formal training was available for ambulance attendants, who remained physician interns, or were even morticians during this time since the stretcher could easily fit in the back of a hearse. Communication between police, fire, and EMS was nonexistent. Rescue techniques were rudimentary and equipment was sparse. During this time, J.D. "Deke" Farrington questioned why lessons learned on the battlefield were not being translated into the civilian world. He, along with Sam Banks, started the first course for ambulance personnel in 1962 through the Chicago Fire Academy. Farrington is generally recognized as the father of modern EMS [2].

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In 1966, the National Academy of Sciences/National Research Council published the landmark article "Accidental Death and Disability: The Neglected Disease of Modern Society." This white paper was the first to recognize trauma as a disease process. It specified deficiencies in prehospital care and suggested guidelines for the development of EMS systems, training of EMS personnel, and advancements in equipment and ambulances [3]. That same year, Congress passed the National Highway Safety Act, which established the Department of Transportation (DOT) as a cabinet-level position. States were forced to develop EMS systems or risk losing federal highway funds. The DOT later funded development of the Emergency Medical Technician –Ambulance (EMT-A) curriculum, published in 1969. In 1973, Congress passed the Emergency Medical Services Systems Act, providing funding for a development of region-wide EMS systems from 1974 to 1981. This legislation outlined 15 individual components that were needed in order to have an integrated EMS system. Education was one of these 15 components and eventually led to the development of the EMT-Basic, EMT-Intermediate, and EMT-Paramedic certifications.

In the 1970s, the National Registry of Emergency Medical Technicians (NREMT) was started. The NREMT, or "Registry," is a nonprofit group providing a nationally recognized testing standard and credentialing for all levels of EMT provider. While each individual state is responsible for credentialing their EMS providers, nearly all states recognize certification by the NREMT in their credentialing process. In addition to providing uniformity in testing, it also allows easier reciprocity for medics wishing to be certified in another state [4].

The 1980s were a period of sustained trauma system development and growth of trauma centers. The Advanced Trauma Life Support (ATLS) course, initially started in 1978, continued to grow as a model for systematic management of the trauma patient. Dr. Norman McSwain, professor of surgery at Tulane University in New Orleans and an initial member of the board of directors of the National Association of Emergency Medical Technicians (NAEMT), began to create a course for prehospital providers based on the ATLS platform. The Prehospital Trauma Life Support (PHTLS) course began in 1983, recognizing the critical role of the prehospital provider in the care of the trauma patient [5].

In the 2000s, foundations were laid to continue to standardize EMS training and curriculum across the country. The National EMS Core Content, published in 2005, defined the skills and body of knowledge to be utilized by EMS providers. The National EMS Scope of Practice Model, published in 2007, identified four new levels of prehospital providers, replacing the former first responder, EMT-Basic, EMT-Intermediate, and EMT-Paramedic. The National EMS Education Standards, published in 2009, set the minimum, entry-level competencies for each level of practice defined in the EMS Scope of Practice [6].

Certification Levels

The four levels of prehospital care provider, as defined by the 2007 National EMS Scope of Practice [7], are:

Emergency Medical Responder (EMR) Formerly known as the "first responder," EMR refers to those who are the initial responders to many emergencies. They are often police and firefighters, although civilians can also be trained as an EMR. These individuals initiate lifesaving care, often with minimal equipment, while awaiting the arrival of EMS. They may also assist EMS during transport to the hospital. They are trained to perform basic airway maneuvers, including head tilt, chin lift, jaw thrust, oropharyngeal airway insertion, suctioning, and oxygen administration. Additional skills include manual cervical spine immobilization, manual fracture stabilization, bag-valve-mask use, utilization of automatic external defibrillators (AEDs), assistance with administration of medication via auto-injector, and eye irrigation.

Emergency Medical Technician (EMT) Previously called "EMT-Basic," the EMT possesses the minimum skills necessary to staff an ambulance and has a greater breadth and depth of training than an EMR. They are trained in spine immobilization, assisting in uncomplicated childbirth, administration of oral glucose and aspirin, use of auto-injectors, and utilizing a greater number of airway adjuncts and oxygen delivery systems.

Advanced Emergency Medical Technician (AEMT) The AEMT possesses a greater level of training and education than the EMT, allowing them to perform more invasive maneuvers. They are able to establish intravenous (IV) access and administer crystalloids. They are also able to perform more advanced airway maneuvers, although not endotracheal intubation. Additionally, they are trained to administer several medications, including sublingual nitroglycerine, subcutaneous epinephrine for anaphylaxis, IV naloxone and 50 % dextrose, inhaled beta-agonists, and nitrous oxide.

Paramedic The paramedic is the highest trained EMT, possessing additional knowledge in anatomy, physiology, pharmacology,

and pathophysiology of disease. Paramedics are trained to perform endotracheal intubation, chest needle decompression, the use of continuous positive airway pressure (CPAP), 12-lead ECG interpretation, intraosseous access placement, and cardioversion/defibrillation. Additionally, they can administer a wide range of cardiac medications, initiate and monitor thrombolytic therapy, and irrigate an eye using a Morgan lens.

EMS System Design

Numerous models of EMS systems exist and are dependent on local needs, community support, call volume, and available resources. An EMS service may be operated by a fire department, a hospital, a private company, a police department, or an agency funded by the government solely responsible for emergency medical care, known as a "third service." Regardless of which type of agency provides service, prehospital care is divided up into one of three categories: basic life support (BLS), advanced life support (ALS), and tiered response.

Basic Life Support (BLS) BLS is used to describe noninvasive prehospital care delivered by the EMR and EMT. BLS provides advanced first aid, oxygen administration, basic airway management, CPR, control of external hemorrhage, spine immobilization, and uncomplicated childbirth. Some BLS systems utilize AEDs for patients in cardiac arrest to recognize and treat ventricular fibrillation. A BLS system is less expensive to establish and maintain than an ALS service, but is also limited in its capability.

Advanced Life Support (ALS) ALS systems provide care that is more invasive than BLS. ALS providers are certified at the AEMT or paramedic level. Specific skill sets for an ALS service can include endotracheal intubation, establishment of IV access, medication administration, cardiac defibrillation, and needle decompression. Advanced therapy is provided at the scene instead of waiting for arrival at an emergency department. This has resulted in impressive results in some aspects of prehospital care, specifically for survival in patients with an out-of-hospital cardiac arrest. ALS systems are more expensive to establish and maintain. More equipment is required and continuing education requirements are greater.

Tiered Response System A tiered response system is a hybrid of both BLS and ALS levels of service. The goal of a tiered response is to match the level of response with the needs of the patient. Often, a BLS unit will respond first, followed by ALS if necessary. The BLS ambulance will assess the patient and determine if ALS-level care is necessary. The BLS unit could initiate transport if ALS is not required. If ALS care is required, the BLS unit can initiate care until arrival of the ALS ambulance. This allows ALS ambulances to respond only when needed and preserve their resource for the seriously ill or injured.

Medical Control

The relationship between EMS and the physician is critical. Each EMS system must have a medical director – a physician who is legally responsible for all aspects of patient care in the prehospital setting. While each state is responsible for issuing licenses to EMS providers, they are not allowed to function independently and must practice under the license of a physician.

In most EMS systems, the medical director is an emergency medicine physician or trauma surgeon. Regardless, the medical director must have a strong interest in EMS, remain committed to the daily activities of their EMS service, and participate in quality improvement within the system. Medical control is divided into two types: direct (online) and indirect (protocols/offline).

Direct (Online) Direct medical control occurs when a physician gives orders directly to EMS personnel via radio or telephone. Depending on local protocols, the EMS provider must call medical control to pronounce a patient dead on scene, administer certain medications, or when a patient is refusing treatment.

Indirect (Offline) Indirect medical control refers to protocols, policies, and practices that the medical director has set up in advance of a call. Protocols are the overall steps in patient care that are to be followed by the provider at every specific contact. Examples of protocols commonly used in the prehospital setting include advanced cardiac life support protocols for cardiac arrest and trauma triage protocols for the injured patient.

Trauma Continuing Education

Two courses are available for prehospital trauma continuing education. They teach basic and advanced skills for the prehospital provider and are available throughout the United States and internationally.

Prehospital Trauma Life Support (PHTLS) The PHTLS course was developed in the early 1980s under the leadership of Dr. Norman McSwain, who remained its medical director until his death in 2015. The PHTLS course is modeled after the ATLS course for physicians and has been modified to meet the needs of the patient in the prehospital setting. It is 16 hours in length and emphasizes the "principles" of patient management over individual protocols or guidelines. PHTLS has been shown to decrease trauma mortality following its promulgation into a new country [8]. PHTLS is administered by the National Association of EMTs (NAEMT) and endorsed by the American College of Surgeons Committee on Trauma (ACS COT).

A new edition of PHTLS is produced every 4 years, 1 year after the release of a new ATLS edition. This schedule guarantees congruence between both courses and helps ensure the prehospital provider remains up to date with the latest changes in trauma care. Currently PHTLS is taught throughout the United States and in over 60 countries throughout the world.

Several new courses have been created by PHTLS to address specific needs within the EMS community. The Tactical Combat Casualty Care (TCCC) course, written by the US military and administered by NAEMT/PHTLS, teaches the tenets of trauma care under fire to the soldier. TCCC has been demonstrated to reduce mortality from combat death among US soldiers [9]. Recently, the Tactical Emergency Casualty Care (TECC) course has modified TCCC to the civilian tactical EMS setting and is ideal for the tactical/SWAT medic. The Law Enforcement and First Response (LEFR) course is an 8-h course for the police officer who may 1 day need to provide on-scene bleeding control techniques to himself or herself or others. Several lives have already been saved by officers who have successfully completed the LEFR course. The Bleeding Control for the Injured (BCon) course is a 2–3-h course designed to teach basic hemorrhage control techniques to the civilian with no prior medical training and was created in direct response to the increase in active shooter events throughout the United States. The BCon course complies with the tenets of the Hartford Consensus and teaches direct pressure, wound packing, and tourniquet application to the civilian.

International Trauma Life Support (ITLS) Also developed in the early 1980s, the Alabama Chapter of the American College of Emergency Physicians (ACEP) developed a Basic Trauma Life Support (BTLS) course. In 2005, BTLS was renamed to International Trauma Life Support (ITLS). It is endorsed by ACEP and is also available throughout the United States and internationally.

Prehospital Patient Care

Geriatric patients pose special challenges to the prehospital provider. Physiologic changes and disease states complicate the assessment and management of the injured elderly patient. The assessment begins with the primary survey in which life-threatening problems are identified in a systematic manner. These problems are then addressed prior to moving on to the next steps in assessment. The secondary survey only begins once the patient has been stabilized and includes a thorough history and physical examination to identify all injuries. It is important for the trauma team to realize that not all trauma patients will receive a secondary survey in the prehospital setting. A critically injured patient may be too unstable for the medic to ever complete the steps of the primary survey (ensuring a patent airway, monitoring breathing, and beginning resuscitation). Using the primary and secondary survey, we will review many of the unique factors complicating the prehospital trauma care of the elderly.

Primary Survey

The primary survey is performed to identify and address any life-threatening injuries in the field. This is done in the same fashion for geriatric patients as for younger patients following PHTLS guidelines with some small caveats.

Airway

Assessment and management of the airway in the elderly trauma patient begins in the same manner as with younger patients but presents some special issues. Geriatric patients can develop decreased range of motion in the muscles controlling the airway, often due to arthritic changes in the neck and jaw. This can affect some of the basic maneuvers such as head tilt/chin lift and can also make advanced airway management such as endotracheal intubation more difficult. In EMS systems where video laryngoscopy is available, this can increase the ability to obtain an adequate view in individuals with decreased neck range of motion. The epiglottis is often more floppy due to decreased collagen in the tissues, and a miller blade may be superior to a Macintosh during endotracheal intubation of the elderly [10]. Geriatric patients often have friable nasal mucosa and an increased incidence of nasal polyps. When considering nasal intubation, it is important to select proper tube size and not use excessive force so as to not initiate bleeding.

Elderly patients frequently have problems with dentition including missing or damaged teeth. Patients without teeth can often have a smaller oral opening and can be more difficult to ventilate with bag-valve-mask ventilation. When available, laryngeal mask airways can improve ventilation in

edentulous patients. In patients with dentures, leaving dentures in situ during assisted ventilation can help maintain a good seal. During intubation, it is best to remove dentures to give added room within the oral cavity. Partial dentures, along with loose dental work or loose teeth, can put the patient at risk for aspiration and need to be carefully evaluated during the airway assessment.

With a decreased physiologic reserve, an appropriately aggressive approach to the elderly airway is likely warranted. However, given the potential difficulties with airway management in this population, prehospital providers must carefully weigh the risks versus benefits when considering advanced interventions for airway management. This is particularly important when contemplating potentially riskier interventions, such as rapid sequence intubation, that will put the patient in jeopardy if definitive airway management proves difficult.

Breathing

Significant physiologic changes occur with respect to breathing in the elderly. The vital capacity can be markedly decreased due to kyphotic changes in the spine, along with decreased compliance of the lung tissue and the chest wall. In addition, the inspiratory and expiratory muscles of respiration have reduced strength, and geriatric patients have a decreased ability to clear secretions [11]. The elderly have a higher incidence of respiratory diseases, particularly chronic obstructive pulmonary disease. Taking these factors into account, a careful evaluation of a geriatric patient's pulmonary status after trauma is critical. Elderly patients are at increased risk for respiratory embarrassment, often presenting in an insidious fashion. Even innocuous injuries such as rib fractures can be lethal, with up to twice the morbidity and mortality in the older population [12]. Strong consideration of transportation to a dedicated trauma center should be considered in any elderly patient with respiratory symptoms. Early treatment to prevent hypoxia in the elderly is crucial as their ability to rapidly recover is diminished.

Circulation

Examination of the circulatory system in geriatric patients is complicated by many factors. The elderly tend to have a blunted response to catecholamines and a relatively fixed cardiac output. This makes heart rate an unreliable predictor of early shock. In addition, many older patients are on medications such as beta-blockers that will blunt this response even more. Further complicating the assessment, chronic hypertension may leave patients with an elevated baseline blood pressure. Therefore, a "normal blood pressure" may actually be representing early shock in the elderly. Classic evidence of shock such as absent peripheral pulses and hypotension should be treated aggressively in the elderly; however, "normal" vital signs should not be reassuring. While patients that have been injured and are in shock should be assumed to be suffering from hemorrhage, it is important to keep in mind that elderly patients are at increased risk of a preexisting condition causing the traumatic event such as myocardial infarction or stroke.

Disability

The evaluation of the mental status in the elderly is particularly difficult. Dementia and other disorders of cognition are common among elderly patients. This can make the evaluation of altered mental status challenging without knowledge of the patient's baseline status. Family members can be particularly useful in this regard when they are present. Traumatic brain injury is a major problem in the elderly population. Loss of brain volume occurs with aging, which places the dural veins on stretch and allowing them to be injured with low energy forces that can occur with falling from standing leading to subdural hemorrhage. Many elderly patients are prescribed anticoagulant medications for management of diseases. All of these factors put the elderly at increased risk for traumatic brain injury. The GCS score is also less reliable in the elderly patients who commonly have more severe injuries despite having a higher initial GCS score [13, 14]. Given this, without good evidence that an elderly patient is at his or her baseline mental status, any decreased mental status should be considered symptomatic of a possible traumatic brain injury and treated appropriately. Given the lack of physiologic reserve in the elderly, aggressive measures should be put into place to prevent hypoxia or hypotension to minimize secondary brain injury.

Exposure/Examine

As with any trauma patient, it is very important to completely expose the patient to identify all injuries. It is of particular importance, however, to keep elderly patients protected from the environment and at an appropriate temperature. Through various mechanisms, the elderly have a decreased ability to maintain normal temperature homeostasis due reduced subcutaneous adipose tissue and thinning of the skin.

Secondary Survey

The secondary survey begins only if all life-threatening problems have been addressed during the primary survey. The goal of the secondary survey is to perform a complete examination of the patient and to obtain appropriate history.

Mechanism of Injury

Elderly patients tend to present with different mechanisms of injury than their younger counterparts. Falls from standing tend to be a much more common cause of severe injury and are the leading cause of trauma death in patients over 75 years of age. An astounding 84 % of elderly trauma patients present with falls, making this by far the most common mechanism of injury [15]. Patients over the age of 70 years have nearly a threefold increase in mortality after ground-level falls as compared to younger patients [16]. Other blunt mechanisms such as motor vehicle crashes and pedestrians struck by automobiles are also seen in this population with elderly typically presenting with more severe injuries.

Medical History/Medications

The collection of an accurate past medical history is paramount to good trauma care. As people age, they have an increasing number of medical problems, which can frequently complicate their care. Collecting as much information as possible not only aids the prehospital provider in their treatment but also greatly assists the hospital providers in the care of the patient. A complete and accurate medication list is valuable information for the treating physicians. These medications can give clues as to the patient's medical problems when they are unable to articulate them. As previously mentioned, the knowledge of whether or not patients are taking anticoagulant, cardiovascular, or other medications can greatly affect a patient's assessment and management.

Musculoskeletal Injuries

Osteoporosis is a common problem in the elderly, particularly in females. Fractures can occur with a low energy impact. Falls from standing that would typically cause no injuries in young adults can result in hip, spine, and long bone fractures in the geriatric patient. A high index of suspicion should be maintained after even seemingly minor trauma in the elder. Given the high incidence of hip fractures in older patients, it is important to look for limb length discrepancies and abnormal rotation of the lower limbs as clues to injury. Appropriate splinting techniques should be applied with attention paid to proper padding. Geriatric patients have skin that is much thinner, and, along with decreased subcutaneous fat, it places them at increased risk for pressure ulcers.

Backboards/Cervical Collars

The long-standing practice for trauma patients at risk for cervical spine injury has been to place rigid cervical spine collars and immobilize them on backboards. This practice has been challenged by recent literature [17, 18]. Both cervical spine collars and backboards are implicated in skin breakdown and possibly in worsening neurologic injury [19]. The elderly in particular are at increased risk of skin problems due to effects of aging on the skin. However, elderly patients are also at increased risk of spinal injury. In fact, patients over 65 years of age are considered a high-risk group and are excluded from clinical clearance of their spine by one of the major algorithms, the Canadian C-Spine Rule [20]. Further study will be essential in determining whether there is clinical benefit to spinal immobilization in the elderly. Many EMS systems are attempting to create protocols that only selectively use spinal immobilization and have eliminated the use of hard backboards during transportation.

Transportation and Triage of the Elderly to Trauma Centers

Possibly due to the increased severity of injury with less significant mechanisms of injury, many elderly patients are often undertriaged and initially transported to hospitals that are not appropriately equipped to handle their injuries. This can lead to a delay in appropriate care and inefficiency in the trauma system. In an effort to guide prehospital personnel in triaging patients to verified trauma centers, the American College of Surgeons Committee on Trauma has provided guidance and an algorithm to aid in decisions. With respect to trauma and the elderly, the field triage guidelines note that all patients over age 55 are at increased risk for worsened outcomes and trauma center transportation should be considered. They also note that in patients over age 65, a systolic blood pressure of less than 110 may represent shock [21]. The addition of systolic blood pressure cutoff for the elderly of 110 has been shown to be associated with undertriage of the elderly [22]. Given the significantly increased risk of mortality in geriatric trauma patients, prehospital providers should transport these patients to the nearest trauma center if there is any concern for significant injuries.

Prolonged Transport Considerations

Prolonged transport situations, in which care may be continued for protracted time, offer special challenges in providing prehospital care for the elderly. Treatment of shock over a prolonged time requires careful and frequent reassessment by the provider. Fluid resuscitation should be monitored closely, with care taken not to avoid excessive fluid administration for a patient with compromised cardiac function.

The potential benefits of spine immobilization should be balanced against the risk of prolonged immobilization on a backboard. Weakened skin and impaired vascular supply can

Table 22.1 Golden principles of prehospital trauma care

1. Ensure the safety of the prehospital care providers and the patient.
2. Assess the scene situation to determine the need for additional resources.
3. Recognize the kinematics that produced the injuries.
4. Use the primary assessment approach to identify life-threatening conditions.
5. Provide appropriate airway management while maintaining cervical spine stabilization as indicated.
6. Support ventilation and deliver oxygen to maintain a SpO2 greater than 95 %.
7. Control any significant external hemorrhage.
8. Provide basic shock therapy, including appropriately splinting musculoskeletal injuries and restoring and maintaining normal body temperature.
9. Maintain manual spinal immobilization until the patient is immobilized.
10. For critically injured trauma patients, initiate transport to the closest appropriate facility as soon as possible after EMS arrival on scene.
11. Initiate warmed intravenous fluid replacement en route to the receiving facility.
12. Ascertain the patient's medical history and perform a secondary assessment when life-threatening problems have been satisfactorily managed or have been ruled out.
13. Provide adequate pain relief.
14. Provide thorough and accurate communication regarding the patient and the circumstances of the injury to the receiving facility.
15. Above all, do no further harm.

From PHTLS [5]

lead to ischemia with necrosis. If possible, the spine should be clinically cleared prior to long transport. If clearance of the spine is not possible, then a padded backboard should be utilized.

Limiting exposure and maintenance of normal body temperature is essential in a geriatric patient during long transport. Loss of core temperature attenuates the shock state, and the elderly are particularly vulnerable to development of hypothermia. Keeping the ambient temperature in the back of the ambulance at a higher than normal level, even at the occasional discomfort of the EMS provider, can help reduce the rate of heat loss in the elderly. Additionally, keeping the patient covered with warm blankets can help maintain normal body temperature.

One final consideration to mitigate the challenges of prolonged transport in the elderly is early and aggressive use of helicopter transport. While the benefits of helicopter transport can be controversial, the elderly may be a population who can achieve the greatest benefit. Aeromedical transport limits environmental exposure and delivers the patient more rapidly to a trauma center where the duration of shock can be minimized [5].

Golden Principles and Summary

Prehospital care of the injured geriatric patient can be difficult. The anatomic and physiologic changes that occur with aging create special challenges in the prehospital environment. Establishment of an airway, control of hemorrhage, determination of baseline mental status, and maintenance of body temperature can all be more challenging in the geriatric patient. PHTLS summarizes optimal prehospital trauma care into 15 golden principles (Table 22.1). These principles are applicable to all prehospital trauma patients.

Quality prehospital trauma care is essential to the success of a trauma system. As the leader of the trauma team, it is critical for the trauma surgeon to actively participate in the education of their EMS personnel. Offer constructive criticism when necessary, invite prehospital personnel to participate in trauma quality improvement, and take an active role in their continuing education.

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Epidemiology of Injury in the Elderly

23

Steven R. Allen, Nicole Krumrei, and Patrick M. Reilly

Introduction

The word epidemiology is derived from the Greek translation that means "the study of what is upon the people," first coined by Hippocrates. The importance of epidemiology was described in his early work entitled *On Airs, Waters and Places* from 400 BCE [1]. In this classic work as well as others written by renowned philosophers and physicians such as James Lind and John Snow, the connection of patterns of health and disease occurrences in humans is studied in an effort to identify factors that influence of historically devastating diseases such as scurvy and cholera. The epidemiologic framework typically identifies the factors related to the host (intrinsic), the agent, and the environment (extrinsic factors) [2, 3]. Epidemiology seeks to understand how these factors interact to affect the risk of disease and, as will be described in this chapter, traumatic injury among the elderly.

The geriatric population, defined as 65 years and older, is growing at an unprecedented rate within the USA and other Western nations. This population has experienced a nearly 25 % increase from 2003 to 2013 (35.9 million in 2003 to 44.7 million in 2013). This population is expected to double to nearly 98 million by 2060. The geriatric population will make up 21.4 % of the US population by 2040. The "older" geriatric population (85 years and older) is expected to triple from 6.1 million in 2013 to 14.6 million in 2040 [4]. As the "Silver Tsunami" approaches, it is critical to thoroughly understand this population and the medical complexities that will intersect with traumatic injuries among these patients. While epidemiology is the study of a disease or injury among the larger population, it gives practitioners the knowledge to better understand the injuries and mitigate the consequences of injury of a population at the level of the individual patient.

This chapter will provide an overview of the general epidemiology of injury among the elderly population and highlight the epidemiologic issues among the most common mechanisms of injury. As the population ages at an unprecedented rate, it is increasingly important to understand this unique population. This will allow for an essential understanding of traumatic injuries as they relate to the aging adult and the myriad of medical challenges that this population affords the trauma specialist.

Factors that Influence the Pattern of Injury

In 1968, William Haddon proposed a new novel approach to epidemiology, prevention, and enhancement in trauma care. In this matrix, Haddon proposed an approach toward delineating the risk factors associated with occurrence and severity of injury [5]. The Haddon phase-factor matrix utilizes the classic epidemiologic framework of the host, agent, and environment. Additionally, this matrix highlights the dynamic process of injury causation by dividing the timing sequence into pre-event, event, and post-event. Each of the three timing phases interacts with the set of host, agent, and environment to determine if an event will occur (pre-event), if an injury will occur (event), and the consequences of the event/injury (post-event). An example is seen in Table 23.1 and illustrates the number of factors that contribute to any injury and can be used to identify strategies for treatment and prevention [5].

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Table 23.1 Haddon phase-factor matrix: pedestrian hit by a motor vehicle

Phases	Host (individual)	Agent (motor vehicle)	Environment
Pre-event (will event occur)	Age, gender, medications, alcohol use, vision, fatigue, ambulatory aids/ability	Speed, size, ability of driver, brakes	Road design, crosswalk design and timing, weather conditions, visibility, speed restrictions, traffic restrictions
Event (will injury occur)	Age, preexisting conditions (e.g., osteoporosis), medications (e.g., bleeding risk)	Speed, size, brakes	Site of crash, landing zone
Post-event (will consequence occur)	Age, comorbid conditions	Ability to extricate	Availability of EMS, distance from emergency care, quality of trauma system and rehabilitation

Note: Each of the three timing phases interact with the set of host, agent, and environment to determine if an event will occur (pre-event), if an injury will occur (event), and the consequences of the event/injury (post-event). Examples illustrate the number of factors that contribute to any injury and can be used to identify strategies for treatment and prevention. Reprint from first edition

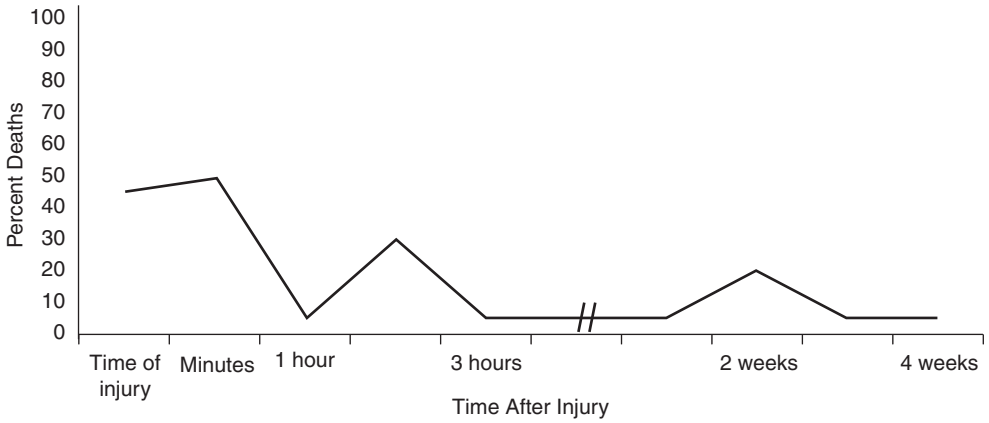

Fig. 23.1 Trimodal distribution of traumatic deaths. Note: Immediate deaths are the result of devastating brain injuries, spinal cord injuries, aortic injuries, etc. Early deaths (within the first several hours) are often due to epidural or subdural hematomas, hemopneumothorax, pelvic fractures, abdominal injuries, and uncontrolled hemorrhage. Late deaths (weeks after injury) are the result of sepsis and multisystem organ failure

Advanced age is a well-recognized risk factor for morbidity and mortality after trauma [6]. There are many well-documented systems-based changes that occur with aging (these will be discussed in detail elsewhere in this text) that result in increased frailty and decreased physiologic reserve among elderly trauma patients. These physiologic changes are associated with the presence of more preexisting medical conditions and are associated with increased morbidity and mortality. These changes not only affect outcomes but may also contribute to the occurrence of a traumatic event (deteriorating visual acuity, poor balance, and gait disturbances).

Despite these physiologic changes and the associated increased morbidity and mortality among elderly trauma patients, the well-described trimodal distribution of death (Fig. 23.1) due to trauma still applies. This distribution demonstrates that deaths among trauma victims occur in one of three periods [7, 8]. Approximately 50 % of deaths occur within minutes of the injury and are most often the result of severe neurologic (brain, high spinal cord) injury or massive hemorrhage (aortic or great vessel disruption or cardiac rupture). These individuals almost universally die at the scene or on the way to the hospital and based on the injury pattern are not salvageable even in the most mature EMS and trauma systems. The second peak occurs over minutes to several hours and is usually due to subdural or epidural hematomas, tension pneumothorax, or injuries associated with significant hemorrhage such as splenic or liver laceration and severe pelvic fractures. These patients require rapid assessment, resuscitation, and treatment of the underlying life-threatening injuries (i.e., craniectomy, needle thoracostomy, or application of a pelvic binder) to improve survival. The third peak occurs over several days to weeks and is most likely due to sepsis and multisystem organ failure. Efforts at the rapid identification and treatment of underlying injuries and subsequent insults such as infectious, cardiac, and pulmonary insults will impact this later peak of trauma-related deaths [8].

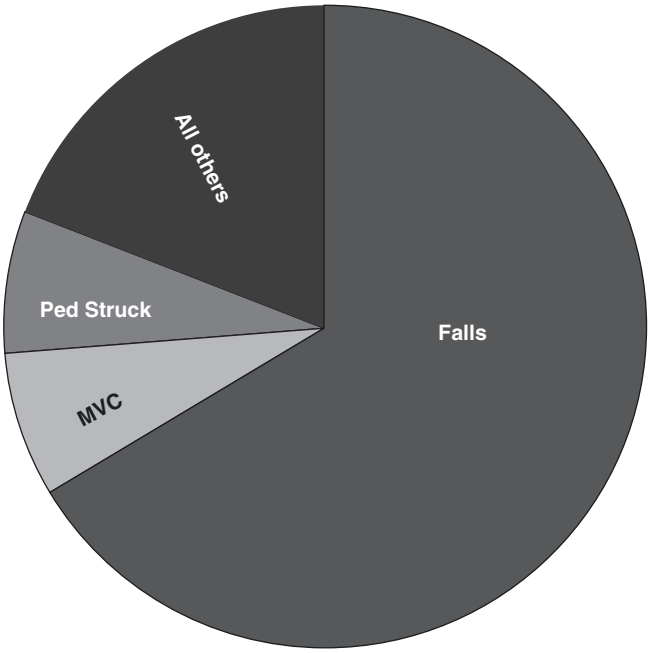

Fig. 23.2 Most common injury mechanisms among the elderly. Note: Falls are by far the most common mechanism of injury (nonfatal *and* fatal) among the elderly (66 %). Motor vehicle collisions and pedestrians struck make up the next most common mechanism overall (7.4 % each), while all other mechanisms combined comprise 19.2 % of all injury in this age group. Information calculated from data provided on http://www.cdc.gov/injury/wisqars/leadingcauses.html

Overview of Injury

Unintentional injury is the fourth leading cause of death over all age groups, both sexes, and all races in the USA in data published from 2013 [9]. For patients 65 years and older, unintentional injury is the eighth leading cause of death [9]. In 2013, over 54,000 people 65 or older died from injuries in the USA that is a rate of nearly 122 deaths per 100,000 persons. To put this into perspective, nearly 150 elderly people are injured every day with one sustaining injury nearly every 9 min [9]. The leading mechanisms of injury in order from most frequent to less frequent are falls, pedestrians struck by motor vehicles, and motor vehicle crashes (Fig. 23.2) [9].

Although the total number of traumatic injuries in the elderly is less than the total number of traumatic injuries in those between the ages of 18 and 45 years, the rate (or risk) of injury per age group is just the opposite. Those 65 years and older are at the highest risk of fatal injuries, a risk that increases with each year of age. From 2013 data, the rate of injury death in those 65–74 years old was 61.5 per 100,000 population; for those 75–84 years, it rose significantly to 127.5 per 100,000; and for those 85 years and older, this rate increased to 361.9 per 100,000 population. These values compare to 58 per 100,000 for the general adult population [10].

Nearly 15 % of the total US population is comprised of people 65 years and older. However, the elderly population accounts for 34.7 % of injury-related hospitalizations and nearly 30 % of all injury-related deaths [11]. With the unprecedented increase in the elderly population projected over the coming years, there will be profound implications on health and trauma care as the burden of geriatric injury will also surely increase at a similar rate.

Mortality is not the only potential consequence of a traumatic event. The morbidity associated with injury can be just as devastating of a consequence and has significant and widespread sequelae such as personal, family, societal, and financial repercussions that negatively impact quality of life and incur astronomical financial burden for both immediate and long-term medical care. In 2013, over 865,000 people 65 years and older were hospitalized as the consequence of an injury, while over 2.9 million elderly people are treated and released from the emergency department. Among the elderly, the leading causes of nonfatal injuries are as follows: unintentional falls, pedestrian struck, unintentional overexertion, and motor vehicle collisions. Total lifetime costs associated with *nonfatal* injuries in those 65–84 years of age occurring in the year 2010(the most recent year these data are available) amount to over $36.8 billion. This cost for nonfatal injuries includes direct medical expenditures ($20.9 billion) as well as the value of lost work productivity ($16.0 billion) but does not factor in the cost of pain, reduced quality of life, or the reduction in years lived [12].

Injury by Mechanism and Intent

Traumatic injuries are classified by their mechanism, their intent, and the place of injury. Mechanism refers to the external agent or activity that caused the injury (e.g., fall, motor vehicle collision, stab wound). Intent is classified as unintentional, intentionally inflicted on someone or undetermined. The place of injury can be classified as urban, suburban, or rural as well as location in the country.

Falls

Falls are the most common mechanism of injury (both fatal and nonfatal) among the elderly. Falls have been estimated to account for over two-thirds of unintentional injuries in 2013. Falls are the most common cause of nonfatal injury in the geriatric population and result in nearly

2.5 million emergency department visits and over 657,000 hospitalizations in the year 2013 [12]. In the USA, each year more than one-third of individuals over the age of 65 will experience a fall and increases to over 50 % for those individuals who live in an institution [13, 14]. Over half of those who suffer a fall will have at least one more unintentional fall within the next 12 months [15, 16]. Of these, it has been demonstrated that 25 % will be injured, and another 25 % will restrict their daily activities due to a fear of falling [17, 18].

In 2013, 84 % of fall-related deaths were among those aged 65 years and older. The rate of falling and being injured increases with age. The rate of fall injuries for adults over the age of 85 is four times the rate for those between the ages of 65 and 74 years. Women are 50 % more likely than men to suffer a nonfatal fall injury, with fall-related fractures twice more likely in women than in men [17, 19]. White females are twice as likely as black females to suffer a hip fracture. Up to 30 % of the elderly will suffer a moderate to severe injury such as a laceration, hip fracture, or head injury [17, 20].

Falls are the most common cause of traumatic brain injury (TBI) in the geriatric population [21]. Over 50 % of fall-related deaths in the elderly population are the result of a TBI [22]. Falls from a standing position is associated with a 5 % risk of hip fractures. This risk increases significantly with age. The consequences of a hip fracture can be devastating as 50 % of those who suffer a hip fracture are no longer able to live independently [23].

Major risk factors for falls among the elderly include those related to the host (intrinsic factors) and include advanced age, history of previous falls, hypotension, dementia and the use of psychoactive medications, postural instability and gait disturbances, decreased visual acuity, and other cognitive, neurologic, and physical impairments. Environmental (extrinsic) factors include loose rugs, objects on the floor, ice or slippery surfaces, uneven floors, poor lighting, and stairs without handrails. While intrinsic factors are significant risk factors for sustaining a fall, the risk of falling increases linearly with each additional extrinsic factor that is present [23].

Motor Vehicle Collisions

There are 36.8 million licensed elderly drivers in the USA, a 27 % increase from 2004. In comparison, the number of total licensed drivers (all age groups) only increased by 7 % over the same time period. Motor vehicle collisions (MVCs) are the second most common mechanism of fatal injury in persons 65 years and older and account for 15 % of unintentional deaths in 2013 [12]. Additionally, there were over 197,000 nonfatal injuries (5 % of total nonfatal injuries) among the elderly population [24]. In 2013, over 17 % of all traffic-related fatalities (5671 deaths) occurred in adults 65 years and older [25].

While drivers in their teens and twenties are at the highest risk of fatal and nonfatal injuries from MVC, drivers over the age of 75 have the highest risk of dying from their injuries [26]. Drivers 85 years and older have the highest rate of fatality (27.85 fatalities per 100,000 drivers), while the rate is lower among younger drivers (10–15 fatalities per 100,000 drivers) [27]. In two-vehicle fatal crashes involving an older driver and a younger driver, the vehicle driven by the elder was 1.7 times more likely to be the one struck (58 % and 34 %, respectively). In 46 % of these crashes, both vehicles were proceeding straight at the time of the collision. In 24 %, the older driver failed to yield to oncoming traffic while turning left, four times more often than the younger driver [28].

In general, older people drive fewer total miles, drive less at night, and drive mostly on the weekdays. Additionally they spend more time on familiar roads and drive at lower rates of speed. For these reasons, most elderly traffic fatalities occur in the daytime (75 %) and on weekdays (69 %) and involve a second vehicle (65 %) [27].

Injury patterns in the elderly are similar to those that are seen in the general blunt trauma population. Risk factors in the elderly that may contribute to MVCs include a larger blind spot (secondary to decreased peripheral vision), limited cervical mobility, slower reaction times, poorer technique for merging into traffic, decreased hearing, and cognitive impairment. Moreover, chronic medical conditions such as dysrhythmias, hypoglycemia (diabetes-related complications), and thromboembolic events such as stroke or myocardial infarction may be the precipitating event that leads to the collision. As with any driver, alcohol and impaired function lead to an increased risk for crash. Compared to all drivers, older drivers involved in fatal crashes are the least likely to be legally intoxicated (defined as a blood alcohol concentration of 0.08 g/dL or greater) (older 7 % vs. 18–64 years 23 %) [27].

Major factors that contribute to the likelihood of a crash include vehicle speed, vehicle stability, braking deficiencies, inadequate road design, and driver alcohol intoxication. When a collision does occur, important determinants of the likelihood of injury and injury severity include speed at impact, vehicle safety features (airbags), and the use of restraints. It should be noted that over three-quarters of older occupants of motor vehicles involved in fatal crashes were using restraints at the time of the collision compared to 64 % for other adult (18–64 years old) occupants [27, 29].

Pedestrians Hit by Motor Vehicles

In 2013, at total 4735 pedestrians were killed with 19 % of those fatalities over the age of 65. On average, a pedestrian is killed every 2 h and one is injured every 8 min [30]. An

additional 18,381 elders were struck by motor vehicles that same year. The fatality rate for the geriatric population in 2012 was 2.2 per 100,000 population, significantly higher than all other age groups. This rate was 1.8 per 100,000 population for those 65–74 years of age but was significantly higher at 2.8 for those 75–84 years of age [31]. Distribution by gender demonstrated that nearly 62 % of elderly pedestrians killed in 2011 were males, with a fatality rate ranging between 2.5 and 3.7 per 100,000 population for males between over the age of 65 years compared to that of 1.2–1.54 per 100,000 for elderly females. The geriatric pedestrian nonfatal injury rate per 100,000 population was 27 for males compared to 21 for females [32].

In 2012, it was estimated that nearly 73 % of pedestrian fatalities occurred in an urban setting versus a rural setting. Data from 2013 demonstrated that pedestrian fatalities were highest in California (701), Florida (501), and Texas (480). However, the states with the highest pedestrian fatality rates per 100,000 populations were Delaware (2.70) and Florida (2.56) [25].

For older adults, 64 % of pedestrian fatalities in 2009 occurred at non-intersection locations (compared to 78 % for all other pedestrians). Ninety percent of pedestrian fatalities occurred during normal weather conditions compared to rain, snow, and fog. Over 72 % of pedestrians were struck during the evening hours. Alcohol was reportedly involved in 49 % of motor vehicle crashes that resulted in pedestrian fatalities. Only 7.6 % of elderly pedestrians who were struck by a vehicle had a blood alcohol concentration greater than 0.08 g/dL, significantly less than the general population of 36 % in 2013 [25]. The ISS for elderly pedestrians is significantly higher compared to younger pedestrians. The elderly pedestrian is also more likely to suffer a severe head injury (including subdural hemorrhages, subarachnoid hemorrhages, intraparenchymal contusions), severe thoracic injury and high associated risk of aortic transection, hemothorax, pneumothorax, as well as spinal cord injury and fractures of the pelvis and lower extremities [33].

Injury patterns for pedestrians struck by a vehicle are dependent on the make and model of the vehicle as well as the environment in which they were struck. Risk factors specific to the elderly pedestrian include preexisting comorbid conditions especially related to their baseline cognitive status, associated sensory deficits, and ambulatory status. With these conditions and physical limitations in mind, it should be noted that 25 % of elderly pedestrians were unable to traverse a crosswalk within the posted time limit [34].

Assault and Domestic Abuse

Violence inflicted upon the elderly is an increasing cause of injury in those 65 years and older with an estimated 38,359 elderly persons treated in emergency departments for nonfatal assault-related injuries (rate of 86 per 100,000 population) in 2013 [24]. This is increased significantly compared to the rate of 63 per 100,000 as reported in 2011. Nearly 80 % of these older victims of violent injury were treated and released from the emergency department, while 17 % required hospitalization [24]. The majority of the injuries included contusions, abrasions, lacerations, and fractures [35].

The National Incident-Based Reporting System (NIBRS) is a reporting system used by law enforcement agencies in the USA for collecting and reporting data on crimes. The NIBRS data are not nationally representative, as it is not mandatory in all states. The Bureau of Justice Statistics (BJS) focused on data from Michigan, which was a complete reporting state from 2005 to 2009 to further investigate the epidemiology of crimes against older adults [36]. In Michigan, the annual rate of assault incidents for males aged 65 or older was 247 per 100,000 population which compared to 172 per 100,000 in females in the same age group. Elderly Caucasians and Asians had a similar victimization rate at 145 per 100,000 and 132 per 100,000, respectively, while blacks had the highest rate of 744 per 100,000. The assailant was more likely to be of the same race than a different race. In Michigan between 2005 and 2009, 85 % of reported violence against the elderly was intra-racial: the majority of victimizations of elderly whites were perpetrated by white offenders (79.6 %) and most attacks of elderly blacks were perpetrated by black offenders (95.8 %). Of note, nearly 90 % of elderly victims were assaulted by a family member, such as intimate partner (19.3 %), the victim's own children (47.3 %), grandchildren (8.5 %), or other relatives (8.8 %). The offender was more likely to be a family member in attacks against an elderly female (60 %) than an elderly male (38.6 %) [37, 38]. Thirty-one percent of incidents involved a nonpersonal weapon (e.g., firearm, knife, or blunt object), and 51 % involved personal weapons (e.g., hands, fists, feet, and teeth), while another 18 % involved no weapon or physical force.

According to the National Center on Elder Abuse, elder abuse refers to intentional or negligent acts by a caregiver or "trusted" individual that causes harm to a vulnerable elder. Each state defines elder abuse differently. As noted above, abuse of the elderly may take many forms, including physical, sexual, emotional or psychological, financial, or material exploitation, neglect, or abandonment. Neglect is the most common type of elder abuse. The National Elder Abuse Incidence Study was the first major investigation into the mistreatment of the elderly in the USA. By soliciting data from the 1996 Adult Protective Service records, it was found that 449,924 persons aged 60 and older had been physically abused, neglected, or in some way mistreated [37, 39]. It is believed that these results significantly underestimate the true scope and magnitude of the problem due to non-reporting and under-identification. An interview survey

performed in 2008 found that approximately 11 % of US elders who responded had experienced some form of abuse or potential neglect in the previous 12 months [37, 40].

Abuse should always be considered during the evaluation and treatment of older trauma patients. Injuries related to falls, or the fall itself, may be the result of abuse or mistreatment. Findings on physical exam that increase the suspicion for elder abuse or neglect include unexplained bruising, skin tears, or injuries not consistent with the mechanism of injury. Additionally, poor hygiene, lack of personal grooming, malnutrition, dehydration, as well as the presence of pressure ulcers, contractures, lice/scabies, and fear of examination should all be signs that alert the provider to the possibility of elder abuse or neglect. Common risk factors for the mistreatment of the elderly include dementia, social isolation, and poor physical health of the elder. Also, the presence of mental health issues and substance abuse among the perpetrator are also associated risk factors for elder mistreatment and neglect [37, 40, 41]. There may be multiple reasons medical providers do not report concern for elder abuse including the signs of elder abuse that go unrecognized and may be unfamiliar with the available screening tools, concern of offending the family member that is present, and unfamiliar with reporting laws [37]. Despite many of these issues, concerns for elder abuse must be brought to the forefront and prompt further evaluation to ensure patient safety and mitigate the risk of future injury and neglect. Elders who experience abuse, neglect, or self-neglect face considerably higher risk of premature death compared to elders who have not been mistreated [42, 43].

Penetrating Injuries

In 2013, penetrating injuries (firearms and cut/pierce injuries) were the third most common cause of traumatic death in those aged 65 years and older, accounting for over 5400 deaths in the geriatric population. A majority of the deaths from penetrating injuries were related to intentional self-harm or suicide and associated mostly with firearms compared to stab wounds [9].

Firearms were the cause of over 5573 deaths in 2013 among the geriatric population. Overall, the elderly population comprised 16.6 % of all firearm deaths in the USA in 2013. The vast majority (91.7 %) of the deaths were intentional (suicide), while only 6.7 % were categorized as homicides. For comparison, when calculated for those aged 20–34 years, the rate of firearm deaths related to suicide is 40 %. The rate of firearm associated suicide increased as the population aged with a rate of 10.1 per 100,000 for those aged 65–74 years compared to a rate of 13.2 per 100,000 for those aged 85 years or greater. Firearms also accounted for over 2288 injuries in the elderly population. Of these injuries, 1390 were categorized as unintentional and 898 were classified as intentional (228 assault vs. 546 self-harm/suicide, respectively) [9].

Although firearms accounted for the majority of penetrating trauma deaths, stab wounds (stabbing, cutting or piercing) were responsible for the majority of nonlethal penetrating traumatic injuries 65 years and older. In 2013, 330 deaths were caused by stab wounds (267 intentional, 62 unintentional), and stab wounds resulted in 159,292 injuries (156,693 unintentional, 1119 assault, 1480 self-harm/suicide attempt) [9].

There are relatively few studies of penetrating injuries in the geriatric population. A recent study from a large urban level 1 trauma center from 2014 demonstrated that elderly patients who arrived alive after suffering a penetrating injury often survived the initial injury and had equivalent survival if they did not suffer a complication during their hospitalization. However, if an elderly penetrating trauma victim incurred a complication, there was a significant increase in mortality compared to an injury-matched younger cohort in addition to longer ICU and hospital lengths of stay for those that did survive [44]. Another study demonstrated that mortality rate for penetrating injuries in patients 55 years and older was significantly higher (14.1 % compared to 9.4 % for those aged 45–54 years). When the data was analyzed for patients older than 64 years, the mortality rate of 26.4 % was significantly higher [45]. A study that utilized the National Trauma Database (from 2002 to 2006) demonstrated that within the elderly age group (65 years and older), all of the following increased with age: ISS, the incidence of self-inflicted injury, and the overall mortality [46]. The most commonly encountered injury in this age group was a gunshot wound to the head, which increased significantly with age. An admission Glasgow Coma Scale score of less than 9 and ISS greater than 15, hypotension on admission, self-inflicted injury, and injury sustained in an assault were factors associated with death in the elderly population [46].

Summary

As the population ages at an unprecedented rate, the burden of geriatric trauma will significantly increase. While the elderly population demonstrates similar epidemiology of many traumatic injuries compared to younger age groups, the elderly have a unique set of host, agent, and environmental combinations that put them at significant risk for severe injury. A greater understanding of the epidemiology of geriatric trauma may lead to greater prevention efforts and help maximize effective clinical practices to mitigate morbidity and mortality in this population.

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Injury Prevention

24

Jeffrey Nicastro

Injury Prevention in the Geriatric Population

Background and Epidemiology

The elderly population is the fastest-growing segment of the population in industrialized countries. According to the US Census Bureau, between the year 2012 and 2050, the population of those aged 65 and older is estimated to nearly double from an estimated 43.1 million in 2012 to a projected 83.7 million in 2050 [7]. Injury prevention is vital to maintaining and improving the quality of life and reducing the morbidity and mortality of the elderly.

According to the CDC, unintentional injuries resulting in death are one of the top 10 leading causes of death among older adults in the USA, with approximately 50,000 deaths each year as a result of an unintentional injury [33]. Each year over 3.9 million unintentional injuries are treated in hospital emergency departments nationally for people aged 65 and over [33]. Falls are the majority of those injuries accounting for nearly 2.5 million injured patients [33]. It was found that those who suffered from an injury were more likely to be white non-Hispanic females than any other demographic, while older adult men have a higher rate of traumatic brain injury (TBI) [5, 32]. In addition, elderly TBI patients are more likely to have prior medical conditions than their younger counterparts. These statistics emphasize the need for injury prevention in the geriatric population [5].

As the US population ages, the number of falls and the cost of treating the injuries associated with falls are anticipated to increase. According to the CDC, the direct medical cost of treating falls in 2013 was $34 billion, which was paid by both health insurance companies and patients [1]. Additional indirect costs not included in the previous figure include loss of income both to the patient and caregiver and the intangible losses of mobility, confidence, and functional independence, which are incalculable [2].

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Risk Factors

When considering injury prevention strategies within a geriatric population, risk factors must be considered and addressed. Some risk factors are categorized to be non-modifiable, such as advancing age, gender, and cognitive decline (especially attention and executive dysfunction). Other risk factors are modifiable, including some visual impairments, environmental conditions, and knowledge about injury prevention strategies [2, 3].

Older individuals are more susceptible to sustaining injury due to their higher prevalence of comorbidities, age-related physiologic changes, and delayed functional recovery. This in turn leads to further deconditioning and more falls and injuries [2]. Comorbid conditions that are commonly found in the elderly who fall include hypertension, diabetes mellitus, cardiac arrhythmias, fluid and electrolyte disorders, dementia, depression, and certain neurological conditions [2, 5, 6]. Diagnoses of Parkinson's disease, Alzheimer's disease, and non-Alzheimer's dementia have been shown to increase the risk of falling compared with healthy older adults. A diagnosis of dementia in both community- and institutional-dwelling older adults confers high risk for both isolated and recurrent falls [2]. Changes in gait patterns of patients with Alzheimer's disease and Parkinson's disease lead to increased instability [2, 9, 13]. These same factors also lead to impaired injury recovery [30, 31].

Medications can have a significant impact on an older adult's risk of falling. Medications used to treat depression, dementia, bipolar disorder, anxiolytics/hypnotics, and antipsychotics have been shown to increase the risk of falling by 47 % in older adults [2]. Other medications that have been

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associated with an increase in the risk of falling include antihyperglycemic, nonsteroidal anti-inflammatory drugs (NSAID), anticonvulsant medication, and diuretics [2]. As a result, physicians should be cognizant when starting or altering the dosage of these medications due to the increased risk of falling [2].

Trauma Centers and Injury Prevention Programs

Trauma centers have the ability to identify key community injury prevention needs by virtue of their statistical information related to local injury demographics and trends. *Resources for Optimal Care of the Injured Patient* (2014), also known as the "Orange Book" from the American College of Surgeons Committee on Trauma (ACS COT), states that "each trauma center must have someone in a leadership position who has injury prevention as part of his or her job description."

The ACS COT guidelines offer the key elements for developing and implementing effective injury prevention programs. Some of these elements include analyzing the data, choosing evidence-based programs as a mechanism to address these injury areas, and partnering with others to maximize efforts. Program evaluation is also an important tool in monitoring prevention program effectiveness.

The following topics are common mechanisms of injuries seen in the older adult population in trauma centers.

Falls

In the USA, falls are the leading mechanism of unintentional injury and the leading cause of unintentional injury-related deaths for people aged 65 years and older [1]. These falls can result in severe injuries such as hip fractures and head traumas [1, 2]. Approximately one-third of community-dwelling older adults fall every year, and this number increases to 40 % for those older than 80 years [2, 6, 34]. In addition, those who have previously fallen are more likely to fall again [2, 8, 14]. Even with these statistics, there is evidence that 75–80 % of all falls without injury are not reported at all [2]. This evidence further reinforces the need for injury prevention and specifically fall prevention efforts in the geriatric population. Of the falls that are reported, women were more likely than men to suffer a nonfatal fall injury; however, after taking age into account, the death rate associated with falls was 46 % higher for men than for women [2]. Among older women, white women are 2.5 times more likely to die from falls than their African American counterparts [2]. In general, the incidence of falls has been shown to be higher in the post-discharge period than community-dwelling older adults who have not been admitted to the hospital recently. A recent large prospective national study in the USA reported that hospital admission is associated with an increased risk of hip fracture in the post-discharge period [3].

Although not all falls lead to injury, about 20 % need medical attention, 5 % result in a fracture, and other serious injuries—such as severe head injuries, joint distortions and dislocations, soft tissue bruises, contusions, and lacerations—arise in 5–10 % of falls [11, 14]. In terms of morbidity and mortality, injurious falls have many serious consequences of which the hip fracture is the most feared [13]. This fear is well founded considering 25 % of geriatric patients will die, 76 % will have a decline in their mobility, and 22 % will move into a nursing home after a hip fracture [2, 13]. Among older adults, approximately one-half are unable to "get up" and remain on the ground [2]. Increased complications associated with these "long lies" include dehydration, rhabdomyolysis, pressure ulcers, and pneumonia [2].

TBI is another common malady associated with falls and is responsible for more than 80,000 emergency department visits each year and 46 % of all fall-related deaths [2]. Of these visits, approximately three-quarters will result in hospitalization as a result of the injury [5]. Adults aged 75 years and older have the highest rates of TBI-related hospitalization and death, with falls consistently proving to be the most common mechanism in the elderly [5].

It has been demonstrated that risk of fall increases almost logarithmically as the patient accumulates several risk factors. An older adult with only one risk factor has a 20 % risk of falling. The risk increases with each additional factor; two factors increase the risk to 30 %, three factors contribute to a 60 % chance of falling, and those with four or more of the six risk factors have an 80 % risk for suffering injuries from a fall [37]. Appropriate intervention can decrease that risk by a third. For example, an older adult with four or more risk factors (an 80 % incidence of a fall) can see a 50 % decrease in their risk if these factors are addressed [21, 37].

The identification of older adults who are at risk of falling and providing them with both medical recommendations and referrals to appropriate resources has been shown to be effective in reducing their risk of falling. The CDC recognized that the STEADI (Stopping Elderly Accidents, Deaths and Injuries) program helps stratify fall risk in geriatric patients. It is encouraged that physicians conduct a routine fall risk assessment on their geriatric patients and refer them for the most appropriate intervention [22]. STEADI includes instructions for gait and balance assessments and an algorithm for physicians to determine best options for risk reduction in their patient population. Physicians may adjust medications, recommend physical or occupational therapy, and/or refer the patient to an exercise program or community-based fall prevention program [22]. The US Preventive Services Task Force recommends

encouraging exercise to improve balance, reducing environmental hazards, and modifying medications. Other possible physician interventions are the recommendation of vitamin D plus calcium, testing for orthostatic hypotension, and several others [35].

As documented in a 2012 Cochrane Review, multifactorial interventions were shown to reduce the number of falls that an individual might sustain but not their risk of falling. Conversely, single exercise-based interventions have been shown to reduce the individual's risk of falling [23]. Other programs that include physical therapy and exercise, home safety assessment and modification, and modification of medications have been shown to be effective [23].

In recent years, "group-based" fall prevention programs have been promoted by the National Council on Aging (NCOA) and the Center for Disease Control (CDC). Four programs in particular are cited:

Stepping On This program is a multifaceted intervention that was originally developed in Australia and is currently licensed in the USA through the Wisconsin Institute for Health Aging. Stepping On brings 12–15 older adults together in community settings including senior centers, libraries, and community places of worship. The groups meet for seven weekly sessions for 2 h each session. The sessions include balance and strength exercises, information on footwear, home safety, vision, medication management, and other topics of interest. Guest experts, including a physical therapist, occupational therapist, pharmacist, and vision specialist, help to provide meaningful information to participants. A home visit is offered for each participant, and participants are invited to return for one 2-h "booster" session 3 months later. Stepping On has been shown to reduce falls by 31 %. For each participant, there is an estimated $134 fiscal net benefit achieved [24].

Otago Otago is a home-based fall prevention program developed in New Zealand and is delivered one-on-one by a physical therapist. This program consists of 17 exercises that focus on strength and balance and are taught over a 6-month period. The program has been shown to decrease falls by 35–40 %. Return on investment for Otago is estimated to be $429 [24].

Tai Chi: Moving for Better Balance (TCMBB) Oregon Research Institute developed the TCMBB program. This evidence-based program provides groups of 8–15 older adults training sessions twice a week for 1 h per session for 24 weeks. Each session consists of warm-up exercises, core practice movements, and a brief cooldown. Program goals include improving strength, balance, mobility, and daily functioning. This program has shown a reduction of falls by up to 55 % for community-dwelling older adults 60 years and older.

A Matter of Balance (MOB) Developed at the Boston University's Roybal Center for Active Lifestyle Interventions, this group-based, lay-lead model was developed as a program to help reduce the fear of falling and increase physical activity. The classes consist of groups of 10–12 older adults that meet for eight 2-h sessions one to two times per week. Through facilitated discussions and activities, participants learn to view falls as controllable and take steps to reduce them. The Office of Medicare calculated a savings of $938 in unplanned Medicare costs for those who participate in MOB [24].

For more information on these and other programs, go to http://www.cdc.gov/homeandrecreationalsafety/Falls/compendium.html to find the publications *A CDC Compendium of Effective Fall Prevention Interventions: What Works for Community-Dwelling Older Adults,* Third Edition.

Motor Vehicle Collisions (MVCs) and the Older Adult

In 2012, the Center for Disease Control estimated that there were 36 million licensed drivers aged 65 years and older in the USA, a 34 % increase from 1999 [25]. Many older adults consider driving to be a key component to maintaining their independence. The risk of being seriously injured or killed in a motor vehicle accident increases as you age, with an estimated 5560 older adults dying and another 214,000 injured in motor vehicle crashes in 2012 [25]. The risk that a MVC will result in fatalities increases, per mile traveled, beginning at the age of 70 and is highest among those aged 85 and older [25]. The disparity when compared to younger drivers is even more evident given the fact that older drivers appear to follow the rules of the road and have less risk-taking behaviors [25]. In addition, older drivers are more likely to wear seat belts (79 % seat belt usage nationally compared to 66 % seat belt compliance for those 18–64 years old) and are less likely to drink and drive [25]. Only 7 % of older drivers who were killed in MVCs were found to have alcohol-related causes, compared to 24 % of drivers who are 21–64 years of age. Older drivers are also more likely to limit their driving at night or during bad weather and on average drive fewer miles [25].

Injuries sustained by older adults are generally more extensive than those of younger drivers who have been in similar accidents [25]. As the number of older drivers on the road increases, along with the number of miles they drive, the

incidence of crashes is expected to rise [25]. Although there are fewer incidences of motor vehicle collisions by older adult drivers, when they do occur, more resources are utilized to provide care. Diagnostic imaging and the necessity of inpatient care are a few examples of how the cost of elderly trauma care after an MVC is higher for older adults [26].

The Center for Disease Control suggests that identification of pertinent risk factors and education could help reduce motor vehicle crashes for high-risk older adults. A medication review by their primary care physician or a pharmacist, regular vision testing, practice safe driving strategies, and exercise to help with strength and flexibility should be implemented to reduce risk. At this time, there are no validated competency tools for assessment by the primary care provider or other medical professionals [25].

Technological innovations in the automobile industry have helped decrease the number of MVCs and therefore associated injuries for older adults. There have been advancements in the design and implementation of automatic emergency braking systems which help to combat problems among older drivers [26]. According to the IIHS (Insurance Institute for Highway Safety), automatic emergency braking will soon be standard in new vehicles for ten automobile manufacturers [26]. Driverless cars, also known as autonomous cars, are now being tested by Google and some car manufacturers. These advancements may allow older adults with impaired vision, slower reflexes, and other effects of aging to continue to be mobile and independent while at the same time safer and have fewer collisions [26].

Prevention strategies exist for reducing the risk of crashes for older adults. Driver safety education courses are offered in different states from the highway patrol, American Automobile Association (AAA), AARP, and other organizations. These courses review laws, recommend safe driving strategies, and provide guidance on when a driver should stop driving. NHTSA offers a resource manual on talking about the difficult decisions about when to stop driving entitled *How to Understand and Influence Older Drivers* [27].

Another intervention available to older adults is CarFit, which was developed by AAA, in partnership with AARP and the American Occupational Therapy Association. CarFit is a device that will determine if an older adult's vehicle is properly fitted, and if it is not, a technician will correct mirror and seat positioning or recommend and install adaptive equipment including extenders for pedals and mirrors [28].

When an older adult or their family is concerned about their driving ability, a referral to a qualified driver rehab specialist should be recommended. Driver rehab specialists evaluate vision, reflexes, coordination, judgment, and the need for adaptive equipment. Some tests are done in a clinic setting, but some specialists will complete driving assessments with the use of simulators or on the road. Additional information is available from the American Occupational Therapy Association or the Association for Driver Rehabilitation Specialists [29].

Other forms of prevention include being active with policy and legislation. This can yield important injury prevention results for advocates from trauma centers. Collaboration and planning with highway safety groups can provide targeted changes to traffic signage and simplified road design. Additional redesign of high-risk intersections can be recommended through tracking of incident occurrences.

Elder Abuse

In general terms, there are several different types of elder abuse. Physical violence, which includes sexual abuse, is defined as an act carried out with the intention of causing physical pain or injury to another person [4, 10]. Neglect, including abandonment, is a type of abuse more commonly seen with the geriatric population and can be defined as the failure of a designated caregiver to meet the needs of a dependent elderly person [4, 10]. Neglect can be both intentional and unintentional. For example, neglect is considered intentional if the caretaker is willfully failing to fulfill the needs (such as withholding food, medicine, or failure to assist with ADLs) of the older adult. Other types of abuse are psychological and emotional abuse or material exploitation [4, 10].

The prevalence of abuse is generally underestimated, with one in ten older adults reporting some type of abuse in the past year [10]. In all likelihood, the incidence of abuse is much higher, since many cases of violence or neglect are not reported due to fear of notifying police, friends, or family about the violence [10]. A report from the House Select Committee on Aging has suggested that between one and two million older Americans experience mistreatment each year [4].

Abuse is a complex issue and will require the efforts of medical providers, social workers, and the community to raise awareness and reduce the ever-increasing occurrences in the elderly population [4]. Even though physicians are not isolated in the identification and prevention of elder abuse, they are often unaware of the resources that are available within communities and how to gain access to them [4]. When considering ways of treating and reducing cases of domestic violence, clinicians should consider such events as they would a chronic disease and understand that like chronic disease, abuse is often typified by periods of quiescence followed by exacerbation [4].

Some studies have found that physicians as a group are not as familiar with the mandatory reporting laws and are less effective at identifying cases of elder abuse and the risk factors associated with it [4]. In addition to limited knowledge of the laws, the term "mandatory reporting" proves to be a roadblock in itself [4]. Many physicians have indicated that "mandatory reporting" implied to them that there was a need to have proof of mistreatment, neglect, or abuse prior to

reporting the issue. In many states, however, the suspicion of abuse alone is grounds for reporting, and the physician is not obligated to provide clear proof [4].

Common risk factors among care providers for elder abuse may include:

Using drugs or alcohol, especially drinking heavily

- High levels of stress and low or ineffective coping resources
- Lack of social support
- High emotional or financial dependence on the elder
- Lack of training in taking care of elders
- Depression [10]

Elder Abuse Prevention (Awareness)

Understanding the scope of elder abuse is crucial to reducing its incidence. One mechanism to reduce elder abuse is to ensure that clinicians take a careful history that includes screening for maltreatment and abuse [4]. In addition to the history, physicians and midlevel providers should be familiar with the different interviewing techniques likely to elicit the most accurate information [4]. It is important for the patient not to be questioned in the presence of the suspected abuser. These interviews may reveal disparities between the two accounts (e.g., of how injuries were sustained). Older adults who have been abused may also be reticent about disclosing information in the presence of staff members or other patients [4].

How can we prevent elder abuse [4, 10]?

- Listen to elders and their caregivers.
- Report abuse or suspected abuse to Adult Protective Services.
- Educate physicians and midlevel providers about how to recognize and report elder abuse.
- Learn how the signs of elder abuse differ from the normal aging process.
- Counsel family members and caregivers in order to prevent abuse. Some suggestions may include getting help from friends, family, or local relief care groups. Taking a break—if only for a couple of hours—involve more people than just family in financial matters. Find a reputable adult day care program, seek counseling or other support if the caregiver is depressed, and suggest that the caregiver seek help if they are having problems with drug or alcohol abuse.

Suicide

Adults aged 65 and above make up approximately 12 % of the total population but account for 18 % of all suicide deaths [16]. This makes them the highest suicide rate for all age groups. Suicide is the third leading cause of injury for adults aged 65 and older, with the most common method involving the use of a firearm [5, 16]. This statistic is particularly alarming due to the estimated growth of the 65-and-over population over the next several decades [7, 16]. In 2002, the annual suicide rate for people over the age of 65 was 15 per 100,000; however, that number increases to 17 deaths per 100,000 in those aged 75–84, and that number increases again for those over the age of 85 [16]. As alarming as these statistics are, it is thought that suicides may be underreported by up to 40 % [16]. This is likely the result of "silent suicide" deaths as a result of an overdose, self-starvation or dehydration, and other "accidents" that go unreported [16]. As with all injury prevention, suicide prevention is centered on the identification of common risk factors. In older adults, the risk factors for suicide include being white and male, a history of depression, chronic pain, illness, and social isolation [5]. Of the older adults who have successfully committed suicide, 70 % had seen their primary care provider within the previous month, signifying that healthcare providers are not fully recognizing the window of opportunity for intervention in this population [5].

The warning signs of suicide include losing interest in activities that the older adult had previously found to be enjoyable, cutting back on social interactions, breaking medical appointments, changes to grooming and self-care regimens, experiencing a personal loss (such as the loss of a spouse), and a preoccupation with death or a lack of concern for their personal safety [16]. Remarks such as "This is the last time that you'll see me" or "I won't be needing anymore appointments" should raise family and provider concern, and the most significant indicator is an expression of suicidal intent [16].

As with elder abuse prevention, the key component to avoiding suicide among the older adults is communication, with both the patient and their families [16]. Other options for prevention include the caregiver's limiting access to firearms and reducing the inappropriate use of sedative medications [16]. Some studies have shown that 80 % of older adults treated for depressive disorders using both medication and therapy have recovered from depression symptoms, thus reducing their risk for a future suicide [16]. Perhaps the most impactful intervention would be educating primary healthcare providers on the identification and treatment options available for late-life depression. Most of these clients are not diagnosed with a psychiatric disorder and have not sought out mental health services prior to committing suicide [16].

Summary In order to reduce the burden on emergency departments and hospitals, communities must increase the adoption and utilization of the injury prevention programs that are currently available to the geriatric communities. In

addition, further research is required to better understand the root causes of these injuries and the modifications that are needed to reduce an individual's risk in the future. If left unchecked, the impact of potential injuries the growing geriatric population is at risk for could reach epidemic proportions. Increasing injury prevention knowledge and access is a key component to increasing an older adult's quality of life, and the additional positive outcome will be the reduction of the burden of geriatric injuries on the nation's healthcare systems.

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Outcomes for Surgical Care in the Elderly

25

Michael D. Grossman

Introduction

Outcomes in geriatric trauma and surgery have received extensive attention in recent peer-reviewed literature. As noted by Maxwell in the previous edition of this chapter [1], there were more than 80 published studies between 1980 and 2014, and in 2015 alone, a search of the Google Scholar web site lists more than 4000 references under the search term "outcomes in geriatric trauma."

The preponderance of recent scholarly activity focuses upon the use of predictive tools that integrate the concepts of frailty, dependence/independence, and function in some combination as prognostic indicators for elderly patients. In this regard, the literature and our understanding have evolved over the past quarter century [2–5] when most reports focused solely upon preexisting conditions (PECs), age, and severity of injury or illness as predictors of survival. It is now understood that PECs may be linked to frailty, but that frailty is not an inevitable consequence of PECs, and that frail patients may have few if any PECs.

Another concept in the contemporary literature on outcomes in geriatric trauma and surgery is the role that systems of care at the regional level (macro) and hospital (micro) level may play in determining outcome for geriatric trauma patients (GTP).

The chapter will focus upon GTP. While some themes are common to all elderly surgical patients, the emphasis in this chapter is upon patients for whom no pre-intervention or planning is possible. We will review factors known to affect outcome in *general* and for *specific conditions* seen commonly in clinical practice. Confounding variables that complicate analysis of outcome will be reviewed. Finally, we will address the concept of *value* associated with traditional versus nontraditional outcome analysis and discuss implications for different approaches to analysis of quality/outcomes in geriatric acute care surgery.

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Factors Affecting Outcome

Patient-Specific Factors

The outcome variables that have been examined in previous studies include primary health-care outcomes (death, complications, disposition, functional status) and surrogate or secondary health-care outcomes (length of stay, ICU length of stay, cost of care, readmission).

Many of the most widely quoted studies examining outcomes in GTP have been retrospective and have utilized institutional, state, and national data sets in order to accumulate large numbers of patients [2–7]. Most have focused upon patient-specific criteria present on admission to the hospital that could be measured, abstracted, and included in registry data sets. These studies have provided useful descriptions of the association between PECs, age, ISS, physiology at presentation, and outcomes such as mortality, inhospital complications, functional status at discharge, length of stay, and discharge destination. The overriding theme of these studies is that most primary health-care outcomes are *negatively* affected by PECs and that more PECs per patient generally portend a worse outcome. Specific PECs such as preexisting cirrhosis and kidney failure [2, 5] are associated with higher odds of death for any given severity of injury. Several studies have also shown that the impact of PECs may be most important in GTPs with moderate injury (ISS 10–20) as opposed to mild or severe injury [2, 8].

Many of these studies also demonstrated that age alone *is* an independent predictor of outcome and that aggregate injury severity and deranged physiology on admission are

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also associated with worse outcomes. Severe traumatic brain injury or low GCS on admission in the elderly [3, 6] has been consistently associated with poor outcomes.

Intuitively, none of these results seem surprising, but favorable outcomes observed for some seriously injured GTP [7, 9, 10] and the feasibility of performing major surgery in geriatric cohorts [11] have led investigators to pursue more precise predictors of outcome. The underlying concept that physiologic reserve is not necessarily predicted by age or even PECs has been accepted. Following trends in general geriatrics research, more recent studies on patient-specific factors affecting outcomes for EGS and GTP have focused upon determination of frailty [12–14] or functional independence [15, 16] in predicting the primary and secondary outcomes described above.

Frailty and functional dependence are related but separate concepts that have been used as theoretical and practical constructs to describe patient-specific characteristics in the elderly and "non-elderly" population. While a complete discussion of the topic is beyond the scope of this chapter, several reviews have been published [13, 17]. What is consistently clear is that frailty and functional dependence have a measurable negative impact on all outcomes including mortality, complications, length of stay, and discharge disposition [11–13].

Some assessments of frailty include subjective criteria, while others are more "rule based" including timed maneuvers such as the "get up and go" assessment or tests of grip strength [14, 17]. While rule-based assessments may be d*ifficult* in the acute hospital setting, several recent studies have confirmed that it is *possible* [12, 18] to perform them. It has also been shown that these scores may be modified to provide rapid assessment for trauma patients for the purpose of prognosis, especially with regard to discharge disposition [13, 18]. Inhospital tools for assessment of functional dependence that relies principally on historic factors [13, 14] are based on the Karnofsky scale or simplified equivalents. These tools are easily reproduced and can also be used for prognostic purposes especially with regard to disposition.

Given the recent emphasis on the importance of assessments of frailty and functional dependence, there are some issues that exist that may limit their routine use in clinical practice for acute care surgeons. Many assessment tools require interaction between assessor and patient, and, where patients are unwilling or unable (dementia, obtundation, language barrier) to participate, a surrogate must be available who can provide accurate, unbiased information. One recent study [13] reported a large number of exclusions related to the surrogate, and of the patients enrolled, more than half relied on the surrogate alone for patient information. In our own experience, family members may overestimate, underestimate, or disagree with respect to some of the variables assessed. Another potential limitation of frailty assessment is that in the outpatient setting there may be opportunities for modification via exercise programs to enhance muscle mass, or management of depression [14], it is less clear that interventions can be undertaken in the acute, inpatient setting. Finally, unlike the elective surgical setting where it might be possible to use these data in making decisions regarding patient selection for surgery, it is less possible to do so under emergent circumstances.

As with previously available information regarding age and PECs, assessment of frailty and dependence in the acute setting will allow more informed discussion regarding prognosis particularly with respect to discharge disposition, but it may not provide information that will help to *improve* prognosis.

Systemic Factors

Given that patients will present themselves to the health-care system with a set of patient-specific factors, there are some attributes of the system that may help in determining primary and secondary health-care outcomes. The system may be broadly defined as a continuum from the macro (state and regional delivery systems) to the micro (specific features of care delivery within institutions).

This continuum of care has been evaluated with respect to outcome for GTP. These data are generally lacking for EGS although studies have been done that suggest emergency general surgery outcomes for certain index cases are improved using the "Acute Care Surgery model" [19]. These studies suggest that a verification process might be warranted for hospitals performing emergency general surgery and by inference it is possible that EGS patients would fare better in such institutions. To our knowledge this hypothesis has not been directly tested for elderly emergency general surgery patients.

Several studies have demonstrated that GTP may be under triaged [20, 21] based upon existing field triage criteria (CDC). The American College of Surgeons Committee on Trauma has recommended alteration in field triage guidelines to improve recognition of injury in patients over the age of 55 [22]. These include using a systolic blood pressure of 110–120 [23] as opposed to 90 to define hypotension in the elderly and therefore establish a higher (presumably more sensitive) threshold for trauma system activation based upon "Box 1" physiologic criteria. For centers utilizing a multitiered response, the highest tier of trauma system activation would be used more often in GTP.

A significant proportion of GTPs are cared for outside of trauma centers or in centers with lower levels of designation [24–26]. Some studies have suggested that GTPs with both major and minor injuries have better outcomes in trauma centers than non-trauma centers [26, 27], while another

recent study [28] demonstrated equivalent outcomes for all trauma patients with minor injuries treated in non-trauma centers as compared to trauma centers. This is a complex issue for several reasons. First, as suggested by regional data in New York state [24], the majority of trauma patients treated in non-trauma centers is elderly and has low injury severity, but these hospitals do not participate in New York state or national trauma registries. Other than mortality, precise outcome data for patients treated in these hospitals is lacking, and it may be inaccurate to assume they are better or worse than in trauma centers. Second, inclusion or exclusion of isolated hip fractures [29] in the registries of trauma centers is highly variable and may bias outcome data for individual centers so that overall survival data between institutions is not comparable. These patients have lower ISS and lower overall rates of complications than age-matched controls with multisystem trauma. Third, and along these same lines, the definition of "trauma" has expanded to include isolated single-system orthopedic injury (hip, upper extremity), many of whom are admitted to trauma centers and included in their registries. It is important to recognize that even within trauma centers, a significant proportion of these patients may be admitted to non-trauma services. This has not been well quantified in studies that suggest admission to trauma centers is beneficial for GTPs. As noted above, such patients tend to have more comorbidity and lower ISS. It may not be appropriate to view such patients as under triaged based simply upon the presence of an injury in a large administrative data set when in fact the principle reason for hospital admission was not the injury but the medical conditions associated with it. These distinctions can be difficult to make in reviewing large databases. Finally, on an intuitive level, the impact of removing a GTP with minor injury from their primary care network to a major trauma center where their medical history is not well known is difficult to measure. Is care less efficient? Do such patients receive unnecessary testing due to lack of familiarity with their preexisting conditions? Are patient-centered values as well understood by treatment teams who may have had no prior relationship with the patient or family? What does seem reasonable is that the triage *threshold* for elderly patients with any physiologic or anatomic criteria should be lowered and that such patients should be treated in trauma centers. This reasoning should probably be extended to patients in "Box 3" (mechanism of injury) but may not always apply for *ALL* elderly patients who sustain same-level falls with isolated extremity fractures.

Recently, the concept of "mandatory" trauma center care for GTPs has begun to focus more upon the value of a *concentrated experience* in geriatric trauma as defined by the proportion of GTPs seen relative to total volume [30, 31]. These studies used state and national data to suggest that the benefit of trauma center care is most pronounced in centers that care for a higher proportion of geriatric patients as opposed to those with high overall volume. One study [31] reports a reduced risk-adjusted mortality in these high-proportion centers which more often tended to be *lower-volume*, *community Level II center*s. This study calls for the regionalization of geriatric trauma and creation of geriatric trauma centers.

Within hospitals or trauma centers, recent studies have focused upon geriatric consultation and geriatric trauma services as possible means of improving outcome and process metrics. Complication rates including delirium and urinary tract infection are improved when GTPs are admitted to geriatric trauma services or receive geriatric consultation [32–34]. Process of care including discharge disposition is also enhanced. Differences in mortality rates have not been demonstrated using these measures. In her recent review of geriatric trauma, Kozar [35] proposes that " …any significantly injured geriatric trauma patient should be admitted by the trauma surgeon with appropriate consultation and multidisciplinary input." This seems to be a reasonable suggestion and allows interpretation and "local rules" to determine where GTP with isolated single-system orthopedic injury will be managed. When available, geriatricians would seem to be an excellent resource, but their presence and availability is limited and likely to remain so. Identifying a hospitalist or internist who can work closely with the trauma team on a consistent basis might be another option.

Discharge disposition is a systemic factor that deserves special consideration because it has been used by many authors as a surrogate [2–4, 33, 34] outcome and quality metric. Most studies have defined discharge to home or acute rehabilitation centers as "favorable," while death or discharge to a skilled nursing facility is "unfavorable." Disposition is a primary health-care outcome that patients know and care about since it is directly related to the level of functional independence. It can be argued that this is one of the more important outcome variables for GTP, but relatively little is known about it. In Kozar's [35] review, a questionnaire distributed largely to academic trauma surgeons indicated that there was strong agreement with the statement that "post discharge rehabilitation is a major issue in the long term outcome of GTP." There are confounding variables that affect post-discharge planning. A recent study examining national data [36] identified clear trends in the reduction of acute rehabilitation beds available for trauma patients and links this trend to the evolution of stroke center certification that closely tracks disposition to acute rehab as a requirement for certification. A recent review of effectiveness of rehabilitative services for traumatic brain injury [37] showed that elderly patients with TBI have more limited access to acute rehabilitative services based upon age alone and typically end up in acute rehab centers only when their cognitive scores are higher than younger TBI patients. These

considerations regarding disposition as an outcome suggest that there may be many other factors determining disposition for GTP that are independent of patient factors or the quality of acute inpatient care. It should be an area of focus for geriatric trauma research.

Specific Outcome Evaluation

It is common for studies to lump GTP and EGS patients together stratifying by severity of illness, PECs, or, more recently, frailty indices. In addition there are biases introduced by lumping high (MVC)- and low (ground-level fall)-energy mechanisms together [38]. In clinical practice, patients may present with multiple injuries or with a single-system injury or illness for which specific considerations are important, and these may have much or more to do with measured outcomes than the general variables mentioned above. For example, a patient with an unstable cervical spine fracture that undergoes surgery will have an outcome likely to be affected by surgical and anesthetic management in addition to the patient and system-based variables cited above. Hospitals that include isolated hip fractures in their trauma registries and have well-established systems for perioperative management [39] are likely to show improved complication rates. The degree to which these relatively common single-system injuries are represented in a data set will determine the impact of disease-specific management on the institution's overall outcome measures. Three common examples of important single-system injuries in GTP are included in the discussion below. Again, the impact of patient determination, surrogate wishes, and the influence of palliative care recommendations on outcomes for these conditions is difficult to estimate from available data, but it is likely to be important.

Traumatic Brain Injury

The outcome of treatment for TBI in the elderly is an especially important example of a specific condition requiring careful outcome analysis since it is a common form of injury in GTP. Canadian Health Ministry data from 2006 to 2011 [40] demonstrate a 24 % increase in admissions to Canadian hospitals for TBI in patients over 65 years of age. Furthermore, these hospitalized TBI patients demonstrated an increased Charlson Comorbidity Index (CCI) over the period of review. While patients with severe TBI and low GCS are known to have very high mortality and likely have a high prevalence of care withdrawal, mild and moderate TBI are less well understood [3]. A recent meta-analysis [41] demonstrated an inhospital mortality of 12.3 and 23.3 %, respectively, for mild and moderate brain injury in GTP. For both groups, mortality increased at 6 months, and for both measures, it was higher than younger counterparts. Not surprisingly, there was a strong correlation between preexisting conditions/chronic health issues and mortality. The management of both acute and chronic subdural hematomas (SDH) has been studied and reported in the neurosurgical literature since the 1960s. The standard of care for younger patients with acute SDH has been evacuation within 4 h [42]. This standard has been challenged in recent years and may be inappropriate in the elderly given the presence or absence of mass affect, underlying brain injury, neurologic exam, and presence of anticoagulants.

Elderly trauma patients have a higher proportion of extra-axial mass lesions (epidural and subdural hematomas) than younger patients, and this trend begins at age 50 [43]. Data from the University of Michigan [44] demonstrate an inhospital mortality of 27/103 (33 %) for patients > 80 years of age undergoing evacuation of *acute* SDH. For patients between 50 and 79 years of age, mortality was 36/103 (22 %), not significantly different than patients *under* the age of 50.

Chronic SDH is a very different entity than acute SDH and may be a blended condition with both elements present. The classic description of a chronic SDH involves cognitive and physical decline with or without an evolving focal motor or speech deficit. There may be NO antecedent history of trauma. It is common for patients to present with recent falls and "acute and chronic SDH." Miranda [45] reviewed 209 cases of chronic SDH seen over an 8-year period. One hundred thirty-nine (66 %) underwent some form of operative decompression, and 72 (34 %) were observed. Overall inhospital mortality was 35/209 (16.7 %); 44/209 (17.5 %) were discharged home. Median survival for the entire group over the period of follow-up was 4.4 years. Options for operative treatment of chronic SDH include burr holes or craniotomy; one recent review and meta-analysis suggests burr holes are favored when possible. This makes intuitive sense and factors into decision-making regarding treatment of acute SDH. When possible, neurosurgeons may wish to delay operative treatment of acute SDH in hopes that the hematoma will liquefy or become more "chronic" in nature so that a less invasive surgical approach may be used.

It seems clear that there is acceptable mortality associated with operative treatment of acute and chronic SDH, but studies have not clearly defined whether operative versus nonoperative therapy is *preferred* for these patients. The use of observational therapy for SDH has been described since the 1970s [46]. The simple presence of an SDH is not sufficient to warrant emergent evacuation and must be weighed against the likelihood that neurologic deficits will be improved or reversed by surgery. These considerations must be balanced against the risks of bleeding and hematoma recurrence associated with antiplatelet or anticoagulant medications.

In summary, the management of acute and chronic extra-axial mass lesions in GTP requires careful judgment and patient selection.

We know that the inhospital mortality associated with mild and moderate brain injury of all types is under 25 %, but we do not have a good sense of the impact of such injury on functional outcomes. Good quality data on functional outcomes after TBI in the elderly is generally lacking, but a recent publication of comparative effectiveness research in TBI rehabilitation [37] sheds light on a few important concepts. Patients entering rehab centers with *higher* cognitive FIM scores tend to be *older*, but older patients also tended to have lower FIM scores 9 months post discharge. Older patients with TBI were less likely to return to independent living, had more returns to acute care hospitals from rehab, and had more readmissions to acute care hospitals during the 9-month follow-up period. The data reveal that a low proportion of elderly patients with severe TBI enter rehabilitation units. Only patients with higher cognitive FIM scores are likely to enter brain injury rehabilitation, but they tend to fare worse than younger counterparts with respect to standard rehabilitation outcome metrics.

In summary, severe TBI in GTP may be more easily identified as a condition from which recovery is unlikely prompting palliative care or hospice intervention. The same is not true for mild and moderate TBI with or without mass lesions. These cases must be individualized, and great care must be taken to consider the degree of improvement expected with operative treatment in cases where it would be an option. The likelihood of recurrent bleeding (particularly in the face of antiplatelet agents), hygroma/chronic SDH formation, and effects of surgery in general must be weighed against the degree of function that appears to have been *lost* as a result of the extra-axial collection. Senior-level discussion between the attending neurosurgeon and trauma surgeon is warranted. We recommended the liberal and early use of palliative care consultation in these cases.

Cervical Spine Fracture

Fractures of the cervical spine are common in elderly patients. In a descriptive study covering 5 years at a busy Level I trauma center, 139/726 (19 %) of cervical spine fractures were in patients over the age of 65 who were injured after ground-level falls [47]. Cervical spine fractures in GTP are most commonly of C1 or C2 (27 and 53 %, respectively), whereas these fractures account for only 13 and 21 % of cervical fractures in a younger cohort. Issues affecting outcome related to upper cervical fractures in the elderly include operative versus nonoperative therapy and the relatively high prevalence of dysphagia and aspiration complicating this condition.

Several retrospective series have addressed the prevalence of complications [48–50], associated with cervical immobilization in rigid collars and/or halo vests. The incidence of pneumonia was 10–14 % for these devices, and mortality ranged between 8 and 13 %. A more detailed retrospective review [51] was conducted examining operative versus nonoperative treatment of C2 fractures. It demonstrated 14 % 1-year and 44 % 2-year mortality for all patients, but slightly higher 30-day mortality for nonoperative treatment. Length of stay was significantly higher in the operative group (15 vs 7 days), and a greater number of operated patients required feeding tubes (18 %) as a result of dysphagia. Based on these retrospective data, the investigators conducted a prospective study of odontoid fracture management in an effort to define the role of operative versus nonoperative therapy and the complication profile associated with each [52–54]. In this non-randomized series, 156 patients were followed for 12 months. 101 underwent surgery by a group of dedicated spine surgeons; 58 had nonoperative treatment in cervical collars. Mortality for all patients was 18 % at 12 months. Dysphagia was more common (11 vs 5 %) in operated than nonoperated patients. The rate of *all* complications was 30 and 38 % in nonoperated versus operated patients. Disability related to neck pain was *less severe* in patients undergoing surgery versus those who did not undergo surgery. Selection bias was acknowledged as a potential issue in this prospective study.

Taken together these studies confirm that cervical spine fractures in the elderly are most often of the upper cervical spine and there is a relatively high rate of complications associated with either approach to treatment. In patients who have a relatively high degree of premorbid function, neck pain and function will be better preserved by surgery, but there is a higher rate of dysphagia. For patients with lower levels of function in whom cervical disability might not be a primary health outcome of importance, nonoperative treatment might be a better option.

Hip Fractures

Isolated hip fractures (IHF) are a relatively new addition to the "trauma" landscape in that trauma center databases have not traditionally captured this mechanism of injury. For many years, some of the more mature state trauma system databases specifically excluded hip fractures [55]. The National Trauma Data Base [56] is the source for many of the studies quoted in this review. A review of NTDB data from 2014 demonstrates a number of interesting findings with regard to IHF. Of 758 facilities reporting data, only 142 (18 %) did NOT report IHF and 431 (56 %) reported ALL IHF regardless of age, thereby including all such fractures associated with ground-level falls in the elderly. The data

also demonstrate that the leading mechanism of injury reported in the NTDB is "falls" and that the incidence of this mechanism has increased from 24 to more than 40 % since 2003. The longest median length of stay is attributed to falls despite this having the lowest ISS range. Taken together these data strongly suggest that the inclusion of IHF has had an impact on the profile of data contained in the NTDB and the benchmarking of outcomes for all GTP [29]. Given these considerations it seems reasonable to include this condition in any discussion of outcomes in GTP.

IHF

IHF has been called the "prototypic geriatric illness" [57] in that it is most often caused by ground-level fall, a common geriatric problem, and usually occurs in patients with comorbidities and frailty or functional dependence. Conversely it does not resemble the "traditional" conditions that have been associated with trauma center care and in many ways more resembles a medical condition or syndrome.

IHF is far more common in women and in patients over the age of 85 years. Osteoporosis is a major risk factor as are any comorbidities that affect gait and balance: polypharmacy, prior use of assistive devices, and dementia. The mortality for IHF 1 year after injury is 25 % and long-term disability is common [58].

Treatment of IHF is surgical with the type of surgery determined by fracture type and location. While technical details of fracture repair are beyond the scope of this review, in general, non-displaced femoral neck fractures are generally the simplest to manage, while displaced femoral neck fractures and intertrochanteric and subtrochanteric fractures require increasingly complex surgical procedures and, in this regard, may behave more like femur fractures with attendant blood loss and physiologic disturbance. Therefore it is important to compare "apples to apples" in any discussion of IHF.

Optimal timing of surgery is generally within 24–48 h with the goal of minimizing hospital stay and the period during which the patient is bedbound. Generally speaking, longer preoperative delays are associated with more comorbidities, and these may be more of a factor in determining outcome than the delay to surgery [59]; nonetheless it would seem that from a patient perspective, early surgery is a worthwhile goal if it can be safely achieved.

Other elements of care that have been studied and shown to provide benefit in patients with IHF include delirium prevention using a structured protocol, a transfusion threshold of 8 gms/dl, and pain managed with an opioid protocol [57]. Areas that show promise but are still somewhat controversial include the use of regional analgesia and anesthesia via iliac or femoral nerve blocks and the use of intermittent versus continuous urinary catheter drainage [57, 60].

The utility or benefit of trauma services in the care of IHF has not to our knowledge been studied. Several studies have demonstrated benefit from the use of geriatric services on the frequency of delirium and other medical complications, but proving benefit attributable to "multidisciplinary care" has been more difficult [61, 62] from 58 to58. As IHF is a common condition that is often treated in a community hospital setting, it is likely that many patients are managed by internists or family physicians who know the patients well and in an environment where they have strong social support and are in familiar surroundings. It is not clear that more formalized levels of organization in management are beneficial.

Access and efficient transition to posthospital rehabilitation would seem to be of obvious benefit, but its value is more difficult to prove [57]. Studies on the benefit of rehabilitative services in general demonstrate that healthier, younger patients tend to have better access to acute rehabilitation facilities (prior), and given the associated comorbidities, it is not surprising that many patients with IHF receive rehab services in skilled nursing facilities or home-based programs. One randomized trial showed that patients who could participate in a facility-based high intensity program had improved functional status when compared to patients receiving in-home treatment [63, 64].

In summary, IHF are frequently "counted" by trauma centers as reflected by the growing number of these patients in the NTDB. Whether these patients are representative of trauma patients as a whole, they are clearly a good substrate for the study of geriatric trauma systems. It is likely that this condition will be encountered more frequently on trauma and acute care surgical services in the future, and, as such, we may anticipate that the makeup and character of these services will also change.

Considerations Regarding Traditional Outcome Measures

The use of conventional primary health-care outcomes for geriatric patients requires careful consideration. It is likely that there are confounding effects in attempting to evaluate whether outcomes are "good" or "bad." Mortality may be the most difficult outcome to evaluate. While many good quality studies have been done utilizing large data sets, these may not allow precision in determining cause of death, factors associated with cause, or whether death may have been a "better" outcome than the alternative available for that patient. Another factor that may be difficult to determine from these large data sets is the decision not to initiate care versus decisions to withdraw it, and if so at what point in the episode of care. In this regard mortality analysis may be more complex in GTP. These are individuals who by definition have many more years behind them than in front of them

and, given the variables discussed above, may be in varying states of physical, emotional, or spiritual decline. Figure 25.1 represents a potential "taxonomy" of mortality analysis that might prove useful in evaluating this outcome measure.

Though it is well established that withdrawal of care is frequently associated with mortality in GTP [65], the role of palliative care services in determining mortality and/or affecting complication rates is less clear and potentially counterintuitive. In one trauma ICU, early institution of palliative care services did not affect mortality but did result in improved time to determination of patient-centered goals and the establishment of DNR orders [66]. The impact on specific complications (UTI, pneumonia) was not reported. A recent survey from the AAST [67] that was heavily biased toward academic trauma centers indicates that the majority of ICUs represented in this survey do *not* routinely involve palliative care in daily rounding despite having these services present in most (93 %) institutions. They tend to employ them only when a tentative judgment of futility has been rendered or there are disconnects between opinions of the health-care team and patients' family/surrogates. Thus in current practice there are likely to be increased opportunities to use palliative care services to improve the patient care process, but we do not know whether improved process from the patient-centered perspective might result in increased rates of traditionally measured complications.

It is clear that quality metrics in US Healthcare are focused upon reduction of adverse events associated with traditional outcome measures. Such measures include infection, length of stay, and readmission rates as well as the use of "core measures" believed to prolong life in patients with specific conditions. Many of these metrics are reported in both the SCIP and TQIP databases. These metrics may not serve the geriatric patient well as markers of quality. For example, the use of indwelling urinary catheters may be preferred by an elderly patient given an understanding of risk/benefit, but it might result in a measurable complication that the patient readily accepts. Is this a negative outcome? Similarly patients may choose not to receive DVT prophylaxis, participate in efforts at mobility, or undergo certain diagnostic or therapeutic procedures. A patient with a cervical spine fracture may willingly accept the risk of not wearing a collar if he or she finds the collar uncomfortable. By extension, the use of chemical or physical restraint to induce compliance with the collar may result in its own set of complications. Finally, the issue of readmission to an acute care facility while regarded as a negative from the administrative health-care perspective may be viewed from the patient/family perspective as a patient preference. If the early and consistent involvement of palliative care services results in better recognition of patient-centered goals and these goals result in more frequent occurrence of measured "complications," it will be important to identify these confounders in large databases used for quality measurement.

These observations are consistent with an evolving theme in the geriatrics and palliative care community that traditionally

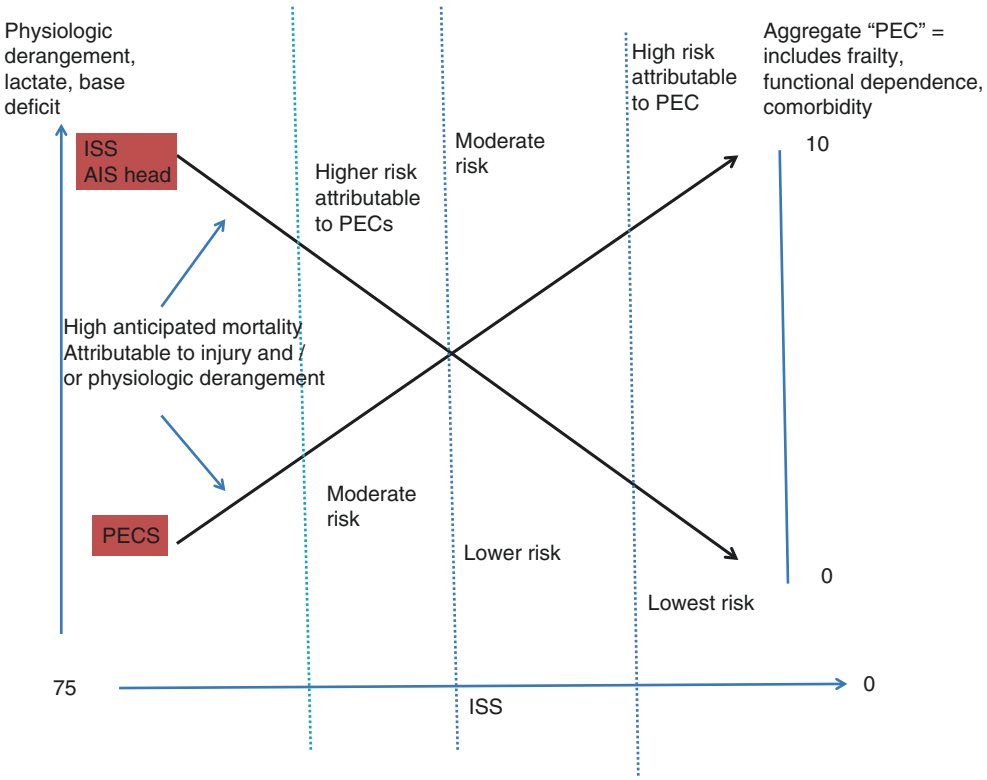

Fig. 25.1 Depicts the relative risk for geriatric trauma patients as a function of injury burden, physiologic derangement and PEC, and an aggregate assessment of frailty, comorbidity, and functional dependence. A taxonomy is suggested that stratifies risk according to the relative contribution of these factors as opposed to more standardized TRISS methodology. It is understood that mortality may occur following decisions not to offer care at the far "left" end of the spectrum or to withdraw it in the face of minimal to moderate complications at the far "right" end of the spectrum

measured outcomes may not be patient centered [68]. Patient values or the values of their surrogate may not be the same as they would have been when the patient was younger with more physiologic reserve. Priorities and goals change with aging, and this is an essential aspect of understanding treatment goals for GTP and EGS patients. Thus, outcomes that might be "bad" in the traditional sense are viewed as "good" under a new construct. The American Geriatrics Society has recently issued a position statement regarding the care of patients with multiple comorbid conditions in which the domain of "patient preference" is considered fundamental to all treatment decisions and is located proximally on all treatment algorithms [69]. Currently available data on outcome in geriatric ACS patients does not allow discrimination at this level. Only carefully done prospective studies will allow a better understanding of these value-based outcomes.

The use of palliative care services does not necessarily imply the presence of inpatient hospice, but the latter may alter mortality rates based upon the manner in which data are entered into institutional data sets. Nathens [70, 71] and others have addressed this issue by reporting the variability in reported risk-adjusted mortality associated with "reassigning" patients to hospice status by defining the disposition of these patients as discharged. Moreover, Shahian [71] reported marked variability in the ability of hospitals in Massachusetts to capture palliative care and/or DNR in mortality estimates. These issues with "bookkeeping" may also occur when patients present from nursing homes to an ED with a traumatic mechanism and futile clinical course. In some institutions, the patient is admitted and counted as mortality; in others they might transition directly from the ED to a hospice setting. Quality of care may have been excellent in the former situation; the patient may have languished in the ED for many hours in the latter. Institutional resources would be more of a factor in determining "mortality" in this case than quality clinical care. It is not clear that either model would be "better" from the patient or family perspective.

Thus it is clear that the determination of outcomes in geriatric trauma and acute care surgery is more complicated than the simple measurement of mortality and standard complications captured from large database reviews. While some complications (delirium) associated with an aged population seem clearly worth avoiding, others may be less obvious. The ability to identify whether patient-centered goals are met may be equally important in defining quality for these patients.

Summary/Conclusions

Outcomes for geriatric acute care surgery and trauma patients seem to be determined by age, preexisting conditions, frailty and functional dependence, and some systemic factors related to appropriate triage and concentrated experience in geriatric care. Unlike elective surgery, it is much harder to modify patient-specific risks, and it is likely these risks predispose patients to traumatic events. Focus upon improved outcomes is most likely to be fruitful if institution-specific systemic factors can be identified and changed. The establishment of geriatric-specific audit filters for performance improvement, involvement of geriatricians or palliative care specialists based upon agreed-upon criteria, and a consistent focus on patient-/family-centered preferences in care are likely to be effective interventions that can be studied as we look for more refined ways to evaluate outcomes for this growing segment of our patient population.

Case Vignette: Outcomes in Geriatric Trauma

A 78-year-old man fell from standing and presented with neck pain and headache. He had a brief loss of consciousness. Radiographic work-up demonstrated an unstable fracture of C6 and no evidence of intracranial bleeding. His past history was significant for hypertension, dyslipidemia, a "mild heart attack in the past", and a right total knee arthroplasty 5 years prior after which the patient had experienced some "confusion" during his hospital stay. He was taking several medications for blood pressure and cholesterol; he admitted to daily intake of a glass of wine. The patient was lucid upon initial evaluation and reported that he was retired, had a daily routine that included walking and helping his wife with household chores; he was capable of performing all activities of daily living. The patient had a supportive family, a wife and two daughters who were employed in the medical profession.

The patient underwent cervical fusion during a procedure that lasted approximately two and a half hours. Neurosurgery felt that an additional posterior approach would be needed, and this was scheduled for 48 h after the initial procedure during which time the patient was in a cervical collar. He experienced agitated delirium during this 48-h period. At the time of his second surgery, the patient had a period of desaturation when placed in the prone position, and the surgery was canceled. He remained in a cervical collar. When evaluated for potential oral intake, the patient demonstrated poor swallowing function and was described by speech therapy as "high risk for aspiration." After discussion with family, a soft nasogastric feeding tube was placed on hospital day 6. The patient's agitation and delirium remained an issue; he was given Haldol and narcotic pain medication for severe neck pain. The patient pulled his feeding tube out. After transfer from the ICU to the general care ward, the patient developed urinary

retention, and a Foley catheter was placed. During an episode of agitation, the patient removed this and developed gross hematuria. Multiple laboratory studies were ordered including thyroid function studies; all were negative.

By hospital day 10, the patient's family expressed concern that the patient had never demonstrated any prior evidence of dementia and had no history of this level of agitation. They were not aware of any history of alcohol intake or use of any medications from which the patient might be withdrawing. They were also concerned that the patient would become malnourished as he could not swallow and kept removing feeding tubes. The option of a percutaneous gastrostomy was discussed; neurosurgery recommended against this in view of the stability of the cervical spine. They had decided to manage the fracture in a collar considering him too "high risk" for a second operation. Repeated efforts to "clear" the patient for a dysphagia diet were undertaken by speech therapy.

On hospital day 14, the patient remained delirious with waxing and waning mental status; hyperactive symptoms were controlled with Haldol after which the patient would be somnolent and unresponsive to family and health-care workers. The patient pulled out several more feeding tubes. On day 16 the patient became hypoxic and tachypneic. He was transferred back to ICU and diagnosed with pneumonia. After several days of treatment with antibiotics and pulmonary toilet, the patient was transferred back to the general care ward. He was not consistently interactive and would not participate with PT. He was not considered a candidate for acute rehab. On hospital day 20, the patient again demonstrated severe hypoxemia and increased work of breathing for which he was transferred back to the ICU. Palliative was consulted and a family meeting held to determine if endotracheal intubation would be desired by the family in the event it was needed. The family elected not to pursue this intervention, the patient became progressively hypoxic and hypercapnic, and, on hospital day 24, he died.

Important points and questions:

- The impact of delirium in this case was significant. Could it have been avoided? Is it possible the patient had a dependence on drugs or alcohol that was not reported or was underestimated that contributed to his agitation?
- Operative treatment of this unstable cervical spine fracture was indicated but did not produce the benefit of "early mobilization" or removal of the cervical collar.
- Clinically significant dysphagia is encountered in nearly 20 % of patients undergoing operative fixation of C2 fractures, but the incidence might be even higher for lower cervical spine fractures and those requiring more complex repair.
- Malnutrition may have played a role in this patient's outcome. What are the preferred methods for providing enteral nutrition in such cases? Would TPN have been of value? An open gastrostomy or jejunostomy?
- How might the care of this patient differed had a geriatrician been involved?

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Geriatric Neurotrauma

26

Jack Wilberger

Introduction

Traumatic brain injury (TBI) in geriatric patients is becoming increasingly frequent with most recent estimates of 155,000 occurrences a year resulting in over 12,000 deaths. This incidence has doubled in the past 18 years and is greatest for those 83–90 years [1]. Overwhelming evidence suggests that those at highest risk for associated morbidity and mortality are the geriatric population, or those patients 65 years and older [2–11]. This increased mortality is not dependent on the injury or its severity, for geriatric patients with mild injuries do not respond as well as their younger counterparts with more severe injury [2, 5, 8, 12–14].

In the central nervous system, normal physiological changes with aging may contribute to the worse outcomes in this patient population following trauma. As a result, it is necessary to evaluate, treat, and manage these patients as a unique patient group in order to optimize outcomes in emergency, inpatient, rehabilitation, and ambulatory settings. Optimal care is difficult to achieve due to the varied mechanisms by which TBI is induced, in addition to the secondary injury that ensues. For example, TBI may not be suspected in an elderly patient who presents with symptoms of delirium, dementia, or psychosis; yet, head injuries may cause similar cognitive and behavioral signs [15]. This care is further complicated in the elderly population due to the natural aging process of the brain and its vasculature as well as the medical complications that are more common in these patients, such as anticoagulation therapy and increased risk for stroke.

While this chapter will primarily focus on moderate and severe TBI – Glasgow Coma Scale (GCS) score of 3–12 – it will also review information on mild TBI, GCS 13–15, also known as concussion, as well as spinal cord injury (SCI) in the elderly.

Epidemiology

The CDC regards traumatic brain injury as a public health problem. In the geriatric population, emergency room visits, hospitalization rates, and deaths increased between 2002 and 2006 [16]. Approximately 8 % of the population >65 years of age is in an emergency department each year for fall-related injury with 25 % of the visits resulting in admission [17]. The overall incidence of TBI in 2010 was 60.6/100,000 in those less than 65 and 155.9/100,000 in those older than 65 (CDC). With fall-related TBI, the overall incidence was 29.6/100,000 while in those >65, 203.9/100,000 [17]. The 2010 US Census estimated the geriatric population to be 40.3 million people [18]. Due to the rapid growth rate of the "baby boomer" generation, the population greater than 65 years of age is expected to reach 86 million by 2050 [19]. Costs to the healthcare system are high, with estimates exceeding $2.2 billion total in 2003 [7] and $70,000 per person in 2005 [19], which logically would increase with increases in the elderly patient population [20].

In Pennsylvania, the incidence of moderate to severe TBI in those aged 65–90 from 1992 to 2009 was 18,164, an 87 % increase over the 18-year period [21]. Between 1995 and 2001 in the US geriatric population, there were 60,000 hospitalizations per year and over 12,000 mortalities [16]. On a global scale, it has been posited that TBI will be the third leading cause of death and disability by 2020 [22, 23]. Given the increasing trend of TBI in the growing geriatric population, adequate knowledge of the mechanism of injury and associated outcomes becomes increasingly important for physicians.

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Although hospital course varies with severity of injury and associated comorbidities, the in-hospital mortality rate or discharge to a residential home correlates positively with age [23]. Some studies indicated a higher prevalence of TBI in older females, which opposes the trend seen in younger populations, in which males more frequently present with TBI [4, 24]. Mechanism of injury is an additional difference found in older patient populations; falls are the most common reason for TBI [3–5, 21–29]. After falling, the most common brain injury is intracranial hemorrhage in addition to upper extremity and facial fractures. Following a motor vehicle accident, it is concussion, with concurrent rib fractures and internal injuries [24]. Alcohol abuse is not typically associated with TBI in this age group, although is commonly associated with TBI in younger patients [30]. Elderly patients experience a greater degree of falling for various reasons, such as vision problems, slower reflexes, decreased bone density, deconditioned muscles, comorbid conditions and their complications, and cognitive impairment and medications [31–35].

The Pathophysiology of TBI in an Aging Brain

Primary Injury

Following a traumatic brain injury, damage occurs in two general stages, primary and secondary. Primary injury refers to the initial insult to the brain resulting in immediate cellular perturbation or death. This results in neural deficits dependent upon the type of injury and specific location within the brain as well as vascular damage which may result in intracranial hemorrhage. Secondary injury is the consequence of primary injury and includes changes in the microenvironment, altered cellular metabolism, diminished vascular response, hypoxia, edema, and inflammation. In the context of a geriatric patient, these mechanisms are enhanced due to the normal physiological changes that occur with increased age [36].

Neuronal change and glial cell loss is an expected occurrence in the normal aging brain. Beginning in the fifth decade of life, normal brains begin to undergo some degree of degeneration [36, 37]. Nerve cells mainly experience death secondary to Wallerian degeneration [38, 39] or decreased efficiency due to diminished synaptic potential [40]. Consequently, aging reduces plasticity and repair mechanisms [4, 38, 41, 43]. Although the natural reduction in cell number and plasticity has been studied in the context of diminished memory [43, 44], plasticity plays an important role following traumatic brain injury. Yager et al. showed decreased plasticity, measured by functional outcome, following a cerebrovascular accident in immature versus mature mice [42].

Evidence from animal studies suggests marked differences in the morphology, number, and/or organization in the supportive cells of the central nervous system. Astrocytes appear to undergo hypertrophy with advanced age, without increasing in number [45–51]. Studies indicate that increased staining with glial fibrillary acid protein (GFAP) supports this hypothesis [52–58]. Additionally, the gap junctions by which astrocytes communicate and uphold the blood-brain barrier appear to undergo reorganization but, likewise, are maintained in number. The changes in microglial cells during the normal aging process are not fully understood. Some studies report an increased phagocytic activity of these protective cells. There is conflicting evidence as to whether these cells proliferate, particularly in females versus males. Further studies suggest that microglia undergo "dystrophy" in which morphological changes occur due to the increased age of the cells. The third type of neuroglial cell, oligodendrocytes, appears to undergo both proliferation and reorganization of cellular alignment [48, 59–61]. Evidence of remyelination of nerve fibers in the CNS supports a need for increased numbers of oligodendrocytes with increased age [62]. Although little is known about the fourth type of neuroglial cell which stains to NG2 antibodies, these cells have been suggested to be precursors to oligodendrocytes and their proliferation during the aging process [63, 64]. Remyelination in the aging brain is thought to occur due to the degenerative processes that have been studied in animals and the consequential nerve fiber loss quantified in humans. Studies have shown that changes in myelin include dense cytoplasmic accumulations, areas of myelin ballooning, and changes in the lipid composition [64–68]. As a result of myelin degeneration, studies have shown that white matter loss also occurs during aging. This data has been quantitated as shown in Table 26.1. Additional imaging studies support the loss of white matter in the normal aging brain [40].

Traumatic brain injury in the elderly contributes to the cellular loss in the natural aging process and may further enhance any pathological diseases in these patients. Immediate cell death in the brain following traumatic brain injury is dependent upon the type of injury. For example, a penetrating injury or localized impact initially causes focal damage, whereas a rotational head injury or larger impact may cause diffuse brain injury. When mechanical damage occurs, it has been shown that axonal damage can be primary from direct injury or secondary from death following initial swelling [69, 70]. In either case, axonal injury leads to cell death and eventually to coma and increased mortality [71].

Another main mechanism of primary injury in traumatic brain injury results from direct damage to blood vessels in the context of naturally changing and weaker vasculature. Geriatric patients are more susceptible to immediate vascular damage. Due to the decreased volume associated with age and decreased neuronal density, the brains of elderly patients allow for more space in which the subdural veins are located [26, 36, 71]. As such, they are less protected and more prone

Table 26.1 Glial reduction in normal aging

Author	Year	No. of subjects	Age of subjects (years)	White matter: location (% reduction)	Total: area (% reduction)
Pakkenberg and Gundersen [166]	1997	94	20–95	Cerebral hemispheres (28 %)	Cerebral hemispheres (12 %)
Tang et al. [167]	1997			Length of fibers in cerebral hemisphere (27 %)	
Marner et al. [168]	2003	26	20–80	Cerebral hemispheres (23 %)	
				Overall nerve fiber length (45 %)	
Meier-Ruge et al. [169]	1992			Precentral gyrus (16 %)	
				Corpus callosum (10.5 %)	

to rupture causing a subdural hematoma. Additionally, the inherent strength of the cellular composition of blood vessels with age is diminished, increasing the incidence of leakage and rupture following less intense mechanical disruptions that might cause hemorrhage in younger patients.

Another important aspect of vascular changes with increased age is a natural decrease in cerebral blood flow (CBF) and altered vascular reactivity [72–75]. Studies suggest the decreased intracranial blood flow with age is associated with arteriolar rarefaction, with conflicting evidence regarding capillary density [73–76]. A combination of factors is most likely responsible from hormonal to structural changes of the vessels in addition to changes in blood flow decreases metabolism and affects signaling, neuronal plasticity, and neurogenesis [76]. Decreased CBF with age and following injury leads to hypoxia and further damage. A study in rats following fluid-percussion injury showed decreased heart rate in aged subjects while increased heart rate in the younger rats. The aged rats showed significantly increased damage using histopathology and mortality end points [77]. Although autoregulation is not markedly diminished in the normal aging process [78–81], studies have shown decreased autoregulation associated with traumatic brain injury [82–84]. This change in vascular reactivity results in worse outcomes following traumatic brain injury [84].

Secondary Changes

Mechanical perturbation from direct injury results in the release of ions, toxins, and neurotransmitters. Damaged cells experience metabolic changes which contribute to the toxic metabolites, namely, lactate, in the microenvironment of the injured brain tissue. Both mechanisms further contribute to secondary cellular loss and subsequent injury mechanisms, such as edema and inflammation, in the aging brain.

One of the first ions to be released following increased membrane permeability or cell death is intracellular calcium [85]. The significance of calcium release is to set in motion the prolonged apoptotic and immediate necrotic pathways via caspase and calpain proteases, respectively [86–88]. Another ion released in secondary brain injury is magnesium, an indicator of cell injury [89–92].

Glutamate is the main excitatory neurotransmitter in the central nervous system as well as the main neurotransmitter responsible for increased damage following TBI in geriatric patients [86, 93, 94]. Hamm et al. suggest this effect is particularly harmful in an aged brain due to the increased density of receptors with age due to a natural loss of neurons. The additional overstimulation may contribute to the injury in an aged brain [78]. Lactate is also released into the microenvironment and increasingly taken up by the brain following traumatic injury [89, 95–106]. The increased concentrations of lactate can lead to edema via breakdown of the blood-brain barrier [89, 107–110], or ischemia [89–111]. The reason for increased production and utilization of lactate remains unclear; however, one study has linked increased lactate uptake by the brain with improved outcomes [106].

Numerous studies have concluded that the formation of free radicals [86, 112, 113] contributes to secondary cell damage and death following TBI. The pertinent free radicals in this context include superoxide anion (O^{2-}), nitric oxide (NO), and peroxynitrite ($ONOO^{-}$). These substances are formed immediately following the rise in extracellular calcium ions [113], as well as in response to altered neuronal metabolism, vascular changes, and the other mechanisms of secondary injury following TBI [112, 114]. Free radicals increase the damage following TBI by interfering with vasodilation [115] and subcellular components [116, 117], in addition to creating oxidative stress [117].

Decreased blood flow, local toxins, and altered metabolism contribute to hypoxia and ischemia of brain tissue

following TBI in geriatric patients. Neuronal and glial cell death adds to the normal aging degeneration of these cells because there is increased susceptibility [118, 119].

Another mechanism of secondary injury following TBI is the resulting inflammation and edema of brain tissue [120]. In addition to hemorrhage, inflammation and edema contribute to increased intracranial pressure (ICP). The decreased ability of the aged brain to compensate for the changes in volume may be another reason for the increased morbidity and mortality in this patient population. Evidence suggests inflammation results from the release of pro-inflammatory cytokines and mediators [121, 122]. Onyszchuk et al. reported the edema that results in young and aged rats yet, in the latter, requires a longer period of time to subside and involves a larger area of the brain [118].

Lastly, studies have reported the formation of thrombin following TBI [123, 124]. This coagulation mediator becomes particularly important in a patient population that is frequently prescribed anticoagulation therapy for atrial fibrillation, ischemic heart disease, and peripheral vascular disease. One study showed the injection of thrombin into the caudate of mice correlated with increased infiltration of inflammatory cells, angiogenesis, and reactive gliosis. In effect, this mediator that is released following trauma contributes to the inflammatory response [125].

Structural Injury

In a geriatric patient, brain injury does not require impact, for damage can result merely from deceleration or rotation of the head [6]. The most common manifestation following TBI in elderly patients are subdural hematomas, which may be of an acute or chronic nature. One study showed that in ≥70 years old, 61 % subdural, 28 % intracerebral, and 4 % epidural occurred compared to 47 % of epidural or subdural hematomas among ages 6–39 [3]. Subdural hematomas are more common than extradural hematomas after 50 years old [4, 126].

Contusions occur at approximately the same rate in patients suffering TBI and will significantly enlarge in approximately one-third. This worsening, however, may occur at a higher rate in the anticoagulated elderly.

Intracerebral hematomas occur at a higher rate in the elderly, presumably related to the decreased blood vessel elasticity associated with atherosclerosis [127].

Treatment/Outcomes

Although overwhelming evidence suggests poorer overall outcomes with increased age following TBI, there is discord about whether this trend is stepwise with an age threshold beyond which outcome is significantly worse versus continuously increasing and whether treatment biases based on age have a significant impact. Studies have shown increased mortality in the geriatric population [3], with up to four to six times higher probability for unfavorable outcomes following TBI [128, 129].

For two decades guidelines for the medical and surgical management of severe TBI have been available with increasing utilization of evidence-based treatments to improve outcomes [131]. However these guidelines do not take into account advanced age and thus may not be universally applicable.

Thomas et al. retrospectively showed hospital and death rates after typically nonfatal TBI to increase within the geriatric age in both men and women [128]. Diminished functioning in all areas, cognitive, motor, and memory, has been reported [4, 130]. One study showed an increased rate of postsurgical infection in patients ≥80 years.

Many studies have been conducted to investigate risk factors for worse outcomes following TBI specific to the geriatric population. It has been shown that gender plays a role; females have poorer outcomes [133–136]. This suggests a possible role of estrogen or progesterone in the reparation process following TBI; however, recent randomized controlled trials did not demonstrate any benefit to the administration of progesterone after severe TBI. The specific type of injury has been shown to be another risk factor, postulated to be due to the increased incidence of intracranial mass lesions, such as non-evacuated hematomas, as opposed to systemic complications [3, 6, 8, 137]. Patients with subdural hematomas have worse outcomes than those with epidural hematomas. In one study of patients who received emergency craniotomy, mortality following subdural versus epidural hematomas was 41 % and 3 %, respectively [138]. It was previously reported that older patients with subdural hematomas who undergo craniotomy have worse outcome than younger patients [129–143], yet more recent studies showed no significant difference between age groups with respect to return to baseline following a craniotomy [132].

Mosenthal et al. studied a group of 235 patients with severe TBI, of which 19 % were >65 years old. Functional outcome was not significantly different for both elderly and younger patients and recommended that aggressive treatment in the elderly is warranted [138].

The mainstay of understanding the pathophysiology and risk factors for worse outcomes in the geriatric population is for optimization with regard to treatment and prevention of TBI. Researchers have identified reasons for the existing worse outcomes in these patients. For instance, older patients do not receive the same intensity of care as younger patients [141]. There is a delay getting geriatric patients to

neurosurgical intervention when compared to younger patients with TBI [9, 142]. This suggests that improvements in timing and logistical care within hospitals are the first step toward improving outcomes.

Another area of "treatment" targets the patient before they arrive at the hospital. Given that the most common reason for TBI in these patients is falls, it is imperative to work toward the prevention of falls. One way in which this might be possible is to monitor medications that may contribute to falls [143]. Another way is to emphasize bone health and exercise. If patients have appropriate bone density, fractures might be prevented that lead to falling. Additionally, if a patient does fall, an improved muscular response may prevent head impact or injury.

For those in which prevention is not successful, treatment may not be the same for these patients as in younger patients. It becomes the responsibility of the emergency room physician to know which medications and therapeutic procedures to administer. Additionally, it is the responsibility of the neurosurgeon to know in whom it is appropriate to operate. In one study, indications for surgery included GCS score greater than 8, age greater than 75 years, without papillary dilation and all subdural hematomas [142].

Special Considerations

Unfortunately, the care in this patient population is unique given their medications and comorbidities at the time of brain injury. This complicated medical picture requires more research to improve knowledge regarding how common medications and pathological processes in elderly patients may affect the treatment needed following TBI.

Anticoagulation

Many patients >65 years are on some sort of anticoagulation or antiplatelet medication given the well-known vascular processes that predispose older patients to cardiovascular disease. However, the data on the effect of this therapy and TBI is conflicting. Some studies have shown that anticoagulation therapy has a significant effect on outcome. One study showed increased mortality in those who fall from standing taking warfarin [144]. In a retrospective study of 384 patients 55 years or older, warfarin use before a closed head injury was associated with more severe injuries and increased mortality [146]. Yet, other studies have not been able to show a significant effect of anticoagulation therapy on outcome. Fortuna et al. found no significant effect of clopidogrel, aspirin, or warfarin on outcome in those with blunt head trauma [145]. Another study analyzed three age groups within the geriatric population without taking into account mechanism of head injury with nonsignificant findings between pre-injury warfarin use and poor outcome [146–148].

Peiracci et al. further evaluated this question by retrospectively grouping the geriatric patients with TBI based on warfarin use with INR greater or less than 2 and those who did not take warfarin. The group with an INR greater than 2 showed significant likelihood for a GCS score below 13 and increased mortality. In those with an INR less than 2 and those who did not take warfarin prior to injury, the difference in mortality rates was not significant [148]. This study suggests that TBI might be affected not merely by anticoagulation therapy, but instead by the degree of coagulation at the time of injury.

Additional studies used this data to evaluate the effect anticoagulation should have on current therapy in elderly patients that present with TBI. In anticoagulated, elderly patients who present without neurologic deficit, Reynolds et al. recommend CT within 6 h for patients despite GCS score of 14 or 15, whereas Gittleman et al. suggest emergency CT is not necessary in those with GCS score of 15 [149, 150]. In a small study of four patients with mild TBI and GCS score of 15 at presentation, it was suggested to keep elderly patients for observation for 1–2 days due to the occurrence of delayed acute subdural hematoma. In this study, 1/3 of patients survived surgery, while the remaining patient survived with medical management [151].

With respect to reversal of anticoagulant effect, the mainstay has been fresh frozen plasma; however, this may require a significant fluid load in an elderly patient who may have limited cardiac reserve and precipitate congestive heart failure and pulmonary edema. Thus, there has been increasing utilization of prothrombin complex concentrate (PCC) which contains factors II, VII, IX, and X.

With respect to antiplatelet agents, platelet infusions and DDAVP administration can be highly effective.

In recent years the FDA has approved a number of direct thrombin inhibitors (DTIs) and factor XA inhibitors (FXA) for the prevention of thromboembolic events. These are being increasingly utilized as they require no monitoring of the international normalized ratio (INR).

Unfortunately, with respect to TBI, there is no known agent to reverse their anticoagulant effect.

Dialysis is the only currently known way of eliminating these agents; however, the time necessary to do so is likely incompatible with aggressive surgical management, if appropriate.

FFP will not reverse DTIs; PCC and rVIIa have been used with limited success. Tranexamic acid can inhibit fibrinolysis; however, while there is literature in trauma patients endorsing its use, there is none in TBI.

Statins

Another very common medication used to treat cardiovascular disease in elderly patients is statins for hyperlipidemia. Interestingly, data suggest statin use is beneficial in those recovering from TBI. Statin use in patients without cardiovascular disease showed decrease risk and incidence of in-hospital mortality as well as improved functional 12-month outcome in geriatric patients with TBI [152]. This therapy has been shown also to decrease the cerebral vasospasm that follows subarachnoid hemorrhage in brain injury [153, 154].

Medical Comorbidities

The vast majority of geriatric patients have medical comorbidities which complicate outcomes following TBI [28, 155]. The most common comorbid conditions that have been reported include hypertension, diabetes, cardiac arrhythmias, chronic pulmonary disease, and electrolyte disorders [30].

Any of these conditions and the medications needed to treat them complicates the care of geriatric TBI patients.

As an example, while still controversial, high blood sugars may worsen outcome after TBI.

Thus, many trauma centers are now including an individual highly involved or specialized in geriatric medical care on the trauma team.

Concussion

Concussion or mild traumatic brain injury – GCS 13–15 – is an increasingly common occurrence in the elderly. As with more severe TBI, falls are the most common mechanism.

Stryke et al. found that in these patients the rate of intracranial hemorrhage was three times higher than in younger adults [156].

The geriatric population presents special challenges in concussion assessment because there may be preexisting cognitive dysfunction, impaired memory, comorbid conditions, and use of multiple medications.

As a result the American College of Emergency Physicians recommends a head CT in any patient >65 who presents with a mechanism or findings suggestive of a concussion [157].

Outcome after a concussion is generally good; however, this may not be the case in elderly patients. Goldstein et al. (in patients >50 years old compared to controls) found a significant decrease in cognitive function, including language, memory, and executive function 7 months post concussion [158].

Additionally in a study of 3244 patients >64 years old, there was a higher incidence of non-survivors in the elderly population (risk ratio 7.8) [2].

Nevertheless there is a paucity of research on concussion in the elderly. Thus, more aggressive evaluation of post-concussive issues may be needed with earlier utilization of neuropsychological evaluations to more precisely identify and treat deficits in this patient population.

Spinal Cord Injury

Over the last several decades, the incidence of SCI in geriatric patients has increased from 4.2 to 15.4 % [159].

Similar to the brain there is a progressive loss of neuronal tissue in the spinal cord. One study showed up to a 46 % loss in those >50 years [160]. In spite of this loss, there is no apparent effect on spinal cord function, but with less reserve the spinal cord may be more vulnerable to the effects of aging of the vertebral column such as spondylosis.

Also similar to TBI, falls account for the majority of geriatric SCI.

In comparison with younger patients, geriatric SCI patients appear to be less likely to suffer severe SCI; however, they have a higher mortality rate [161].

One study found that older patients with SCI are less likely to undergo surgery for their spinal injury, and when they do there is a significant delay between the injury and any subsequent surgery [161]. This may be related to coexisting medical comorbidities or treatment bias due to advanced age.

Palliative Care

Discussions of palliative care in trauma patients are becoming increasingly common. In elderly patients with severe TBI or SCI the issue takes on even more importance. While an advanced directive may exist, such is difficult to access in an emergency situation, in a comatose patient whose family may very well not be immediately available. Thus operative decisions are often left to the surgeon. Unfortunately assuming advanced age is always associated with death is not supported in the literature.

The American College of Surgeons Optimal Resources Manual defines an ideal trauma system as one that includes "all the components identified with optimal trauma care, such as prevention, access, acute hospital care, rehabilitation and research activities." There is no mention of palliative care [162].

Several studies have shown that those >55 are more likely to suffer multiple organ failure and even seemingly mildly

injured patients >60 have a fivefold greater risk of dying [163, 164].

A high likelihood of death is not the only factor in considering palliative care over surgery or other aggressive treatments. The patient's subsequent quality of life and likely functional outcome should play a role in making this decision.

Thus, in an "optimal" trauma system, it is important to integrate palliative care concepts in all members of the trauma team [165].

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Chest Wall Injury: In Geriatric Trauma and Emergency Care

27

Eileen M. Bulger

Introduction

Thoracic injury accounts for up to 25 % of fatalities among injured patients. Chest wall injuries are common with rib fractures identified in approximately 10–26 % of patients presenting to a trauma center and sternal fractures in <1 % [1–3]. Elderly patients are at increased risk for both rib and sternal fractures when compared to younger patients [4, 5]. Several studies have reported that these injuries are associated with increased morbidity and mortality in this patient cohort [4, 6–10]. The purpose of this chapter is to review the current literature regarding the patterns of chest wall injury in the geriatric population, evaluate the factors contributing to worse outcome, and discuss injury prevention and management strategies for patients with these injuries.

Epidemiology

A recent report from the National Trauma Data Bank noted that 9 % of patients in this database carried a diagnosis of one or more rib fractures with an overall mortality rate of 10 % [2]. The incidence of rib fractures in the elderly has been reported at 60 per 100,000 persons per year [11]. Elderly patients are thought to be at greater risk for rib fractures due to loss of cortical bone mass, which allows the bones to fracture with less kinetic energy than is required in younger patients. In the study by Bergeron et al., more than 50 % of elderly patients presenting with rib fractures had suffered a fall from standing [8]. The second most common etiology is motor vehicle crashes (MVC). A recent report from the Crash Injury Research and Engineering Network (CIREN) database noted that the majority of rib and sternal fractures occurring in elderly patients following MVCs result from compression of the thorax by the seat belt system [5]. They suggest that with the increasing number of elderly drivers, attention should be paid to the design of these safety systems relative to the increased fragility of older patients.

Several studies report increased morbidity and mortality among older patients subjected to chest wall injury compared to a younger cohort. Most studies evaluating disparity in outcome between younger and older patients focus on the population >65 years of age; however, some studies have noted impaired outcome beginning at age 45 [10]. Mortality reports range from 2 to 22 % and are likely heavily influenced by inclusion of patients with multisystem injury. Bulger et al. reported that mortality for elderly patients (>65 years) was more than twofold higher than the younger cohort (22 % vs. 10 %) [7].The risk of mortality increased 19 % and the risk of pneumonia by 27 % for each additional rib fracture. Several others have noted increased morbidity with increasing number of rib fractures. A recent meta-analysis, which evaluated the risk factors associated with poor outcome, reported a combined odds ratio for mortality of 1.98 (95 % CI, 1.86–2.11) for age >65 years and 2.02 (95 % CI, 1.89–2.15) for three or more rib fractures [12]. Another report noted a significant increase in mortality for six or more fractured ribs [2].

Another contributing factor to impaired outcome in the elderly is likely the increased rate of associated medical comorbidities. Bergeron et al. reported a nearly threefold increased risk of mortality for patients with a pre-existing medical condition (OR 2.98; 95 % CI, 1.1–8.3) [8]. In a recent multicenter study, focusing on elderly patients with isolated blunt chest injury, 19.9 % of patients had coexisting coronary artery disease, 13.5 % lung disease, and 7.1 % congestive heart failure [13]. Pre-existing congestive heart failure was one of the strongest predictors of mortality in this series. Similarly, Brasel et al. reported an adjusted odds ratio of 2.62 (95 % CI, 1.93–3.55) for mortality following blunt chest trauma in patients with congestive heart failure [14].

The primary complication which develops in these patients after hospitalization is pneumonia. Pneumonia rates vary depending on the population studied. For the entire population

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hospitalized with one or more rib fractures, the rate of pneumonia is reported to be 6 % [14]. However, when one reviews patients admitted to a trauma center reports range from 11 to 17 % for patients younger than 65 years to 31–34 % for patients older than 65 years [7, 8]. Bulger et al. reported that elderly patients had a risk of pneumonia exceeding 30 % [7]. The impact of pneumonia on mortality is debated. Bergeron noted a nearly fourfold increase in mortality risk for patients who developed pneumonia (OR 3.8) (95% CI, 1.5–9.7) [8]. However, Brasel et al. reported that pneumonia was associated with increased mortality among those with no associated injuries but was not a major factor for those with multisystem injury [14]. Regardless, the development of pneumonia has been associated with increased duration of mechanical ventilation and prolonged ICU stay, thus significantly impacting the resources required to care for these patients.

Injury Prevention

The leading causes of chest wall injury in the elderly are falls and motor vehicle crashes. There are several programs which have been proposed for elderly fall prevention which are beyond the scope of this review. However, recent data also supports consideration for specific injury prevention strategies associated with chest wall fractures resulting from motor vehicle crashes. Bansal et al. reported an analysis of 287 elderly patients with rib and sternal fractures after MVCs and noted that the primary source of these injuries in frontal impacts was compression from the seat belts or contact with the steering rim [5]. For side-impact crashes, contact with the side interior (door panel) was the primary etiology. For seat belt-related injuries, they suggest that a four-point safety belt system or wider shoulder straps may allow more even distribution of the force to the chest, and thus have the potential to reduce these injuries. For side-impact crashes, advances in side airbags/torso bags should be investigated. The use of "elderly" and more fragile crash test dummies might be needed to test these innovations.

Treatment

Hospital Admission

The first question to address in the management of elderly patients with rib fracture is which patients will benefit from hospital admission. This is an issue for the elderly patient with isolated chest wall injury, which can occur after even a minor fall from standing. Several authors have advocated that based on the increased risk of poor outcome in this patient cohort, patients over age 65 with >3 rib fractures should be admitted to the hospital, and those with >6 rib fractures should be admitted to an intensive care unit for monitoring even without evident respiratory compromise on admission [6, 10]. A recent study identified risk factors for intubation and pneumonia in a cohort of elderly trauma patients in an effort to develop a predictive score that might guide ICU admission decisions [15]. The variables that were included in the score were chronic obstructive pulmonary disease, congestive heart failure, low albumin, assisted living status, tube thoracostomy, ISS score, and a number of rib fractures. While this score requires additional validation, it highlights that the impact of medical comorbidities, frailty, and severity of injury should all be factored into decisions regarding ICU admission.

Pain Management

The cornerstone of management for multiple rib fractures is attention to pain control. Patients with inadequate pain control will minimize their chest wall motion by reducing their tidal volume and coughing and as a result are at significant risk of developing nosocomial pneumonia. The options for initial inpatient pain control include intravenous narcotics and regional anesthetics. These may be supplemented with injectable or oral NSAIDs as indicated, with eventual transition to oral narcotics prior to discharge. There have been a number of studies, which have investigated pain control strategies for these patients. These are discussed for each option below. Regardless of the approach selected, involving a dedicated pain relief service to monitor the effectiveness of the strategy chosen is critical. Development of a multidisciplinary pathway for management of these patients has been associated with improved outcome [16–18].

Todd et al. recently reported on a pathway for patient with four or more rib fractures over the age of 45 years [16]. In this study pathway, patients were monitored closely for pain and cough scores and incentive spirometry volume. Based on this assessment, a pain service was consulted to optimize pain control, respiratory therapy was consulted for a volume expansion protocol, physical therapy was consulted to increase patient mobility, and attention was paid to nutritional support and medical comorbidities. Patients managed with this clinical pathway were found to have a shorter ICU and hospital stay and lower mortality.

A group from WellSpan York Hospital, York, Pennsylvania, recently presented the use of a standardized scoring system to assess patients over time as part of an inpatient pathway. This score referred to as the PIC score assesses pain control, inspiratory volume on an incentive spirometer relative to individualized patient goals, and the strength of the individual's cough (Fig. 27.1). They reported that implementation of this approach resulted in a reduction in unplanned ICU admissions for respiratory distress (data not published). This pathway includes a family and patient engagement in their care by posting the PIC scoreboards in the patient's room, so they can track their progress and a patient brochure, which explains the PIC score and their goals of care.

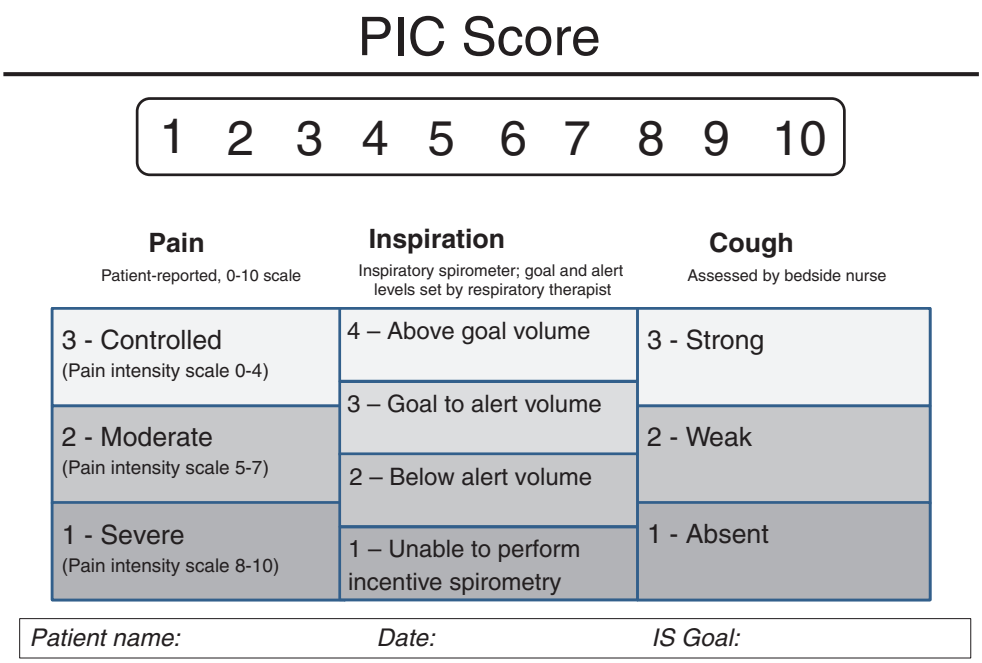

Fig. 27.1 Bedside scoreboard for tracking PIC score (pain, inspiration, cough) for patients with rib fractures (Courtesy of WellSpan York Hospital, York, PA)

Oral Pain Medications

Oral narcotics are generally reserved for patients with minimal rib fractures who may be managed as outpatients. Patients on intravenous or regional medications may be transitioned to oral agents several days after injury in anticipation of discharge. Nonsteroidal anti-inflammatory drugs may be given in concert with narcotics to reduce the opioid need, although there are no studies specific to rib fracture pain management. NSAID use is limited by bleeding concerns and potential renal toxicity, so it should be avoided in trauma patients with significant early bleeding risk, such as ongoing hemothorax or solid organ injury, and in those with renal insufficiency. A recent case series of intravenous ibuprofen use in patients with rib fractures demonstrated a reduction in the narcotic need [19]. Routine acetaminophen and gabapentin have also been used to augment a multimodal approach to pain management in these patients.

Intravenous Narcotics

Intravenous narcotics are usually the first method of pain control employed for patients with multiple rib fractures. This route of administration is preferred over subcutaneous or intramuscular injection, as the onset of action is more rapid and more predictable. Patients must be closely monitored for excessive sedation or depression of respiratory drive, especially among the elderly. Patient-controlled analgesia is a good option for patients who are alert as they can control the delivery of the medication, which may provide a more timely response and diminish excessive sedation. Excessive sedation of elderly patients is associated with a significant increased risk of aspiration, which can further compromise pulmonary function. Thus, for patients who are particularly sensitive to narcotics, regional analgesia regimen should be considered.

Regional Anesthetics

There are several approaches to the administration of regional anesthetics/narcotics. These include continuous epidural infusion of local anesthetics and/or narcotics, paravertebral or intrapleural infusion of local anesthetic, intermittent intercostal nerve blocks, and continuous local anesthetic infusion in the subcutaneous space following thoracotomy.

The most widely studied approach is the use of epidural catheters for infusion of local anesthetics, with or without narcotics. Previous studies have shown that the use of epidural catheters results in improved pulmonary function tests and better pain scores when compared to intravenous narcotics [20–24]. These studies have generally included all adults and have not focused specifically on the elderly population. In the trial by Bulger et al., patients were randomized to receive intravenous narcotics vs. epidural catheter. There was a significant reduction in the risk of pneumonia and a 2-day reduction in the average duration of mechanical ventilation for the epidural group [23, 25]. A recent multicenter review of the impact of epidural analgesia on outcome for patients with multiple rib fractures demonstrated a significant reduction in the risk of death at 30, 60, and 365 days after injury for those patients managed with an epidural catheter [26].

A recent systematic review of the literature failed to identify a clear impact of epidural analgesia on mortality or ICU length of stay but did suggest a benefit on the duration of mechanical ventilation [24, 27]. Another meta-analysis of five randomized controlled trials of epidural analgesia following rib fracture (223 patients) failed to show clear benefit but highlighted the significant heterogeneity in these studies and the presence of bias [28]. The use of epidural catheters for pain control after severe blunt chest wall injury is a Level 1 recommendation in the 2004 EAST guidelines [29].

Epidural catheter use is limited in some cases due to the many contraindications to catheter placement in patients with multisystem injury. The most common contraindications are associated spine fractures and coagulopathy. In a recent survey of pain service directors at major trauma centers in the USA, it was evident that there remains considerable controversy in this area, and better definition of the absolute and relative contraindications is needed to weigh against the potential benefit of this approach [30]. A common side effect of epidural infusion is systemic hypotension, which thus mandates close monitoring especially in the elderly patient population. One retrospective series noted a higher rate of complications among elderly patients receiving epidural analgesia; however, this analysis was limited due to significant differences in the baseline characteristics between the treatment groups [31].

Several recent studies have evaluated the use of paravertebral infusion of local anesthetics and found this approach to be as effective as epidural infusion [32–35]. This approach is effective only in patients with unilateral rib fractures and was associated with a lower rate of systemic hypotension. The authors also note that placement of these catheters is technically easier than epidural catheters. The sample size for these studies was small, so more work needs to be done in this area.

Another option is the placement of intrapleural catheters for infusion of local anesthetics directly into the pleural space. In some cases these are placed adjacent to a thoracostomy tube. One study, which was placebo controlled, failed to find clear benefit with this approach [36]. Another study which compared intrapleural to epidural analgesia found the epidural approach associated with better pain relief [37].

Intermittent injection of local anesthetics to block the intercostal nerves has been reported as one approach to pain management for these patients. This approach is limited by the duration of the block and thus requires repeated injections to achieve continuous relief. This is very labor intensive, and as a result, this approach has largely been replaced by the continuous infusion strategies noted above. There is also a device available that can be placed in the subcutaneous tissue after thoracotomy for continuous infusion of local anesthetic, but it has not been evaluated in patients who do not require thoracotomy [38].

Respiratory Therapy

The second cornerstone of management of patients with multiple rib fractures is to provide close attention to respiratory function and encourage deep breathing through incentive spirometry and coughing to clear secretions. A recent study reported that every 10 % increase in vital capacity in the first 48 h after injury was associated with a 36 % decrease in the development of pulmonary complications [39]. The use of chest physiotherapy may be limited by chest wall pain. The indications for mechanical ventilation are based on the underlying pulmonary physiology and traditional signs of respiratory failure including increased work of breathing, hypercapnia, and hypoxia [40]. In general, adequate attention to pain control is key to reducing pulmonary collapse and thus avoiding intubation. For intubated patients, there was one study that suggested that intermittent recruitment maneuvers may improve oxygenation, but it is not clear if this will affect outcome [41].

Operative Stabilization of Rib Fractures

The operative stabilization of rib fractures has been controversial, and the procedure has evolved as better technology has become available to stabilize the ribs with a minimally invasive approach. A recent survey of trauma and thoracic surgeons in the USA suggested that the majority felt that rib fracture fixation was appropriate for selected patients, yet only 26 % of these surgeons had performed this procedure [42]. One generally accepted indication is the stabilization of significantly displaced ribs identified at the time of a thoracotomy for other reasons, known as "on the way out fixation." Other potential indications for primary rib fixation include: flail segment with failure to wean from mechanical ventilation, unstable ribs refractory to conventional pain management, chest wall deformity/defect, and rib fracture nonunion [43].

Several single-center studies have suggested that rib fracture stabilization may facilitate ventilator weaning and thus shorten the duration of mechanical ventilation. There have been two small, randomized trials. Tanaka et al. randomized 37 patients with flail chest, requiring mechanical ventilation to surgical stabilization vs. nonoperative management [44]. Patients in the surgical group spent fewer days on the ventilator, had a lower incidence of pneumonia, and had better pulmonary function at 1 month. Granetzny et al. randomized 40 patients with flail chest to operative stabilization vs. external splinting with adhesive plaster [45]. The operative group had a shorter duration of mechanical ventilation and a lower rate of pneumonia. A case-controlled study by Nirula et al. was consistent with these results [46]. Patients with significant pulmonary contusions are less likely to benefit [47]. A recent systematic review of the literature focusing specifically on patients with a diagnosis of flail chest reported significant benefit from rib fracture fixation [48].

The guideline from the Eastern Association for the Surgery of Trauma recognizes surgical fixation as a Level III recommendation for management of flail chest given the small numbers of patients randomized and the lack of comparison with more recent care pathways for these patients including the use of epidural analgesia [49]. Another area of ongoing investigation involves the potential impact of operative fixation on long-term morbidity for this patient population [50]. There are no studies, which focus specifically on the risks and benefits of rib fracture fixation in the elderly population.

These patients may face greater surgical risks due to medical comorbidities, and the poor bone quality may also limit the success of fixation. Further studies are needed to determine the optimal use of this approach in the elderly population.

Summary

In summary, elderly patients are not only at greater risk to have chest wall fractures even with minor mechanisms of injury but also suffer from significantly increased risks of morbidity and mortality. As a result, care protocols should focus on a low threshold for hospital and ICU admission and close attention to pain management and respiratory therapy. The role of operative fixation in this population requires further study.

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Solid Organ Injury

28

Cherisse Berry and Rosemary Kozar

Abbreviations

CT	Computed tomography
EAST	Eastern Association for the Surgery of Trauma
GFR	Glomerular filtration rate
NOM	Nonoperative management
NTDB	National Trauma Data Bank
SAE	Splenic artery embolization

Summary

- Elderly patients in shock do poorly, and the recognition of shock may be more challenging; thus, early recognition, utilizing tissue-specific endpoints, and treatment of shock are important including prompt laparotomy when indicated.
- In general, the decision to perform nonoperative management for a solid organ injury in the elderly should follow the same principles as that for younger patients.
- Caveats to consider when deciding to perform nonoperative management of a solid organ injury in the elderly may include physiologic reserve to tolerate hemorrhage or shock should bleeding develop, the use of anticoagulants, presence of comorbid conditions, and underlying renal function should angiography be necessary.
- The mortality for injured elderly after operative and nonoperative management of solid organ injuries is higher.
- There is a paucity of data on the management of solid organ injuries in the elderly.

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Caveats in the Decision for Nonoperative Management of Solid Organ Injuries in the Elderly

The mainstay of management of solid organ injury is nonoperative management (NOM) for hemodynamically normal patients. There may be several caveats in the elderly that complicate the decision to pursue nonoperative management.

The major requirement for nonoperative management for solid organ injury is the presence of normal hemodynamics. However, signs of shock in the elderly may not be recognized, and the assumption that a normal blood pressure and heart rate equate with normovolemia can have detrimental consequences in the injured elderly. The aging myocardium is less able to respond to circulating catecholamines [24]. Therefore, the elderly patient may not develop tachycardia in the presence of hypovolemia. Beta-blockers, a common drug in the elderly, can also block the normal tachycardic response to hypovolemia. As blood pressure increases with age, elderly patients with blood pressures in the normal range may indeed be hypotensive if their pre-injury pressure was in the hypertensive range [1]. Thus, a systolic blood pressure less than 110 mmHg may indicate relative hypotension in the geriatric trauma patient [8]. Evaluation of base deficit can help with diagnosis of shock. Though an elevated base deficit is a marker of severe injury and significant mortality in all trauma patients, it is particularly portentous in the elderly [12]. However, the injured elderly may not develop the same magnitude of base deficit or lactate as younger patients, so the absence of an elevated base deficit or lactate should not be used to eliminate the presence of shock in these patients [8, 12, 24].

The prevalence of thromboembolic disease and risk factors leading to thromboembolic disease both increase with age [37]. As a result, many injured elderly now present on antiplatelet agents or anticoagulants. A careful medication history is important to help assess the risk of bleeding. Coagulation parameters should be measured, and assessment of platelet function should be performed if indicated

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and available. A medical history to ascertain the reason for the medication and knowledge of thromboembolic risk of holding the agent while the injured organ heals is important as both factors may affect treatment decisions. In a study by Boltz et al., using data from the National Trauma Data Bank (NTDB), elderly patients who fell while on anticoagulants had a higher mortality than those not on anticoagulants [4]. Additionally, patients on anticoagulants were more likely to sustain liver, spleen, and kidney injuries as well as skull fractures. In those who died, skull fractures and intracranial hemorrhage, gastrointestinal injuries, and injuries to the liver and spleen were more commonly identified. As the cause of death was not reported, the contribution of these injuries to death is not known. There are no studies specifically addressing the risk of failure of nonoperative management for patients on anticoagulants, but it seems reasonable to assume that bleeding risk from an injured solid organ would be increased. The degree of coagulation abnormality present at the time of injury, the grade of organ injury, ease of reversal, and risk of holding further anticoagulation should all be factored into the decision for nonoperative management [4, 37].

Age alone is not the sole factor in predicting outcome in the injured elderly. The impact of comorbid conditions also needs to be considered. Using a large state database, Grossman et al. found that overall mortality after trauma increased with age; for each 1-year increase after the age of 65, the odds of dying increased by 6.8 % [19]. Using logistic regression, the preexisting conditions with the strongest effect on mortality were hepatic disease, renal disease, and cancer [19].

When deciding on the need for angioembolization in stable patients, consideration should be given to underlying renal dysfunction and comorbid conditions such as diabetes, as both increase the risk of contrast-induced nephropathy [10]. In a study of blunt trauma patients, preexisting diabetes and injury severity score of greater than 25 were independently associated with risk for contrast-induced nephropathy. Patients undergoing angiography will have already had one contrast load for their computed tomography (CT) scan and will require additional intravenous contrast for angiography. The decision for a second contrast load is particularly important when an active contrast blush is seen on CT. There are a number of guidelines published on contrast-induced acute kidney injury, but other than the importance of pre-contrast hydration, none are well agreed upon [44]. Though the incidence is negligible in patients with normal renal function, the incidence does increase with glomerular filtration rate (GFR) less than 45 mL/min/1.73 m^2 and is highest in patients with GFRs less than 30 mL/min/1.73 m^2 [10, 11, 44].

Hemodynamic instability mandates operative intervention, regardless of age, but the decision to operate on an elderly patient who may have less well-defined indications for laparotomy, such as declining hemoglobin, inability or difficulty reversing anticoagulants, or contrast blush on CT scan, is more difficult. In a small retrospective study by Joseph et al. on injured elderly requiring laparotomy, a direct correlation with mortality exists with every decade after 55 years of age [22]. Logistic regression found that only age and lactate were associated with mortality. The risk of laparotomy versus the lack of physiologic reserve in the elderly to tolerate hemorrhage needs to be balanced and cannot be guided by definitive data at this time.

Management of Splenic Injuries

Following traumatic abdominal injury, the spleen and liver are the two most commonly injured organs [43]. While splenectomy remains the gold standard of care in hemodynamically unstable patients, hemodynamically stable patients without peritonitis who have suffered a traumatic, low grade (I to III), blunt splenic injury, NOM is the standard of care [34]. NOM includes observation, splenic artery angiography and embolization, or observation followed by splenic artery angiography and embolization if bleeding ensues. Advantages of NOM include preservation of splenic function, lower hospital costs, avoidance of nontherapeutic laparotomies, earlier discharge, and a lower incidence of intra-abdominal complications [38, 42]. In adults, the failure rates of NOM in patients with blunt splenic trauma range from 8 to 38 % [42]. While the severity of splenic injury grade, large hemoperitoneum, and vascular blush or pseudoaneurysm are all associated with an increased risk of failure of NOM, age >55 years as a risk factor for failure has been assessed but with inconsistent results. Despite the historical controversy, current guidelines state that age >55 years in the hemodynamically stable patient is not a contraindication to a trial of NOM [42].

The elderly had previously been excluded from NOM as many believed that increasing age results in increased fragility of the spleen, decreased physiologic reserve, increased comorbidities, and a decreased tolerance to insult [15]. Morgenstern and Uyeda suggested in the 1980s older patients have deteriorating functional smooth muscle and elastica in the splenic vasculature and capsule, which could predispose the spleen to hemorrhage [31]. This belief was supported by a study published by Godley et al., showing a 91 % NOM failure rate among patients 55 years or older [18]. McIntyre et al. evaluated 2243 patients with blunt splenic injury to determine factors associated with failure of NOM and found that age >55 years was associated with failure [28]. Of the 141 elderly patients evaluated, 69 % failed NOM within 24 h. However, other studies refute these findings. A study published by Barone et al. showed a much lower NOM

failure rate of 17 % [3]. In fact, eight studies from 1999 to 2001 reported a 63 to 100 % success rate of NOM among patients 55 years or older with blunt splenic injury [2, 5, 9, 16, 17, 27, 32, 33]. Despite this success rate, Harbrecht et al. found that when comparing patients, age ≥55 years to patients <55 years, the failure rate for NOM in the elderly patient with blunt splenic injury was significantly greater (19 % vs. 10 %) [21]. When these patients were stratified by grade of splenic injury, older patients had lower success rates of NOM for grade II (73 % vs. 54 %) and grade III (52 % vs. 28 %) splenic injury. For grade IV and V splenic injuries, all patients age ≥55 years required operative management. In addition, the failure of NOM was associated with a mortality rate 2.5 times that of patients <55 years (12 % vs. 29 %).

Siriratisivawong et al. sought to compare subsets of older patients (55–64 years, 65–74 years, and 75 + years) who sustained blunt splenic injuries and found an overall failure rate of NOM of 25 % [40]. Although not statistically significant, an increase in failure rate was observed with increasing age (19.0 %, 27.1 %, and 28.3 %, respectively). However, Bhullar et al. also evaluated the failure rate of NOM among subsets of the elderly up to 90 years of age and found no significant difference between the groups [6]. While the highest failure rate of NOM occurred in patients ages 61–70 (11.5 %), those patients between the ages of 71 and 90 had 100 % success rate of NOM.

NOM of blunt splenic injury includes observation and splenic artery embolization (SAE). Indications for SAE include vascular blush/extravasation, pseudoaneurysm, arteriovenous shunting, or large hemoperitoneum on CT scan [20]. SAE is an effective and widely used adjunct to NOM of hemodynamically stable patients with blunt splenic injury [13, 14]. However, this adjunct is not without risks, especially among the elderly. The overall complication rate of SAE ranges from 7.5 to 27 % and includes splenic infarction, post-procedural bleeding, coil migration, contrast-induced nephropathy, abscess, pleural effusion, and fever [39]. Wu et al. retrospectively evaluated 53 patients with blunt splenic injury who underwent SAE and found age ≥65 was significantly associated with complications (AOR 5.97 [1.15–31.00]) [45].

Historically, splenic injury was always treated with laparotomy and splenectomy [43]. Over the last 50 years, NOM of blunt traumatic splenic injury has become the standard of care. While the elderly were previously excluded from the NOM paradigm because of increased NOM failure rates, many studies began supporting NOM of blunt traumatic splenic injury among the elderly by demonstrating high success rates. Current EAST guidelines state that age >55 years in the hemodynamically stable patient is not a contraindication to NOM [42]. While SAE is an effective adjunct to NOM of blunt traumatic splenic injury, post-procedural complications are increased among elderly patients.

Management of Liver Injuries in the Elderly

As for splenic injuries, nonoperative treatment of the hemodynamically normal patient with blunt injury has become the standard of care in most trauma centers. There are no reports in the literature specifically examining the management or outcomes of liver injuries in the elderly. In a recent study by Polanco, using data from the National Trauma Data Bank, they examined 3627 patients with grade IV or higher blunt liver injuries and found that 7 % of the patients failed nonoperative management. Importantly, patients who failed had a statistically significant increase in mortality [35]. On logistic regression, age, sex, injury severity score, Glasgow Coma Score, hypotension, and hepatic angioembolization independently predicted failure of NOM. Each year of increasing age was associated with a 2 % failure rate. Patients undergoing successful NOM were 24 (16–37) years of age compared to 29 (22–42) years of age for those patients who failed nonoperative management. Although age was a significant predictor in this study, patients were not of advanced age.

A patient with a CT finding of contrast blush or extravasation may benefit from angioembolization, though precise indications for angiography have not been well defined. Misselbeck et al. found that hemodynamically stable patients with contrast extravasation on CT scan were 20 times more likely to require hepatic angioembolization than those without extravasation [30]. Sivrikoz and colleagues have shown that angiography in severe blunt hepatic injury is associated with improved survival in both operatively and nonoperatively managed patients; however, patients managed with angiography did have more complications [41].

Most, but not all, patients with blunt nonoperative liver injuries recover without complication [26]. In a retrospective multi-institutional study of over 500 patients with high-grade injuries, 12.6 % developed hepatic complications that included bleeding, biliary pathologies, abdominal compartment syndrome, and infection [25]. Significant coagulopathy and grade V injury were found to be predictors of complication. The elderly trauma patient would likely not tolerate these complications as well as younger patients, though data is lacking.

Management of Renal Injuries in the Elderly

The trend of nonoperative management for blunt renal injuries reflects that of the spleen and liver [23]. More aggressive use of angiography and angioembolization is primarily responsible for the decrease in nephrectomy rates for high-grade injuries, as shown in a study using the National Trauma Data Bank [36]. Important for the elderly, many of these

patients required additional interventions including repeat angiography. Additionally, patients who fail angiography for blunt renal injury require more blood transfusions [29]. There is one study specifically looking at geriatric patients who sustained blunt renal injuries. Bjurlin et al. found similar rates of renal embolization, nephrectomy, and nonoperative management when comparing geriatric to younger cohorts. Not surprisingly, this multi-injured group of patients had a higher mortality and morbidity and longer intensive care unit stays [7].

In conclusion, management of solid organ injury in the elderly should in general be managed similar to that for younger patients. Elderly patients in shock do poorly, and the recognition of shock may be more challenging. Early recognition and treatment of shock are even more important in the injured elderly patient. This may equate to earlier and more aggressive operative intervention. Certain caveats present in the elderly should be taken into consideration when deciding on the course of management and may include the patient's physiologic reserve to tolerate hemorrhage or shock should bleeding develop, the use of anticoagulants, presence of comorbid conditions, and underlying renal function should angiography be necessary. Morbidity and mortality are higher after both operative and nonoperative management in the injured elderly with a solid organ injury.

Case Study

A 69-year-old female on home aspirin presented to an outside hospital after falling down three stairs. She was evaluated then discharged home. While at home, she became dizzy and had a syncopal episode. She returned to the outside hospital to be reevaluated where a CT abdomen/pelvis revealed a 3 cm subscapular splenic hematoma compressing the splenic upper pole (Fig. 28.1a), consistent with at least a grade III splenic injury, and large hemoperitoneum (Fig. 28.1b). She was transferred to a level 1 trauma center for higher level of care. She presented alert, oriented, and following commands. She reported abdominal pain and dizziness. Her blood pressure was 144/71 mmHg and her heart rate was 69 bpm. Past medical history was significant for hypertension, for which she was taking an antihypertensive medication and aspirin. Her abdomen was soft, nondistended, and mildly tender in the left upper quadrant. She was anemic with a hematocrit of 30.1. Coagulation was within normal limits (PT/INR 14.5/1.1). Her remaining labs were unremarkable. She was 24-h post-injury at the time of transfer. Given her persistent pain, dizziness, tenderness, and post-injury syncopal episode, she was considered a failure of nonoperative management. Her antiplatelet medication, acute blood loss anemia, and large hemoperitoneum in this elderly female were also considered into the decision. She was taken to the operating room for an exploratory laparotomy and splenectomy. She received one unit of packed red blood cells intraoperatively and had an uncomplicated postoperative course. The patient was discharged to home on postoperative day 3.

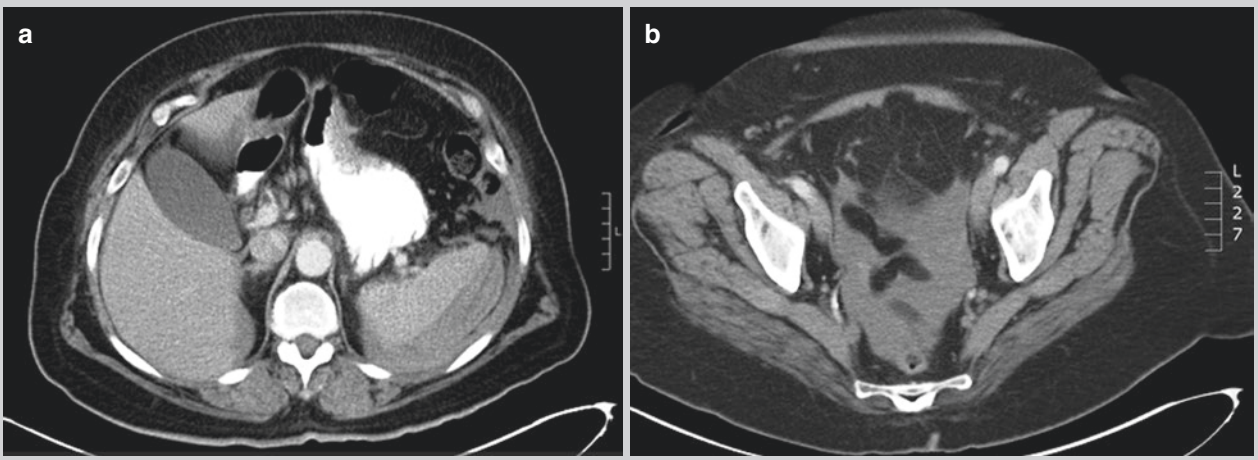

Fig. 28.1 CT scan of the abdomen with intravenous contrast. (**a**) A 3 cm subcapsular hematoma with (**b**) associated large hemoperitoneum

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Pelvic Fracture

29

Sharon Henry and Jay A. Yelon

Introduction

The presence of a pelvic fracture has special significance to trauma surgeons. Pelvic bones are considered the strongest in the body. Therefore, significant kinetic energy is required to fracture them. Such forceful trauma frequently is associated with injury to other organ systems and the extremities. The injury itself can also result in significant mortality related to hemorrhage and morbidity resulting from imperfect healing and/or nerve injury. There are differences in the mechanism of injury and associated injuries expected between younger and older patients with pelvic fractures. Younger patients typically sustain injury through high-energy mechanisms (motor vehicle collision), while older patients' injuries occur in the context of osteoporosis and from low-energy mechanisms (falls from standing or repetitive physiologic loading).

Trauma is the fifth leading cause of death in patients over the age of 65 years. They account for 28 % of deaths due to trauma though only representing 12 % of the population [1]. For each year increase in age over 65, the risk of dying following trauma increases by 6 % [2]. The US population over the age 50 years is predicted to increase by 60 % between 2000 and 2025 [3]. As of 2010 there were 40.3 million persons aged 65 or older, representing 13.0 % of the US population [4]. By the year 2030, it is estimated that those aged 65 and older will represent 19 % of the population. The average life expectancy of those reaching the age of 65 years is an additional 18.8 years [5]. Over a third (37 %) of elder Americans report some type of disability, ranging from major to minor. A study of Medicare beneficiaries over the age of 65 found 27 % reported difficulties with activities of daily living (ADL) [6]. Despite this, the vast majority of older Americans are living independently. The percentage of older adults (age 65 and older) living in nursing homes declined from 4.2 % in 1985 to 3.6 % in 2004 according to the National Nursing Home Survey (NNHS) [7]. Clearly injury that occurs with pelvic fracture has the potential to worsen the disability that many older adults are successfully coping with. There is substantial likelihood that such an injury could lead to increasing dependency and result in the need for institutionalized care.

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Epidemiology

The incidence of pelvic fracture is 9.3 % among patients who have suffered major blunt trauma. A high-energy mechanism is associated with 13–18 % of all pelvic fractures. Fractures involving the pelvis account for 3–8 % of all skeletal injuries [8]. Pelvic fractures display a bimodal age and gender distribution. Young males are overly represented in the early peak and elderly females in the later peak. Pelvis fractures vary significantly in initial presentation. Three subgroups can be recognized. There are mechanically stable minimally displaced fractures that occur after simple falls and high kinetic energy-associated injuries that occur in patients with multiple injuries with potential for hemorrhage from pelvic ring disruptions. A population-based study from England found the incidences of both high-energy and low-energy pelvic fractures to be 10 cases per 100,000 persons per year. The incidence of pelvic fracture with prehospital death occurred in 3 persons per 100,000 person years [9]. Among older patients, the incidence and rates of pelvic fracture increase after the age of 55 years in females and 65 years in males. By age 85 years, 2 % of white females will have suffered a pelvic fracture (Fig. 29.1) [10]. A Finnish study documented a 23 % per year increase in the age-adjusted incidence of pelvic fracture from 1970 to1997 [11].

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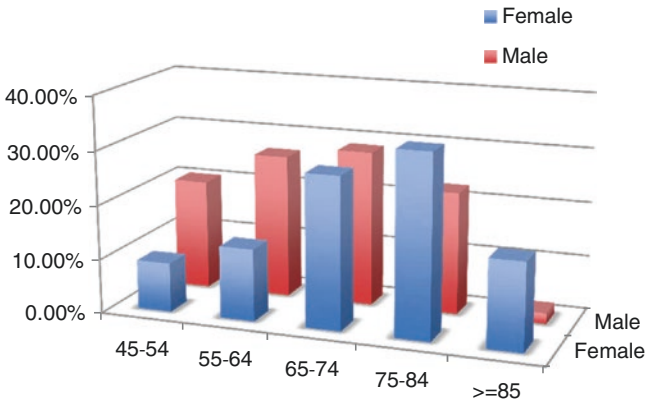

Age	Female	Male
45-54	9.10%	20.40%
55-64	13.30%	26.50%
65-74	28%	28.60%
75-84	33.50%	22.50%
>=85	16.10%	2%

Fig. 29.1 Distribution of pelvis fracture cases and controls by age and gender

A 2009 retrospective review found the mechanism of injury associated with pelvic fracture in patients younger than 65 years was motor vehicle collision (MVC) in 86.7 % and fall in 13.3 %; however, in those over the age of 65 years, nearly 30 % had a fall as the mechanism of injury [12]. Another study of pelvic fractures in patients over the age of 65 years found 83 % suffered injury from low-energy trauma as a result of fall from standing or transferring [13]. These fractures continue to present treatment dilemmas and can be a major source of morbidity and mortality.

Risk Factors

The older population is disproportionally impacted by falls. Patients older than 65 years represent 43 % of those injured by falls. Ground-level falls are traditionally thought to be a low-impact mechanism associated with inconsequential injuries. However, age greater than 55 years is independently predictive of significant injury in patients with low-energy mechanisms of injury [14]. Ground-level falls are the immediate cause of injury in nearly 80 % of elder patients with a pelvic fracture. Since falls are a significant mechanism for the disruption of the pelvic ring, it stands to reason that the risk factors for falls (Table 29.1) would be similar for pelvic fracture. Osteoporosis is an important comorbidity affecting elderly patients. In fact, fragility fractures of the pelvis (FFP) are one of the most visible and debilitating consequences of osteoporosis. It is estimated that 64 % of fractured pelvis are osteoporotic, and in patients over the age of 60 years, the incidence increases to 94 % [15]. Seeley et al. in a prospective cohort study demonstrated that pelvic fractures among others were related to reduced bone mass [16]. Fractures of the pelvic bones represent 7 % of all osteoporosis-related fractures in people 50 years or older in the USA. Several other associations have been suggested (Table 29.2) [10].

Anatomy

The pelvis is composed of five bones, the ilium, the ischium, the pubis, the sacrum, and the coccyx. The bones are connected to each other by several strong ligaments that resist transverse and longitudinal rotational forces to maintain pelvic stability. In general high energy is required to disrupt these strong bones and ligaments. However, in the elderly complex fracture can occur through low-energy impacts due to the presence of osteoporosis. The lumbosacral and coccygeal nerve plexuses are anterior to the sacrum and coccyx. These nerves arise from the T12 to S4 spinal nerves. Somatic and autonomic nerve injury is a real threat with injury to the pelvis. A thin-walled venous plexus is intimately attached to the sacrum and pubic bones. A rich blood supply arising from the iliac arteries supplies the soft tissues of the pelvis. These structures are all at risk for injury when the bones and ligaments in the region are injured. When the skin and superficial fascia are degloved as result with a closed shearing injury between the skin and superficial fascia, a Morel-Lavallee injury is produced [17]. In the elderly patient, these injuries can result in enormous blood loss compared to a younger patient where the bleeding is self-limiting. With the loss of tissue elasticity and the loss of blood vessel compliance, this kind of injury can result in ongoing hemorrhage leading to hemodynamic instability. The pelvis contains the lower genitourinary viscera, and injury to the pelvis may also result in injury to these organs by proximity.

Classification

Several classification systems to describe pelvic fractures exist. Initially fractures are assessed for stability. Stable fractures are characterized by single fractures of the pelvic ring, pure acetabular fractures, straddle fractures of the pubic rami, and chip fractures or avulsion fractures. Unstable fractures, on the other hand, involve disruption of the pelvic rim in more than one place, such as involvement of the posterior pelvis, sacrum, and sacroiliac complex. This includes the so-called Malgaigne (fractures of both rami and a posterior fracture of the sacroiliac complex) and open-book fractures (diastasis of the symphysis pubis and external rotation of one or both iliac bones). Arguably the most widely used classification system is the Young and Burgess system (see Table 29.3) [18]. Such classifications guide surgical intervention for fixation of these fractures. They are dependent on knowledge

Table 29.1 Contributing factors to injuries in elderly patients

Chronic medical condition	Environmental factors	Acute medical conditions	Other
Osteoarthritis	Rugs	Syncope	Older age
Osteoporosis	Lighting	Dysrhythmias	Female gender
CVA	Stairs	CVA, TIA	Alcohol and drug use
Ischemic heart disease	Bathtubs/showers	Acute MI	Elder abuse
Anemia	Footwear	Seizure	
DM	Uneven ground	Acute renal failure	
HTN	Weather	Infection	
Gait and balance disturbances	Walking aids	Hypoglycemia	
Visual impairment	Acute fractures	AAA	
Depression	Self-inflicted injury	New medications	
Polypharmacy		Dehydration	
Parkinson's disease			
Dementia			

From Aschkenasy and Rothenhaus [2]

Table 29.2 Associations with pelvic fracture in the elderly

Potential risk factors for pelvic fracture
History of previous fracture after age of 45 years[a]
Maternal history of hip fracture[a]
Cigarette smoking[a]
History of hysterectomy[a]
History of seizure[a]
History of Parkinson's disease
Caucasian female[a]
Use of assistive devices
Low body weight[a]
Need for assistance with ADL[a]
History of stroke
Wearing corrective lenses
Frequent use of hearing aid
Increased height
Left-handedness
Use of walking aids

[a]Statistically significant in multivariant analysis

of direction of injury force in addition to the anatomic site of injury. Many investigators have tried to correlate injury classification with likelihood of associated injury and transfusion needs with variable results. Many studies of patients with pelvic fracture conclude that patients with disrupted ligaments and high-grade fracture patterns are at highest risk of arterial bleeding. The patterns identified include APC II, APC III, LC III, and vertical shear (VS). Angiographic embolization has been noted to be required more frequently in patients with APC, VS, or combined fracture patterns. It was required in 20 % of the former while necessary in only 2 % of patients with lateral compression injuries (Table 29.3) [19]. A 2002 study of 234 patients with pelvic fracture found that lateral compression mechanisms were most common in patients over the age of 55 years, with 80 % classified as LC1. Despite this, patients with lateral compression fractures that were over the age of 55 were 3.9 times as likely to require blood transfusion as those younger than 55 [20]. Metz et al. found older patients with stable fracture patterns demonstrated more vascular injury than would be predicted. The average age of patients in the older group was 67 years. They postulated that these patients had decreased vascular compliance making them more vulnerable to shearing injury to blood vessels [21].

Diagnostics

Patients are initially assessed clinically. The hallmark of injury is pain. A non-tender pelvis in a neurologically normal patient is unlikely to be fractured. Palpation should include the symphysis pubis, the iliac crest, and sacroiliac region. Patients with severe fractures may have other findings on physical examination such as hematoma, abrasions, and lacerations (see Table 29.4). Leg length discrepancy may be seen, and rotational or vertical instability may be elicited on physical examination. Bimanual compression and distraction of the iliac wings can discern vertical or rotational instability but can also recreate bleeding from a stabilized hematoma so should be performed with care and only once when an abnormality is elicited.

In patients with suspected osteoporotic fractures, levels of thyroid-stimulating hormone (TSH), parathyroid hormone (PTH), calcium, phosphorous, albumin, 25-hydroxyvitamine D, creatinine, full blood count, liver function tests, C-reactive protein (CRP), and erythrocyte sedimentation rate (ESR) may be useful in addition to routine trauma laboratory studies.

Radiographic evaluation begins with an anterior posterior pelvic x-ray. These may be supplemented with inlet, outlet, and Judet views. There are those who would argue that pelvic x-rays are sufficiently insensitive to render them unnecessary in patients who are going to undergo computed tomography [22]. Pelvic films are most useful in

Table 29.3 Young and Burgess fracture pattern and 24 hour blood loss

Fracture type	Common characteristic	Differentiating characteristic	Avg EBL 24 h
Lateral compression (LC)	Anterior transverse fracture of the pubic rami		2.4
Type I	Anterior transverse fracture of the pubic rami	Sacral compression on side of impact	2.8
Type II	Anterior transverse fracture of the pubic rami	Crescent (iliac wing) fx	
Type III	Anterior transverse fracture of the pubic rami	Contralateral open-book (anterior posterior compression) APC injury	5.7
Anterior posterior compression (APC)	Symphyseal diastasis		
Type I	Symphyseal diastasis	Slight widening of pubic symphysis and/or sacroiliac (SI) joint; stretched but intact anterior and posterior ligaments	
Type II	Symphyseal diastasis or anterior vertical fx	Widened (SI) joint; disrupted anterior ligaments; intact posterior ligaments	6.4
Type III	Symphyseal diastasis	Complete hemipelvis separation, but no vertical displacement; complete SI joint disruption; complete anterior and posterior ligament disruption	20.5
VS	Symphyseal diastasis or anterior vertical fx	Vertical displacement anteriorly and posteriorly, usually through SI joint, occasionally through iliac wing and/or sacrum	7.8
Combined mechanism	Anterior and/or posterior, vertical and/or transverse components	Combination of other injury patters LC/VS or LC/APC	7.1

From Burgess et al. [19]

Table 29.4 Physical findings seen in severe pelvic injury

Acronym	Finding	Significance
Destot's sign	Superficial hematoma above the inguinal ligament or in the scrotum or thigh	
	Leg length discrepancy with leg fracture	
Earle's sign	Bony prominence or large hematoma and tenderness on digital rectal examination	Pelvic hematoma
Grey-Turner's sign	Bruising on the flank	Retroperitoneal hematoma
Morel-Lavallee lesion	Closed internal degloving injury over the greater trochanter Subcutaneous tissue avulsed from underlying fascia creating a cavity and hematoma May be delayed in appearance	High-energy injury Acetabular fracture
Roux's sign	Decreased distance from the greater trochanter to the pubic spine	Lateral compression pelvic fracture

the evaluation of the hemodynamically abnormal patient who has suffered high-energy blunt trauma. Diagnosing pelvic fracture based on x-ray may be challenging in the osteopenic patient especially when compounded by overlying bowel gas. This is a common finding in the elderly patient population. A recent study analyzed the radiologic reports for patients over the age of 75 years who had blunt pelvis trauma (including fall from ground level) and who had standard AP pelvic x-rays and CT scans. In this retrospective review of 233 patients, they demonstrated that plain films were likely to miss fractures of the posterior pelvic ring (sensitivity of 10.5 %). These authors suggest that CT be performed in all patients having any fracture seen on an AP x-ray of the pelvis. Bowel contrast may also limit the ability to interpret pelvis x-rays as well as computed tomography. When computed tomography is equivocal, magnetic resonance imaging may aid the diagnosis. This may be particularly helpful in patients with stable fractures and low-impact mechanisms associated with osteoporosis. Advanced radiography may also be necessary in patients who are unable to provide history because of cognitive limitations. Elderly patients with their

low-energy mechanism frequently present with hemodynamic normalcy but remain at risk for decompensation and subsequent death. It is important to maintain vigilance in their reassessment.

Treatment

The management of the geriatric patient with pelvic fracture injury depends on the patient's clinical presentation. In patients presenting with hemodynamic instability following moderate and high-energy mechanisms, the priority is to identify and control the site of hemorrhage. The danger with these patients is the risk of bleeding comes from multiple sites. External blood loss and internal bleeding in the thorax, abdomen or retroperitoneal space, and multiple long bone fractures may be present. In severe pelvic injury, there is a high incidence of combined intra-abdominal trauma, which will influence the therapeutic interventions. As often as one third of the time, bleeding will be identified from a non-pelvic source [23]. Rapid identification of intra-abdominal source begins with the use of focused abdominal sonography for trauma (FAST). Thoracic, head, long bone, and vertebral fracture or injuries should also be considered, identified, and treated or stabilized. When the pelvis is the source of hemorrhage, the site of bleeding needs to be determined. Bleeding from the fracture site or from torn veins or soft tissue is controlled by stabilizing and immobilizing the fracture site or performing pelvic packing. When an AP compression pelvic fracture is identified, the placement of a pelvic wrap or binder can be lifesaving. More permanent stabilization with external or internal fixation may be necessary. Loose, inelastic skin combined with antiplatelet and anticoagulant use can produce major blood loss from lower-grade injury. Arterial injury is more uncommon and less likely to be controlled with immobilization; angioembolization or surgical control may be necessary. Noncompressible blood vessels may require angioembolization or even operative ligation or repair. Concomitant injuries must be identified and treated. Early correction of coagulopathy is imperative. Correction with fresh frozen plasma can be time-consuming and result in high infusion volume to produce the desired international normalized ratio (INR). The use of clotting factor complexes or factor VIIa may result in more rapid correction, lower infused volume without substantively increasing the cost of therapy [24]. When patients are taking antiplatelet therapy, correction can only be accomplished through replacement with functioning platelets despite a normal platelet count. Patients with chronic kidney disease who are uremic may benefit from the administration of 1-deamino-8-D-arginine vasopressin (ddAVP) [25].

The nonurgent management of pelvic fracture in the elderly patients requires thoughtful assessment of their physiologic reserve and healing capacity. Compromise of these factors, which occur commonly in the elderly, results in less favorable outcome. Osteoporosis is prevalent in this population and may limit the treatment options available. The clinical presentations of the fracture in the elderly range from high energy to low energy and insufficiency fractures resulting from extreme frailty. Treatment includes conservative measures such as bed rest, percutaneous or minimally invasive procedures, open reduction and fixation, and total hip arthroplasty. When determining the management of high-energy pelvic fracture in the elderly patient, the patient's comorbidities must be weighed against the benefits of improved reduction, more rapid mobilization, easier nursing care, decreased pain, decreased blood loss, decreased pneumonia, decreased decubitus ulcer formation, and decreased deep venous thrombosis.

Low-energy injuries in the elderly are typically stable fractures. These injuries are most often treated with bed rest until the patient is able to tolerate increased mobility. Newer minimally invasive techniques to stabilize the posterior pelvic ring now allow earlier mobilization and avoidance of the morbidity associated with prolonged immobilization. Pain medication is often necessary. Medication interactions must be prevented and dosage decreased to avoid lethargy and confusion. Complications related to immobility and to the provision of pain medication may be seen (Table 29.5). LC1 and AP1 injuries can be managed with pain medication and bed rest with weight bearing and ambulation progressing as tolerated. Early rehabilitation and moderate weight bearing may increase bone formation. Prolonged immobilization can result in bone reabsorption, not to mention the increased risk of deep venous thrombosis, pulmonary embolus, increased pulmonary complications, increased gastrointestinal complications, and decreased muscle strength. Unstable fractures require operative intervention. Insufficiency fractures are frequently of the sacrum and occur predominately in elderly women. Risk factors include osteoporosis, corticosteroid use, a history of radiotherapy to the area, rheumatoid arthritis, and fluoride treatment (see Table 29.6). Trauma is causative in only 30 % of these types of fractures. Incapacitating pain and neurologic symptoms are the presenting complaints [26]. These injuries are most frequently treated with bed rest, though percutaneous fixation may also be utilized. The osteoporosis seen in the majority of these elderly patients should also be addressed. Table 29.7 lists the possible treatments. These injuries can be challenging for a variety of reasons. Osteoporosis can make the operative intervention challenging and increase the likelihood of nonunion. Older patients are more likely to have comorbidities that lessen their ability to tolerate general anesthesia and operative intervention.

Table 29.5 Timeframes and complications following pelvic fractures

Time scale	Life threatening	Increased morbidity, disability, or deformity
Acute (hours)	Hemorrhage, hypotension, tissue hypoxia	Neurological: lumbar and sacral root avulsion, autonomic nerve disruption (bladder sphincter control, erectile dysfunction and incontinence), sciatic, orburator or superior gluteal nerve injury, pain
		Open injury: degloving skin injury, perineal, urinary vaginal, or rectal injury
Subacute (days, weeks)	Pelvic hematoma, open injury, sepsis, multiorgan dysfunction syndrome (MODS), systemic inflammatory response syndrome (SIRS), pulmonary embolism (PE)	Secondary wound drainage or debridement, deep venous thrombosis, postphlebitic syndrome
		Urinary or fecal diversion
Late (months, years)		Bony malunion or nonunion: leg length discrepancy, sitting disturbance, gait disturbance (foot drop), muscle weakness, disuse osteoporosis, chronic pain
		Genitourinary: incontinence, impotence, dyspareunia, rectovaginal or rectovesical fistula

Modified from *Surgery*. 27:292–6

Table 29.6 Risk factors for osteoporosis

Risk factors for osteoporosis
Hyperparathyroidism
Osteomalacia
Renal osteodystrophy
Lumbosacral fusion
Paget's disease
Reconstructive surgery of the lower limb
Transplantation of the lung, heart-lung, kidney, and liver
Rheumatoid arthritis
Radiation therapy
Vitamin D deficiency
Pregnancy and lactation

Table 29.7 Possible treatments for osteoporosis

Agent			Action	Cautions
Vitamin D			Increase Vitamin D to improve calcium absorption	
Bisphosphonates	Alendronate	Fosamax	Inhibit bone reabsorption Can reduce incidence of new fractures in patients with osteoporosis Increase bone mineral density (BMD) Most beneficial during first 5 years of therapy	Oversuppression of bone turnover Paradoxical inhibition of bone formation reduced osteoblastic activity Gastrointestinal discomfort, acute influenza-like illness, renal insufficiency, osteonecrosis of the jaw, and atypical stress fractures
	Ibandronate	Boniva		
	Risedronate	Actonel, Atelvia		
	Zoledronic acid	Reclast		
Calcitonin	Fortical, Miacalcin		Increases bone mass by reducing turnover Analgesic for bone pain	Use in postmenopausal osteoporosis
Anabolic agents	Teriparatide Forteo (recombinant human PTH and selective estrogen receptor modulators (SERMS)		Increases BMD	Increased risk of osteosarcoma

Outcome

Pelvis fractures are associated with significant morbidity in older patients. Deaths can be related to hemorrhage from the associated soft tissue injury, to complications related to the fracture, from other injuries suffered as a result of the trauma, or from underlying comorbidities. The mortality is four times higher than in younger patients. A retrospective review of patients hospitalized for pelvic fracture that were over the age of 65 years found the mortality to be 7.6 %. Those patients were found to have a 1-year mortality of 27 % and all-cause mortality at 3 years of 50 %. The length of hospital stay for these patients was 21.4 days [13]. These patients seldom return to their preoperative mobility status. Recently, a review of 85 geriatric polytrauma patients identified contrast extravasation on CT, and a hemoglobin level <12 g/dL were predictors of mortality. Following discharge most required walking assistance with at least a cane, and more than half required the assistance of another person. One third of patients required institutional care. Furthermore, a retrospective review of German nursing home patients demonstrated an increased risk of death in the first 2 months following pelvic fracture in women and up to a year following pelvic fracture in men [27].

Summary

The population is aging, and many are maintaining active lifestyles that place them at risk for a traumatic injury. Pelvic fractures are sustained by the elderly through two predominate mechanisms. High-energy mechanisms common in the younger patient, such as motor vehicle crashes, or low-energy mechanisms are seen strictly in the elderly ground-level falls (fragility fractures). Declining physiology, medical comorbidities, and medications affect the response to injury in high- and low-energy mechanisms. The expected mortality in the elderly is higher for a given injury severity than in the younger patient. Low-energy mechanisms commonly result in mechanically stable fracture patterns. Nonetheless these injuries can have significant impact on the older patient's ability to live independently or ambulate unassisted. Though representing only 12 % of the injured population, the elderly account for 28 % of the deaths [2]. Vigilance and anticipating decompensation are important in assuring optimal outcome when treating this population.

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Extremity Injury

30

Scott Ryan, Lisa Ceglia and Charles Cassidy

Prevention of Osteoporotic Fractures

Osteoporosis is a condition of fragile bone defined by a bone density, as measured by dual-energy x-ray absorptiometry (DXA), of more than 2.5 standard deviations below the average for healthy adults. Regardless of the absolute DXA score, geriatric patients with a fragility fracture (a fracture during normal activities, particularly a fall from standing height or less) can be considered to have fragile, osteoporotic bone [1]. The incidence of fragility fracture has risen exponentially in the last century, leading to considerable cost, morbidity, and mortality [2–4]. Prevention of osteoporotic fractures must address risk factors in two major categories – those associated with trauma or falls, and those associated with bone strength [5–7].

Non-pharmacologic Interventions

Falling is one of the most common risk factors associated with fragility fracture, with 33 % of elderly in the community and up to 60 % of institutionalized patients falling each year [7–10]. Fractures occur in 3–12 % of falls, with hip fracture occurring in less than 1 % [6]. However, for patients who fall frequently, the annual prevalence of hip fracture is 14 % [11]. Fall prevention is a primary target of non-pharmacologic interventions for the prevention of osteoporotic fractures.

Fall prevention can be achieved through improvements in strength and balance, with the use of assistive devices, or through environment modification. Strength training and weight-bearing exercise improve muscle tone, balance, and agility as well as bone density [12]. Some patients may require orthotics, a cane, or a walker in order to ambulate safely. Patients at risk for falls should avoid uneven ground or strenuous activities that increase their risk [13].

To improve skeletal health, nutritional counseling can address dietary calcium and vitamin D needs as well as general dietary needs for peak health and performance. However, many North-American patients will require supplementation to achieve desired serum levels [14–17].

Perhaps the most crucial first line intervention for patients at risk for fragility fracture is effective management of comorbid conditions. A wide range of neurological, cardiac, gastrointestinal, metabolic and other conditions can be counterproductive for both fall prevention and skeletal health maintenance. Furthermore, significant comorbidities affecting gait, cognition, and nutrition are common among the elderly. The risk of polypharmacy is an additional consideration for these patients, and must be addressed [18, 19].

Pharmacological Interventions

The American College of Physicians strongly recommends that physicians offer pharmacologic treatment to patients with osteoporosis [20]. Drugs with good or fair evidence for preventing hip fractures are estrogen, alendronate, risedronate, zoledronic acid, and denosumab. Drugs with good or fair evidence for preventing vertebral fractures are estrogen, raloxifene, alendronate, ibandronate, risedronate, zoledronic acid, calcitonin, teriparatide, denosumab [21]. Physicians should assess risks and benefits on an individual basis to determine a pharmacological program for each patient [20].

Calcium and Vitamin D

Calcium and vitamin D supplementation are at the forefront of nutritional interventions for the prevention of osteoporotic fractures. Calcium intakes of up to 1200 mg/day from either dietary sources or supplements are recommended to slow the rate of bone loss in the elderly. Vitamin D has known beneficial effects on calcium and phosphate homeostasis.

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Interventional studies have examined the impact of vitamin D on fracture prevention [22]. A recent meta-analysis of randomized controlled trials in the elderly showed that vitamin D supplementation lowered risk of hip and nonvertebral fractures particularly at higher doses of at least 700 IU per day and in conjunction with calcium supplementation [23]. Furthermore, doses of vitamin D (most commonly available as vitamin D_3) 700–1000 IU daily are known to be safe and do not require monitoring [24].

Estrogen and Estrogen-Related Compounds

Estrogen reduces bone loss in postmenopausal women, particularly in combination with adequate calcium supplementation. Estrogen reduces the risk of hip and vertebral fractures, and is effective at maintaining bone mineral density for as long as the drug is taken. When estrogen is stopped, bone loss proceeds at the high rates characteristic of menopause [25–27]. However, hormone replacement is a broadly-acting therapy with long term risks such as stroke, MI, breast cancer, and venous thromboembolism [28].

Raloxifene (Evista) is a selective estrogen receptor modulator with antagonistic effects in the breast and endometrium but agonistic effects in the bone. Raloxifene has been shown to decrease risk of vertebral fractures and risk of breast cancer in women at increased risk for breast cancer, but is associated with a risk of venous thromboembolism at a similar rate to estrogen hormone replacement therapy [29–31].

The synthetic steroid tibolone acts on estrogen, progesterone, and androgen receptors and has been shown to prevent bone loss in postmenopausal women. A 2008 study demonstrated a reduction in vertebral fracture and breast cancer with an increased risk of stroke in the group treated with tibolone when compared to placebo. Tibolone is not FDA approved for the treatment of osteoporosis and is not available in the United States [28].

Bisphosphonates

The bisphosphonates are a diverse class of compounds that bind strongly to hydroxyapatite crystals in bone with a half life of several years. Bisphosphonates reduce the recruitment of osteoclasts and induce their apoptosis, limiting bone resorption and decreasing turnover. As a class of drugs, bisphosphonates are supported by the greatest body of evidence indicating reduced fracture rates among osteoporotic patients. They are available in oral and intravenous administrations given daily, weekly, monthly, quarterly or annually [32–36].

Side effects of oral bisphosphonates include esophagitis, dyspepsia, diarrhea and abdominal pain, which are sometimes severe. Oral bisphosphonates should be taken fasting with a full glass of water and not mixed with any other medication, with instructions to remain upright for 30–60 min. Intravenous bisphosphonates may cause a brief period of flu-like symptoms, particularly following the first dose [33, 34]. Rare but serious possible complications of bisphosphonates exist, including aseptic osteonecrosis of the jaw and atypical subtrochanteric fractures of the femur. The long-term effects of bisphosphonate use are not yet studied, despite half lives of many years in bone. Patients with an extensive history of bisphosphonate use or a history of fracture despite bisphosphonate treatment should be considered for other therapies [32].

Bisphosphonates approved for the treatment of osteoporosis include alendronate (Fosamax, generic), ibandronate (Boniva, generic), risedronate (Actonel, Atelvia, generic) and zoledronic acid (Reclast) [32].

Calcitonin

Calcitonin is an osteoclast-inhibiting hormone produced by the C cells of the thyroid. FDA approved formulations of salmon calcitonin (Miacalcin, Fortical) for the treatment of osteoporosis in post-menopausal women are administered by nasal spray and have shown fair effectiveness in reduction of vertebral fractures. Nasally-administered calcitonin is not associated with any serious side effects but may cause irritation of the nasal mucous membranes [36–37].

Parathyroid Hormone

Prolonged sustained exposure to parathyroid hormone (PTH) ultimately leads to increased bone turnover and decreased bone mineral density. However, brief "pulses" of PTH daily can be used to stimulate new bone formation and prevent resorption [38, 39]. Teriparatide (Forteo) is a biosynthetic PTH fragment administered daily by subcutaneous injection into the thigh or abdominal wall for up to 2 years. Teriparatide has been shown to be effective in reducing vertebral and non-vertebral fractures in postmenopausal women with a history of fracture, and may be more effective than alendronate for this purpose. The safety of teriparatide beyond 2 years has not been established. The drug carries a black box warning because of possible increased risk of osteosarcoma as demonstrated in rats. Teriparatide is contraindicated in patients with any elevated risk of osteosarcoma, Paget's disease of bone, open epiphyses, cancer of the bone, metastases of other cancers to the bone or prior radiation therapy affecting the skeleton. Common side effects of teriparatide include hypercalcemia, transient orthostatic hypotension, pain, gastrointestinal symptoms and flu-like symptoms [38, 40].

Bisphosphonates administered immediately following teriparatide result in a greater potential increase in bone mineral density [41, 42].

Denosumab

Denosumab (Prolia) is a human monoclonal antibody which binds receptor activator of nuclear factor kappa-B ligand (RANKL), a key part of the osteoclast activation cascade.

Denosumab was approved by the FDA in 2010 for use in women with osteoporosis and at high risk for fracture [43]. Based on a randomized controlled trial of 7868 osteoporotic women, denosumab showed decreased risk of vertebral fractures and nonvertebral fractures including hip fractures specifically. Denosumab was associated with increased risk of flatulence, eczema and severe adverse events of cellulitis, and may be contraindicated in patients with a history of severe rash or cellulitis [44].A later systematic review of additional denosumab trials confirmed these findings, including the risk of serious adverse events of cellulitis [45].

Strontium

Strontium ranelate (Protelos, Protos) takes advantage of the chemical similarity between calcium and strontium to achieve good uptake into bone, where it decreases resorption and may increase formation. Strontium ranelate is not FDA approved and not available in the U.S, but a review of four controlled trials has demonstrated a decrease in vertebral fractures relative to placebo. Adverse effects were rare but included diarrhea, venous thromboembolism, pulmonary embolism, headache, seizure, memory loss and altered consciousness [46]. Strontium therapy has also raised concerns about cost effectiveness, and is not believed to have any advantage over bisphosphonates in this category [47].

Fluoride

Fluoride therapy is controversial and is not approved by the FDA for the treatment of osteoporosis. Although fluoride is incorporated into bone and may stimulate osteoblast activity to increase bone mineral density in the spine, systematic reviews have shown no fracture protection. Furthermore, fluoride may be associated with an increased risk of nonvertebral fractures at higher doses [48–50].

Summary and Conclusions

Management of elderly patients at risk for fragility fracture must address the two major risk categories of fall risk and skeletal health. A crucial first step is careful review of comorbid conditions and medications to minimize counterproductive effects on function and nutrition. Weight-bearing exercise has favorable effects on both fall risk and skeletal health. Many elderly patients, particularly in institutional settings, are candidates for supplementation with calcium and vitamin D. Patients at an increased risk for future osteoporotic fracture should consider FDA approved drugs with demonstrated effectiveness at reducing vertebral and nonvertebral fractures. Among these, bisphosphonates are the most common and the most affordable. However, their long-term use has not been adequately studied and serious adverse events have been reported. Alternatives include raloxifene, calcitonin, teriparatide, and denosumab, each with a different profile of costs, risks, and benefits. Ultimately, each patient should receive a personalized multi-faceted therapy combining pharmacologic and non-pharmacologic approaches as needed.

Prevention strategies must be considered by the trauma surgeon. It is the responsibility of the entire team to identify possible osteoporotic fractures and ensure appropriate referral for long-term management.

Consideration in Treatment of Osteoporotic Bone

The goals of treating elderly patients with lower extremity fractures are to control pain and to assist with early mobilization and weight-bearing. This is done by providing stable fracture fixation. Achieving such stability can be difficult in the elderly due to poor bone quality and more comminuted and complex fracture patterns. Osteoporosis is a contributing factor in 75 % of fractures caused by low-energy falls [51]. In addition, fractures around implants such as total hip or knee replacements can turn a simple fracture into a much more complicated operation if it affects the stability of the prosthesis. Non-operative care can result in complications from being immobile, such as pressure sores, respiratory problems, deconditioning and a diminished likelihood of full recovery [52]. Other objectives in treating elderly patients with fractures include minimizing surgical morbidity by performing the safest operation and decreasing the chance of reoperation from a failed initial surgery. Ultimately, the surgeon's goal is to return the patient to pre-injury functional activity. Unfortunately, this is not always possible.

Advances in implants (i.e. locking screws and plates) and augments such as polymethylmethacrylate have aided in the ability to provide stable fixation in poor quality bone [53, 54]. This is paramount, as the ability to heal fractures correlates negatively with age [55]. It is important to preserve the biology of the fracture to aid in healing. Some newer implants are designed to be inserted percutaneously, thereby minimizing additional soft tissue disruption. With the improvement in implants, failure of operative fixation is typically through cutout of the implant construct due to poor quality bone, rather than by implant breakage [52].

Intramedullary nail fixation of long bone fractures is preferred to plate and screw fixation as it is biomechanically superior and can permit immediate weight bearing. These prostheses are load-sharing devices and allow the surrounding bone to experience some stress, which encourages bone healing [24]. Plate and screw constructs are considered to be a load-bearing devices, since the weight is transferred from the bone to the plate, bypassing the fracture site. With either type of fixation, full weight bearing should be allowed within

several weeks of fixation if not appropriate immediately [56]. Elderly patients have difficulty regulating weight bearing status after lower extremity operations. Physical therapists should assess the patient's ability to ambulate.

Treatment of most geriatric fractures in the lower extremity is similar to younger patients. This section will focus on the perioperative management of the most common types of fractures (i.e. hip fractures), controversial fractures (i.e. acetabular fractures) and care of fractures specific to this population (i.e. periprosthetic fractures).

Pre-operative Evaluation and Considerations

Caring for elderly patients with fractures requires a multidisciplinary approach. This involves constant communication with orthopaedics, the acute care surgery service, medical service or geriatric service, and anesthesiology since these patients typically have multiple medical co-morbidities. Medical problems, which may have been stable prior to the injury, may resurface as a result of the physiologic stress from a fractured long bone. When a long bone fractures, it not only results in blood loss into the extremity that can affect the cardiac status, but also causes the release of inflammatory cells that can cause a stress response affecting other organ systems [57]. During the initial history and physical, it is important to ask about the pre-ambulatory status and living situation of the patient. This is predictive of how likely the patient is to return to their baseline function and living arrangements [58].

Most of the studies on preoperative evaluation of elderly patients with lower extremity fractures come from the hip fracture literature. The role of the acute care surgery service or geriatric service is to assess the risk stratification of the patient and medically optimize the patient's cardiovascular function prior to surgery. Risk stratification is important to know in order to have an informed discussion with the patient and their family regarding non operative versus operative fracture care. Advanced age is not an independent risk factor for complications after surgery, but medical co-morbidities are. Patients with an ASA of III or IV have nine times higher mortality than patients with an ASA of I or II [59]. The American College of Cardiology and the American Heart Association have recommended a preoperative echocardiogram for patients with a history of angina or decreased left ventricular dysfunction. This information can be useful for perioperative fluid management and risk stratification. In addition, they recommend a preoperative cardiac stress test for patients with new onset angina or a change in the pattern of angina.

Recently, Stitgen et al. reviewed the adherence to preoperative cardiac clearance guidelines and found that 70 % of patients received unnecessary cardiac consultations [60]. According to the American Heart Association (AHA) four heart conditions require cardiac evaluation; unstable coronary syndrome (i.e. recent myocardial infarction in the past 30 days), decompensated heart failure, significant arrhythmias and severe valvular disease [61]. Of the 70 % of patients who received unnecessary cardiac consultation, more than half of those patient received testing beyond EKG, including echocardiogram and stress test, but none required invasive cardiac procedures pre operatively. Not surprisingly, this group of patients with cardiac consultation had a significant delay to the operating room for fracture fixation and longer hospitalization. The authors concluded that preoperative cardiac consultations are frequently overused and this leads to delay in time to surgery and time to discharge. They recommended stricter adherence to AHA guidelines.

The appropriate admitting service for a geriatric patient with a lower extremity fracture is often an issue of debate. Vidin et al. [62], performed a randomized controlled trial of over 300 patients who were admitted with a hip fracture. One group was admitted to an orthopaedic surgery service with a medical consultation as needed and the other group was admitted to a geriatric service with the orthopaedic service as a consultant. The primary outcomes evaluated were medical complications, mortality and functional status. There was a significant decrease in mortality, medical complications and improved functional status at 3 months when hip fracture patients were admitted to a geriatric service. The authors concluded that early geriatric intervention during the acute phase of hip fracture in the elderly reduces the in-hospital mortality and medical complications.

We recommend a protocol for pre-operative evaluation of these patients in the emergency room. Whichever service is primarily taking care of these patients, they require medical management or consultation throughout the perioperative period.

Timing of Surgery

The timing of surgery has also been extensively studied in the hip fracture population. It is commonly extrapolated to other long bone fractures in the lower extremity in this population because the complications from delay are from being bedbound and in pain. The decision of when to take an elderly patient to the operating room is a balance between medical stabilization and mobilization. Kenzora et al. [63] studied over 400 patients with hip fractures and found that patients operated on less than 24 h after admission had a 34 % 1-year mortality rate. Those patients operated on hospital day 2–5 had a 6 % 1-year mortality rate and those operated on after 5 days had a 35 % 1-year mortality. They rationalized this by stating that the patients who underwent surgery early may not have been medically optimized.

Sexson et al. [64] found that those patients with less than 2 medical co-morbidities had a higher survival if they were operated on less than 24 h following admission, and those that had more than 3 co-morbidities had a higher mortality if operated on early. They recommended taking healthier patients to the operating room as soon as possible and waiting for medical optimization on sicker patients. Moran et al. [65], in a prospective study of over 2600 patients, found that a surgical delay of greater than 4 days increased mortality in hip fracture patients. Egol [66], in a review of the literature on hip fractures, recommended operative fixation of hip fractures within 48 h in the majority of patients and medical optimization and delay no longer than 4 days in patients with more than three medical co-morbidities.

Egol and Zuckerman followed up on their previous study and attempted to define what a "delay" in hip fracture surgery actually means [67]. The authors reviewed over two million patients with hip fractures identified in the National Inpatient Sample over a 10 year period. Surgery 2 or more days after admission was associated with a higher mortality rate. Operation at ≥2 days after admission (hospital day 3) had a 33 % increased risk of overall complications and were twice as likely to have a complication if operated on 3 or more days after admission. The authors concluded that a "delay" to the operating room was defined as 2 or more days after admission. Currently there is a multicenter randomized control trial underway evaluating whether surgery within 6 h of admission in patients with hip fractures improves outcomes [68].

Ricci, et al. evaluated the factors which are associated with delay to surgery in patients with hip fractures [69]. Preoperative cardiac testing, increasing ASA score and admission day of the week were found as independent variables delaying surgery. Patients admitted later in the week (Thursday through Sunday) had a greater delay than those patients admitted earlier in the week. The authors rationalized this by suggesting better access to hospital resources being available earlier in the week. These variables also increased the overall length of stay. Patients who received preoperative cardiac testing and each increase in ASA class over 2 increased the length of stay approximately 2 days. Garcia, et al. also found that each increase in ASA class increased length of stay by 2 days. [70].

Type of Anesthesia

Best evidence is lacking in determining whether regional (spinal) or general anesthesia is safer for these patients. There are risks and benefits to both and the anesthetic plan should be discussed with all services involved with care, as well as the patient. In a meta- analysis of 15 randomized controlled trials of regional versus general anesthesia in hip fracture patients [71], regional anesthesia had the benefits of a decreased 30-day mortality rate and a lower DVT rate. The long-term mortality rate was however, the same. Regional anesthesia should be considered in patients with severe pulmonary disease. The risk of regional anesthesia is hypotension, which increases the risk of stroke. The patients in the general anesthesia group had a trend for a lower incidence of stroke and fewer episodes of intra operative hypotension. Parker, et al. had similar results in a Cochrane Database Systematic Review [72].

Summary

Recent literature supports prompt fixation of most geriatric hip fractures (i.e. either on day of admission or hospital day 2). Patients often receive unnecessary preoperative evaluations and studies that delay fracture fixation and increase length of stay. The delay for unnecessary preoperative workup may negatively affect patient outcomes. A multicenter randomized controlled trial is underway to determine if urgent surgery for patients with hip fractures affects outcomes.

Treatment of Specific Fracture Types

The goals of treatment of lower extremity fractures in the elderly patient population is to provide pain control, early mobility and return the patient as close as possible to their baseline function and living situation. This section will review the treatment options for fractures specific to the elderly patient population.

Hip Fractures

The general term of hip fractures describe three different types of fractures that require a variety of treatment options; femoral neck, intertrochanteric, and subtrochanteric. These fractures are typically sustained in low energy falls. All elderly patients with hip fractures should undergo a preoperative evaluation as described previously.

Epidemiology

Fractures of the hip are common, with lifetime incidence of hip fracture ranging from 40 to 50 % in women and 13–22 % in men [73]. Multiple factors contribute to the epidemiologic trends in hip fractures. While increased life expectancies and demographic shift raise valid concerns about a growing population at risk, medical management of

risk factors, specifically osteoporosis, is improving [74]. Thus, the age-adjusted incidence of hip fracture fell between 1995 and 2005, while the total number of hip fractures remains high. The patients at highest risk are elderly, as incidence increases exponentially with age. Females are at greater risk than males, due to increased risk factors such as osteoporosis and different anatomy of the hip joint [75]. There is some racial variation in incidence, with increased incidence in Caucasians relative to African-Americans [76]. The vast majority of cases are treated surgically, comprising 20 % of the operative workload of an orthopaedic trauma unit [77].

Femoral Neck Fractures

Fractures of the femoral neck are typically sustained during a simple fall on the trochanteric region (Fig. 30.1). The greater trochanter transmits the force of the fall along the femoral neck, which fractures [78]. Other mechanisms of injury include high-trauma events, stress fracture, and pathologic fracture, which together account for less than 10 % of these fractures among geriatric patients [79, 80].

Plain radiographs with anteroposterior and lateral are sufficient to diagnose fracture in 98 % of cases. MRI is a low-radiation, high sensitivity and high specificity alternative when there is a high suspicion of fracture without conclusive findings on X-ray [81]. Treatment plan and outcome measures are correlated with displaced vs. non-displaced fracture features [82]. Eighty-five percent of femoral neck fractures are displaced at the time of diagnosis [24].

Non-displaced [83] or valgus impacted femoral neck fractures are generally treated with percutaneous pinning using a cannulated screw system (Fig. 30.2) [84]. Fixation with a sliding hip screw construct is another option for patients with femoral neck fractures. Despite the improved biomechanical stability with a sliding hip screw, most surgeons still use multiple cannulated screws for fixation of nondisplaced femoral neck fractures [85]. Patients can bear weight as tolerated after surgery and should be followed with serial radiographs to evaluate union [86, 87].

There is a high risk of complications treating nondisplaced fractures non-operatively. Rates of subsequent displacement range from 19 to 46 % [88–90]. Ultimately, these complications lead to worse outcomes overall than operative treatment. Thus, non-operative treatment should be reserved for those patients whose comorbidities make them very poor candidates for surgery, or non-ambulatory patients in a palliative care setting. Additionally, patients may elect to try non-operative treatment, but should be made aware of the alternatives [91].

Displaced femoral neck fractures are typically treated with hemiarthroplasty or total hip arthroplasty (Fig. 30.3). These procedures eliminate the risk of nonunion and fixation failure by using a prosthesis to bridge the joint space. Prostheses may be cemented or uncemented. Cemented femoral components may offer a decreased risk of intraoperative fracture and improved postoperative function over many uncemented components; however, comparative studies are not available for current generation uncemented systems [92–95]. These procedures are performed with the patient in a lateral position through either the lateral or posterior approach to the hip.

The anterior approach is becoming more popular with surgeons because the exposure goes between muscle planes

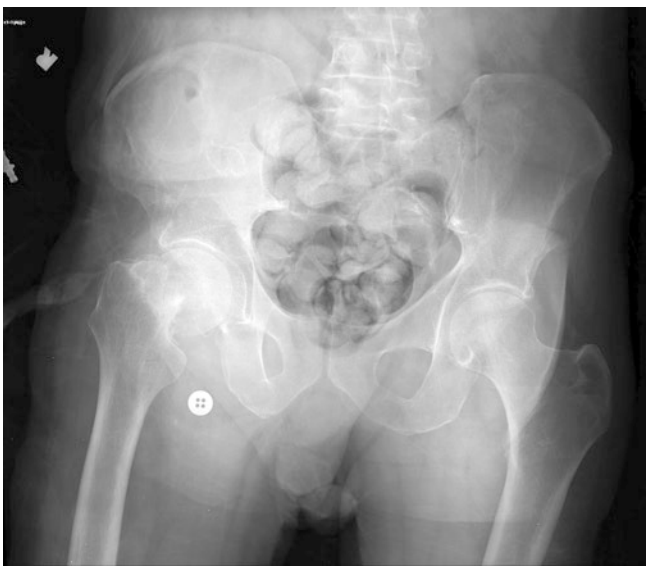

Fig. 30.1 AP pelvis X ray of a right displaced femoral neck fracture

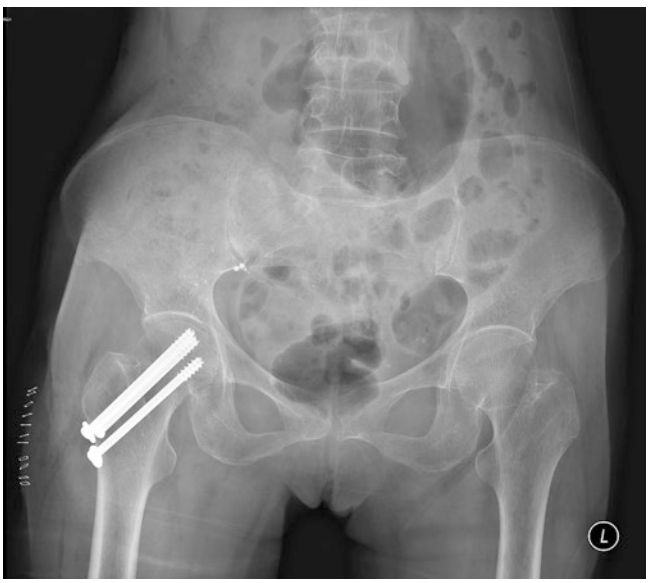

Fig. 30.2 AP pelvis X ray of percutaneous screws for fixation of a valgus impacted femoral neck fracture

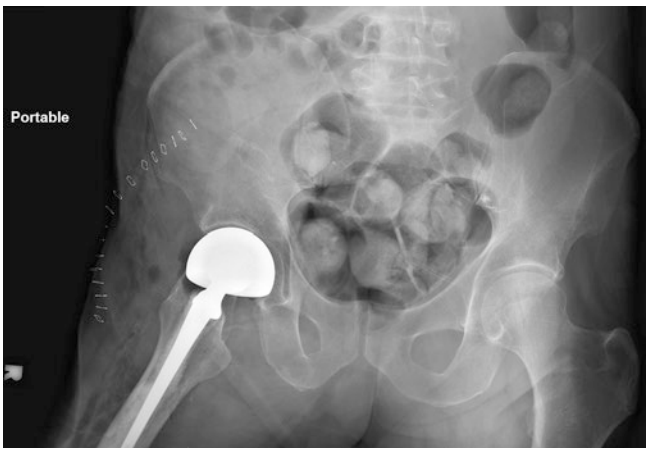

Fig. 30.3 AP pelvis X ray of a bipolar hemiarthroplasty for treatment of a displaced femoral neck fracture

instead of through muscles. This approach is just now being studied in patients with total hip for osteoarthritis and may lead to a quicker recovery, decreased dislocation rate and decreased hospital stay [96]. Because of these promising results, this has translated to surgeons performing anterior approach for replacement surgery for fracture of the femoral neck [97]. The downside of the anterior approach is the need for a specialized operative table and the learning curve associated with the procedure [98]. The selection of procedure and implant type depends on surgeon experience, patient demographics, baseline function, and functional goals.

In unipolar hemiarthroplasty, the femoral neck and head are replaced by a non-modular implant. The modularity of bipolar hemiarthroplasty is thought to provide an advantage over the unipolar design. In bipolar hemiarthroplasty, an inner head articulates with a shell that in turn articulates with the acetabulum. In theory, this reduces wear and acetabular protrusion (femoral head migration into the pelvis) [99–102]. The modularity of a bipolar system allows the surgeon to test a variety of head/neck options in order to optimize stability. Despite these theoretical advantages, results are comparable with unipolar hemiarthroplasty [103, 104].

Total hip arthroplasty has been shown to have better outcomes for treatment of displaced femoral neck fractures in cognitively intact patients [105]. This comes at a risk of a higher dislocation rate [106]. Total hip arthroplasty is a longer and more complex procedure, and may have higher cost [107]. Although the procedure is more complex than hemiarthroplasty or percutaneous screws, 30-day mortality is low at 2.4 % [108]. Long term mortality and reoperation are low at 12 % and 5 % respectively. All of these data compare favorable to other methods of treatment. Rates of complication are understandably higher for secondary total hip arthroplasty to revise failed internal fixation [94, 109–111].

Summary

Nondisplaced femoral neck fractures should be treated with fixation using cannulated screws or a sliding hip screw and displaced femoral neck fractures in the elderly should be treated with replacement, either hemi or total hip arthroplasty. This decision is based on age, activity level and cognitive status of the patient [112–116]. Patients with pre-existing hip arthritis may also benefit from total hip arthroplasty [117–118].

Intertrochanteric Fractures

Intertrochanteric fractures are extracapsular, proximal metaphyseal fractures between the greater and lesser trochanter. In older patients, these injuries are predominantly due to low-energy trauma such as falls from standing height [119, 120]. The greater and lesser trochanters and the intertrochanteric region are sites of extensive muscle attachment, and fractures in this region are subject to considerable stress. Stable anatomic reduction and fixation are the paramount challenges of treating fractures in this functionally essential region [121, 122].

Non-operative treatment is reserved for patients with very low baseline function or very short life expectancies where medical palliation is adequate to control pain. Patients should be quickly mobilized to an upright position to minimize the risks of prolonged bedrest [123].

Operative fixation of intertrochanteric hip fractures is the standard of care. For stable fractures, which are either nondisplaced or displaced but a stable fracture pattern, a sliding hip screw is often preferred (Fig. 30.4a, b) [124, 125]. Sliding hip screws are designed to provide dynamic compression across the fracture to enhance stability and healing. If additional rotational stability is required, an additional screw can be placed in the femoral neck, parallel to the sliding screw system [126]. If possible, a closed reduction to anatomic position is achieved under fluoroscopy. Otherwise, open reduction is performed. The sliding screw system is placed using a lateral approach to the proximal femur. Guide wires placed under fluoroscopy are used to direct the screw in the correct position, and a plate is placed over the screw and secured to the femur [24, 127]. The typical mode of failure is cutout, which occurs in 4–7 % of patients. Reoperation is required in around 4 % of patients [24].

For unstable fractures, an intramedullary device should be chosen to avoid excessive settling of the fracture (Fig. 30.5a, b) [128, 129]. The intramedullary approach requires

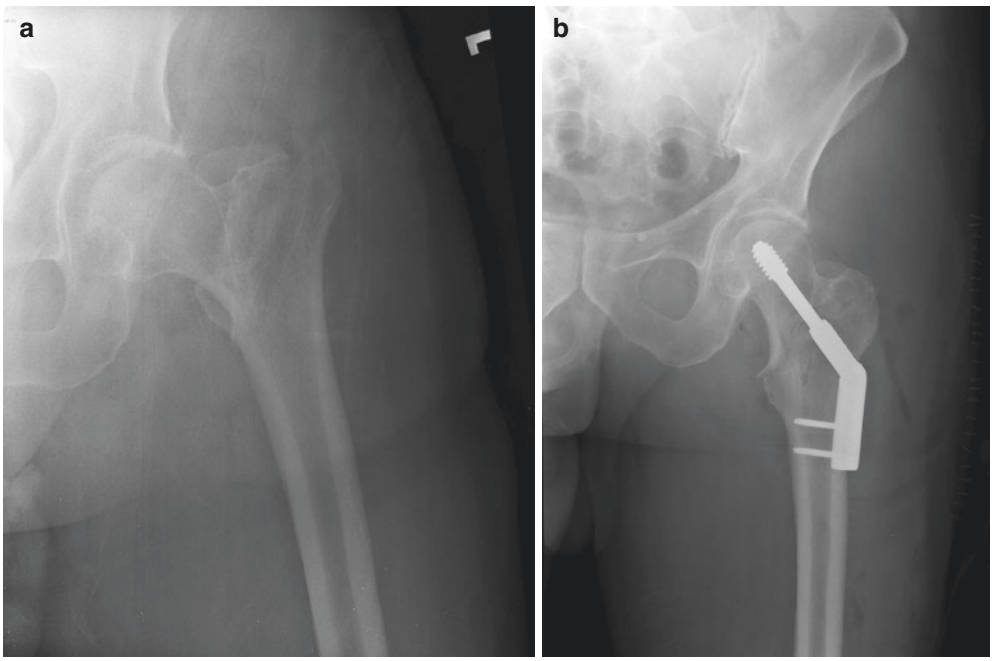

Fig. 30.4 (**a**, **b**): Pre (**a**) and Post (**b**) operative radiograph of a stable intertrochanteric hip fracture fixed with a sliding hip scew

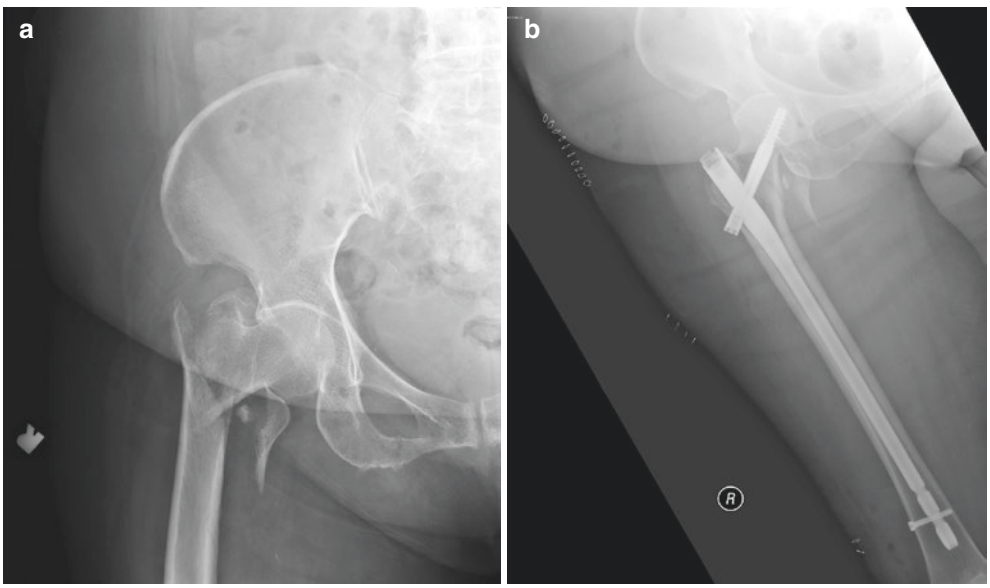

Fig. 30.5 (**a**, **b**): Pre (**a**) and Post (**b**) operative radiograph of a stable intertrochanteric hip fracture fixed with a sliding hip scew

a small incision over the proximal femur, marked with a guide wire under fluoroscopy. The nail is stabilized by an interlocking screw or blade extending into the femoral neck and head [130, 131]. This design provides linear compression across the fracture and the nail itself provides a buttress for the fracture to settle against. Nails vary in length, curvature, and diameter. Care must be taken to select the implant that will optimally reduce and stabilize the patient's fracture [24].

The definition of an unstable intertrochanteric hip fracture is debatable. In a retrospective study [132] of over 4400 patients identified in the NSQIP database, the only differences between patients treated with an intramedullary implant and an extramedullary implant was a lower rate of urinary tract infection (5.5 % vs. 9 %) and shorter postoperative hospital stay (5.4 days vs. 6.5 days) in favor of intramedullary implants. The authors rationalized this by citing the decreased soft tissue dissection in patients who received an intramedullary nail. They concluded that the decreased hospital cost for postoperative length of stay justifies the cost of using an intramedullary implant over a sliding hip screw.

After fixation of both stable and unstable intertrochanteric fractures, patients can begin weight-bearing as tolerated with a walker or crutches [133].

Subtrochanteric Fractures

Subtrochanteric fractures are less common than femoral neck and intertrochanteric fractures, but are a significant surgical challenge. These fractures occur in the proximal femur, distal to the lesser trochanter by up to 5 cm (Fig. 30.6). In elderly patients, the majority of subtrochanteric fractures are due to a simple fall [134, 135]. Due to enormous compressive, tensile, and torsional stresses in the region, deformation of the fracture segments is common. Often the proximal segment is deformed by the action of the hip flexors and abductors. The distal segment is subject to the action of adductors and knee extensors. Furthermore, the region is poorly vascularized, posing another obstacle to successful union [24].

A unique pattern of subtrochanteric fractures associated with bisphosphonate therapy has emerged in recent years. These are short, oblique fractures of the metaphyseal junction showing lateral cortical thickening and a medial cortical spike (Fig. 30.6). Patients can report prodromal symptoms prior to the fracture event. The proposed mechanism behind this is impaired healing of a stress reaction in the subtrochanteric region due to the bisphosphonate-induced inhibition of osteoclasts, which are normally required for fracture remodeling [136]. Patients who have been on bisphosphonate medication for 5 years or more are at increased risk for subtrochanteric or femoral shaft fractures [137]. However, patients taking bisphosphonates have a decreased risk of osteoporotic fractures, such as vertebral or more proximal femur fractures [138]. It is recommended that any patient on bisphosphonates should be evaluated with radiographs for stress fractures. [139].

All subtrochanteric fractures are treated operatively unless a severe co-morbidity precludes this. Operative treatment is typically with intramedullary nail (Fig. 30.7) [134, 140]. The same percutaneous approach for intramedullary nailing is used as was described for intertrochanteric fractures. Reduction is achieved under fluoroscopy or by an open approach and the nail inserted in the prepared canal. Most nailing systems will offer a choice of locking mechanisms, with a cephalomedullary locking device preferred in an unstable, osteoporotic fracture or any fracture without an intact lesser trochanter. A single large lag screw, or two smaller screws directed into the femoral head may offer added protection of the femoral neck in osteoporotic patients [141]. Otherwise, a standard greater trochanter to lesser trochanter oblique trochanteric locking screw can be placed through the nail [142].

Patients are made weight-bearing as tolerated after fixation with an intramedullary nail. Subtrochanteric hip fractures, as

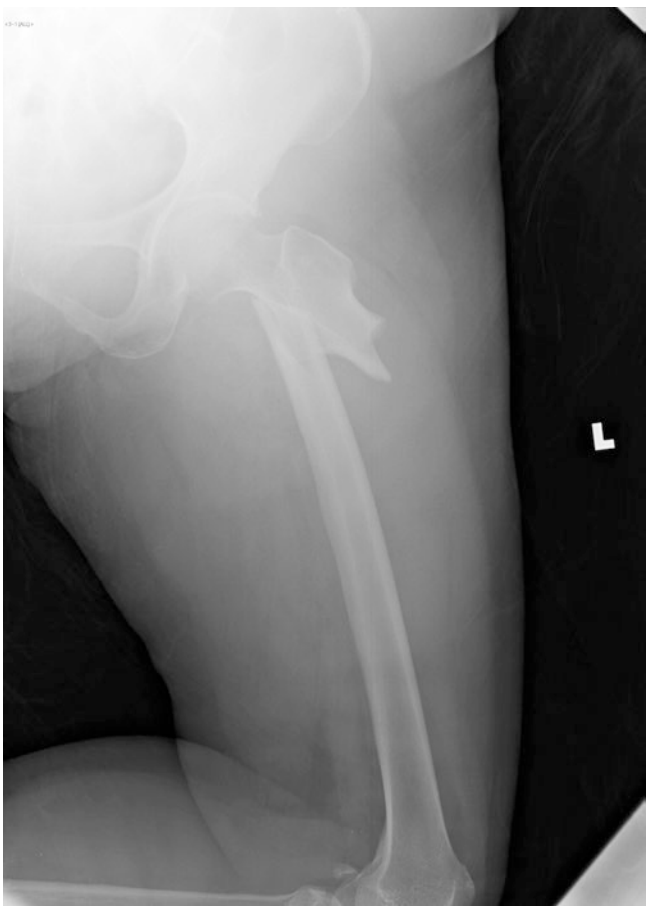

Fig. 30.6 AP femur X ray of a left subtrochanteric hip fracture

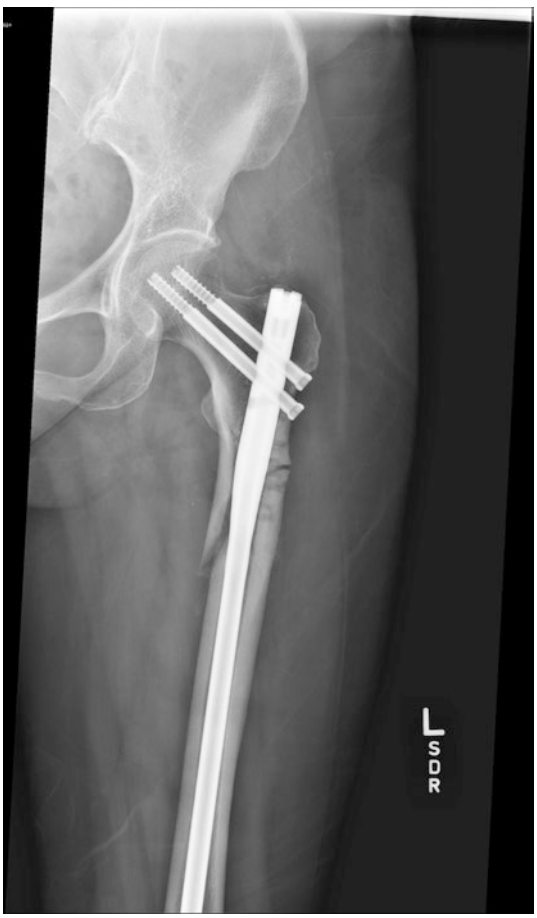

Fig. 30.7 AP femur X ray of an intramedullary nail for treatment of a left subtrochanteric hip fracture

with other fractures around the hip joint, are associated with significant morbidity and mortality. Although they comprise a minority of proximal femoral fractures, these fractures are typically complex to treat and may be associated with an underlying pathologic cause, such as bisphosphonate use [143].

Mortality After Hip Fractures

Unfortunately, mortality after hip fracture is surprisingly high. It is clear that hip fractures are truly a surgical problem as the early mortality is almost double compared to non operative treatment of hip fractures [144]. Richmond et al. [145] reviewed 830 patients with hip fractures and found the highest mortality was within the first 3 months. Younger patients (age <85) also had a higher mortality, as were patients with a higher ASA classification. The in-hospital morality was 3 %. 1-year mortality rates in multiple studies have varied, but estimate a 30 % 1-year mortality. This is higher for cognitively impaired patients (50 %) and lower for cognitively intact patients (12 %) [24].

More than the fracture itself, the broken hip is a marker for declining functional and physiologic status. This is evident because the most common causes of death after hip fracture is not a complication from the broken bone, but circulatory disease, followed by complications of dementia. The risk of mortality in hip fracture patients is three times higher than in the general population [146].

In a recent study of over 4300 patients identified from NSQIP database, 30-day mortality after hip fracture was approximately 6 %. Age greater than 80 years, ASA class, dependent functional status, history of cancer and male gender were predictive of short-term mortality [147].

Return to Functional Status

Return to baseline ambulatory status and living situation is dismal after hip fracture. Sixty-percent of patients lose a level of ambulatory mobility at 1-year, i.e., community ambulators return as household ambulators after hip fracture surgery. Patients who are younger than 85 years, lower ASA or have a lower pre operative ambulatory status (low demand), are more likely to return to their baseline function [148]. Seventy-five percent of independent community ambulators are able to return to their pre-injury living status [58].

Summary

Despite advances in orthopaedic implants, mortality and outcomes after hip fracture are largely unchanged. This is mainly because a broken hip is a marker of overall declining health, not simply a broken bone.

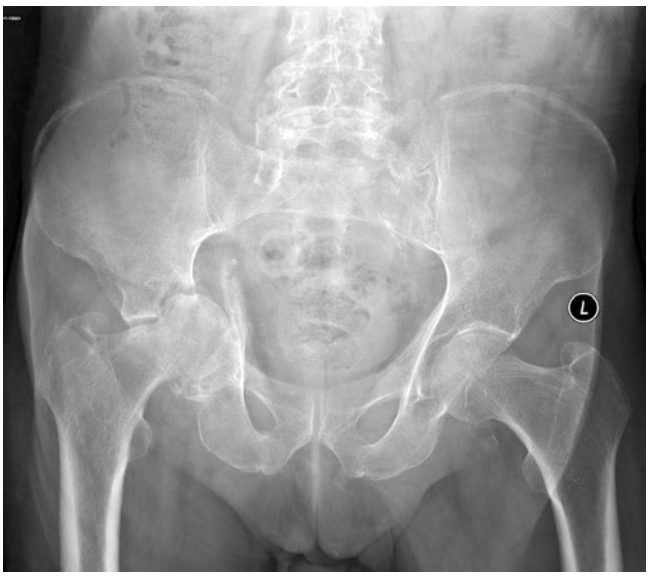

Fig. 30.8 AP pelvis X ray of a displaced right acetabular fracture

Acetabular Fractures [132–143]

Acetabular fracture patterns in the elderly are different and often more complicated than in the younger population (Fig. 30.8). This is because of poor bone quality, which leads to more comminution and femoral head impaction, both of which can impact the ability to accurately repair these fractures [149]. In certain instances, fracture characteristics are predictive of early failure, such as impaction of the superior acetabular dome [150].

Evaluation of these patients in the emergency department should parallel the evaluation of the hip fracture patient. Radiographic studies should include an AP pelvis and Judet (obturator and iliac oblique) radiographs, as well as a CT scan with coronal and sagittal reconstructions. The technology of three-dimensional imaging has improved our understanding of these fractures and can be a useful teaching tool.

The best method of treatment of acetabular fractures in the elderly population is controversial. Patients are living longer [151] and enjoying a more active lifestyle. Clinicians likely agree that elderly patients should be defined by a physiological rather than chronological age. Treatment of acetabular fractures in the elderly population needs to be individualized with consideration of fracture pattern, activity level, and medical comorbidities [152].

Non operative Management

Consensus has been that nonoperative treatment of displaced acetabular fractures in the elderly leads to poor results; however, these reports are substantially flawed by lack of validated functional outcome data, short follow-up duration, and

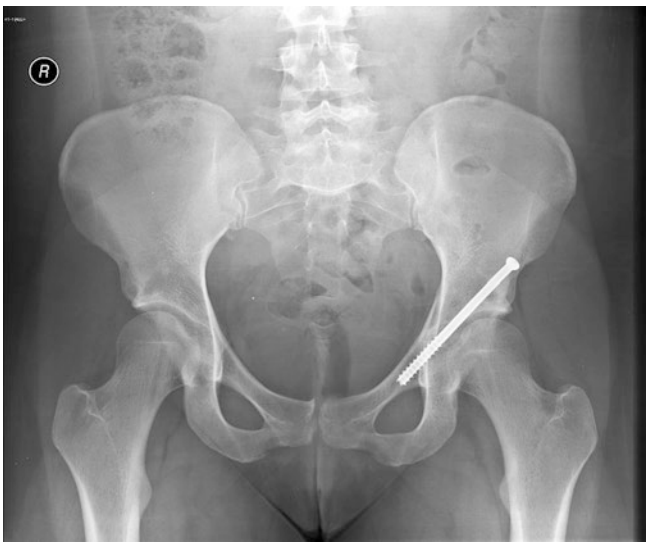

Fig. 30.9 AP pelvis X ray of a percutaneously treated acetabular fracture

use of outdated treatment, such as prolonged traction or external fixation [153–157]. Spencer [156] presented a report of a cohort of 25 patients older than 65 years who were treated nonoperatively. The author had difficulty assessing types of fractures because of inadequate radiographs. The exact outcome measurements could not be determined despite the author's conclusion that 16 patients had satisfactory results and 30 % had unacceptable results. Matta [153] reported similar results in a series of eight patients treated nonoperatively. The overall study population had only 12 patients older than 50 years. Two patients (25 %) were reported to have poor results. The clinical outcome used was a non-validated, modified scoring system originally used to study outcomes of acrylic hip prostheses [153] (Fig. 30.9).

No studies have reported modern functional outcome measures for elderly patients with acetabular fractures treated non operatively. Although these types of studies are lacking, one cannot conclude that results are poor [158, 159].

Comparison of Operative Versus Non Operative Care

Several studies have been presented (but not published) on operative versus non operative care for patients with acetabular fractures. Lucas et al. [159], in a retrospective study, reported that the 1-year mortality was less for the non operative group (15 % vs. 35 %) and the return to baseline living arrangements better in the non operative group. There was no difference in the ability of either group to return to baseline ambulation. Only 40 % of patients in either group were able to return to their baseline ambulatory status.

Ryan et al. presented data suggesting that hip function scores and general health scores are equivalent when comparing operative versus non operative treatment. The results continued to be not statistically significant when controlling for fracture pattern. A flaw of this study was that the conservatively treated patients were significantly older and had more medical comorbidities, which may mean they were lower demand [160].

Percutaneous Fixation

Proponents of percutaneous fixation cite the advantages of decreased blood loss, decreased physiological risk of surgery, decreased risk of infection, and good pain relief for early mobilization [161–163]. Percutaneous reduction of displaced acetabular fractures requires a specialized clamp set and the surgeon must be able to obtain and interpret special radiographic views intraoperatively to safely place the fixation. The goal is not necessarily to obtain anatomic reduction, as it is with open surgery, but to restore the columns of the acetabulum for healing, pain relief and preservation of bone stock.

Total Hip Arthroplasty

Fracture patterns with posterior involvement, dislocation, and either posterior wall or femoral head impaction have a high risk of symptomatic postoperative arthritis [164–166]. These patients may be better served with total hip arthroplasty for treatment of the fracture. Proponents of acute total hip arthroplasty with or without stabilization of the columns argue that benefits include immediate weight bearing [167] and eliminating the need for secondary surgery for symptomatic postoperative arthritis [165, 168].

Initial treatment, whether it is nonoperative, percutaneous, or open reduction internal fixation, may not influence whether conversion to total hip arthroplasty will be needed in the future. It is unclear whether total hip arthroplasty after operative fixation is associated with improved outcomes compared with total hip arthroplasty after nonoperative treatment. Reports comparing this will likely have unequal patient populations, with differences in age, activity level and medical comorbidities leading to their initial treatment decision.

Mortality

The type of treatment does not have an effect on mortality. Gary et al. [169] compared mortality of 454 elderly patients who sustained an acetabular fracture and were treated with open reduction internal fixation, acute total hip arthroplasty, percutaneous fixation, and nonoperative management. After controlling for risk factors, such as medical comorbidities, mortality among the treatment groups was similar.

Summary

There is no consensus on the best treatment for acetabular fractures in the elderly. Complicating this is the fact that there is no clear definition of "elderly". Most studies define elderly patients over the age of 60. Fractures with posterior instability should be fixed with open reduction and internal fixation with or without total hip arthroplasty. Fractures with medial displacement may be amenable to nonoperative management.

Periprosthetic Fractures

With the increasing number of total hip and total knee replacements being performed, the incidence of periprosthetic fractures is increasing [170]. These fractures are difficult to manage secondary to poor bone quality and the presence of a prosthesis already in the bone, which may or may not be well-fixed.

Pre-operative workup should mirror that done for a hip fracture patient previously described. It is important to obtain operative notes from the replacement surgery in order to plan for any revision of the components if necessary.

Imaging should include radiographs of the entire extremity, being sure to include the prosthesis. If possible, it is important to compare previous radiographs of the extremity before injury to see if there are any subtle changes in the prosthesis, which would indicate loosening of the implant.

The principles of management are based on whether the prosthesis is stable or loose. Sometimes it is not possible to know whether a prosthesis is loose until testing it in the operating room, so one should be prepared to both fix the fracture and revise the prosthesis if necessary.

Fractures Around a Total Hip Replacement

The most useful classification is the Vancouver classification, which is both reliable and valid [171]. Fractures around the greater or lesser trochanters (Vancouver A), are typically minimally or non-displaced and can be managed non-operatively [24]. If the fracture affects the stability of the prosthesis, fixation of the fracture or revision of the prosthesis is required.

Fracture at or around the shaft of the prosthesis is classified as a Vancouver Type B. Fractures can either involve a stable prosthesis (Fig. 30.10) or an unstable prosthesis. Fractures with well-fixed prostheses can undergo primary bone fixation with retention of the prosthesis (Fig. 30.11), while those that have loose prosthesis require revision.

There is limited data on comparisons of techniques, but general principles include using implants with sufficient length and stability and preserving the biology of the fracture if possible [170]. There are multiple options for fixation of these types of fractures, which include plate and screw fixation [172], cable plates [173], with or without allograft struts for support [174].

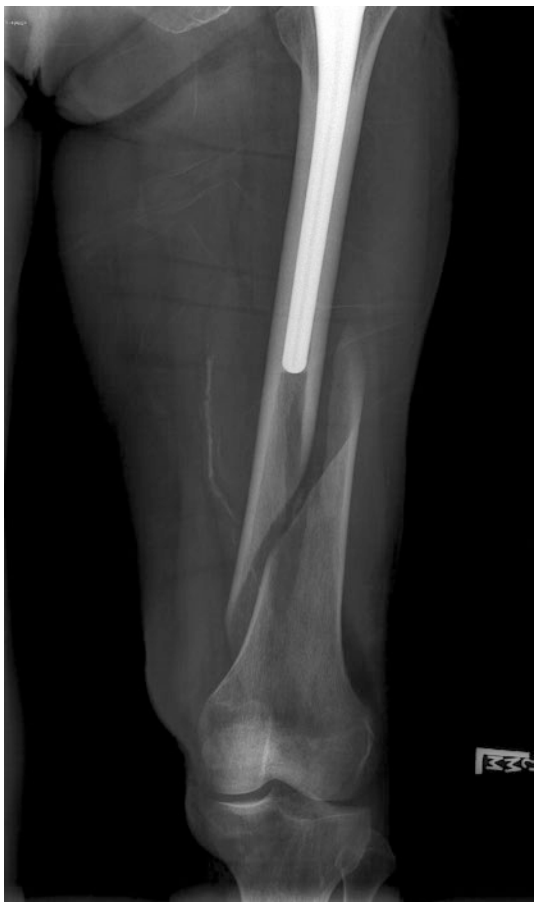

Fig. 30.10 AP femur X ray of a fracture around a hip prosthesis with a stable implant

Post operative care should involve immediate mobilization. Unfortunately, restricted weight-bearing is usually necessary given the poor bone quality and limited fixation around a prosthesis.

Union rates have been reported as high as 85–100 % [175, 176]. Ricci reported 75 % of patients returned to baseline functional status [174]. Mortality after periprosthetic fracture has not been extensively studied as in the hip fracture population, but the 1-year mortality has been reported at 11 % [177].

Fractures that are distal to the prosthesis are classified as a Vancouver Type C. Without the hip prosthesis, these fractures are typically treated with an intramedullary nail. With the prosthesis in place, this is not an ideal construct as it leaves a stress riser between the nail and the prosthesis. Thus, the treatment should be with a laterally based plate that spans the hip prosthesis proximally (Fig. 30.11).

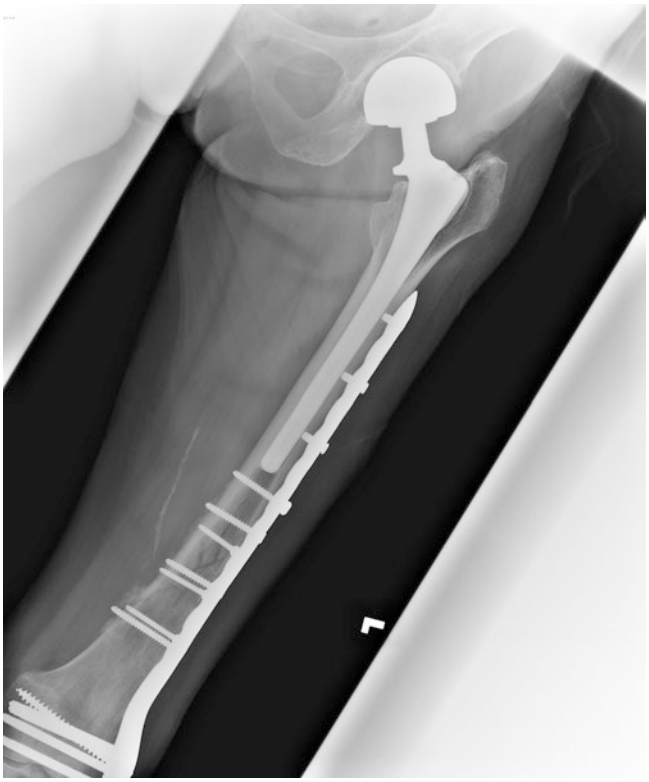

Fig. 30.11 AP femur X ray of fixation of a periprosthetic fracture

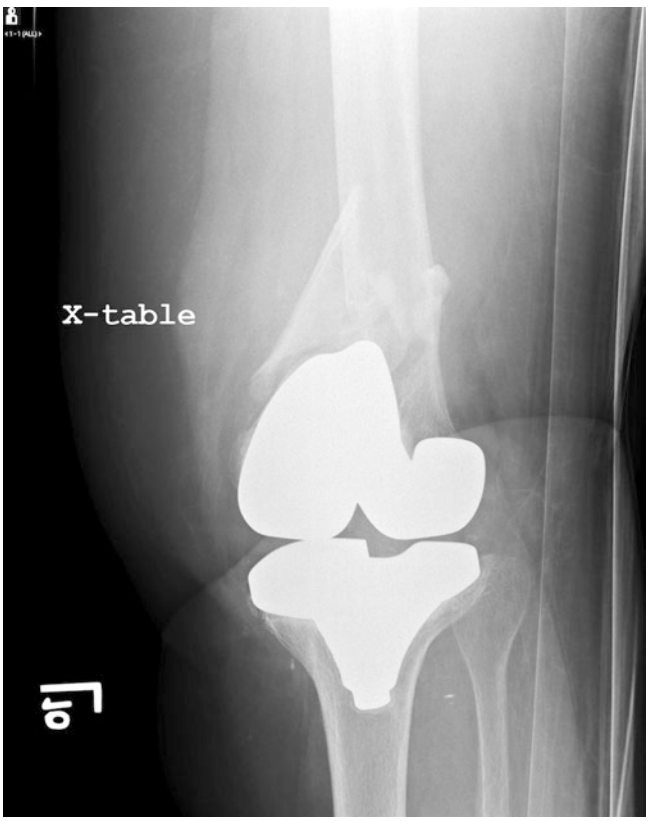

Fig. 30.12 AP knee X ray of a periprosthetic femur fracture above a knee replacement

Fractures Around a Total Knee Replacement

Fractures around a total knee replacement happen twice as frequently around the femoral prosthesis than the tibial or patellar. Risk factors for fracture include osteopenia, osteolysis (wear of the prosthesis) and technical errors such as notching of the anterior femur [24]. Treatment of supracondylar femur fractures around a total knee prosthesis is also based on whether the component is stable or unstable (Fig. 30.12).

The goals of treatment include restoration of alignment and early return to function Non-displaced, stable supracondylar femur fractures can be managed non operatively in low-demand patients [178]. Operative fixation gives the advantages of immediate range of motion, earlier weight bearing and less risk of late displacement. All displaced distal femur fractures are indicated for surgical stabilization.

Displaced fractures can be treated with either lateral locked plating (Fig. 30.13) or intramedullary nailing. Results were similar in a comparison of a small group of patients [179].

Intramedullary nailing of these fractures is challenging. Meticulous pre operative planning is necessary, as the surgeon must be familiar with the type and dimensions of the implant to ensure that the nail will pass [180]. There must

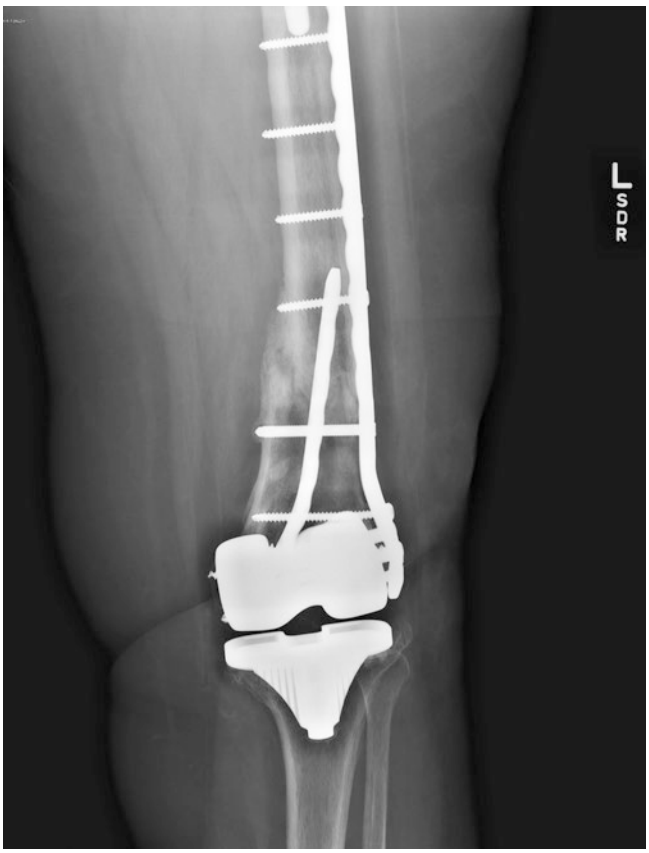

Fig. 30.13 AP knee X ray of fixation with lateral plating of a periprosthetic femur fracture

also be enough bone stock in the distal segment in order to support the interlocking screws. In addition, placement of additional fixation (i.e. blocking screws) may be necessary in order to achieve and maintain alignment [24].

Lateral locked plating has also been reported to successfully treat these fractures [181]. Because of osteoporotic bone, supplemental fixation may be necessary to help avoid varus collapse (Fig. 30.13). Unfortunately, supracondylar femur fractures have a high re-operation rate due to delayed or non-union of the fracture [182]. In a large study of 335 patients, 20 % required secondary surgery to promote union. Diabetes, open fracture, smoking, increased BMI >30 kg/m^2, and shorter plate length were predictors of reoperation for union and other complications.

If the implant is loose, revision total knee surgery is required. This surgery is technically challenging, and is often best accomplished by an experienced arthroplasty surgeon. Revision involves not only fixing the fracture, but ensuring stability and alignment to the knee [178].

Upper Extremity Fractures

Although upper extremity fractures in the elderly are not typically life-threatening, the resultant impairment may be so functionally debilitating that the injured patient can no longer manage independently. The majority of such upper extremity fractures may be treated non-operatively. However, the physician must be aware of the potential consequences of prolonged immobilization on the entire limb. Locking plate technology is particularly suitable for providing stable fixation in poor bone, permitting early mobilization and functional recovery.

Distal Radius Fractures

Distal radius fractures in the elderly are quite common. The incidence rate increases with age, and is highest in patients 80 years and older. These typically occur as isolated, low energy injuries resulting from a fall onto the outstretched hand. However, a neurovascular examination is essential, focusing on the median nerve. Preexisting carpal tunnel syndrome may be exacerbated by the energy of injury and/or the displacement of the distal radius. Concomitant progressive or severe median nerve dysfunction is an indication for urgent carpal tunnel release; in such instances, the fracture is usually stabilized with plate fixation.

The method of treatment of displaced distal radius fractures in the elderly population remains controversial. While restoration of anatomy is a goal of treatment in the younger patient, the relevance of such an approach in the elderly is unclear. A prospective, randomized study [183] comparing closed reduction and cast treatment with open reduction and internal fixation using a volar locking plate demonstrated better grip strength in the operatively treated group; however, there was no difference in wrist motion, pain, or function at 1 year between the two groups. Although 78 % of non-operatively treated patients had a visible deformity (prominent ulnar head), none of them was dissatisfied with the clinical appearance or the result. The complication rate in the surgical group was 36 %, including tendon ruptures. Similar results have been reported retrospectively in an analogous patient population [184]. A systematic review concluded that, in spite of worse radiographic results with cast treatment, functional outcomes are equivalent to surgical repair of distal radius fractures in patients older than 60 years of age [185].

Interestingly, the patients treated surgically reported better function during the first 3 months following injury. This is not surprising, since non-operatively treated distal radius fractures are casted for approximately 6 weeks, whereas patients may be placed into a removable splint soon after plate fixation. This highlights the importance of patient factors in the decision-making process. Older patients who are living alone may be able to retain their independence if treated surgically.

When the decision is made to operate, a number of options are available for fixation. As a rule, percutaneous pin fixation is unreliable when the bone quality is poor. Volar locking plates, in which the screws thread into the plate itself, are ideal for managing osteoporotic fractures [186]. Equivalent results may be obtained with external fixation. Surgeon experience is a principal determinant in the type of implant selected.

Distal Humeral Fractures

One of the most challenging fractures to treat are articular fractures of the distal humerus, particularly in the setting of osteoporosis. With rare exception, these fractures require surgery. A 1984 study demonstrated good-to-excellent results in 76 % of operatively treated fractures compared with 9 % for those treated non-operatively [187]. These injuries require anatomic reduction and stable fixation in order to allow for early motion, as prolonged casting (>14 days) results in permanent stiffness. The advent of locked, pre-contoured plates has simplified the surgery to some extent. For the elderly, low demand patient, primary total elbow arthroplasty may be a better alternative.

The initial evaluation should include an assessment of associated soft tissue injuries, such as an open fracture, and neurovascular status, with particular attention to the ulnar nerve which rests in close proximity to the elbow joint.

Ipsilateral orthopaedic injuries, such as fractures of the distal radius, are not uncommon; the entire limb should be examined and radiographed if necessary. History should include specific inquiry as to the pre-injury status of the elbow, since pre-existing arthritis may influence the decision-making process. Radiographic evaluation must include AP, lateral, and oblique views of the elbow; these may be difficult to interpret because of fracture displacement and patient positioning. On occasion, traction views performed in the emergency department may provide additional detail regarding the complexity of the fracture. Virtually all patients with distal humeral fractures will require a non-contrast CT scan of the affected elbow as an element of preoperative planning. In the absence of an open fracture, these injuries are managed semi-electively in order to ensure that appropriate equipment is available.

Surgical repair of distal humeral fractures involves multiple steps; on many occasions, exposure includes ulnar nerve transposition and olecranon osteotomy for exposure. Surgery is performed under tourniquet control to limit blood loss and enhance visualization. Typical fixation includes a minimum of two plates in order to maximize stability and permit early motion. Locking plates have decreased the likelihood of failure of fixation. Nevertheless, complications are not uncommon, and include ulnar nerve injury, stiffness, heterotopic ossification, and infection. Pain relief is fairly predictable, with one study reporting 83 % of patients having no or mild pain [188].

In the 1990s, dissatisfaction with the results of surgical repair of distal humeral fractures in the elderly using non-locking plates led Morrey to manage some of these injuries in a way analogous to femoral neck fractures –total elbow arthroplasty [189]. A more recent review of these patients at the Mayo Clinic showed an average range of motion of 24–132° and a high degree of patient satisfaction. The reoperation rate was 12 % [190]. Two distal humeral fracture studies comparing repair and total elbow arthroplasty in patients older than 65 years of age have come to similar conclusions [191, 192]. Elbow arthroplasty was associated with shorter surgical times, better elbow scores, less disability (as measured by DASH scores) than open reduction internal fixation. Range of motion was at least equivalent. However, given concerns about wear, the typical postoperative restrictions include lifting no more than 10 pounds as a single lift or 2 pounds repetitively with the affected arm. Consequently, total elbow arthroplasty is reserved for low demand, elderly patients with pre-existing arthritis or with comminuted low articular fractures with limited bone for fixation.

Proximal Humerus Fractures

In the elderly population, fractures of the proximal humerus typically are the result of a fall from standing height. These fractures are about half as common as hip fractures in this population, accounting for 10 % of fractures in people >65 years of age. Associated injuries, such as head trauma and rib fractures, should be excluded. Displaced proximal humerus fractures may be associated with neurovascular injury, including subclavian artery and brachial plexus injuries. If pulses are diminished, Doppler studies should be performed, and the blood pressure recording should be compared with the other arm. If the pulses remain altered following gentle realignment of the limb, an urgent vascular consult must be obtained. The neurologic status of the extremity may be difficult to assess due to pain; the examiner should check for altered sensation in the deltoid area to assess for axillary nerve dysfunction. Other relatively painless maneuvers include assessment of sensation in the median (index finger), radial (first web space), and ulnar (little finger) distributions and motor function, including elbow flexion (musculocutaneous), wrist and digital extension (radial), thumb flexion (anterior interosseous branch of median nerve), and ability to cross-fingers (ulnar).

Radiographs must include a shoulder trauma series, which consists of an AP of the shoulder, a lateral "Y" view, and a supine axillary view. The latter view may be difficult to obtain because of patient discomfort, but orthogonal views are necessary to exclude a dislocation. An alternative view, termed a Valpeau lateral, may be obtained with the patient sitting comfortably in a sling.

The Neer classification [193] is commonly used as a guide for treatment. The proximal humerus is considered as four components: the head, the greater tuberosity, the lesser tuberosity, and the shaft. To be considered a part, the component must be displaced more than 1 cm or rotated more than 45° [193]. Between 45 and 80 % of proximal humerus fractures are non-displaced, and may be managed in a simple sling. For non-displaced two-part distal humerus fractures, early mobilization appears to result in less pain and faster and potentially better recovery than 3 weeks of immobilization [194]. Nevertheless, at least 40 % of these elderly patients will require pain control and basic care [195].

For displaced fractures, fracture factors and patient factors are critically important in deciding whether to operate. A prospective study [196] of internal fixation versus nonoperative treatment for 3-part proximal humerus fractures in the elderly demonstrated slightly improved motion and function (although most parameter did not reach statistical significance). However, 30 % of the surgically-treated patients required additional surgery. Fracture comminution and poor bone quality make fixation somewhat tenuous in spite of locking plate technology. Disruption of the blood supply to the humeral head is common with four-part frac-

tures; this poses a relative indication for primary hemiarthroplasty in the elderly patient [196]. However, the data is not compelling enough to convincingly argue for surgery in patients with significant medical co-morbidities. In fact, a prospective, randomized study showed no demonstrable benefit of hemiarthroplasty over nonoperative treatment in patients older than 65 years of age [197].

A principal difficulty with hemiarthroplasty is stable fixation of the tuberosity fragments, to which are attached the rotator cuff muscles that are essential for shoulder motion. Reverse total shoulder arthroplasty (RSA) was developed as a way to substitute for irreparable, severe rotator cuff deficiencies in the elderly. The device is "reverse" in that the spherical component is secured to the glenoid and the socket is attached to the proximal humerus. In doing so, the implant resists proximal migration of the humerus when the deltoid fires. Recently, this technology has been adopted to the management of difficult proximal humerus fractures in the elderly. A prospective, randomized study comparing hemiarthroplasty and RSA have demonstrated less pain, better motion, and fewer complications in the RSA group [198]. Late conversion of a hemiarthroplasty to an RSA does not improve outcomes.

Conclusion

Caring for elderly patients with osteoporotic fractures is challenging and requires a multidisciplinary approach. Treatment of hip fractures is typically a surgical problem, while the optimal treatment of displaced acetabular fractures is still unknown. Periprosthetic fractures around hip or knee replacements often require unconventional surgical techniques. Surgical management of these fractures often decreases morbidity and mortality compared to non operative management, even faced with multiple medical comorbidities. Upper extremity fractures can often be treated without surgery. However, seemingly minor fractures may seriously affect the functional status of the elderly patient. Although not always possible, the goal is the return the patient to their baseline functional status, living situation and decrease pain.

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Penetrating Injury in the Elderly

31

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and Demetrios Demetriades

Introduction

Although penetrating injuries in the elderly are rare, they account for a significant number of deaths in this age group. Due to the reduced physiologic reserve and presence of comorbid conditions, the prognosis of elderly patients is worse than for their younger counterparts. The management of trauma in the elderly can present specific triage, diagnostic, and management challenges. For these reasons, it is important to appropriately triage elderly trauma patients and ensure rapid and aggressive evaluation, monitoring, and treatment.

Epidemiology

The leading causes of death in patients 65 years of age and older in the USA remain heart disease, neoplasm, respiratory disease, and cerebrovascular incidents. As of 2013, the CDC reported unintentional injury as the eighth most common cause of death in this population. This is in contrast to unintentional injury being the clear leading cause of death from ages one to 44 (National Vital Statistics system, CDC, 2013). Similar to other age groups, trauma in the elderly is primarily due to blunt mechanism.

In a 5-year National Trauma Databank study looking at gunshot wounds in the elderly, out of a total of 98,242 gunshot injuries, only 3190 (0.7 %) occurred in patients age 55 and older (Fig. 31.1) [1]. Although the rate of assault decreased with increasing age, the percentage of injuries caused by self-inflicted wounds increased with advancing age from 29.2 % in age 55–64 years to 56.4 % in patients 75 and older ($p < 0.001$, Table 31.1), underscoring the significant problem of suicide risk in the elderly. These data are supported by an earlier epidemiologic study of trauma deaths in Los Angeles County in which patients over age 65, especially Caucasian males, have a significantly higher incidence of suicide by penetrating mechanism than their younger counterparts [2].

Special Considerations: Physiologic and Pharmacologic Changes

A direct relationship of increasing age and mortality is seen with gunshot injury in the elderly (Fig. 31.2) [1]. In addition, elderly patients with penetrating trauma present with higher rates of comorbidities and have been found to have longer hospital and ICU length of stay [1, 3, 4]. Significant physiologic changes occur with aging, which may affect the clinical presentation, hospital course, and outcomes of elderly trauma patients.

In a comparison study between younger (age 15–40) and older (age 65 and older) penetrating trauma patients, the older patients were found to have significantly more comorbidities on admission, primarily cardiac and endocrine

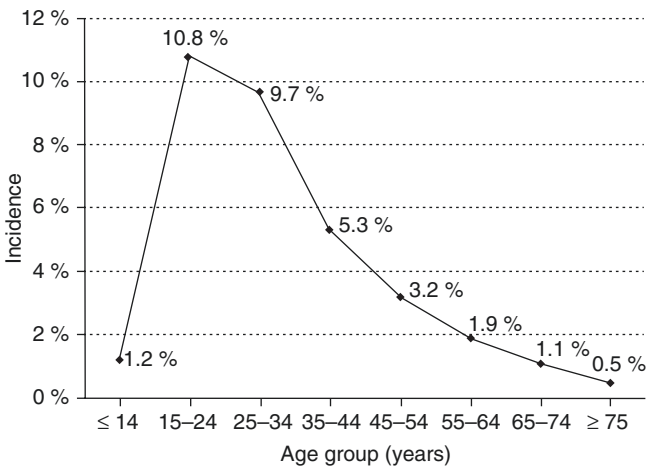

Fig. 31.1 Incidence of gunshot wounds stratified by age groups in 98,242 hospital admissions with gunshot injuries (Reference Lustenberger et al. [1])

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Table 31.1 Intent of gunshot injury in the elderly

Intent of injury	55–64 years *N* = 1676	65–74 years *N* = 727	>75 years *N* = 787	*p*-value
Assault	804 (48.0 %)	232 (31.9 %)	225 (28.6 %)	<0.001
Self-inflicted	489 (29.7 %)	336 (46.2 %)	444 (56.4 %)	<0.001

(Reference Lustenberger et al. [1])

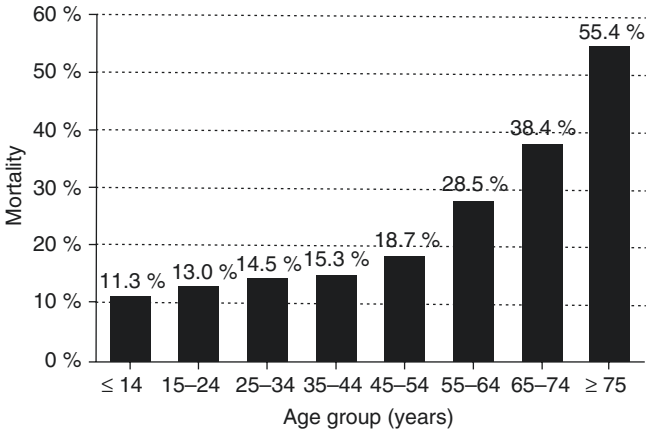

Fig. 31.2 Mortality rate after gunshot injury, stratified by age (Reference Lustenberger et al. [1])

comorbidities including hypertension, coronary artery disease, and diabetes [3]. These comorbidities result in a diminished ability to compensate for acute blood loss and increased risk of peri-traumatic cardiac events. In the respiratory system, increased dead space and decreased compliance are often associated with increased age as is a reduction in kidney mass and glomerular filtration rate. For these reasons, early aggressive invasive monitoring and treatment of elderly patients has been shown to improve outcomes [5].

In addition to the physiologic changes noted in the elderly population, pharmacologic differences can influence outcome. In a 2005 report, 48.5 % of adults in the USA age 65 and older reported taking aspirin (Agency for Healthcare Research and Quality). Aspirin, clopidogrel, warfarin, and the newer Xa inhibitors and antithrombin agents are becoming increasingly common in the aging population and have significant effect on trauma outcomes. These medications are often unknown at the time of presentation and can complicate management in the bleeding trauma patient and lead to increased mortality [6]. Elderly patients on these medications require urgent reversal and aggressive monitoring with liberal use of imaging, angioembolization, and operative intervention.

Cardiac medications are also common in the elderly population including medications that block the response to endogenous catecholamines after trauma. These medications may dampen the physiologic response to bleeding resulting in earlier hypotension and shock. Further exacerbating this response is the common use of diuretics resulting in an earlier state of dehydration and sensitivity to acute blood loss.

Triage of the Elderly Trauma Patient

Clear guidelines have been established to allow for prehospital identification of the most injured patients and effectively triage these patients to trauma centers with a graded level of activation based on the suspected level of injury. Patients with the highest level activation receive priority for triage, imaging, intervention, and overall care. Given the known diminished physiologic reserve and effect of cormorbid conditions and medications on outcome in the elderly population, there is concern that level of injury is underestimated using standard parameters applicable for a younger population.

Of particular concern is the use of vital sign criteria for activation as the baseline physiology and potential alterations due to medications in the elderly patient may be misleading. This can potentially result in significant undertriage in this population. In a study of 883 patients >70 years meeting trauma center criteria at Los Angeles County Medical Center, only 25 % of patients met criteria for the highest level of activation. In those that did not meet hemodynamic criteria for highest level activation, 63 % had an ISS >15, and 25 % had an ISS >30 signifying a significant rate of undertriage. In this group, 24 % required ICU admission, 19 % required a non-orthopedic operation, and mortality was 16 % [7]. These findings support the concern for high mortality in this population and underscore the importance of modified hemodynamic criteria in the elderly population. As a result of this study, the activation criteria were altered to include age >70 as an automatic activation of the highest level trauma. This change resulted in improved overall mortality as well as improved mortality in patients with higher ISS [5].

The vital sign criteria suggestive of increased mortality risk differ in the geriatric population. In the young trauma patient, SBP less than 90 mmHg and heart rate greater than 120–130 are considered physiologic indicators of shock or near shock state. These findings were supported in a young population (age 17–35) in a study out of Rhode Island, with an increased mortality noted at SBP less than 95 mmHg and heart rate greater than 130 [8]. These results differ significantly in the elderly population (age 65 and older), with a mortality increase identified at SBP less than

110 mmHg and significant mortality increases with even mild tachycardia. With the recognition that an SBP of less than 110 in the elderly may represent shock, Brown et al. used the National Trauma Data Bank to determine that increasing the SBP criterion from less than 90 mmHg to less than 110 mmHg in the elderly resulted improved rates of undertriage [9]. These results further validate the need for early and aggressive triage and monitoring of the elderly trauma patient.

The geriatric trauma patients can be identified as an "at-risk population," with increased risk of complications and mortality after trauma. For this reason, several prediction models including the shock index, frailty index, and the vulnerable elders-13 survey, have been established to identify which patients may be at increased risk and potentially benefit from additional resources [10–12]. These scores are important as we increase prehospital awareness of the elderly as a vulnerable population and triage elderly patients to trauma centers and have more liberal criteria to initiate highest level activation; there is a resultant increase in overtriage and resource utilization. Identifying which patients are at highest risk after evaluation could help direct resources appropriately within the hospital system. Improved outcomes have been reported when geriatric patients are triaged to trauma centers [13] and treated at centers with a higher proportion of older patients [14, 15]. Further, involvement of specialty geriatric care through a system of routine geriatric consultation was shown to improve functional recovery and potentially improved quality of care [16, 17].

Initial Evaluation and Management

Geriatric patients represent a specific subset of the population and have an increased risk of mortality after trauma. The initial evaluation and management of these patients, therefore, should take into account this increased risk.

In the emergency department, a detailed history should be obtained including close attention to comorbid conditions and medications, specifically anticoagulants, cardiac and blood pressure medications. Baseline hypertension can result in relative hypoperfusion with "normal" blood pressure readings in the trauma bay. Cardiac medications may inhibit normal physiologic response to catecholamines, and significant blood loss may be present despite a lack of tachycardia. Minor bleeding may be prolonged due to anticoagulants or lack of vasoconstriction in atherosclerotic vessels. Early and aggressive monitoring is important to screen for these potential complications. Anticoagulation reversal is imperative with platelets, plasma, or prothrombin complex concentrate as appropriate, followed by continued monitoring and intervention as needed. Early resuscitation is essential as baseline cardiac and respiratory function may not tolerate rapid alterations in fluid status or large volume resuscitation. Early attention to airway needs is essential with consideration for early intubation. Any transport needs should be accompanied by full support with resuscitation, medications, and potentially blood products as needed due to the high risk of rapid decompensation.

Imaging has become an essential part of the trauma workup; however, when necessary in the elderly population, attention to renal function and hydration status is key. Early attention to prevention and treatment of hypothermia, the liberal use of angioembolization, and appropriate and timely operative intervention are essential for acceptable outcomes. Although penetrating trauma in the elderly is rare, special attention to psychiatric evaluation in the setting of potential suicide attempt is an important consideration in this population.

Conclusions

Penetrating injury in the elderly is rare but accounts for a significant number of deaths including self-inflicted injury. Elderly patients have limited physiologic reserve and increased rates of comorbid conditions. The initial clinical examination may be misleading and elderly patients are noted to have higher mortality after trauma. For these reasons, age-based criteria and age-adjusted parameters have been discussed to better triage this patient population and encourage early aggressive management algorithms. Early monitoring, imaging, consultation, and intervention with liberal use of intensive care unit admission should be practiced in this population.

Summative Points

- Penetrating injury in the elderly is rare and is more commonly associated with self-inflicted injury.
- Geriatric patients have higher mortality after trauma than their younger counterparts.
- Physiologic changes associated with aging contribute to the diminished physiologic reserve of the geriatric trauma patient.
- Comorbid conditions and associated medications including cardiac and anticoagulant medications can contribute to increased difficulty in evaluation and treatment of the elderly trauma patient.
- Vital sign parameters for severe are different in the geriatric population with hypotension occurring at a higher systolic blood pressure and difficulties interpreting variations in heart rate.
- Geriatric patients require early aggressive triage, evaluation, and treatment after even minor trauma.

Case Vignette

Case: An 85-year-old male is brought in by ambulance after a single gunshot wound to the right upper abdomen. On presentation, he is protecting his airway, breathing spontaneously, and unlabored, and the initial vital signs include BP 105/40, HR 78, O2 Sat 95 %. He is moving all four extremities, is confused, and has a single bullet wound to the right anterior abdomen, just above the costal margin. His cardiac and abdominal FAST views are negative, no lung sliding on the right eFAST.

Commentary: Although vital signs on admission are "normal," several things about this patient's presentation in the context of his age should be concerning to the treating physician. First, the blood pressure for this age group is low. Although this could be his norm, this reading should raise suspicion for either relative hypotension in a normally hypertensive patient or the presence of antihypertensive medication. The former could result in poor cerebral, renal, or coronary blood flow leading to confusion, relative insufficient flow to the kidneys increasing the risk of renal failure, and increased strain on the heart. The presence of medications could alter his normal physiologic response to trauma or potential hypovolemia. For example, progressive hypovolemic shock may initially present with tachycardia, in this patient blocked by beta-blocker medication. This will deprive the provider of this early sign of decompensation and potentially leave the patient under-resuscitated.

The first decision in this patient is where does he need to be next – CT scanner, ICU, interventional radiology, or the operating room. The tract of the bullet will be integral to this decision process. If the patient decompensates and requires urgent operation, the first decision will be incision placement.

Case: CXR shows a retained bullet at the level of the right costal margin and a moderate right hemothorax. A chest tube is placed with return of 500 cc dark blood. One unit of PRBC is given to the patient in addition to autotransfusion from the chest tube. His repeat vital signs are blood pressure 115/65, heart rate 82, O2 Sat 88 % on FM. His family arrives and provides a bag of medication including ASA, warfarin, and *beta-blocker.*

Commentary: Several priorities exist at this point and rapid, aggressive management is imperative. First, the patient requires urgent reversal of anticoagulation. There is known bleeding in the chest with a potential additional source in the abdomen. Platelet transfusion is needed for ASA reversal. Warfarin may be reversed with either prothrombin complex concentrate (PCC) or plasma infusion. Given the urgent need for reversal in combination with advanced age, PCC is an ideal choice for warfarin reversal. PCC is a low volume, highly concentrated, rapidly infused medication that immediately reverses the anticoagulant effects of warfarin. Advantages over plasma include immediate availability without need for thawing and low volume infusion decreasing the risk of resultant volume overload. Second, this patient requires urgent intubation. The presence of respiratory decline with a need for ongoing resuscitation and likely transport are all risk factors for rapid decompensation. Early and aggressive airway management is necessary. Finally, depending on his stability, the patient will need further imaging and/or operative intervention to determine the tract of the bullet and proceed with definitive management.

Case: The patient's vital signs remain unchanged, repeat FAST is negative, and the patient is transported to the CT scanner where a clear trajectory is noted through the lower lobe of the right lung and through the liver. There is no hemoperitoneum; however active extravasation of contrast is noted within the liver parenchyma.

Commentary: At this point, the patient is taken urgently to interventional radiology for angioembolization. He has been resuscitated with blood, including autotransfusion, minimal crystalloid, and reversed with a low volume concentrate. He was intubated for airway protection with the decreasing O2 saturations; however, the controlled resuscitation prevented him from progressing to acute lung injury or volume overload.

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The Elderly Burn Patient

32

Tina L. Palmieri

Case Vignettes

1. A 75-year-old woman with a long history of chronic obstructive pulmonary disease sustains burn injury to her face when her nasal cannulae for her home oxygen ignite when she is lighting a cigarette. What is the optimal airway management?
2. An 80-year-old man's pants ignite when he is burning leaves in his backyard. He sustains 59 % circumferential burns to his legs and anterior torso. How should you proceed?
3. A 92-year-old diabetic male sustains 2 % burns to his feet when immersing them in water. What are the effects of this comorbidity on his outcome?

Bullet Point Summary

Burn and fire-related injury are a leading cause of death in the elderly.

Skin changes due to aging increase the likelihood and depth of injury and impair wound healing.

Burn resuscitation in the elderly must be individualized based on patient physiology and an understanding of advance directives and goals of care.

The optimal timing and extent of surgical intervention in the burned elderly has not been defined.

Prevention of burn injury in the elderly is essential.

Introduction

Burns and fire-related injuries remain a leading cause of death among the elderly [10]. The mortality rate for burn injury has markedly declined in the past 20 years, particularly in young adults and children [12, 35]. Likewise, mortality in the elderly has decreased since 2001 [34, 40]. Yet the overall mortality of the elderly after burn injury remains markedly higher than in either children or young adults [40]. The higher burn mortality in the elderly may be attributable to many factors, ranging from comorbidities to the effects of aging on wound healing. A working knowledge of the treatment of burn injury in the elderly is important, as the number and proportion of the elderly is increasing rapidly: it is estimated that the 40.3 million people aged 60 or over in 2010 will increase to 88.5 million by 2050 [44]. The purpose of this chapter is to discuss the epidemiology, pathophysiology, treatment, and outcomes of the elderly burn patient.

Epidemiology

The epidemiology of burn injury in the elderly (defined as ≥65 years of age) has been described both in the USA and internationally. Overall, the elderly constitute approximately 9–10 % of burn injuries documented in national registries [5, 40]. The majority of burn injuries in the elderly occur at home, particularly in the kitchen and bathroom [25, 26, 36]. It is not surprising, given their decreased mobility, that the elderly are more frequently burned within the home in locations where the majority of the activities of daily living occur. The predominant etiology of elderly burns is due to flame (32 %) or scalding liquid (16 %) burns. Contact burns, electrical burns, and chemical burns occur less frequently (<2 % for each type) [5] Although somewhat variable between studies, there is a larger proportion of elderly women sustaining burns compared to adults or children, and women tend to sustain more scald

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and contact injuries than men [2, 4]. Flame burn injury tends to have a higher mortality, likely due to the extent and depth of a flame burn [11, 43].

Outcome predictors for elders with burn injury share characteristics with their younger counterparts, but additional factors also come into play in the elderly. Age, inhalation injury, and burn size (regardless of age) are independent predictors of burn mortality [26, 40, 45]. Total body surface area (TBSA) burn size, in particular, has a greater effect on outcomes in the elderly. The impact of burn injury increases mortality in the elderly with each decade of age. Comorbidities, such as dementia, cardiorespiratory disease, smoking, and alcoholism increase the incidence and severity of burn injury on the elderly [4, 10, 17–19].

Changes in skin associated with aging may also play a role in elderly burns. Intrinsic aging (ubiquitous changes due to the aging process) and extrinsic aging (caused by exposure to light, chemicals, or environmental factors) both impact wound healing [14, 31]. As part of the aging process, the skin undergoes both epidermal and dermal changes. Epidermal changes include changes in melanocytes (15 % decline per decade, increased density on sun-exposed skin, and increased lentigines) and Langerhans cells (reduced density and responsiveness). Although the epithelium thins with aging, the epidermis thickens from exposure to the environment, and the epidermal-dermal junction flattens. Changes in the rete pegs decrease shear strength of the epidermis. Dermal changes include decreased collagen (1 % annual decline), dermal atrophy, loss of dermal appendages, loss of elasticity, decreased glands (dry skin), loss of immune cells, and thinning of the subcutaneous fat, all of which make the patient more susceptible to a full thickness burn injury [1, 13].

Other skin changes associated with aging are not restricted to the dermis or epidermis. The elderly experience decreased cold/warm sensation in a distal to proximal direction, making them unable to detect a thermal injury [14, 15]. The elderly have decreased angiogenesis, impaired lymphatic drainage, loss of vascularity, and skin hydration, all of which can impair healing. Finally, the elderly lose lean muscle mass and adipose tissue, increasing their risk of deep tissue injury.

The majority of burns in the elderly involve <10 % TBSA, and only 11 % have inhalation injury [34]. Extremities are most commonly injured, followed by the trunk and head [5]. One of the key differences between the elderly and the young is the incidence and impact of comorbidities on injury. Multiple diseases directly impacting the skin include atherosclerosis-(perfusion), diabetes (keratinocyte migration, perfusion), and congestive heart failure (perfusion). Hence, morbidity and mortality after burn injury may be related to comorbidities [27]. The presence of a single comorbidity in the elderly increases mortality by 1.37, an effect that does not occur in children or adults, and three or more comorbidities doubles mortality for the elderly. (Taylor [42], submitted for publication) However, the influence of comorbidities on patient function may be variable. Promising research measuring elderly frailty at admission have demonstrated a correlation between frailty and survival [37]. Other factors that may increase mortality include preexisting malnutrition and postburn complications [3, 29]. Finally, a recent study of the NBR utilized the Baux score (age + total body surface area burn) to predict mortality in the elderly. A Baux score >93 increased mortality, and mortality was nearly universal at a Baux score of ≥130 [20].

Pathophysiology

Accurate characterization of the physiologic response to burn injury in the elderly is confounded by the ubiquitous presence of comorbidities and medications administered for other pathologic processes. Recent work has suggested that the elderly respond to burn injury differently than younger adults [21]. Changes reported included a less severe hypermetabolic response (compared to younger patients) with a steady increase in metabolic needs in the first 4 weeks postinjury, higher daily average glucose levels and maximum glucose levels, greater glucose variability, increased lipolysis with increased circulating fatty acids, an abundance of saturated fatty acids, lower expression of c-peptide and GLF-1 in the acute phase, decreased endoplasmic reticulum stress response in adipose tissue, and lower myeloperoxidase in adipose tissue. The elderly may have an initial hypoinflammatory response followed by a hyperinflammatory response with fewer macrophages and IL-1B cells. As mentioned above, the skin has both a reduced stem cell pool as well as alteration in the activation of essential signaling pathways for wound healing. The result is that patients are slow to heal wounds and have a longer hospital length of stay.

Treatment

Treatment of the elderly burn patient can be challenging. The initial management should adhere to basic trauma principles: airway, breathing, and circulation. Airway and respiratory management can be particularly challenging in the elderly, who often have compromised pulmonary function prior to their injury. Patients on home oxygen for pulmonary disease at the time of their burn (and therefore hypoxic at baseline) require careful and thoughtful evaluation, as intubation may lead to death or permanent need for a tracheostomy [30]. Particular care needs to be exercised during dressing changes, as the elderly are susceptible to oversedation as well as delirium due to the changes in pharmacokinetics accompanying aging [39].

The elderly often have a narrow therapeutic window for resuscitation. Under- or over-resuscitation can lead to organ failure and death. While the elderly are often dehydrated due to diuretic use or malnutrition, they also frequently have impaired cardiac function, making the traditional urine output goal of 30–50 ml/h less useful. In general, elderly patients with burn injury >20 % should have intravenous fluid resuscitation started using standardized formulas, such as the Parkland formula (4 ml/kg/%TBSA burn, half in the first 8 h). The fluid infusion rate should be modified based on the urine output (>20 ml/h but no greater than 50 ml/h) and clinical evaluation of the patient. The ideal monitoring for the elderly burn patient has not been established. However, central venous pressures, lactate levels, and echocardiography may be helpful during the resuscitative phase. Nutrition provision is extremely important in the elderly. In addition to a decreased muscle mass, many elderly are also malnourished at the time of presentation. Nasoenteral nutrition provision should be initiated for burns >20 % in the elderly.

Burn wound closure is the goal of treatment; however, the most effective wound treatment protocol for the elderly has not been defined. Early excision with immediate grafting is the standard of care for children and adults [16, 46]. This early excision policy has been used successfully in the elderly by some groups [6, 7, 22]. Other groups have reported no survival benefit or increased complications with early operative intervention [23, 18]. We advocate a "common sense" approach that considers the elderly burn patient on a case-by-case basis based on their physiological health, response to resuscitation, and advance directives to formulate the most appropriate treatment plan. Early excision in the "healthy" elder with no comorbidities and a small hand burn is safe, efficacious, and restores an essential component for activities of daily living: the hand. However, a patient with an indeterminate depth burn on the chest and severe cardiac disease may benefit from watchful waiting to define the excision area and minimize anesthetic risk. Frailty index may, in the future, help to provide a measurable parameter that can be used to identify surgical candidates.

Choice of surgical procedure also depends on appropriate consideration of patient physiology with the extent of the wound. The ideal option for the "healthy" elder is tangential excision to viable tissue with placement of a skin graft. The laxity of elderly skin (particularly the abdominal skin) often makes excision and closure or full thickness skin grafts possible without the morbidity of the split thickness donor site. If a full thickness graft is not feasible, the surgeon must remember that elderly skin is thinner than adult skin, with appropriate adjustment in donor site depth. A common error in the inexperienced surgeon is to create a full thickness tissue loss when trying to harvest a split thickness skin graft in the elderly. In the ill elder, fascial excision, which has less blood loss, may be necessary. However, it must be remembered that fascial excisions are more deforming and result in a higher incidence of joint contractures. An option that combines both strategies is to excise the wound early and use a skin substitute at the first operation with application of a thinner skin graft 2 weeks later [38]. This approach, which subjects the patient to two operations and prolongs hospital stay, has yet to be proven in prospective trials.

Outcomes

The mortality rate for elderly burns, at 18 %, is significantly higher than that of younger adults [5]. However, the LA50 (burn at which half the patients die) is approximately 35 % in those 60–69 years of age, 13.1 % in those >80 years of age, and 80 % in young adults [8, 45]. Mortality continues to be a priority for elderly burn research. Fortunately, the overall mortality after burns in the elderly has decreased in the twenty first century [5, 26, 43]. Further improvements in treating the elderly burn patient are in order. Hospital length of stay and costs are higher in the elderly burn patient [34, 41]. The elderly have slower wound healing, require more rehabilitation to achieve therapeutic goals, and often drop a level of independence after burn injury [28]. The elderly also require more extensive medical support and monitoring.

Additional consideration is warranted for elderly patients who survive burn injury. In one report approximately 30 % of elder burn patients report that they are dependent on others at 1–5 years post discharge [36]. Elderly patients discharged home have better functional status and lower mortality than those patients discharged to a skilled nursing facility, where almost 50 % were dead 2 years post-injury. (Palmieri et al. [32].) Approximately 23 % of elderly burn patients have burn-related sequelae such as contractures and amputations [45]. In another study using the burn model system data, burn injury and age were a predictor of discharge to non-independent living after burn injury [33]. Future study is clearly needed. In the interim, however, one of the goals for elderly burn care needs to be to restore independence in functional activities of daily living in the elderly burn patient.

Prevention

Preventing burn injury in the elderly is essential, as the majority of elderly burn injuries are preventable [24, 36]. Prevention strategies should encompass both legislative initiatives and personal evaluation and supervision. Successful legislative efforts include limiting temperature on water heaters, self-extinguishing cigarettes, and smoke alarms. Further work is needed to restrict smoking while on home oxygen. Critical evaluation of home safety and elderly capabilities, including mobility and home safety, is needed. Sadly,

only 4 % of elderly patients presenting to an emergency room with burns are referred for a home safety evaluation [9]. Decreasing the elderly burn burden will require a coordinated effort between caregivers, primary care physicians, burn centers, firefighters, and the public.

Conclusions

The elderly are at high risk for burn injury, and burn injury in the elderly poses a life and quality of life threat to the elderly patient. Aging of the skin results in delays in wound healing, and comorbidities complicate fluid resuscitation in the elderly burn patient. Treatment should focus on a thorough evaluation of the patient's injury and physiologic status, and resuscitation adjusted based on patient response. Although improvements have been made in elderly burn patient treatment, further work is needed to define the optimum timing, extent, and conduct of burn excision and grafting in the elderly. Prevention of the burn injury, ultimately, would yield the best outcome.

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Geriatric Medicine

33

Tatyana Kemarskaya and Catherine M. Glew

The two essential bodies of knowledge that comprise the science of geriatrics are gerontology and geriatric medicine. *Gerontology* (from the Greek γέρων, geron, "old man" and -λογία, -logia, "study of," coined by Ilya Ilyich Mechnikov in 1903) is the branch of basic sciences that explores the process of aging, with a focus on the psychological, cognitive, and biological aspects of aging. Geriatric medicine, or *geriatrics* (from the Greek γέρων geron meaning "old man" and ιατρός iatros meaning "medicine related," coined by Ignatz Leo Nascher), is the branch of medicine that deals with the problems and diseases of old age and aging people [1].

Gerontology

Aging per se is not a disease, although diseases are most definitely among the most common and detrimental consequences of aging. If one considers aging a disease, then, at least theoretically, it should be possible to achieve a disease-free state [2]. Unfortunately, unlike any disease, the aging phenomenon is universal within and across species and occurs to all without exception after reproductive maturity [3]. Understanding that aging is a process, rather than a disease, helps to transform our approach to older adults. A focus on the maintenance of function and health mechanisms may help to develop realistic and practical methods for maintaining health throughout life span and to restoring health when challenged with an acute disease or injury [2].

Multiple theories of aging have been introduced in the last five decades, and gerontology is progressing from an observational to an interventional branch of science.

One of fascinating breakthroughs was the discovery of the role of telomeres, (protein-bound repetitive DNA sequences that constitute the natural end of linear chromosomes) and the enzyme telomerase in governing cellular senescence. Telomeres progressively shorten with each division. When they are too short, telomeres signal the arrest of cell proliferation, senescence, and apoptosis. Use of the enzyme telomerase, which regulates the length of telomeres, restored the ability of a cell culture to divide [4, 5]. One practical application of this discovery, the study conducted by Lapham et al. on 110,266 subjects, as part of Genetic Epidemiology Research on Adult Health and Aging (GERA) cohort, showed that telomere length, measured in the saliva, decreased for both men and women with increasing age. In the age group 80–90, age positively correlated with longer telomeres, indicative of an association of longer telomeres with more years of survival. Females on average had longer telomeres than males [6]. In the future, it may be possible to test for telomere length permitting prediction of the potential longevity of an injured patient!

It appears, however, that a single intervention, such as a calorie-restricted diet, or single gene modification, while extending life span in flies, worms, and mice and delaying such age-associated changes as cataract development, either failed to demonstrate similar results as the model becomes more complex or faced significant obstacles, scientific, political, economic, and legal obstacles on the pathway from discovery to implementation in the area of basic science [7–10].

Life span is the duration of a life. There is a distinction between observed, potential, and essential life span (ELS). ELS covers such biological milestones as growth, development, maturation, reproduction, nurturing, and, for human and some other species, grandparenting. At the end of ELS, which covers the first 40–50 years in humans, the process of senescence and the emergence of the geriatric phenotype begins [3, 11]. In most developed countries, people are not considered elderly until at least 65. However, a large study at a level 1 trauma center revealed a significant "breakpoint" for increased risk of mortality and change in pattern of postoperative complications at 45 years of age, a much younger age than we

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currently consider elderly but in full agreement with the end of "warranty" period as defined by biogerontology [12]!

The day-to-day survival of an organism depends on the process of maintenance and repair of systems with the goal of maintaining homeostasis. One concept describing aging as "a decline of the ability to maintain homeostasis due to diminishing physiological reserves, called homeostenosis," was proposed in the 1940s by Walter Cannon [13]. Recently a concept of homeodynamic space, or a buffering zone, has been proposed. The response to an injury will depend on the ability of this system to generate a stress response, achieve damage control, and maintain the ability for remodeling and adaptation. Shrinkage of the homeodynamic space which occurs with increasing age leads to an increased zone of vulnerability and decreased ability to respond to injury effectively [3]. Age-associated molecular changes occurring in the intracellular compartments affect the cellular response and organ function. Functional impairment accrues in every physiological system, at the rate of 5–10 % per decade starting around 30 years of age [14].

The standard Injury Severity Score does not fully capture the potential for mortality in older adults, and with the same degree of severity of injury, outcomes are usually worse in the aged [15]. The physiological changes occurring with age undermine the ability to withstand the impact of an injury. Specific changes in different organ systems are described in more details in the subsequent chapters so we will only provide a brief summary. Older persons tend to have decreased elasticity of tissues and organs, leading to increased risk of hip, rib, and skull fracture and lowered viscous tolerance, the ability of organs to withstand rapidly applied strain forces during high-speed impact [16]. Changes associated with aging, especially loss of muscle and bone mass, development of cataracts, postural hypotension, cognitive comorbidities, and polypharmacy, contribute to development of the geriatric syndromes and functional impairment, which, in turn, increases the risk for traumatic injury. Shrinkage of the homeodynamic space and loss of reserve affect the ability to cope with the stress of injury. These changes, especially the presence of senile emphysema and decrease in maximum heart rate, lead to an approximately 20 % decrease per decade in maximum oxygen uptake in older adults. Sedentary lifestyle, reduced responsiveness to β-adrenergic stimulation, and comorbidities, especially coronary artery disease and hypertension, contribute to decline in the functional capacity of the cardiovascular system [17]. On a cellular level, age-associated decline in mitochondrial function leads to increased vulnerability of multiple organs to ischemic/reperfusion damage, associated with hypoxic and ischemic conditions following injury [18].

The current definition of old age is strictly chronological, with everybody age 65 and above brought together under one large umbrella considered elderly adult. While aging is a universal phenomenon, there is a great heterogeneity in the age-related changes in physiological functions between individuals. Thus, a concept of "successful aging" was proposed in 1987 by Rowe and Kahn. It has three components: few if any chronic diseases, maintenance of a high level of mental and physical function, and social engagement [19]. Successfully aging older adults with few comorbidities, few medications, and good pre-injury functional status are excellent candidates for trauma team activation and aggressive management. Advanced age alone should not be used to predict poor outcome as functional very elderly have a good probability of regaining function and return to the community with optimal medical and surgical management as has been shown in several studies of octogenarians and nonagenarians [20, 21].

Geriatric Medicine

Traditionally physicians are taught to work through the differential diagnosis of a problem, to arrive at a single diagnosis consistent with the clinical presentation and then confirm this by laboratory and imaging studies. This concept is difficult to maintain when dealing with an older population, when the presenting symptoms often have more than one cause and involve more than one organ. Diagnosis and management of the medical conditions in older adults require a shift from a disease-centered approach to a patient-centered approach [22]. Thus the concept of a *geriatric syndrome* which is a multifactorial condition that involves the interaction between an identifiable situation, specific stressors, and underlying age-related risk factors, resulting in damage across multiple organ systems [23]. Comprehensive geriatric assessment for identifying and managing geriatric syndromes has emerged. Introduction of geriatric syndromes, most relevant to trauma and critically ill patients, such as frailty, polypharmacy, pain management, falls, delirium, and some recommendations to avoid common hazards of hospitalization in older adults are described below.

Geriatric trauma as a separate entity was defined in "Resources for Optimal Care of the Injured Patient," published in 1990. In the past 25 years, tremendous gains have been achieved by trauma surgeons in recognizing the physiological and psychosocial aspects of aging trauma victims and modifying care to account for them. Based on data from multiple trials, and expert opinion, Geriatric Trauma Management Guidelines have been developed as a program of the American College of Surgeons: the Trauma Quality Improvement Program (ACS TQIP®). One element of the ACS TQIP Best Practice Guidelines is based on the identification of seniors at risk (ISAR) screening tool. It prompts for asking seven questions, such as "do you have serious problems with your memory?"

and "before you were injured, did you need someone to help you on a regular basis?." The recommendation is that a positive answer for at least two of these questions should prompt a formal geriatric consultation. *ACS TQIP® Geriatric Trauma Management Guidelines* [24].

The comprehensive geriatric assessment (CGA) is a multidimensional, multidisciplinary diagnostic process used to determine medical, functional, and psychosocial problems and capabilities in an elderly patient who may be at risk for functional decline. All models of CGA include a comprehensive evaluation of medications including nonprescription, a full history and physical, cognitive assessment, functional assessment, review of nutritional status, and psychosocial assessment of both patient and caregiver. CGA is usually performed by multiple disciplines; most models include a geriatrician, social worker, and physical therapist with some groups adding pharmacist, occupational and speech therapists, dietician, and psychologist or geriatric psychiatrist. The ultimate goal of CGA is to improve the quality of life. It is a three-step process: targeting appropriate patients, assessing those patients and developing a set of recommendations, and thirdly implementing those recommendations [25].

Initially developed for use in office patients, CGA has been successfully adapted for use in the Emergency Department (ED) and was effective for decreasing functional decline and ED readmission in a review of eight studies [26]. In hospitalized patients, CGA demonstrated a decrease in hospital mortality rate, increased chance of return to the community, and better cognitive and functional outcomes [27].

CGA allows for early identification of those geriatric syndromes that most affect the management of an injured older patient, specifically frailty, falls, polypharmacy, and delirium.

Frailty

Frailty was defined by Dr. Linda Fried as a clinical syndrome in which three or more of the following criteria were present: unintentional weight loss (10 lbs. in past year), self-reported exhaustion, weakness (grip strength), slow walking speed, and low physical activity [28].

At the biological level, frailty is associated with sarcopenia, i.e., loss of muscle mass, strength, and function [17, 29]. Sarcopenia alone is associated with increased perioperative mortality, complications, and higher costs in surgical patients [30], yet frailty as a geriatric syndrome is much more than just physical impairment. Frailty can be viewed as a "state of low physiological capacity, and increased susceptibility to disability because of age-related loss of physical, cognitive, social and physiological functioning" [31].

While the overall prevalence of frailty in the community varies from 6.9 to 14 %, it increases sharply with age, and prevalence may be as high as 65 % in 90 + years old as shown in the English Longitudinal Study of Ageing [28, 32].

There are three major approaches used to define frailty: by phenotype, by frailty index (FI), and by clinical evaluation.

There are two most commonly used phenotype-based approaches, one consisting of the presence of three out of five components as described by Fried and delineated above. The second includes only three components: unintentional weight loss, self-reported low energy level, and inability to stand up from a chair five times without using arms [33]. Both of these models are not practical for injured trauma patients and cannot be calculated from a history given by a proxy.

Frailty can be defined using a frailty index (FI), which is based on the results from CGA and calculated as the number of the deficits a patient has divided by the number of potential deficits considered. The higher the frailty index, the more frail is the individual. An example is the 40-point index proposed by Rockwood, where an FI of 0.25 or above is consistent with frailty [34]. A shorter 15-item adaption to the FI was proposed by Joseph et al. and was able to identify frailty in elder trauma patients with the same predictive value as a full FI. This study found that frailty predicted mortality and discharge disposition better than chronological age [35].

These sophisticated indices are useful for research, but when the goal is the broad identification of people at risk, a dichotomized approach (frailty is present or absent) is more appropriate [36].

Some of the most user-friendly instruments for evaluation of frailty are based on clinical indicators present prior to injury and can be applied using a proxy.

One is based on the mnemonic "**F-R-A-I-L**" developed by John Morley [37]:

Fatigue – Are you fatigued?
Resistance – Are you unable to climb one flight of stairs?
Aerobic – Are you unable to walk one block?
Illness – Do you have five or more illnesses?
Loss of weight – Have you lost 5 % of your weight in the last 6 months to 1 year?

The other one was proposed as the Clinical Frailty Scale (CFS) in 2005 and updated in 2008 [38]. It is based on personal ability to perform instrumental and basic ADLs and stratifies the heterogeneous cohort of elderly people into nine categories: from group 1, very fit, who are robust, active, energetic, and motivated, to group 7, severely frail, completely dependent for personal care, while groups 8 and 9 comprise severely debilitated people, unable to recover from even a minor illness, and those who are terminally ill from any causes.

Clinical Frailty Scale*

1 Very Fit – People who are robust, active, energetic and motivated. These people commonly exercise regularly. They are among the fittest for their age.

2 Well – People who have no active disease symptoms but are less fit than category 1. Often, they exercise or are very active occasionally, e.g. seasonally.

3 Managing Well – People whose medical problems are well controlled, but are not regularly active beyond routine

4 Vulnerable – While not dependent on others for daily help, often symptoms limit activities. A common complaintis being "slowedup", and/or beingtired during the day.

5 Mildly Frail– These people often have more evident slowing, and need help in high order IADLs (finances, transportation,heavy housework, medications). Typically, mild frailty progressively impairs shopping and walking outside alone, meal preparation and housework.

6 Moderately Frail – People need help with all outside activities and with keeping house. Inside, they often have problems with stairs and need help with bathing and might need minimal assistance (cuing,stand by) withdressing.

7 Severely Frail – Completely dependent for personal care, from whatever cause (physicalorcognitive). Even so, they seem stable and not at high risk of dying (within ~ 6months).

8 Very Severely Frail– Completely dependent, approaching the end of life. Typically,they could not recover even from a minor illness.

9. Terminally Ill - Approaching the end of life. This category applies to people with a life expectancy <6months, who are not otherwise evidently frail.

Scoring frailty in people with dementia

The degree of frailty corresponds to the degree of dementia. Common symptomsin mild dementia include forgetting the details of a recent event, though still remembering the event itself, repeating the same question/story and social withdrawal.

In moderate dementia, recent memory is very impaired, even though they seemingly can remember their pastlife eventswell. They can dopersonal care with prompting.

In severe dementia,they cannot do personal care without help.

* 1. Canadian Study on Health & Aging, Revised 2008.

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2.K.Rockwoodetal. A global clinical measure of fitness and frailty in elderly people. CMAJ2005; 173:489-495.

The CFS was highly correlated ($r = 0.80$) with the full FI and much easier to apply. Each one-category increment of the scale significantly increased the medium-term risk of death (21.2 % within about 70 months, 95 % confidence interval CI 12.5–30.6 %) and entry into an institution (23.9, 95 % CI 18.8–41.2) in multivariable models adjusted for age and sex [38].

Frailty has been predictive of increased mortality, postoperative complications, and discharge to a nursing facility in elderly injured and surgical patients [39, 40]. In a meta-analysis by Kojima et al., prevalence of frailty in nursing home residents is 40–50 % which predicts poor outcome for many of these patients [41]. This data corresponds with a recent large-scale study by Newman et al. evaluating survival and functional outcomes after hip fracture among nursing home residents that demonstrated a 36.2 % mortality in 180 days and functional decline in all activities of daily living domains assessed [42].

The British Geriatrics Society recommends a comprehensive geriatric assessment (CGA) for all older people identified with frailty. This will identify medical illnesses, allowing treatment optimization; apply evidence-based medication review checklists, such as the STOPP/START criteria which are discussed later in the chapter; establish dialogue with older people and their caregivers to assess the impact of illness or injury; and create an individualized care plan that is congruent with patient's goals and beliefs.

Those who are defined as vulnerable or mildly frail (groups 4 and 5 on CFS) and/or who met some but not all criteria for frailty as assessed by Fried's phenotype may benefit the most from the input of a multidisciplinary team. These elders have potentially reversible issues that, if addressed early, will allow for longer functional independence. Very frail injured elders (groups 7, 8, and 9 on CFS) may benefit from referral to palliative care specialists who can assist the trauma team in discussing goals of care with patient and family, weighing the risks and benefits of any proposed treatment with quality of life after the injury [43, 44].

Falls

Fall-related injuries are among the leading causes of functional impairment, loss of independence, and death in older adults. Falls are common in community-dwelling older people with an incidence of about 30 % annually for those over the age of 65 [45] and increasing up to 40 % for those over the age of 80 [46]. Falls are even more common in nursing the home residents, with between 50 and 75 % of residents falling every year [47].

Falls rarely have a single cause: most are multifactorial [48], with the risk of falling increasing in a linear manner with the number of risk factors involved [46]. The most common risk factors for falls are history of previous falls, gait and balance impairment, and medications [49]. In 1 year, 9 % of community-dwelling elders had more than one fall [50], and nearly 30 % of patients seen in the ED [51] and 40 % of admitted trauma patients [21] were recidivist, having had more than one fall. Medication use, especially the combination of polypharmacy and medications affecting central nervous system, has been shown to be closely associated with falls [52]. Cognitive impairment, especially deficits in executive function, has been shown to increase the risk of both falls and injurious falls [48, 53].

The fact that falls are a widespread and recurrent problem, with significant morbidity and mortality, and have identifiable risk factors makes falls (from a public health perspective) akin to an epidemic, which warrants preventive measures [54, 55]. Randomized controlled trials have investigated both single and multiple interventions. A meta-analysis of multiple trials showed multifactorial interventions to be more effective in reducing the risk of falls, although the effects were moderate. The most effective interventions were those aimed at improving strength and balance, such as exercises, especially Tai Chi, medication adjustment, and home safety modification [56, 57, 58]. A meta-analysis of fall prevention programs in nursing homes found that these programs produced a smaller number of falls, and fewer recurrent fallers, but had no effect on the overall number of those who fell [59]. A meta-analysis from 2009 showed a 9.5 % absolute risk reduction in falls among community-dwelling and institutionalized adults given supplementation with 700 to 1000 i.u. of vitamin D daily [60].

Dissemination of evidence about fall prevention, coupled with interventions to change clinical practice, undertaken as part of Connecticut Collaboration for Fall Prevention (CCFP) initiative, showed a lower rate of hospitalizations for injurious falls [61] and for traumatic brain injury [62] in the treatment regions versus usual care regions.

And yet, despite the evidence that falls, and especially injurious falls can be prevented with a multifactorial prevention program and despite the fact that even minor falls may affect function in the frail elderly patients [63], many elders presenting to the ED or even hospitalized following a fall receive no education on these interventions. Most are not seen by a geriatrician or receive comprehensive geriatric assessment or any significant education on prevention strategies appropriate for them [64].

An excellent resource was compiled by researchers at the Centers for Disease Control and Prevention's (CDC) Injury Center who created an algorithm based on the American and British Geriatric Societies' Clinical Practice Guideline for falls screening and risk assessment. They used the mnemonic Stopping Elderly Accidents, Death, and

Injury (STEADI). The site also includes basic information about falls, case studies, conversation starters, and description of standardized gait and balance assessment tests: the Timed Up and Go (TUG) Test, strength (the 30-Second Chair Stand Test), and balance (the Four-Stage Balance Test). This information is readily available at [65] http://www.cdc.gov/homeandrecreationalsafety/Falls/steadi/about.)

Polypharmacy

There is no standard definition of polypharmacy; multiple studies have defined this differently from "four or more" to "more than nine medications" daily. However, there is no doubt that it is common in the older adults. Surveys of community-dwelling elderly showed that on average two to nine prescription medications are taken daily by American seniors [66], while other studies, conducted in the United States and other countries, found out that 51 % of elderly people took more than six prescription medications a day, to say nothing of nonprescription medications [67]. This burden is especially heavy in the case of frail patients, who frequently have multiple comorbidities [68].

While there is a nonlinear association between the number of medications used and the frequency of adverse drug events (ADE) with the risk of ADE increasing fourfold for those taking eight or more medications [69], certain classes of medications have significantly higher risk.

In a large study by Budnitz et al. conducted between 2007–2009, there were nearly 100,000 emergency hospitalizations for adverse drug event annually for those over 65 years of age. The main drugs or medication classes implicated were warfarin and oral antiplatelet agents, which were associated with bleeding, and insulins and oral hypoglycemics, which were associated with severe hypoglycemia [70]. In this study, only 3.6 % of emergency department visits for ADE were associated with potentially inappropriate medication (PIM) use.

The Beers Criteria for potentially inappropriate medication (PIM) use in older adults, or "Beers list," was created by Dr. Mark Beers and colleagues in 1991 and has undergone several revisions. The most recent was in 2015 by the American Geriatrics Society based on evidence-based guidelines and expert opinion of a 13-member panel. The recommendations were rated for the quality of the evidence supporting the panel's recommendations and the strength of their recommendations. It comprises a list of medications to be avoided in older adults in general and in those with certain diseases or syndrome. There are additional lists of medications to be prescribed with caution and a table of medications with strong anticholinergic properties. The latest revision added list of drugs to be used with caution in patients with impaired kidney function and common drug-drug interactions [71].

The causative link between trauma and subdural hematoma for a patient on warfarin is generally obvious and seldom overlooked. The link between a fall or change in mental status and a PIM or polypharmacy may be less clear-cut, but there are numerous studies, implicating polypharmacy and/or the use of certain classes of medications, in both falls and delirium.

To illustrate, in the study by Richardson et al. [72], taking five or more medications, one of which was an antidepressant, was associated with a greater risk for falling, a greater number of falls, and a higher risk of injurious falls, but antidepressant use without polypharmacy and polypharmacy without antidepressants was not. The use of benzodiazepines was associated with injurious falls when coupled with polypharmacy (aRR 1.40, 95 % CI 1.04–1.87) but was also associated with a greater number of falls independent of polypharmacy (aIRR 1.32, 95 % CI 1.05–1.65). The risk of falling in an acute care hospital was increased more than threefold in those on tricyclic antidepressants and almost twofold on those on diuretics and narcotics [73]. The risk of falls in community-dwelling elders was found to be one and a half times greater in those who took one CNS active drug and 2.3 times greater in those who took more than one CNS active drug [74].

Polypharmacy and the use of psychoactive medications (benzodiazepines, anticholinergic, antihistamines, and antidepressants) have been identified as strong risk factors for postoperative delirium [75].

Thorough evaluation of elders presenting to the ED with nonspecific complaints, such as generalized weakness or dizziness, revealed 10 % increase in the probability of ADE with each additional drug, and this link was not recognized by the ED physician in 40 % of cases. The most commonly missed drug-related diagnoses were electrolyte abnormalities, such as hyponatremia [76]; another study recently linked hyponatremia with an increased risk of hip fracture in older persons [77].

Hospital admission after injury usually necessitates adding medications to address pain, nausea, deep venous thrombosis prophylaxis, and other possible complications of acute injury, predisposing injured elderly patients to polypharmacy and potential side effects, such as falls, delirium, constipation, and anorexia. The best way to approach polypharmacy in injured elderly patients is to review the medication list for medications that may be nonessential in the context of severe injury. Medications

that may cause withdrawal, if discontinued abruptly (such as benzodiazepines), should be continued but consideration given to reducing the dose, as recommended by the jointly created American College of Surgeons National Surgical Quality Improvement Program and American Geriatrics Society ACS NSQIP ®/AGS Best Practices Guidelines regarding Optimal Preoperative Assessment of the Geriatric Surgical Patient [78]. Principles of appropriate prescribing should be used when adding new drugs, such as Screening Tool of Older Persons' potentially inappropriate Prescriptions (STOPP) and Screening Tool to Alert Doctors to Right Treatment (START) criteria [79] and Beers criteria.

Pain Management

There is limited availability of evidence-based recommendations regarding the use of pain medications in older adults, because, although they are the fastest-growing segment of the population, they are largely underrepresented in clinical trials, despite their disproportionally high use of prescription drugs [80].

Elderly patients constitute a heterogeneous group and so predicting the optimal dose of medications, providing effective pain relief, while minimizing the complications such as delirium, nausea, and vomiting is difficult. The best approach is to start with low doses, 25–50 % of the usual starting dose, followed by careful upward titration until the goal of pain relief is achieved [81].

We will try to address some issues that deserve further elucidation when considering pain management in injured elders.

Pain is frequently underdiagnosed in older adults, especially those with cognitive impairment. Accurately assessing for pain presents the first challenge. Cognitively intact older adults and those with mild to moderate dementia are able to respond to simple questions and standard screening tools, rating their pain on traditionally used 1–10 scale. Patients with advanced dementia and nonverbal patients might be able respond to simple "yes" or "no" questions. Observation of facial expression or body language can give another clue and may be the only marker for nonverbal or intubated patients. Grimacing, frowning, or rapid blinking may be indicative of pain, as is guarding, rocking, or resistance to care. Caregivers, familiar with the patient, may observe change in behavior, usual pattern, or mental status. In a cognitively impaired patient, new onset of agitated or aggressive behavior may be caused by pain that the patient is unable to convey verbally and could be indicative of occult fracture. Although not validated to be used for trauma patient in randomized controlled trials, there are several tools that help to assess pain and its severity in cognitively impaired patients, such as the Abbey Pain Scale [82] and PAINAD scale [83]. The Abbey Scale assesses vocalization and behavioral and physiological changes, while the PAINAD scores behavioral changes only. When potential causes for pain, like a recent injury, are obvious, an empiric analgesic trial should be considered even if the patient is not complaining of pain.

Abbey Pain Scale

For measurement of pain in people with dementia who cannot verbalise.

How to use scale: While observing the resident, score questions 1 to 6

Name of resident: .....

Name and designation of person completing the scale: .....

Date: .....**Time:** .....

Latest pain relief given was.....**at** .....**hrs.**

Q1. Vocalisation
eg. whimpering, groaning, crying **Q1** ☐
Absent 0 Mild 1 Moderate 2 Severe 3

Q2. Facial expression
eg: looking tense, frowning grimacing, looking frightened **Q2** ☐
Absent 0 Mild 1 Moderate 2 Severe 3

Q3. Change in body language
eg: fidgeting, rocking, guarding part of body, withdrawn **Q3** ☐
Absent 0 Mild 1 Moderate 2 Severe 3

Q4. Behavioural Change
eg: increased confusion, refusing to eat, alteration in usual patterns **Q4** ☐
Absent 0 Mild 1 Moderate 2 Severe 3

Q5. Physiological change
eg: temperature, pulse or blood pressure outside normal limits, perspiring, flushing or pallor **Q5** ☐
Absent 0 Mild 1 Moderate 2 Severe 3

Q6. Physical changes
eg: skin tears, pressure areas, arthritis, contractures, previous injuries. **Q6** ☐
Absent 0 Mild 1 Moderate 2 Severe 3

Add scores for 1 – 6 and record here ⇨ **Total Pain Score** ☐

Now tick the box that matches the Total Pain Score ⇨

0 – 2 No pain	3 – 7 Mild	8 – 13 Moderate	14+ Severe

Finally, tick the box which matches the type of pain ⇨

Chronic	Acute	Acute on Chronic

Dementia Care Australia Pty Ltd
Website: www.dementiacareaustralia.com

Abbey, J; De Bellis, A; Piller, N; Esterman, A; Giles, L; Parker, D and Lowcay, B.
Funded by the JH & JD Gunn Medical Research Foundation 1998 – 2002

Pain Assessment in Advanced Dementia Scale (PAINAD)

Pain Assessment in Advanced Dementia Scale (PAINAD)Instructions Observe the patient for 5 min before scoring his or her behaviors. Score the behaviors according to the following chart. Definitions of each item are provided on the following page. The patient can be observed under different conditions (e.g., at rest, during a pleasant activity, during caregiving, after the administration of pain medication).

Behavior	0	1	2	Score
Breathing Independent of vocalization	1. Normal	Occasional labored breathing Short period of hyperventilation	Noisy labored breathing Long period of hyperventilation Cheyne-Stokes respirations	
Negative vocalization	None	Occasional moan or groan Low-level speech with a negative or disapproving quality	Repeated troubled calling out Loud moaning or groaning Crying	
Facial expression	Smiling or inexpressive	Sad Frightened Frown	Facial grimacing	
Body language	Relaxed	Tense Distressed pacing Fidgeting	Rigid Fists clenched Knees pulled up Pulling or pushing away Striking out	
Consolability	No need to console	Distracted or reassured by voice or touch	Unable to console, distract, or reassure	
Total score				

(Warden et al. [83])

Scoring The total score ranges from 0 to 10 points. A possible interpretation of the scores is 1–3 = mild pain, 4–6 = moderate pain, and 7–10 = severe pain. These ranges are based on a standard 0–10 scale of pain but have not been substantiated in the literature for this tool.

Source Warden et al. [83].

The general principles of pain management are well established, with WHO's 3-step ladder approach being the cornerstone. Non-opioids, such as acetaminophen, and oral or topical nonsteroidal anti-inflammatory drugs (NSAIDs) are step 1, and they remain first-line therapies for mild to moderate pain. Caution should be exercised when considering oral NSAIDs for patients with low creatinine clearance, cardiovascular diseases, or intravascular depletion state such as congestive heart failure. Step 2 for moderate pain includes mild opioids, or opioid-like drugs, such as tramadol, usually in combination with acetaminophen. Step 3 recommends the drugs for severe pain and includes narcotics such as morphine, fentanyl, and hydromorphone. Adjuvant medications and non-pharmacological treatment can be utilized at any step. Opioids should be started at 25–50 % of the recommended dose for adults [84].

Opioids have been implicated in falls and delirium, but this class of drugs is generally safe and provides effective analgesia for moderate to severe pain when initiated at low doses, and with preemptive strategies to minimize side effects. Untreated pain alone has been associated with postoperative delirium [85]. Age-associated changes in *pharmacokinetics* (absorption, distribution, metabolism, and elimination) and *pharmacodynamics* (increased or decreased sensitivity of the receptors to drugs) need to be recognized. Older patients are more sensitive to the effects of opioids. Changes in body composition cause a prolonged half-life of lipid-soluble drugs, such as fentanyl, necessitating longer intervals between the administrations of doses. Opioids are metabolized in the liver and excreted 90–95 % by the kidneys; therefore adjustments should be made for patients with hepatic and renal impairment [84].

Water-soluble opioids, such as morphine, achieve higher concentrations in plasma due to a relative decrease in total body water [86]. Morphine may cause severe respiratory depression in patients with renal impairment, due to accumulation of active metabolites. It may require a continuous infusion of naloxone rather than a bolus dose because the half-life of naloxone is much shorter than that of morphine-6-glucuronide, which can be up to 50 h in patient with renal failure [87]. Methadone is primarily excreted through the feces, but due to a prolonged half-life, it is not recommended in the elderly [88]. Buprenorphine is also excreted primarily via feces and considered a safe choice in patients with renal impairment [84]. Fentanyl is primarily metabolized in the liver; therefore it has a role in patients with advanced renal disease or acute renal failure [89].

All opioid medications have predictable side effects. Constipation is the most common due to binding to μ-opioid receptors located in the enteric nervous system which leads to increased non-propulsive contractions: patients never develop tolerance to this. All patients started on narcotics should be simultaneously started on stimulant laxatives, such as senna or bisacodyl, and the dose titrated up to achieve regular bowel movements. There are also newer (and more

expensive) peripherally acting μ-opioid receptor antagonists such as naloxegol. These agents limit the effects of opioids on the gastrointestinal tract while preserving centrally mediated analgesia and have been shown effective for constipation without reducing opioid-mediated analgesia [90]. Stool softeners such as docusate are ineffective as monotherapy for opioid-induced constipation.

Other common opioid side effects are nausea and vomiting which can be treated with small frequent meals and either dopaminergic or serotonergic blocking agent, such as prochlorperazine or ondansetron. Opioids affect patients differently, and sometimes a change of type of opioid may achieve better pain control. It is important to follow opioid converter principles when changing between intravenous and oral route of administration and between different opioids.

Scheduled administration should be considered choice for patients with cognitive impairment who are not able to request medication appropriately. Scheduling medications 4 times a day, or while awake, rather than every 6 h, will avoid sleep interruption. The use of scheduled acetaminophen as a background pain medication may reduce the need for narcotics.

Most muscle relaxants (such as methocarbamol, cyclobenzaprine, metaxalone) are considered potentially inappropriate for older adults and should be avoided [71]. If used, treatment should be initiated at 25–50 % of the generally recommended dose. Long-acting benzodiazepines have a long half-life which could be further prolonged due to relative increase in adipose tissue and, therefore, larger volume of distribution. For example, the half-life of the active metabolite of diazepam can be up to 200 h leading to increased potential for the accumulation and side effects.

Non-pharmacological approaches, such as repositioning, use of ice or heat, and relaxation techniques, should be part of effective pain management strategies for all older adults.

Delirium

Delirium takes an especially high toll of surgical patients, especially those in the intensive care unit. As summarized in the first meeting of the American Delirium Society in 2011, the pathophysiology and neuropsychology of delirium are still poorly understood. While there is a correlation between delirium and such biomarkers, as S-100 beta and insulin-like growth factor-1 and inflammatory markers, no specific diagnostic studies are accurate to diagnose delirium, which remains a clinical diagnosis. While some studies have shown reduction in rates or duration of delirium, there are no proven medications to prevent or treat delirium [91]. As with many other geriatric symptoms, there is no single definitive causative pathway but rather many predisposing and precipitating risk factors, many contributing pathophysiologic pathways and multiple presentations, and therefore, a variety of preventative and treatment strategies [92].

Overall the risk of developing delirium depends on the relationship between the severity or the impact of a stressor and the quantity or severity of patient-associated risk factors [93]. The most common risk factors for delirium in hospitalized patients are age, underlying cognitive impairment, vision or hearing impairment, severe illness, and presence of infection [94]. It has been demonstrated in multiple studies that delirium in medical and surgical patients alike causes increased mortality, morbidity, prolonged length of stay and increases rates of functional decline and discharge to an institution [95, 96].

Prevention and management of delirium in a surgical patient, summarized in Clinical Practice Guidelines for Postoperative Delirium in Older Adults, are applicable to injured older adults [97]. Non-pharmacological interventions delivered by an interdisciplinary team are considered the approach of choice for prevention and management of delirium. Education of healthcare providers is recommended as a first step. Medication management such as appropriate prescribing, reduction of polypharmacy, and adequate treatment of pain plays a significant role in prevention and management of delirium. The full version of this guideline is available at www.geritricscareOnline.org.

The issue of delirium is discussed in more depth later in the textbook, in the chapter on Geriatric Psychology and the Injured Elderly.

Management of the Hospitalized Older Adults

The most dreaded consequence of hospitalization for an older adult, a fate that to some may be worse than death, is loss of independence and inability to return home. The possible development of long-term disability results from an interplay of pre-illness vulnerability, the acute stress of the illness or injury, and the treatment that is received in an acute care hospital.

More than 60 years ago, Dr. Sidney Katz noted a correlation between regaining basic functions (such as ability to bathe and dress independently) and the ability to return back home in older adults with hip fracture. This observation led to the creation of Katz' Index of Activities of Daily Living (ADLs) which is still widely used as a measure of functional evaluation of older adults [98].

In his original article published in the *Journal of the American Medical Association* (JAMA) in 1963, Katz described "environmental artifacts": "some patients were kept in bed either for convenience of the staff or due to restrictive safety policies" [98]. It has been demonstrated that inability to improve or regain function during hospital admission was associated not only with worse discharge outcomes

but with increased mortality [99]. The process of aging itself causes some loss of muscle mass and strength and a decline in aerobic capacity [17]. Bed rest, whether intentional or unintentional, accelerates these processes. A study of bed rest in healthy older adults showed that 10 days of bed rest resulted in substantial loss of all measures of lower extremity strength and stair-climbing power and a 12 % loss of maximal aerobic capacity [100]; this effect is likely more marked in those who are frail. An older person admitted for observation for a small intracranial hemorrhage on Friday may be unable to wash, dress, or ambulate alone by Monday having spent most of the previous 72 hours in bed.

While bed rest after an injury may be a medical necessity, it is rarely the case. Patients in ICU setting are at higher risk for imposed immobility. Establishing an ICU early mobilization quality improvement program resulted in reduced ICU and hospital length of stay in three pilot institutions, and decreased rates of delirium and the need for sedation for the patients enrolled in the Johns Hopkins ICU early mobility program [101]. Details of the QI program and the tools can be found at www.iculiberation.org

Models to improve care for older adults in hospitals across specialties and disciplines include Nurses Improving Care for Healthsystem Elders (NICHE), The Hospital Elder Life Program (HELP), and the Acute Care for the Elderly (ACE) model. Each of these programs have different interventions, but all address to some degree the risk factors faced by older adults during hospitalization and have been shown to decrease functional decline and rates of falls, shorten hospital length of stay, reduce the rate of delirium, and increase the likelihood of returning home. Each has been proven financially feasible and sustainable [102, 103].

Aging alone may affect food intake due to loss of dentition, changes in the quantity and quality of taste buds, decreased saliva production, and altered sense of smell [105]. Delirium, pain, and GI complications, such as nausea and constipation, caused by new pain medications and/or iron supplements, further affect food intake in an older adult hospitalized with an injury. Imagine an injured person, whose dentures have either been left at home, or lost, who is not capable of using utensils due to cognitive impairment or loss of dexterity due to injury (or both), at risk for aspiration attempting to eat while reclining in bed rather than sitting upright in the chair. This is a common event and leads to inadequate intake. Impaired nutritional status predisposes older adults to multiple complications, including delirium [105]. Review by a dietician for food preferences and the early use of nutritional supplements can ensure adequate calorie intake. At present there are no evidence-based recommendations for any particular appetite stimulant in older people with dementia as per a review article based on 13 randomized controlled trials [106]. Many commonly used medications in fact are more likely detrimental. Megesterol caused new onset fatigue, leg swelling, fluid retention, and case reports of DVT, and dronabinol caused increased somnolence [106]. Altered thirst perception, self-imposed restrictions in order to improve urination pattern, and no access to fluids due to physical inability to reach or due to altered mental status all predispose older injured adult to dehydration [107].

Nursing measures to reverse these issues are essential. While we have made great progress with limiting the use of formal restraints, the use of informal ones (oxygen cannulae, intravenous lines, indwelling urinary catheters) remains high and limits a patient's ability to ambulate. Indwelling urinary catheters, in particular, may be considered as one-point restraint. Cognitively impaired patient may pull the catheter out directly or indirectly, by simply walking away from the bed to which the catheter bag is firmly attached, pulling out the catheter with the inflated balloon as a result. The risk of catheter-associated urinary tract infection (CAUTI) is well known and now the focus of CMS scrutiny. Multiple CAUTI prevention strategies, such as educational interventions to improve appropriate placement of catheter and catheter removal protocols, have been successful in reducing CAUTI by 53 % (rate ratio 0.47; 95 % CI 0.30–0.64, $p < 0.001$) as shown in a meta-analysis of 11 studies [108]. As an example, introduction of a geriatric curriculum for ED residents, consisting of six lectures, resulted in a significant decrease of inappropriately placed urinary catheters from 16 to 2 %, illuminating the importance of teaching the basics of geriatrics to diverse medical professionals in order to improve the care of the elders [109]. NICHE has nurse-driven protocols for Foley removal and has also shown success in reducing prevalence.

Models of Care and the Role of a Geriatrician

Over the past 15 years, the rate of admission of older adults is increasing among overall trauma admissions with a 17 % increase in trauma admission for older adults but only a 2 % increase in younger adults and an 18 % decrease in pediatric trauma admissions based on a statewide database covering 15 years up to 2010 [110].

Providing adequate care for the injured older adult is a complicated task requiring the participation of multiple specialists and disciplines. Evidence from several observational studies while supporting the value of routine involvement of a geriatrician in managing older adults after hip fracture or general trauma in improving outcomes shows significant variability in specific outcomes.

There are two major models for managing geriatric trauma.

The most common is a traditional consultation model. The primary team is surgical, with medicine or geriatric consult which can either be standardized referrals by protocol or on an as-needed basis. There have been many studies assessing

the role of a geriatrician, the optimal time for consultation, and which outcomes are improved.

A study by Fisher and colleagues evaluating the impact of a geriatric consultation instead of traditional general medical one in a level 1 trauma center demonstrated decrease in postoperative complications, reduction in mortality, and decreased rehospitalization, but no reduction in length of stay or discharge destination in patients with hip fracture [111]. Similar results for patients with hip fracture were observed in another study by Vidan and colleagues, conducted in Madrid, Spain, where the geriatric team included a geriatrician, a rehabilitation specialist, and a social worker, with the geriatrician visiting daily and being responsible for medical care [112].

Fallon and colleagues suggest that the best time to involve a geriatrician in managing all geriatric trauma patients is at the time when a patient is admitted to a ward or intensive care unit and suggest specific domains of concentration for that consultation: assisting with pain management, addressing polypharmacy, and diagnosis and management of hitherto undiagnosed conditions, such as dementia [113].

Another study of geriatric consultation in a level 1 trauma center also advocated for involvement of a geriatrician at the time of admission, and demonstrated reduction in rates of delirium and decreased rates of discharge to long-term care facilities among inpatients admitted from home. There was some trend toward decreased length of stay, but this was not statistically significant. Both of these studies are noticeable for an unusually high level of adherence to geriatric recommendations by the trauma team (91–93, 2 %) [114]. It has been shown that CGA, combined with the continuous involvement of geriatricians in clinical care, led to improved implementation of recommendations and produced better results, while multidisciplinary conferences not involving a physician, did not [115].

A Cochrane review on CGA evaluated 22 trials. One model of CGA occurred in discrete units with an interdisciplinary team who had full control of the care delivery. The second was mobile teams that assessed patients on their usual care units and made recommendations to the primary treating team. In their results they reported: "More older patients are likely to survive and return home if they receive CGA whilst an inpatient. Fewer will suffer death or deterioration. These effects are consistently demonstrated from trials of geriatric wards, but not replicated from trials of mobile peripatetic geriatric consultation teams on general wards although trial and participant numbers are much lower for this subgroup. CGA also appears to result in improved cognitive functioning. Timing of admission is less critical than place of admission and there is evidence of benefit from trials recruiting in the acute stage (admission from the Emergency Department) through to the postacute stage (step down rehabilitation wards). The benefit of CGA is adequate to justify the reorganisation of services where possible. This does not appear to result in increased costs to hospitals and from a societal standpoint appears to result in potential cost reductions. Systems evaluating compliance with best care are required to ensure healthcare providers are accountable for the delivery of in-hospital CGA for this growing sector of society" [116].

The second model involves specialized units for injured older adults.

In the United States, Acute Care for the Elderly (ACE) units are designed to help hospitalized elders maintain or regain independence. The ACE programs all have:

- An environment designed to promote orientation and mobility
- Medication review
- Interdisciplinary patient-centered care with nurse-driven protocols for common issues such as skin care and sleep disorders
- Social work intervention for early discharge planning and resource assessment

An example of a dedicated unit for care of injured older adults is the G-60 unit in a level 2 trauma center. Care is started in the ED and continued through the admission to a specially designated ward G-60. The team consisted of a trauma surgeon, a hospitalist, therapists, a nutritionist, a G-60 nurse supervisor, a social worker, a case manager, and a pharmacist. The key factors for improved outcomes were the multidisciplinary team approach, effective communication, and continuous quality improvement efforts. This model of care showed a decrease in hospital-acquired complications, such as pneumonia and UTI, decreased mortality rates, and decrease in LOS [117].

A model created in Germany, named a Certified Centre for Geriatric Trauma Surgery, provided geriatric trauma care for patients over 70 with fractures. Patients were seen by trauma surgeons, geriatricians, therapists, and a pharmacist. The outcomes were shorter time to surgery, with 81 % been done within 24 h of admission; mobilization within 24 h of surgery was achieved in 79 %. Implementation of a decubitus prevention protocol decreased the rate of decubitus from 8 to 3.2 %. Mortality rates for proximal femur fracture decreased from 5.7 % in 2010 to 5.1 % in 2011, 2.9 % in 2012, and 3 % in 2013. Most of the patients were discharged either to rehabilitation or directly home. Financially the model was not only sustainable but profitable [118]!

Conclusion

Older adults now constitute 35 % of all nonfatal acute trauma injury admissions and 27 % of all fatal trauma cases nationally, despite constituting only 17 % of the adult population [119]. One in five Americans will be eligible for Medicare by 2030.Those 65 and older are

expected to account for almost 20 % of the US population by 2030.

There are currently over 7500 allopathic and osteopathic certified geriatricians in the United States [120]. It is projected that approximately 30 % of the 65 plus patient population will need to be cared for by a geriatrician and that each geriatrician can care for a patient panel of 700 older adults. Based on these numbers, approximately 17,000 geriatricians are needed now to care for about 12 million older Americans [121].

Due to the projected increase in the number of older Americans, it is estimated that approximately 30,000 geriatricians will be needed by 2030. To meet this need, this would require training approximately 1200 geriatricians per year over the next 20 years which is not realistic under the current system.

Geriatricians must undertake teaching of other professionals and assist in the creation of evidence-based protocols that focus on outcomes such as maintenance of independence to ensure that other healthcare providers have training that prepares them to meet the unique healthcare needs of older people.

Programs to educate physicians and advanced practice clinicians raise awareness of geriatric issues and may lead to improvement in clinical practice and outcomes. One example is the program developed by the University of Chicago: Care for the Hospitalized Aging Medical Patient (CHAMP). This has modules on geriatric topics which can be used to educate providers and has been designed to be taught by non- geriatricians. http://champ.bsd.uchicago.edu

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Critical Care Epidemiology and Outcomes/Resource Use in the Elderly

34

Samantha L. Tarras and Lena M. Napolitano

Growth of the Elderly Population

Elderly is defined as age ≥65 years by the World Health Organization and the US Census Bureau [1]. According to the 2013 US Census data, the population with age ≥65 years is 44.7 million (25.1 million females, 19.6 million males) comprising 14.1 % of the total population. The elderly population continues to increase (Fig. 34.1) [2].

The USA has seen a rapid growth in its elderly population during the twentieth century. There has been an 11-fold increase in the number of Americans age ≥65 years, with 35 million in 2000 vs. 3.1 million in 1900. For the same years, the ratio of elderly to the total population jumped from 1/25 to 1/8. The trend is guaranteed to continue in the coming century as the "baby-boom" generation grows older. Between 1990 and 2020, those aged 65–74 is projected to grow 74 %.

The elderly population explosion is a result of an impressive increase in life expectancy. When the nation was founded, the average American could expect to live to the age of 35. Life expectancy at birth had increased to 47.3 by 1900, and the average American born in 2000 can expect to live to the age of 77.

The "oldest old" (those age ≥85) are the most rapidly growing elderly age group (Fig. 34.2). Between 1960 and 1994, they increased 274 % (three million, 10 % of elderly, 1 % of population) compared to 100 % increase in the elderly and a 45 % increase in the entire population. It is expected the oldest old will number 19 million in 2050, comprising 24 % of the elderly and 5 % of all Americans.

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Critical Care Resource Use in the Elderly

Elderly patients (age >65 years) currently comprise 42–52 % of ICU admissions and account for almost 60 % of all ICU days in the USA [3]. In addition, 40 % of Medicare patients who die are admitted to the ICU during their terminal illness, with decedents accounting for 25 % of all Medicare expenditures. Thus, a significant amount of critical care resources are used at the end of life caring for elderly patients.

Current estimates predict that by 2050, the percentage of the population older than 80 years will double, which will lead to an increasing demand for health-care resources, including intensive care [4]. In a large multicenter cohort study of 57 ICUs across New Zealand and Australia, elderly (age ≥80 years) patient ICU admissions increased roughly 6 % per year between 2000 and 2005 and represented approximately 14 % of total admissions in 2005 [5].

Although increasing numbers of very elderly patients are requiring ICU care, few large sample studies have investigated ICU admission of very elderly patients. An observational cohort study from 15 hospitals in France examined interhospital variability of ICU admission rates from the

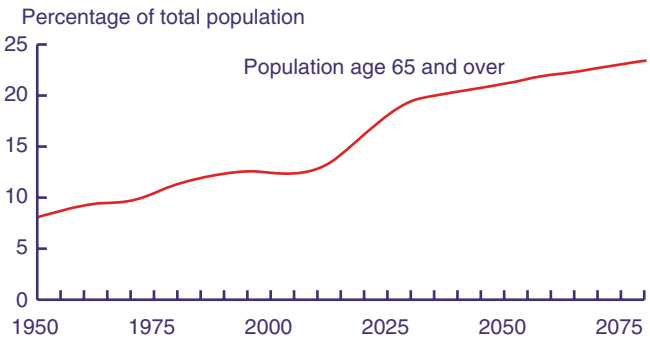

Fig. 34.1 Growth in the elderly population in the USA (*Source*: Social Security Administration, Office of the Chief Actuary. *Note*: Projections based on intermediate assumptions of the *2003 Annual Report of the Board of Trustees of the Federal Old-Age and Survivors Insurance and the Federal Disability Insurance Trust Funds*)

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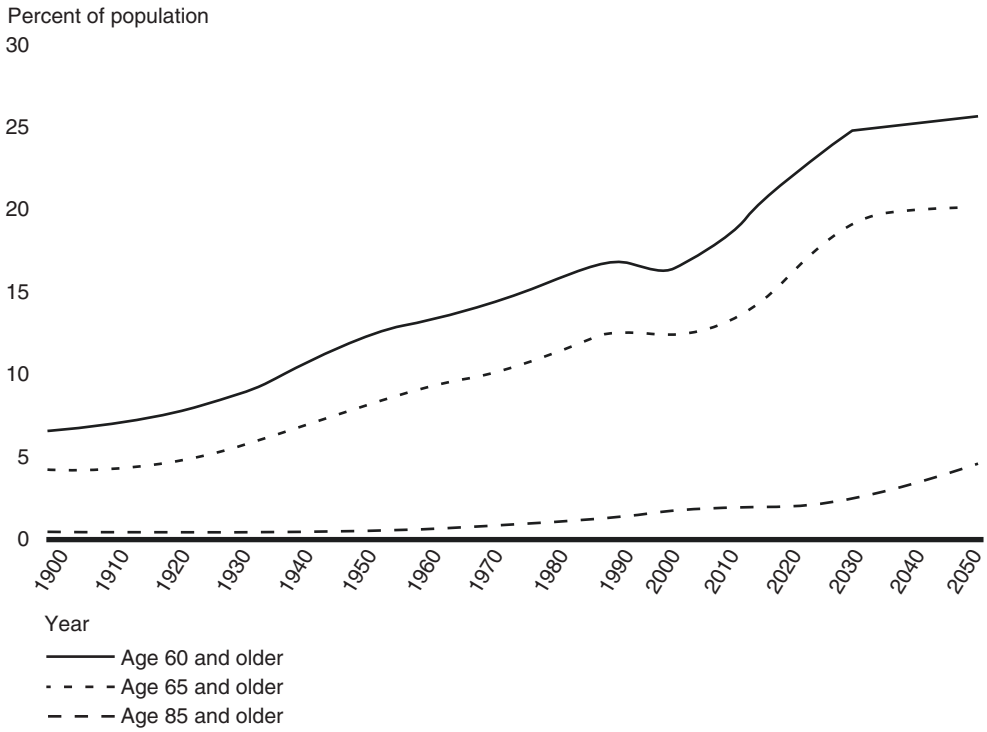

Fig. 34.2 Growth in elderly vs. super-elderly population in the USA (*Source*: GAO analysis of US Census Bureau data by the Administration on Aging)

emergency department and its association with elderly patients' (age >80) outcomes over a 1-year period. Rates of patients deemed eligible for ICU admission ranged from 5.6 to 38.8 % across the participating centers, and this variability persisted after adjustment for patients' characteristics. Despite this variability, no association between level of ICU eligibility and either in-hospital death or 6-month death or functional deterioration was identified. In France, the likelihood that an elderly person will be admitted to an ICU varies widely from one hospital to another, and influence of ICU admission on elderly patients' outcome remains unclear [6].

Critical Care Outcomes in the Elderly

ICU mortality for those older than 65 years (36.8 %) is significantly higher when compared to that for those less than 45 years old (14.8 %). In addition, elderly patients discharged from the ICU to subacute facilities have a higher mortality rate than similar patients discharged home.

In a study of 484 patients admitted to medical, surgical, and coronary ICUs in a large urban teaching hospital, it was determined that one-third (1/3) of adults older than 64 years admitted to the ICU die within 6 months of hospital discharge. Independent predictors of death at 6 months were number of days during the 30 days before hospitalization that the patient felt their "physical health was not good" on the health-related quality of life survey [odds ratio = 1.08; confidence interval 1.04–1.12], a higher Acute Physiology and Chronic Health Evaluation II score [OR 1.09; 95 % CI 1.06–1.12], and chronic pulmonary disease as a comorbidity [OR 2.22; 95 % CI 1.04–4.78]. Among survivors at 6 months, health-related quality of life had significantly worsened over time in the oldest patients but improved in the youngest survivors [7].

A larger study has confirmed similar findings [8]. A matched, retrospective cohort study was conducted using a 5 % sample of Medicare beneficiaries older than 65 years. There were 35,308 ICU patients who survived to hospital discharge. The ICU survivors had a higher 3-year mortality (39.5 %; n = 13,950) than hospital controls (34.5 %; n = 12,173) (adjusted hazard ratio [AHR], 1.07 [95 % CI, 1.–1.10]; $p < .001$) and general controls (14.9 %; n = 5266) (AHR, 2.39 [95 % CI, 2.31–2.48]; $p < .001$).

Those receiving mechanical ventilation had substantially increased mortality (57.6 % [1234 ICU survivors] vs. 32.8 % [703 hospital controls]; AHR, 1.56 [95 % CI, 1.40–1.73]), with risk concentrated in the 6 months after the quarter of hospital discharge (6-month mortality, 30.1 % (n = 645) for those receiving mechanical ventilation vs. 9.6 % (n = 206) for hospital controls; AHR, 2.26 [95 % CI, 1.90–2.69]). Discharge to a skilled care facility for ICU survivors (33.0 %; n = 11,634) and hospital controls (26.4 %; n = 9328) also was associated with high 6-month mortality (24.1 % for ICU survivors and hospital controls discharged to a skilled care facility vs. 7.5 % for ICU survivors and hospital controls discharged home; AHR, 2.62 [95 % CI, 2.50–2.74]; $p < .001$ for ICU survivors and hospital controls combined).

This study confirmed that there is a large US population of elderly individuals who survive the ICU stay to hospital discharge but who have a high mortality over the subsequent years in excess of that seen in comparable controls. The risk is concentrated early after hospital discharge among those who require mechanical ventilation.

Frailty and ICU Outcomes in the Elderly

It is important to consider not only age but functional status in elderly patients. The scoring systems currently used do not precisely assess comorbidity and prehospital functional status or disability. Frailty has recently been established as a concept to assess loss of physiological reserves and an inability to maintain homeostasis to combat disease or injury. Common signs include fatigue, weight loss, weakness, low activity level, slow motor performance, and cognitive loss. Frailty can be assessed by different scoring systems (frailty phenotype, clinical frailty score, Katz Index of Independence in activities of daily living). Recent studies have confirmed that frailty is a frequent occurrence in elderly ICU patients and is independently associated with increased ICU and 6-month mortality. Furthermore, frailty scales predict outcome more effectively than the commonly used ICU illness scores.

Planned Surgical Versus Medical and Unplanned Surgical ICU Admissions

Elderly patients requiring ICU admission after planned surgery have better long-term outcomes compared to elderly medical and unplanned surgical ICU admissions. This is likely related to the ability to optimize the elderly patient physiologically for surgical intervention.

Guidelines were recently published for optimal preoperative assessment of the geriatric surgical patient from the American College of Surgeons National Surgical Quality Improvement Program and the American Geriatrics Society. The guidelines recommend and specify 13 key issues of preoperative care for the elderly: cognitive impairment and dementia; decision-making capacity; postoperative delirium; alcohol and substance abuse; cardiac evaluation; pulmonary evaluation; functional status, mobility, and fall risk; frailty; nutritional status; medication management; patient counseling; preoperative testing; and patient-family and social support system [9].

Outcome Measures: Mortality Versus Long-Term Functional Outcomes

ICU survival may not be the most appropriate endpoint when evaluating the role of critical care, particularly in the elderly. The goal of critical care medicine is to restore patients to a level of function similar to that of their preadmission status. A practical goal, therefore, is to define the most accurate criteria for identification of elderly ICU patients most likely to benefit from ICU care regardless of age.

A study of long-term outcome in medical patients aged 80 or over following admission to an ICU documented a hospital mortality rate of 55 % with only 47 % of the ICU patients still alive at 2 years. Interestingly, factors independently associated with mortality were SAPS II score at ICU admission and the McCabe score. Conversely, functional status prior to admission (as assessed by Knaus or Karnofsky scores) was not associated with long-term mortality. In long-term survivors, SF-36 physical function scores were poor, but scores for pain, emotional well-being, and social function were not much affected. In addition, the group that was discharged had increased mortality compared to the general population of the same age not admitted to an ICU [10].

A prospective cohort study from a 10-bed, medical-surgical ICU in a 460-bed, tertiary, university hospital in France examined the outcome, functional autonomy, and quality of life of elderly patients (≥70 years, $n = 75$) hospitalized for more than 30 days in an ICU. The survival rate was 67 % in the ICU and 47% survived to discharge. Independence in activities of daily living was decreased significantly after the ICU stay, except for feeding. However, most patients remained independent (class A of the activities of daily living index) with the possibility of going home. Perceived quality of life scores remained good, even if the patients estimated a decrease in their quality of life for health and memory. Return to society appeared promising regarding patient self-respect and happiness with life. The estimated cost per survivor was of 55,272 EUR ($60,246 US). This study suggested that persistent high levels of ICU therapeutic intensity were associated with a reasonable hospital survival in elderly patients experiencing prolonged mechanical ventilatory support. These patients presented a moderate disability that influenced somewhat their perceived quality of life. These results are sufficient to justify prolonged ICU stays for elderly patients [11].

Elderly Critical Care Trauma Outcome and Resource Utilization

Elderly patients are at high risk for mortality after injury. According to 2010 National Vital Statistics Report preliminary data, accidental death was the ninth leading cause of death for those greater than 65 years old, with 15 % of these accidental deaths from motor vehicle collisions. Elderly trauma patients have increased mortality risk compared to younger trauma patients in all injury severity categories (Fig. 34.3).

A review of 26,237 blunt trauma patients admitted to all trauma centers ($n = 26$) in one state over 24 months confirmed that elderly (age ≥65 years, $n = 7117$) patients had

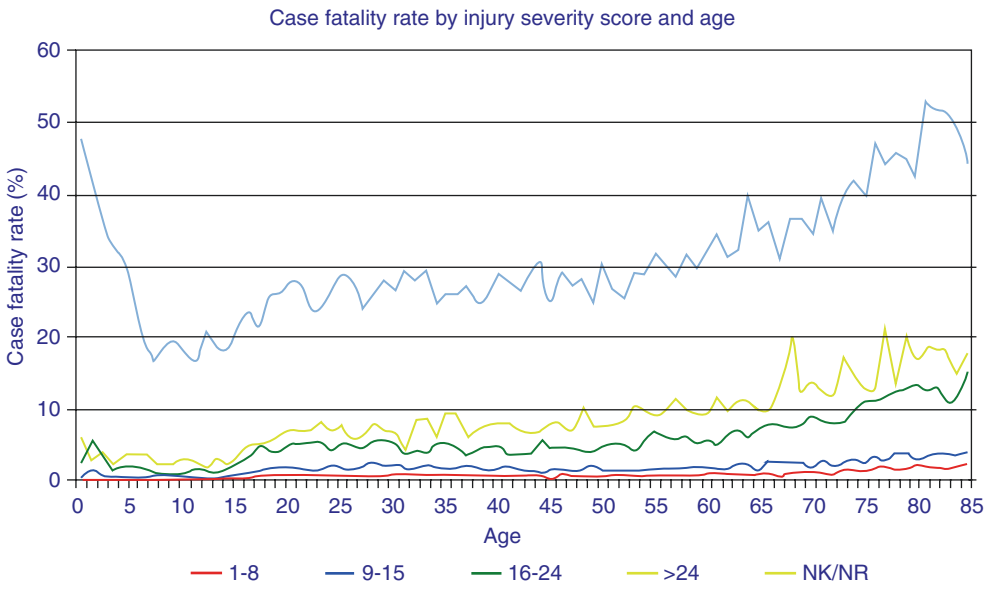

Fig. 34.3 Data from National Trauma Data Bank, Case Fatality Rate by Injury Severity Score and Age (American College of Surgeons NTDB)

significantly higher mortality rates than younger (age <65 years) trauma patients after stratification by Injury Severity Score (ISS), revised trauma score, and other pre-existing comorbidities. Age greater than 65 years was associated with a two- to threefold increased mortality risk in mild (ISS <15, 3.2 % vs. 0.4 %; <0.001), moderate (ISS 15–29, 19.7 % vs. 5.4 %; <0.001), and severe traumatic injury (ISS ≥30, 47.8 % vs. 21.7 %; <0.001) compared with patients younger than 65 years. Logistic regression analysis confirmed that elderly patients had a nearly two-fold increased mortality risk (OR 1.87; confidence interval, 1.60–2.18; <0.001). Elderly patients also had significantly longer hospital LOS after stratifying for severity of injury by ISS (1.9 fewer days in the age 18–45 group, 0.89 fewer days in the age 46–64 group compared with the age over 64 group). Mortality rates were higher for men than for women only in the ISS <15 (4.4 % vs. 2.6 %, <0.001) and ISS 15–29 (21.7 % vs. 17.6 %, = 0.031) groups. ICU LOS was significantly shorter in elderly patients with ISS ≥30. This study confirmed age as an independent predictor of mortality in trauma after stratification for injury severity in this largest study of elderly trauma patients to date. Interestingly, elderly patients with severe injury (ISS >30) had decreased ICU resource use secondary to associated increased mortality rates [12].

In a single-center Level I trauma center study, it was confirmed that age alone was associated with increased odds of being admitted to the hospital, independent of injury severity and other physiologic parameters. A total of 451 (8.68 %) elderly patients were 65 years or older; 62 % of the total population was admitted. Elderly patients had a significantly higher hospital admission rate (86.7 %; $p < 0.001$). Multivariate analysis showed that age over 64 years (OR 3.76), head injury (OR 5.3), ISS (OR 17.5), Glasgow Coma Scale score on arrival (OR 0.753), and initial systolic blood pressure (OR 0.987) were significant independent factors predictive of hospital admission ($p < 0.001$). Elderly patients were also admitted to the ICU at a higher rate (60.9 % vs. 38.5 %, $p < 0.001$) and were more likely to remain there for a longer period of time. Greater than 75 % of the elderly patients stayed for over 3 days. This has implications for trauma centers that see a significant proportion of geriatric trauma patients and for trauma systems that must prepare for the "aging of America" [13].

Trauma benchmarking efforts benefit from development of a geriatric-specific model for risk-adjusted analyses of trauma center outcomes. A total of 57,973 records of elderly patients (age older than 65 years) with data from the National Trauma Data Bank (NTDB) and the National Sample Project were used to construct a multivariable logistic regression model, which was compared with the American College of Surgeons Committee on Trauma's Trauma Quality Improvement Project's (TQIP) existing model. Additional analyses were performed to further objectively quantify the physiologic differences between geriatric patients and their younger counterparts. The geriatric-specific and TQIP mortality models shared several covariates: age, ISS, motor component of the Glasgow Coma Scale, and systolic blood pressure. This new model additionally used temperature and the presence of mechanical ventilation. This geriatric-specific regression model compared with the TQIP approximation (0.85 vs. 0.77; $p = 0.048$). Spline analyses demonstrated that elderly patients appear to be less likely to tolerate relative hypotension with higher observed mortality at initial systolic blood pressures of 90–130 mmHg. Although the TQIP model includes a single-age component, these data suggest that each variable needs to be adjusted for age to more

accurately predict mortality in the elderly. Clearly, a separate geriatric model for predicting outcomes is not only warranted but necessary [14].

Super-Elderly Trauma Patients

The fastest-growing segment of the population is the "super-elderly," i.e., those greater than 85 years old. It is projected that those 85 years and older will double from 2000 to 2030. By 2050 this age group will be five times larger than in 2000 and will make up a little over 4 % of the total population. Despite this growth there is little information of trauma outcomes in this group.

In a retrospective cohort study from a countywide trauma registry, overall mortality of very elderly trauma patients (n = 455, mean age 85.9 years, range 80–101) was 10 %, with head injury and injury severity as independent risk factors for increased mortality. They also confirmed that very elderly patients admitted to trauma centers (Levels I and II) had better outcomes than nontrauma centers, especially in the high injury severity (ISS 21–45) cohort (mortality 56 % vs. 8 % survival; $p < 0.01$) [15].

Another study compared the post-injury outcomes of super-elderly patients (n = 422, age ≥80 years) to elderly patients (n = 898, age 60–79 years) treated at a Level I trauma center after adjustment for gender, mechanism of injury, Glasgow Coma Scale, ISS, and admission vital signs. Super-elderly patients had significantly higher risk-adjusted in-hospital mortality compared with elderly patients [13.4 % vs. 7.7 %, adjusted OR 1.94 (95 % CI 1.14, 3.31), $p = 0.015$]. Of patients surviving hospitalization, super-elderly patients experienced shorter ICU and hospital length of stay but were more likely to require discharge to another level of care, defined as nursing facility, acute rehabilitation facility, or long-term acute care facility (AOR 3.78, CI 2.75–5.28, $p < 0.0005$). Importantly, super-elderly patients were more likely than elderly patients to die during hospitalization as a result of withdrawal of medical support (9.5 % vs. 5.5 %, $p = 0.007$) [16].

Performance Improvement in Elderly Trauma

Given the high mortality rate for elderly trauma patients, attention to modifiable risk factors in establishing a performance improvement program is imperative. Delays in recognizing the special needs of older trauma patients may result in suboptimal care.

We have reported our performance improvement efforts in elderly trauma care. In 2004 (baseline data), the in-hospital mortality rate for the most severely injured trauma patients (ISS >24) at our trauma center was 30 %, consistent with the reported mortality rate from the NTDB for patients with this severity of injury. Over 5 years, our mortality rate decreased significantly for severely injured patients with an ISS > 24–18 %, representing a 12 % absolute reduction in mortality ($p = 0.011$). During the same 5-year time period, the proportion of elderly patients cared for at our trauma center increased from 23.5 % in 2004 to 30.6 % in 2008 ($p = 0.0002$), while there was a significant reduction in mortality over this time period. Class I trauma activations increased significantly from 5.5 % in 2004 to 15.5 % in 2008. A greater percentage of patients were admitted to the ICU (25.8 % vs. 30.4 %) with no difference in the mechanism of injury throughout the 5 years. Trauma Quality Improvement Program (TQIP) data for our institution confirmed improved trauma outcomes with observed-to-expected ratio and 95 % confidence intervals of 0.64 (0.42–0.86) for all patients, 0.54 (0.15–0.91) for blunt single-system patients, and 0.78 (0.51–1.06) for multisystem patients [17].

One method to improve trauma geriatric outcome is to establish geriatric-specific triage criteria to identify trauma center care in injured older adults. It has been established that standard adult EMS triage guidelines provide poor sensitivity in older adults and that geriatric trauma triage guidelines significantly improve sensitivity. A recent study has confirmed that trauma center care improves outcomes even in older, minimally injured patients and proposed that an age threshold (age ≥ 70 years) should be considered as a criterion for trauma center triage.

Another method to improve trauma geriatric outcome is to establish *geriatric trauma patient care protocols*. These protocols are created from evidence-based guidelines that serve to reduce variation in care. Patient care protocols have been found to positively impact patient care with reduced duration of mechanical ventilation, shorter LOS in the ICU and shorter overall hospitalization time, reduced mortality, and reduced health-care costs.

A single-institution study documented that use of new protocols helped guide practical changes in geriatric trauma care that resulted in a 32 % decrease in LOS for elderly trauma patients. The four protocols implemented were a VAP bundle, massive transfusion protocol, reversal of coagulopathy protocol, and rib fracture protocol [18].

Some trauma centers have created a dedicated *geriatric trauma service*. This concept was studied in a Level II trauma center which documented a significant decrease in the ED LOS and ICU LOS, decreased time from ED to OR, decreased hospital stay, and decreased mortality (3.8 % vs. 5.7 %). There was also a significant decrease in pneumonia, respiratory failure, and UTI rates [19]. Other institutions have been able to show similar results once standard protocols are initiated in the care of geriatric patients [20].

A number of trauma centers have developed an inpatient geriatric trauma consultation service (GTCS), a proactive geriatric consultation model aimed at preventing and managing age-specific complications, and discharge planning for

elderly patients admitted to the trauma service. A report by Fallon and colleagues in 2006 documented that geriatricians identified 14 % of patients who presented with alcohol issues, 36 % of patients exhibited signs of delirium, and 46 % of patients presented with a new medical condition(s). Geriatricians assisted with advanced care planning in 15 % of cases and disposition decisions to promote function in 49 %, made medication changes in 65 %, decreased inappropriate medications in 20 %, and assisted with pain management in 42 %. Trauma surgeons followed 91 % of one or more recommendations. They concluded that outcomes of older patients can be improved through geriatricians' expertise by addressing new and existing medical issues and reducing hospital-acquired complications such as functional decline, falls, delirium, and death [21].

A recent single-center before (n = 238)/after (n = 248) case series documented that the rate of adherence to recommendations made by the GTCS team was 93.2 %. There were fewer consultation requests made to Internal Medicine and Psychiatry in the post-GTCS group. Interestingly, there were no differences in any of the prespecified complications except delirium (50.5 % pre-GTCS vs. 40.9 % post-GTCS, p = 0.05). Among patients admitted from home, fewer were discharged to long-term care facilities among the post-GTCS group (6.5 % pre-GTCS vs. 1.7 % post-GTCS). This study documented that a proactive geriatric consultation model for elderly trauma patients may decrease delirium and discharges to long-term care facilities. Future studies should include a multicenter randomized trial of this model of care [22].

Most recently, the American College of Surgeon published the ACS TQIP Geriatric Trauma Management Guidelines. This document summarizes efforts to improve elderly trauma outcome, including initial evaluation (Table 34.1), standardizing when to obtain a geriatric consultation (Table 34.2), focus on medication management (Table 34.3), and pain control and delirium avoidance (Table 34.4). It serves as an important repository of performance improvement information relevant to the care of the elderly injured patient [23].

Table 34.1 Consideration in initial trauma evaluation of elderly patients

The primary survey for the elderly is the same as for any injured patient, but the secondary survey should emphasize the following:
Determine medications that affect initial evaluation and care
Coumadin
Clopidogrel
Other anticoagulants
ASA
Beta-blockers
ACE inhibitors
Consider common, acute, nontraumatic events that could complicate the patient's presentation, including:
Acute coronary syndrome (EKG)
Hypovolemia/dehydration
Urinary tract infection
Pneumonia
Acute renal failure
Cerebrovascular event
Syncope
Lab assessment:
Hypoperfusion is often underappreciated in the elderly. Base deficit should be assessed expediently to identify those patients in occult shock who need resuscitation, abbreviated evaluation, and admission to an intensive care unit. The following panel of laboratory studies is suggested for all elderly patients with injury:
Lactic acid or blood gas (arterial or venous) for baseline base deficit
PT/PTT/INR
Renal function (BUN, Cr, estimated GFR)
Blood alcohol level
Urine toxicology screen
Serum electrolytes

Table 34.2 Criteria for geriatric consultation

Develop criteria for early geriatric consultation and geriatric expertise on the multidisciplinary trauma care team
If the response to two or more of the following questions is "yes," geriatric consultation should be obtained:
Before you were injured, did you need someone to help you on a regular basis?
Since the injury, have you needed more help than usual to take care of yourself?
Have you been hospitalized for one or more nights during the past 6 months?
In general, do you have problems seeing well?
In general, do you have serious problems with your memory?
Do you take more than three different medications every day?

Outcomes in Special Populations

Respiratory Failure Requiring Mechanical Ventilation

The incidence of acute respiratory failure (ARF) in the 65–84 age group is twice that of the 55–64-year-old group [24]. Since respiratory failure is a common reason for ICU admission in the elderly, examination of outcomes is important. Underlying etiology of ARF is no different than those for younger patients, but the ICU and hospital courses may be very different.

A large prospective observational study evaluated patients (n = 514) greater than 65 years old who presented to the ED for acute dyspnea. Only 29 % were admitted to the ICU. The main causes of ARF were cardiogenic pulmonary edema (43 %), community-acquired pneumonia (35 %), acute exacerbation of chronic respiratory disease (32 %), pulmonary

Table 34.3 Geriatric trauma patients are at particular risk for medication-related adverse events

Establish past medication history
Attempt to communicate with the patient's immediate family and physician
Document the patient's complete medication list, including over-the-counter and complementary/alternative medication
Use the following geriatric medication prescribing recommendations:
Follow Beers Criteria. Use Beers Criteria in decision-making about pharmacotherapy
Discontinue nonessential medications
Continue medications with withdrawal potential, including selective serotonin reuptake inhibitors (SSRIs), tricyclic antidepressants, benzodiazepines, antipsychotics, monoamine oxidase inhibitors (MAOIs), beta-blockers, clonidine, statins, and corticosteroids
Continue β-blocker or start if indicated
Continue statins when appropriate
Adjust doses of medications for renal function based on glomerular filtration rate

Table 34.4 Pain control and delirium avoidance in elderly trauma patients

Effective pain management can be a central determinant of success in the drive to improve pulmonary and toilet functions, optimize mobility, and mitigate delirium
The following pain medication strategies are recommended:
Use elderly appropriate medications and dose
Avoid benzodiazepines
Monitor use of narcotics; consider early implementation of patient-controlled analgesia
Consider early use of nonnarcotics, including NSAIDs, adjuncts, and tramadol
Epidural algesia may be preferable to other means for patients with multiple rib fractures to avoid respiratory failure

embolism (18 %), and acute asthma (3 %); 47 % had more than two diagnoses. In-hospital mortality was 16 %. A missed diagnosis in the ED was noted in 101 (20 %) patients. The accuracy of the diagnosis of the emergency physician ranged from 0.76 for cardiogenic pulmonary edema to 0.96 for asthma. An inappropriate treatment occurred in 162 (32 %) patients and led to a higher mortality (25 % vs. 11 %; $p < 0.001$). In a multivariate analysis, inappropriate initial treatment (OR 2.83, $p < 0.002$), hypercapnia greater than 45 mmHg (OR 2.79, $p < 0.004$), creatinine clearance less than 50 (OR 2.37, $p < 0.013$), elevated B-type natriuretic peptide (OR 2.06, $p < 0.046$), and clinical signs of ARF (odds ratio 1.98, $p < 0.047$) were predictive of death. The rates of ICU admission and mortality (25 % vs. 11 %, $p < 0.001$) were significantly higher in patients with an inappropriate initial ED treatment and error in initial diagnosis. Most of the difference in mortality occurred within a few days of admission [25].

Older studies examining outcomes of elderly patients requiring mechanical ventilation reported ICU risk-adjusted mortality as 38 % and all-cause mortality 60, 63, and 67 % at 6, 12, and 18 months, respectively [26]. More recent studies have reported ICU mortality rates between 31 and 52 % for 6 months post-discharge [27].

Prolonged mechanical ventilation (greater than 21 days) is associated with even higher rates of mortality in the elderly. One year out from prolonged mechanical ventilation, 67 % of those older than 65 years had died. The cost of prolonged mechanical ventilation, although this study also included patients less than 65 years old, per 1 year survivor was $423,596 [28].

In a study of functional outcomes after mechanical ventilation, only 11 % of geriatric patients were doing well and achieved a Functional Independence Measure (FIM) scale score greater than or equal to 90 at 1 year [29]. This cohort also had poor survival rates of 33 % at the end of hospitalization and 22 % at 1 year. Are we able to predict which elderly patients will have improved outcome on mechanical ventilation? In a study of critically ill, mechanically ventilated medical patients, severity of acute illness and chronic comorbidities, but not age, were independent predictors of ICU and hospital mortality [30]. As intensivists, we should then focus on determining the cause of ARF and implement appropriate management based on the disease etiology.

Respiratory Failure Requiring Noninvasive Ventilation

Noninvasive ventilation (NIV) is frequently used for the management of ARF in very old patients (≥80 years), often in the context of a do-not-intubate order (DNI). A number of studies have examined the efficacy of NIV and its impact on long-term outcome.

A prospective cohort study documented outcomes of all patients admitted to the medical ICU of a tertiary hospital during a 2-year period and managed using NIV. Characteristics of patients, context of NIV, and treatment intensity were compared for very old and younger patients. Six-month survival and functional status were assessed in the very old patients. During the study period, 1019 patients needed ventilatory support and 376 (37 %) received NIV. Among them, 163 (16 %) very old patients received ventilatory support with 60 % of them successfully managed using NIV compared with 32 % of younger patients ($p < 0.0001$). Very old patients received NIV more frequently with a DNI order than in younger patients (40 % vs. 8 %). Such cases were associated with high mortality for both very old and younger patients. Hospital mortality was higher in the very old than in younger patients but did not differ when NIV was used for cardiogenic pulmonary edema, acute-on-chronic respiratory failure (20 % vs. 15 %), and in post-extubation (15 % vs. 17 %) out of a context of DNI. Six-month mortality was 51 % in very old

patients, 67 % for DNI patients, and 77 % in setting of NIV failure and subsequent endotracheal intubation. Of the 30 hospital survivors, 22 lived at home and 13 remained independent for activities of daily living. This study confirmed that very old patients managed using NIV have an overall satisfactory 6-month survival and functional status, except for endotracheal intubation after NIV failure [31].

The effectiveness of NIV in treating patients with ARF is related to the ability to diminish endotracheal intubation, the reduction of ventilator-associated lung infections, as well as related mortality. A specific issue is the outcome of NIV in patients admitted to the ED for ARF who receive a DNI order because of severe acute illness or advanced age. Recent data show that elderly patients (mean age 81 years) with ARF who have a DNI order can be successfully treated by NIV, as demonstrated by a survival rate of 83 %. The positive outcome was confirmed by a subsequent 3-year observation that demonstrated an overall survival rate of 54 %. These findings clearly suggest that NIV treatment in elderly patients may be effective, even in the presence of a DNI order [32].

Critical Care Resource Utilization and Physiology of Aging

The most common organ systems that require support in the critically ill are cardiac, pulmonary, and renal, and the physiology of these systems changes significantly in the elderly, resulting in increased need for organ support and critical care resource utilization in these patients.

Cardiac Physiology

There is a lack of cardiac reserve once a person reaches the age of 70. Other structural changes are a progressive decrease in the number of myocytes and an increase in myocardial collagen content. Autonomic tissue is replaced by connective tissue and fat, and fibrosis causes conduction abnormalities through the internodal tract and the bundle of His. Clinically, this contributes to the increased incidence of sick sinus syndrome, atrial arrhythmias, and bundle branch blocks. The older heart also becomes less responsive to sympathetic stimulation. Therefore, to increase cardiac output in the aged heart, the stroke volume has to increase by increasing ventricular filing (preload). Elderly patients are very sensitive to fluid status and even minor hypovolemia can induce cardiac dysfunction. Arteries become stiffer with age which results in a compensatory myocyte enlargement and left ventricular hypertrophy. This leads to diastolic dysfunction which accounts for the majority of heart failure in patients over 80 years. Resting heart rate is the same as seen in younger patients; however, the chronotropic response to exercise decreases with age. Diastolic ventricular filling is dependent on atrial contraction which is why atrial fibrillation is poorly tolerated particularly in the elderly patient population, especially if diastolic dysfunction is present. Furthermore, age is a significant risk factor for coronary artery disease and its associated complications. As a person ages, atypical presentations of cardiac ischemia and dysfunction are more prevalent and may go unrecognized or silent in greater than 40 % of patients older than 75 years old. Chapter 2 reviews in detail the impact of aging on cardiac physiology.

Pulmonary Physiology

Changes both in chest wall mechanics and lung compliance alter pulmonary physiology. Structural changes of kyphosis and vertebral collapse decrease chest wall compliance, and decrease in muscle strength can result in reduction of inspiratory and expiratory force as much as 50 %. Total lung capacity and vital capacity decline in the elderly while the residual volume and functional residual capacity are increased. Within the lung parenchyma, there is a loss of elasticity with collapse of small airways and uneven alveolar airflow with air trapping. The alveolar to arterial difference for oxygen (Aa gradient) increases significantly with aging due to this ventilation-perfusion mismatch. Control of ventilation is also affected by aging. The respiratory centers response to hypoxia and hypercapnia decreases by 50 and 40 %, respectively. With aging, the respiratory reserve declines just as with respect to cardiac reserve. These pulmonary changes result in increased incidence of acute respiratory dysfunction and failure requiring noninvasive or invasive mechanical ventilation. Please see Chap. 3 for a detailed discussion of the physiologic changes of the pulmonary system with aging.

Renal Function

Between the ages of 25 and 85 years, approximately 40 % of the nephrons become sclerotic. While the remaining functional units hypertrophy in a compensatory manner, there is a decline in the glomerular filtration rate (GFR). However, the serum creatinine remains unchanged as one ages because of the concomitant decrease in lean body mass and decrease in creatinine production. In the critically ill, the GFR may be affected by other factors such as nephrotoxic medications and muscle breakdown from sepsis, trauma, and immobility. The aging kidney also has diminished capacity to regulate fluid and acid–base status. This is thought to be due to a decline in activity of renin–angiotensin system and decreased responsiveness to antidiuretic hormone. The elderly patient is therefore at high risk for development of hypovolemic

shock. Finally, as many ICU medications undergo renal excretion, dose adjustment is required in elderly patients with diminished GFR to avoid toxic levels.

Efforts to Improve Elderly Outcomes

As critical care treatment and organ support continues to improve, we must examine efforts to improve elderly patient-centered outcomes in the ICU, which is not always consistent with ICU survival.

Advance Directives/POLST

It is important to establish goals of care in elderly patients as soon as possible and ideally before admission to an ICU. We must aspire to make certain that all of our patients have advance directives, so that treatment goals are in line with patient's wishes.

Most recently, some states have mandated that all patients should have physician orders for life-sustaining treatment (POLST) [33]. POLST was originally developed in Oregon in 1991 to create a coordinated system for eliciting, documenting, and communicating the life-sustaining treatment wishes of seriously ill patients. There are 12 states that have endorsed POLST programs and 28 states in the development stages. The POLST document is completed by the health-care professional with a patient or surrogate decision-maker. How this differs from an advance directive is that it gives clear orders to a physician who might not be familiar with the patient and specifies what to do if the patient is confronted by a serious illness. Advance directives can be vague or not specific enough (e.g., not to prolong dying through artificial means, feeding tube vs. no feeding tube) and are usually not filled out in the presence of a health-care professional to encourage a discussion between the patient's family and physician.

The form includes a section on cardiopulmonary resuscitation, whether to resuscitate or do not resuscitate in the event of a cardiopulmonary arrest. The second section is about medical interventions, whether to perform comfort measures vs. limited additional intervention (usually means no ICU involvement) vs. full treatment. The second section also includes the decision of whether to transfer to a hospital or not. The third section is about medically administered nutrition, such as no tube, no permanent tube, or a defined trial of nutrition. The last section is the signature section that is to include both the patient and the physician. A copy of this form is included in the medical record, and another copy is to remain with the patient as they transfer across settings of care. In California and Oregon, these forms are maintained in a registry that can be access by emergency personnel and any hospital 24 h a day.

Studies have documented that POLST use significantly reduces unwanted hospitalizations, provides treatment consistent with patient's wishes more than 90 % of the time, and decreases the medical errors in their care. Eighty-five percent of transfers to a hospital are because the nursing facility could not control the patient's suffering. In several studies, the POLST form is embraced by health-care professionals. In comparison to those that have a power of attorney for health care appointed, those with POLST were more likely to die in a nursing home and die from a terminal or chronic illnesses, saving the cost of a hospital admission. Concerns that some patients and/or their families have voiced are that the form might be misplaced and not be honored outside of the nursing home. This study was from North Carolina where there is not a government-maintained registry as in California and Oregon.

Delirium Prevention, Diagnosis, and Management

An important area for improvement in the care of the critically ill elderly is the prevention, recognition, and treatment of delirium. Delirium is characterized by inattention and acute cognitive dysfunction. It is extremely common in the ICU setting. The incidence can reach as high as 70–87 % of elderly patients admitted to the ICU.

Risk factors for delirium are numerous; however, there are specific ones that have the potential to be modified. These included sensory impairment, such as not providing a patient with their glasses or hearing aid, or not speaking loudly enough, in order for a patient to hear. Immobilization is another risk factor; this not only includes restraints but excess catheters, tubes, and IVs that place the patient a risk for a fall, so they are less likely to get out of bed. Medications, pain, and sustained sleep deprivation are risk factors for delirium in the elderly. After controlling for baseline patient characteristics and etiological factors, patients with delirium have poorer outcomes, and the more severe the episode, the worse the outcome.

Specific risk factors for dementia during a critical illness in elderly have been determined. A cohort study of a random 5 % sample of Medicare beneficiaries who received intensive care in 2005 and survived to hospital discharge, with 3 years of follow-up, was conducted. Over the 3 years of follow-up, dementia was newly diagnosed in 4519 (17.8 %) of 25,368 patients. After accounting for known risk factors, having an infection (adjusted hazard ratio (AHR) = 1.25; 95 % CI, 1.17–1.35), or a diagnosis of severe sepsis (AHR = 1.40; 95 % CI, 1.28–1.53), acute neurologic dysfunction (AHR = 2.06; 95 % CI, 1.72–2.46), and acute hemodialysis (AHR = 1.70; 95 % CI, 1.30–2.23) were all independently associated

with a subsequent diagnosis of dementia. No other measured ICU factors, such as need for mechanical ventilation, were independently associated [34].

The most commonly used screening tool for delirium is the Confusion Assessment Method for the ICU (CAM-ICU). This has high sensitivities of 93–100 % and high specificities of 98–100 % when performed by trained critical care nurses. In addition, most ICU patients when they experience delirium are characterized by the hypoactive subtype and so often go unrecognized but are still at risk for prolonged ICU course and increase risk of complications.

It is estimated that 30–40 % of cases of delirium are preventable, and we should strive to prevent the adverse outcomes associated with delirium. One strategy that can be initiated is the Hospital Elder Life Program (HELP). It includes maintaining orientation to surroundings; meetings needs for nutrition, fluids, and sleep; promoting mobility within the limitations of physical condition; and providing visual and hearing adaptations for patients with sensory impairments. This program decreases the development of delirium from 15 % in the control group vs. 9.9 % in the intervention group. This program also decreased the total number of episodes and days of delirium in the hospital and hence decreased overall costs and resource utilization. The complications of delirium include aspiration, pressure ulcers, pulmonary emboli, and decreased oral intake.

Another measure used to decrease the risk of delirium is proactive geriatric consultations. This measure was shown to decrease the risk of delirium by 40 % in acute hip fractures. In addition, hospital staff education about delirium and its management can reduce delirium rates and/or duration.

Once delirium develops, goals should be made to decrease its duration and prevention of any harm to the patient by themselves. First-line delirium treatment is always nonpharmacological strategies, including providing a quiet patient care setting with minimal noise, minimal sleep interruptions, and support from family members or people that the patient is familiar with to reorient them. Other methods to help patients sleep include providing a glass of warm milk or herbal tea, relaxation tapes or relaxing music, and finally a back massage. If these methods do not work, then pharmacological strategies must be added to the treatment regimen, and this is particularly true with those in hyperactive delirium, where the agitation could be harmful.

Several national quality agencies have used delirium as a marker for quality of care and patient safety. Delirium is an important independent determinant of hospital stay, mortality, rates of nursing home placement and functional, and cognitive decline. Delirium results in increased nursing time per patient, higher per day hospital cost, and increased length of hospital stay. In addition, many of these patients will go to nursing facilities or additional home health care which will add to increase costs. Thus, if delirium can be prevented in one patient, cost saving up to $64,000 per year can be appreciated.

Nutrition Support

With the aging process, there are physiological changes and social factors that play a role in nutrition in the elderly. Dietary inadequacy is present in 7–21 % of community elderly from poor enteral intake. As a person ages, their sense of smell and taste decrease, leading to a decreased desire for food. Loss of appetite in the elderly is referred to as the physiological anorexia of aging and may predispose to protein and energy undernutrition. In addition there is impaired absorption of some micronutrients and mineral, especially vitamins B12 and D, calcium, and iron. The social factors of isolation, poverty, loss of spouse, and alcoholism also may contribute to reduced food intake. Thus, when elderly patients present to the hospital, they are already undernourished, and critical illness may worsen their malnourished state. Early and prompt attention to nutrition in the elderly critically ill and trauma patient is of utmost importance [35].

Infection Prevention

Infection and sepsis are common complications that occur in critically ill elderly patients, and all efforts to prevent these infectious complications should be implemented [36]. Most ICUs focus on infection prevention directed at catheter-associated urinary tract infection (CA-UTI), ventilator-associated pneumonia (VAP), and central line-associated bacteremia (CLABSI). The compendium of strategies for prevention of health-care-associated infections in Acute Care Hospitals provides an evidence-based foundation for infection prevention [37].

Conclusion

Elderly patients comprise an increasing percentage of ICU admissions requiring significant critical care resource utilization. Aging is associated with a progressive increase in the risk of ICU death. A significant amount of critical care resources are used at the end of life in elderly patients. It is imperative to determine goals of care in all elderly patients considered for ICU admission. Efforts to decrease resource utilization in elderly patients require prevention of complications (infection, delirium, respiratory failure) and performance improvement strategies, including use of

protocols, geriatric consultation, and specialized elderly units. Optimal goals of care in elderly ICU patients should be consistent with patient desires.

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Cardiovascular/Invasive Monitoring

35

Jay Menaker and Thomas M. Scalea

Introduction

The elderly population, those over the age of 65 years of age [1–4], represents one of the fastest-growing sections of the US census. In 2010, there were 40.3 million people aged 65 and older, 12 times the number in 1900 [5]. It is estimated that by the year 2050, the population of elderly is expected to double as compared to 2000 and account for almost 21 % of the US population [5]. Additionally, it is predicted that by the year 2030, those over the age of 85, the oldest old, will number more than 9 million [6]. This increase in the number of elderly is multifactorial but is due in large part to longer life expectancy as well as the aging baby boomers.

Physiologic Changes

As people age, their physiologic reserve decreases. This loss of physiologic reserve is a slow process of deterioration often starting in people's 30s and continues with increasing age. Despite this decrease in reserve, most elderly people can compensate physiologically to meet needs under normal condition. However, when stressed, including acute trauma or illness, the demand is too much, and they are unable to effectively compensate and meet the physiologic demand to ensure adequate perfusion. The rate of physiologic change is variable from organ to organ and individual to individual [7].

Age is a major risk factor for the development of cardiovascular disease (CVD), and as such many elderly patients have some degree of CVD. CVD has been shown to be responsible for more than 40 % of death in patients over the age of 65 years [8]. Age-related changes in the myocardium affect anatomical as well as physiologic and electrophysiologic activity of the heart [9]. The elderly often have decreased myocardial contractility and ventricular compliance for a given preload as a result of loss of myocytes and increased myocardial collagen [10]. Autonomic tissue is replaced with connective tissue and fat, while fibrosis of the myocardium results in conduction abnormalities. The change in the conduction system increases the incidence of dysrhythmias including sick sinus syndrome, bundle branch blocks, and atrial arrhythmias and subsequent syncope in the elderly [11–13].

As one ages, systolic blood pressure increases due to augmented afterload from stiffening of the outflow tract. During times of stress, such as acute illness or injury, this results in decreases in peak ejection fraction and cardiac output [10, 14–[16]. Compounding the situation is that between the ages of 20 and 85 years, it is estimated that maximum heart rate decreases by as much as 30 % [17]. Additionally aged myocardium does not respond as well to increased levels of endogenous and exogenous catecholamine [18]; thus, cardiac output in the elderly must be augmented by increasing ventricular filling and stroke volume [10, 19]. This reliance on adequate volume (preload) makes the elderly very sensitive to even minimal hypovolemia and the resulting cardiac collapse. However, one must be diligent during times of volume resuscitation in the elderly and balance the need for adequate cardiac output with the potential for pulmonary edema due to decreased ventricular compliance.

Atrial Fibrillation

Atrial fibrillation (AF) is the most common arrhythmia [20–24]. Its reported incident varies but is less common after non-cardiothoracic surgery than cardiothoracic surgery [24]. However, the true incidence of AF may be underestimated due to a lack of continuous monitoring outside an intensive care unit [24]. Advanced aged has been shown to be independently associated with higher incidence of

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AF. AF is associated with the higher daily fluid requirements, the prevalence of severe infections, and the need for vasoactive and inotropic support [23]. It has been shown to be associated with significantly longer intensive care unit (ICU) and hospital length of stay (LOS) as well as increased morbidity and mortality [22–24].

The mechanism for the development of AF can be multifactorial. Underlying myocardial disease in the elderly along with increased systemic inflammation can cause further myocardial dysfunction causing AF [24, 25]. Increased intravascular volume from large quantity resuscitation increases the chance of AF. Alternatively, hypovolemia leading to an increased adrenergic state can increase the likelihood of AF [24, 26]. Regardless of the cause, atrial fibrillation in the geriatric ICU patient appears to be a marker of severity of illness as demonstrated by higher simplified acute physiologic scores II, nursing workload in the ICU (OMEGA), and mortality [23].

There is a wide variation in the treatment of elderly patients with AF [27]. Clinicians should investigate for any treatable causes including thyroid dysfunction, electrolyte abnormalities, or acute cardiac ischemia. Therapy goals include rate control, rhythm control, and prevention of thromboembolism [24].

Elderly patients in the ICU with AF often become hemodynamically unstable as a result of the loss of the atrial contribution to ventricular filling and leading to a decreased cardiac output [27]. Those with hypotension, altered level of consciousness, angina, or heart failure should be immediately cardioverted with synchronized direct current cardioversion [24]. For those with a normal blood pressure and no evidence of hypoperfusion, medical therapy should be initiated.

Over the years, there has been a debate whether it is more important to focus pharmacological intervention on rate control versus rhythm control. Two large studies demonstrated no benefit from rhythm control over rate control [28, 29]. Unfortunately most of the patients in the studies had persistent AF as opposed to postoperative new onset AF; thus, the results may not be extrapolated to this patient population [30]. Thus, many believe that pharmacological interventions should focus on controlling the ventricular rate with atrioventricular nodal blockers [24].

Currently, there are a number of treatment options available. Amiodarone, for many, has become the initial drug of choice for atrial fibrillation. It is a class III antiarrhythmic agent that depresses atrioventricular conduction and controls the ventricular rate. It is safe to use in patients with reduced ejection fraction. Side effects include bradycardia, thyroid dysfunction, as well as drug interaction, specifically warfarin. Intravenous (IV) amiodarone has been associated with acute elevation in liver enzymes; however, levels normalize with discontinuation on the IV form [31]. Additionally, long-term amiodarone use has been associated with the development of pulmonary fibrosis. Dronedarone, similar to amiodarone, has been studied for rate and rhythm control in AF. It reduces morbidity and mortality in inpatients with high-risk AF; however it is contraindicated in patients with acute severe heart failure [32].

Other pharmacological options include β-blockers and calcium channel blockers (CCB). β-blockers may be more appropriate for postoperative hyperadrenergic states, while CCB, specifically diltiazem, may be better suited for patients with severe asthma or chronic obstructive pulmonary disease. Side effects of CCB include hypotension, heart failure, and heart block. Both should be used with caution in patients with systolic heart failure [24]. Digoxin, one of the oldest antiarrhythmic agents for AF, is still used by many clinicians. Digoxin works by slowing down conduction at the atrioventricular node by parasympathetic activation. It may be the ideal pharmacological choice if patients have simultaneous heart failure or left ventricular dysfunction. Digoxin may be synergistic with β-blockers or CCB. However, it is less effective in situations of high sympathetic tone (postoperative period) [24]. Additionally, digoxin has many drug-drug interactions which often limit its use in critically ill patients. Furthermore, digoxin is renally metabolized, and drug levels need to be closely monitored and adjusted accordingly.

Duration of antiarrhythmic therapy remains unknown. There is no specific data that guides the duration of therapy. Some authors suggest 1–2 weeks of therapy if the AF was transient [24]. Longer therapy may be necessary for patients with recurrent or extended episodes of AF [24]. Some patients do not respond to pharmacological interventions and remain in AF. Patients who remain in AF for more than 48 h have an increased risk of atrial clot formation, and it is reasonable to consider anticoagulation therapy [24]. The CHADS2 score or the newer developed CHA2DS2-Vasc score may be used to determine which patients have an indication for anticoagulation [33]. However, clinicians need to take into account the risks of systemic anticoagulation in the critically ill geriatric patient including falls risks and drug interactions. Additionally, bleeding risks can be calculated using the HAS-BLED score [34]. Alternatively, additional medical attempts at rate control and rhythm alone may be safer in this patient population.

Myocardial Ischemia/Infarction

Age and preexisting cardiovascular disease predispose the elderly to cardiac complications when critically ill. Cardiac complications have been reported to range from 12 to 16.7 % in this patient population especially for those over the age of 80 years [35–37]. Cardiac complications are one of the highest causes of mortality in the elderly surgical patient, and for those over the age of 80 years, myocardial infarction (MI) has been shown to be the leading cause of postoperative

death [38]. The prevalence of postoperative MI in the elderly ranges from 0.1 to 4 % [39–41], with most occurring within 72 h following surgery [39].

β-blockers have traditionally been considered a mainstay of treatment to help prevent perioperative cardiac complications in the elderly. They are believed to decrease the shear force across atherosclerotic plaques that when ruptured can be the culprit of up to 50 % of perioperative MI [42]. Additionally β-blockers assist in minimizing ventricular dysrhythmias, improve myocardial oxygen balance, and decrease sympathetic tone leading to fewer perioperative cardiac complications. Initially a number of studies and reviews were published supporting the use of β-blockade to prevent postoperative complications [43–47]. In 2002 Auerbach and Goldman reviewed the efficacy of perioperative β-blockade in reducing myocardial ischemia, infraction, and cardiac-related mortality [47]. The authors concluded a benefit from β-blockade in preventing perioperative cardiac morbidity. These benefits were similar to those found in patients with myocardial infarction, and thus the use of perioperative blockade was quickly adopted due to the potential benefit with few adverse side effects demonstrated [43, 48].

Subsequent studies have demonstrated no differences in cardiac complications or mortality between patients treated with β-blockers and those not treated [49, 50]. While others have demonstrated potential harm and increased surgical mortality [43, 51, 52]. In 2008 the POISE study group evaluated the use of perioperative β-blockade and concluded that although the treatment group has significantly lower rates of MI, there was a significantly higher death rate and stroke rate in patients receiving β-blockers [53].

Despite the vast literature on the use of β-blockers, there is little consensus regarding the appropriate patient population that would benefit from their use. Some authors believe patients having one or two risk factors (high-risk surgery, known ischemic heart disease, history of congestive heart failure or cerebrovascular disease, baseline creatinine >2 mg/dl) would benefit, while others believe patients with more than three risk factors are more appropriate [42, 52, 54]. The 2014 ACC/AHA guidelines state that patients having surgery who are on chronic β-blockers should continue therapy [43]. The remaining recommendations are based on less convincing data and should be individualized to the patient.

Hemodynamic Monitoring

During times of acute illness or trauma, many elderly patients cannot augment their cardiac output and rather increase their systemic vascular resistance [55]. As a result, elderly patients may demonstrate a normal blood pressure while having severely depressed and compromised cardiac function leading to overall poor systemic perfusion. In a landmark study of geriatric trauma patients, Scalea and colleagues demonstrated as many as 50 % geriatric trauma patients who appeared clinically stable with "normal" blood pressure had unrecognized cardiogenic shock and a poor outcome [56]. Using a pulmonary artery catheter, resuscitation was optimized using volume, inotropes, and afterload reduction, and survival increased from 7 to 53 %. The authors determined that identifying occult shock early in the geriatric population with the use of invasive monitoring improves survival.

Despite years of attempting to identify the ideal method for assessing a critically ill patient's intravascular volume, clinicians still struggle [57]. Physical exam has not been shown to be helpful in accurately determining intravascular volume; thus, continued efforts to identify the best method continue [57, 58]. Unfortunately, there is little to no data specifically looking at invasive monitoring in the elderly, and as such, data must be extrapolated from existing literature based on various patient populations.

Long considered the gold standard of hemodynamic monitoring, the pulmonary artery catheter (PAC) was first described and used in 1970 by Swan et al. [59]. However, the literature on its utility is variable with some showing no effect [60, 61], some with decreased mortality [56, 62, 63], and some showing increased morbidity, mortality, and utilization of resources [64, 65]. It has been suggested that the reason some studies do not show a benefit or even a detriment with the use of the PAC is due to incorrect interpretation and subsequent clinical decision making based on the information provided [66–68]. Over time, newer and less invasive modalities have been developed, but still there is no consensus on the ideal method.

Continuous Central Venous Oximetry

Continuous central venous oximetry ($ScvO_2$) has been used as an alternative to the PAC (SvO_2). Using a modified central venous catheter with fiber-optic technology, clinicians are able to continuously monitor venous oxygenation in the superior vena cava. $ScvO_2$ is generally higher than SvO_2 in critically ill patients with circulatory failure [69]. The literature varies on the correlation between $ScvO_2$ and SvO_2 [69–71]. Some authors advocate the use of $ScvO_2$ which can help identify global tissue hypoxia allowing earlier intervention in the clinical course and affect outcome [72, 73]. Additionally, it has potential for time and cost savings as well as fewer risks than the PAC.

Pulse Contour Analysis

Other alternatives to the PAC include pulse contour analysis. The idea is based on the Windkessel model first described by Otto Frank in 1899 [74]. It is centered on the principle that

stroke volume can be continuously estimated, on a beat-to-beat basis, using arterial waveform from an arterial line. Calculations using the area under the curve of the systolic arterial pressure waveform helped develop an algorithm for monitoring stroke volume [75]. Limitations of pulse contour technology include its accuracy in patients with irregular cardiac rhythms, right heart failure, spontaneous breathing, and mechanical ventilation using low tidal volumes (<8 mL/kg body weight) [76].

Examples of pulse contour technology include the FloTrac™ (Edwards Lifesciences, Irvine, CA). It provides continuous cardiac output, stroke volumes, and stroke volume variation. The device does not require a central venous access, only an arterial catheter. The technology concept is based on arterial waveform analysis and the principle that pulse pressure is proportional to stroke volume [77], thus deriving a cardiac output on a beat-to-beat basis. Studies by Cannesson et al. and Button et al. showed clinically acceptable agreement between the PAC and FloTrac™ [78, 79]. Others, however, have had less favorable results [57, 80, 81].

The PiCCO™ (Pulsion Medical Systems, Munich, Germany) is another pulse contour analysis device. Unlike the FloTrac™, it requires both an arterial line and a central venous catheter. The arterial line must be placed in either the femoral or axillary artery, which may limit its use. The PiCCO™ system can provide clinicians with similar data to that of the FloTrac™; however, it also has the ability to measure a number of volumes including intrathoracic blood volume (ITBV), global end-diastolic volume (GEDV), and extravascular lung water (EVLW). These volumes have been shown to better measure cardiac preload than traditional values including central venous pressure (CVP) and pulmonary capillary wedge pressure (PCWP) [82, 83]. Additionally, ITBV and GEDV are not affected by mechanical ventilation. Unfortunately, unlike the FloTrac™ which does not need any calibration, the PiCCO™ system requires calibration on a regular basis depending on the hemodynamics of the patient. A study by Della Rocca and colleagues compared the PAC and the PiCCO™ and found that the two methods yielded similar measurements [84]. A study by Uchino et al. looked at outcomes when using a PiCCO™ versus using a PAC. The authors concluded that the choice of monitoring did not influence major outcomes [85].

Noninvasive Methods

A number of noninvasive techniques have been used to measure cardiac output and other hemodynamic parameters. These techniques include partial gas rebreathing (NICO system), thoracic bioimpedance, impedance plethysmography, and portable Doppler devices. Currently these techniques are not widely available or used. Additionally they have not been validated versus other more invasive techniques [86].

Despite much effort, an accurate and reliable marker to guide fluid management has yet to be determined. Traditional measurements of preload including CVP and PCWP have not been shown to reliably predict cardiac preload and the need for volume to optimize cardiac function [87]. A study by Boulain and colleagues demonstrated that passive leg raises (PLR) change pulse pressure and can predict the need for fluid administration in mechanically ventilated patients [77]. As stated previously, pulse pressure is proportional to stroke volume thus allowing pulse contour technology to calculate a stroke volume variation (SVV). SVV has been used to try to answer the never-ending, possible unanswerable critical care question of "is a patient wet or dry?" Some believe it to be an accurate marker of fluid responsiveness in patients and may be the simplest way to predict fluid responsiveness [88]. In general, a lower SVV implies adequate fluid balance, while elevated measurements of SVV imply the need for ongoing volume resuscitation. Both the FloTrac™ and PiCCO™ systems can calculate SVV. Studies have demonstrated that the PiCCO™ system can predict fluid responsiveness in a variety of clinical situations [89, 90]. Studies regarding the FloTrac™ system ability to predict volume responsiveness are more varied [78, 79, 91]. When compared head to head, the FloTrac™ and PiCCO™ system both predict fluid responsiveness in a similar manner [92].

What is the exact threshold of SVV for determining fluid responsiveness? Unfortunately, the literature has yet to answer this question [92]. A report by Berkenstadt and colleagues determined that an SVV value of 9.5 % or more will predict an increase in stroke volume [93]. Suehiro and Okutani determined an SVV cutoff value of 10.5 % to predict fluid responsiveness [94]. When comparing values derived from the FloTrac™ to those of the PiCCO™, Hofer and colleagues found that although both equally predicted fluid responsiveness, the FloTrac™ had a lower threshold of 9.6 % versus 12.5 % for the PiCCO™ [92]. In general, normal SVV values are thought to be 10–15 %.

Echocardiography

The role of ultrasound and echocardiography continues to grow and expand in the critical care setting. Although echocardiography cannot provide continuous monitoring, it is the best method to repeatedly assess cardiac function [95]. Information including fluid status and inferior vena cava diameter and collapsibility can rapidly be attained at bedside providing reliable monitoring of intravascular volume in the mechanically ventilated patient [96]. Echocardiography allows clinicians to choose a therapeutic intervention and rapidly asses the hemodynamic and functional response to the therapy [95]. Additionally echocardiography can provide a number of dynamic responses to preload augmentation.

The gold standard to evaluate cardiac function is transesophageal echocardiography (TEE); however, it is invasive and requires specialized training to perform. Transthoracic echocardiography (TTE) however is less invasive, requires less specialized training, and can effectively assess cardiac function. Handheld echocardiography (HHE) using a smaller device has been shown to be as accurate and clinically helpful as TTE [97].

The first focused echocardiography ultrasound protocol for non-cardiologists was the "focused assessment with transthoracic echocardiography" (FATE) [98]. The authors demonstrated the ability to describe the hemodynamics of patients as well as the ability to optimize care. Since then a number of similar protocols have been created. In 2008, Gunst et al. used the "bedside echocardiographic assessment in trauma" (BEAT) to compare function and volume status in critically ill patients with a PAC [99]. The authors demonstrated a significant correlation with cardiac index and CVP between the two modalities. However, as stated previously, CVP has been suggested to be a poor measurement of volume status. In 2011, the "focused rapid echocardiographic examination" (FREE) was first described by Ferrada and colleagues [100]. It was designed to be performed by both surgeons and intensivists. It is a "transthoracic examination, which incorporates hemodynamic information from the echo with the patient's clinical scenario to generate broad treatment recommendations about fluid, inotropic agents and vasopressors" [100]. When compared to PAC, the FREE was found to have similar results in the measurement of cardiac index; however, when compared to the FloTrac™, there was less agreement, especially in patients with low (<40 %) ejection fractions [101].

Conclusion

The population of those over the age of 65 years continues to increase. As people age their physiologic reserve decreases, and when stressed, including acute trauma or illness, they are unable to effectively compensate and meet the physiologic demand to ensure adequate perfusion. Underlying cardiac dysfunction becomes more pronounced, and complications including cardiac dysrhythmia, myocardial ischemia, and infarction occur. Early aggressive hemodynamic monitoring has been shown to improve survival in the elderly patient population; however, the optimal method by which to do this has yet to be definitively determined.

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Pulmonary Critical Care and Mechanical Ventilation

36

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Aging has a negative impact on all organ systems in the body. Age-related diminution in reserve is felt on the respiratory system the earliest [1], and trauma to the chest has a disproportionate influence on outcomes following injury at all ages [2]. In addition to this direct impact chest trauma has on outcomes, even in the absence of direct chest injury, adequate oxygenation is critical to healing of all injured tissues/organs with the injured brain being at greatest risk of even brief periods of hypoxemia during the immediate post-injury period. For these reasons adequate pulmonary care following injury is critically important not only from the respiratory standpoint but also for overall recovery.

Age-Related Changes to Respiratory Physiology

While this subject is addressed in detail in other chapters, a brief review here is important to fully understand the basis of pulmonary care in the elderly especially following injury. The respiratory system consists of two fundamental elements: (1) a gas exchange mechanism in the lung that leads to inspired oxygen being transferred from the alveolus into the blood and carbon dioxide being transferred in the opposite direction and (2) the pump consisting of the rigid rib cage, respiratory muscles, and the neural mechanisms that govern the act of breathing including the brain stem that responds to levels of oxygen and carbon dioxide in the blood [3]. Both elements of the respiratory system change with age in a manner that reduces reserve and our ability to increase the delivery of oxygen to the tissues following injury. In the lung, while the total lung volume remains relatively constant, there is a decrease in vital capacity primarily caused by an increase in residual volume [4]. This directly limits the degree to which minute ventilation can be increased to facilitate greater oxygen delivery and removal of carbon dioxide. At the same time, the closing volume increases, so even minor chest trauma leads to alveolar collapse and increased shunting resulting in ventilation/perfusion (V:Q) mismatch [5]. On the pump side, respiratory muscles participate in the overall decline in muscle mass with aging, limiting the ability to take deep breaths and effectively clear the airways of secretions [6]. Also the sensitivity of the brain stem to hypoxemia and hypercarbia is diminished leading to decreased respiratory drive. In addition to these age-related physiological changes, older patients may also have pulmonary comorbidities that further diminish respiratory reserve. Finally, all narcotic analgesics used for pain control diminish respiratory drive even more [7]. In summary, there is less drive, diminished strength, and poorer gas exchange setting the stage for respiratory failure.

Principles of Pulmonary Care in the Elderly

Certain principles apply to any elderly patient admitted to the hospital for any reason but may especially apply after injury. These are:

1. Optimizing gas exchange
2. Preventing aspiration
3. Prevention of pulmonary infections – on or off ventilator
4. Early detection of deterioration
5. Early detection and prompt therapy of pulmonary infection – on or off ventilator
6. Assistance with ventilation if required
   (a) Noninvasive ventilation
   (b) Endotracheal intubation and assisted ventilation
7. Weaning from ventilator and extubation
8. Role of tracheostomy
9. Ethical considerations and end-of-life care

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Optimizing Gas Exchange

Gas exchange in the lungs is dependent upon ventilation of the alveolus and perfusion of the ventilated alveolus or V/Q matching. Over time, there is an age-related decrease in the partial pressure of oxygen in arterial blood (PaO_2) of 4 mmHg per decade without any change in the partial pressure of alveolar oxygen (PAO_2) or partial pressure of arterial carbon dioxide ($PaCO_2$) [8]. This is due to decreased efficiency of gas exchange across the respiratory membrane caused by increased thickness and reduced surface area, decreasing from nearly 75 m^2 at age 20–60 m^2 by age 70 [9].

Simple measures that maintain V/Q matching go a long way in ensuring adequate V/Q matching. These include:

1. Preventing atelectasis
   (a) Raising the head end of the bed 30°: Semi-recumbent position is the preferred positioning adopted by the Institute for Healthcare Improvement (IHI) in their ventilator bundle [10, 11]. Since patients in the supine position have lower spontaneous tidal volumes on pressure support ventilation than those in an upright position, it has been assumed that a semi-recumbent position may facilitate ventilatory efforts [11, 12].
   (b) Incentive spirometry: A normal alveolar sac measures 0.3 mm in diameter. During normal breathing the alveolar sac inflates and then deflates but does not completely collapse. The inflation and deflation stimulates surfactant production, a key to maintaining adequate compliance. Complete collapse of the alveolus leads to alveolar damage (see atelectrauma below) and reduces surfactant production thus making re-expansion difficult. Incentive spirometers, or sustained maximal inspiration devices, encourage deep breathing by augmenting pulmonary ventilation through the re-expansion of alveoli [13]. The routine use of incentive spirometers has been shown be effective in reducing pulmonary risk [14–16].
2. Providing adequate analgesia while minimizing sedation: Poor pain control may result in respiratory splinting and contribute to diminished inspiratory effort. On the other hand, narcotic analgesics depress the cough reflex and may be sedating and limit the patient's ability to clear airway secretions which may lead to atelectasis and V/Q mismatch. A multimodal approach to analgesia consisting of epidural pain control, local analegesic delivery (i.e., topical lidocaine patches), and local nerve blocks may be effective at minimizing narcotic use [17].
3. Encouraging pulmonary toilet: Pulmonary toilet (or hygiene) refers to a set of procedures to clear secretions from the airways. Deep suctioning, chest physiotherapy and percussion, and prone positioning are widely accepted adjuncts to facilitate the removal of airway secretions and prevent atelectasis [18, 19].

Preventing Aspiration

Aspiration is a common cause of respiratory failure among the elderly and occurs with oropharyngeal and/or gastric contents that may carry pathogens. Aspiration results in a sterile chemical pneumonitis that damages type I pneumocytes impeding gas exchange, reduces surfactant causing alveolar collapse, and makes the patient prone to the development of microbial pneumonia – usually bacterial but sometimes viral or fungal. Risk factors contributing to aspiration include the positioning of the head of the bed <30°, presence of a nasogastric tube, enteral feeds (especially in the presence of a nasogastric tube), mechanical ventilation >7 days, Glasgow Coma Score <9, and burns [20–24].

Measures to prevent aspiration include:

1. Raising the head end of the bed 30°: Head of bed elevation has been incorporated in ventilator bundles and has been shown to decrease the rates of ventilator-associated pneumonia from 34 to 8 % in the semi-recumbent position likely from a reduction in aspiration [10]. Unless contraindicated, this is a low-cost approach to preventing aspiration.
2. Encouraging pulmonary toilet: Regular pulmonary toilet consisting of deep suctioning and chest physiotherapy facilitates removal of secretions.
3. Avoiding nasogastric tubes if at all possible: Although the exact mechanism remains unknown, nasogastric tubes have been associated with aspiration likely caused by disturbance to the lower esophageal sphincteric mechanism by the tube. Mechanically ventilated patients who undergo early gastrostomy have been shown to have a lower incidence of ventilator-associated pneumonia compared with nasogastric tube-fed patients with stroke or closed head injury [25]. If nasogastric tubes are to be used, frequent assessments are necessary to confirm that the tubes are in the appropriate position in the stomach; nasogastric tubes malpositioned in the esophagus have been associated with aspiration [26].
4. Closely monitoring enteral feeding: Monitoring residuals to detect non-tolerance early and using intestinal tubes (post-ligament of Treitz, if possible) are good measures to reduce the chances of aspiration. Gastric residual volumes in excess of 200–250 cc every 4 h indicate non-tolerance and should be cause for concern [27–29]. Other signs and symptoms of intolerance include abdominal pain, bloating and distention [30].

Prevention of Pulmonary Infections: On or Off Ventilator

Respiratory infections are common in the elderly and contribute to significant morbidity and mortality, especially in the presence of underlying comorbidities [31, 32]. These are usually caused by bacteria, and less often by viruses, other atypical pathogens, or fungi. The body has numerous mechanisms of clearing potentially infected material from the upper airways – mucociliary escalator, cough reflex, etc. All of these are diminished with age and hence the elderly are more prone to the development of pulmonary infection. The problem is more pronounced in the intubated and ventilated patient as the protective mechanisms are completely bypassed and there is pooling of oropharyngeal and eructed gastric secretions just above the balloon of the endotracheal tube that is a source of frequent micro-aspiration [33]. The gastric secretions very often are colonized since in the elderly acid production is diminished with age or drugs (proton pump inhibitors, Histamine receptor-2 blockade). Studies have shown that this supraglottic pool has potentially pathogenic organisms and that the upper airway of the ventilated patient gets colonized by such organisms within 3–5 days of endotracheal intubation.

The following measures should be taken to prevent the development of pulmonary infection in any elderly patient admitted to the hospital:

1. All measures noted above to prevent aspiration.
2. Strict hand washing by health-care providers. Hand hygiene is an important tool in the prevention of nosocomial infections, especially pneumonia. Strict hand washing should be employed to prevent cross-contamination between patients [34].
3. Minimizing the use of antacid medications. Administration of antacids increases the risk of pneumonia by neutralizing gastric acidity and thus altering an innate host defense mechanism [35].
4. Strict oral hygiene. Routine oral decontamination with agents such as chlorhexidine gluconate decreases bacterial contamination of the oropharynx and may decrease ventilator-associated pneumonia [36].
5. Consideration for specialized endotracheal tubes that have mechanisms for aspirating supraglottic pooled secretion and/or are silver impregnated. One of the suggested mechanisms for the development of VAP is the micro-aspiration of supraglottic secretions that have formed a pool of pathogens just above the balloon of the endotracheal tube. To prevent this from happening, specialized tubes have been developed that allow for the aspiration of the pooled secretions. The use of these tubes in an ICU setting have been shown to increase the time to development of VAP [37–39]. Another method to tackle the secretions has been the use of silver impregnation of the endotracheal tubes. The silver ion kills the pathogens within the pool and thus can reduce the incidence of VAP. The efficacy of these tubes was demonstrated in a large multicenter randomized study [40].
6. The use of ventilator bundle for all ventilated patients. Prevention of nosocomial infections, including pneumonia, relies on a comprehensive set of interventions "bundled" together to achieve more significant outcomes than possible if each were implemented individually. One of the most widely accepted bundles is promoted by the IHI to reduce the incidence of VAP. The bundle consists of (i) elevation of the head of bed, (ii) daily "sedation vacation" and assessment of readiness to extubate, (iii) appropriate peptic ulcer and deep venous thrombosis prophylaxis, and (iv) oral hygiene with chlorhexidine swabs. Thorough education of physicians, nursing staff, and respiratory therapists is necessary to ensure proper implementation of these bundles in an effective manner. If consistently used, the VAP bundle has been shown to decrease VAP rates [41].

Early Detection of Deterioration

Despite all measures, some patients, especially the elderly, admitted to the hospital after trauma, will deteriorate. In such cases, the earlier the deterioration in their condition is detected and appropriate therapy provided, the better will be the outcome. To improve the chances of rapid detection, all health-care providers caring for such patients should be aware of the subtle and not-so-subtle signs of deterioration. These include (i) alteration in mental status, caused by neurologic event or sepsis, (ii) alteration in vital signs (heart rate, blood pressure, respiratory rate, pulse oximeter saturations), and (iii) all subtle signs of stroke and myocardial infarction – the elderly may not manifest the more obvious signs/symptoms of these conditions. The use of rapid response teams has been shown to improve outcomes as from subtle signs/symptoms picked up by the nurse, a lot of resources can be rapidly brought to the bedside for quick action [42]. Lastly, specific to the respiratory system, the use of the incentive spirometer is an excellent method of not only preventing problems but also detecting them early. If the volume of air moved as shown by the incentive spirometer demonstrates a downward trend, this may be an early indicator of a developing problem and should lead to a careful evaluation of the patient [43].

Early Detection and Prompt Therapy of Pulmonary Infection: On or Off Ventilator

Infection may present in a vastly different manner in elderly patients compared to the young due to altered physiologic reserves [44]. Elderly patients with infections may fail to illicit a fever or elevated white count. Instead, alterations in behavior including agitation and altered mentation may provide the only clues of the presence of infection. In any elderly patient manifesting subtle or overt signs/symptoms of infection, a systematic search should be instituted to identify (or rule out) the source of the infection and if detected to treat it appropriately. From a respiratory standpoint, infection could be anywhere from the larger airways – sinusitis, pharyngitis, or tracheobronchitis – to the lower respiratory tract in the form of pneumonia. If a respiratory infection is suspected, then appropriate culture specimen should be obtained and empiric antimicrobials initiated. Additionally, any unnecessary tubes in the aerodigestive tract should be removed if at all possible. For sinusitis and pharyngitis in a non-intubated patient, a sputum culture is usually an adequate specimen. The diagnosis of deep respiratory infection – pneumonia – in such patients rests on fever, leukocytosis, new or changing infiltrate on chest radiograph, and productive sputum with predominant growth of a single pathogen. If based on clinical and radiographic criteria, pneumonia is suspected, a deep tracheal aspirate should be obtained and empiric antimicrobials initiated. The choice of the empiric therapy is based primarily on whether the patient has or has not had contact with any health-care facility or use of antimicrobials over the past 90 days. Patients admitted for less than 5 days and who have not had any contact with a health-care facility or used antimicrobials over the past 90 days can be treated with standard therapy for community-acquired pneumonia. On the other hand, in a patient who has been admitted for 5 days, or who has had contact with health-care facility and/or used antimicrobials in the past 90 days, the possibility of hospital-acquired organisms should be strongly considered. In such situations, empiric therapy should cover methicillin-resistant *Staphylococcus Aureus* (MRSA) and hospital-acquired resistant gram-negative organisms – *Pseudomonas*, *Enterobacter*, *Acinetobacter*, etc.

The diagnosis of pneumonia in an elderly traumatized ventilated patient poses additional challenges. Leukocytosis and fever are nonspecific and, as noted above, may be absent in the elderly; infiltrates on chest radiograph too are nonspecific and may be due to other conditions such as cardiac pathology or pulmonary contusion; and sputum culture may be positive due to nonpathogenic colonization of the tracheobronchial tree and may not represent true pathogenic infection. In such situations, the quantitative evaluation of a clean lower respiratory specimen can offer a way of differentiating between nonpathogenic colonization and true VAP (CDC definition: pneumonia occurring in a patient who is or was on the ventilator in the previous 48 h) [45]. The clean deep respiratory specimen could be either bronchoalveolar lavage (BAL) or brush specimen and could be obtained bronchoscopically or blindly by specially designed catheters. At the authors' institution, any patient demonstrating any two of fever, leukocytosis, changing infiltrate, or productive sputum undergoes a bronchoscopic BAL, and the specimen is analyzed quantitatively. Empiric antimicrobials are initiated immediately after obtaining the specimen. There is ample evidence that delay in appropriate antimicrobials in patients with VAP worsens outcomes [46]. If the quantitative cultures demonstrate $>10^5$ microorganisms/ml of BAL fluid, the patient is labeled as having a VAP, and if $<10^5$, then VAP is considered unlikely, and further search for the source of infection is continued. In either case, the empiric antimicrobials that started after the BAL are de-escalated; for patients diagnosed with VAP (BAL $>10^5$ microorganisms/ml), the spectrum is narrowed to an agent with activity against the cultured organism and good lung penetration; and for patients with no VAP (BAL $<10^5$ microorganisms/ml), antimicrobials are discontinued unless another indication for their continuation is present. A similar strategy could be utilized using protected brush specimens. The exact threshold to treat is not well defined in the literature. While almost all agree that for the brush specimen, 10^3 microorganisms/ml is the correct threshold, for BAL, different institutions use differing thresholds that vary from 10^3 to 10^5 [47]. The duration of therapy of any diagnosed infection is another area of active investigation. There is a move to treat all infections, including pulmonary, based on the response – reduction in fever, reduction in leukocytosis, improvement in other signs of sepsis, etc. – rather than arbitrary durations [48].

Besides upper and lower respiratory infection, from the pulmonary standpoint, infection may also reside in the pleural space. Traumatized patients may have hemothorax that may have required a tube thoracostomy for drainage. The presence of blood, a foreign object and, a pathway to the skin offer the perfect conditions for infection of the pleural cavity. If the patient has developed a pneumonia, there may be a parapneumonic effusion that gets secondarily infected. In any instance where there is infected fluid within the pleural cavity, it needs adequate drainage. The drainage can be achieved by a simple thoracostomy tube but, if loculated, may need either thoracoscopic or open surgical therapy for adequate drainage. Finally, in rare instances, either from a very virulent organism or after an embolism has decreased the blood supply to a part of the lung, there may develop a lung abscess that too may need invasive drainage before the patient will improve.

Identification of Failure of Therapy

One of the key pillars of critical care is to identify failure of any therapy early and investigate the cause(s). In the infection arena, this implies nonimprovement or deterioration despite what is thought to be appropriate therapy. If the therapy is appropriate, then the patient should demonstrate signs of improvement within 48–72 h of therapy. These signs consist of improvement in signs of sepsis, reduction in fever, and leukocytosis. If improvement is not observed in this time frame, failure of therapy should be investigated. The cause(s) of failure when treating a pulmonary infection are:

1. Inappropriate antimicrobial therapy. This may be in the form of (i) an agent that does not target the causative organism; (ii) an agent that has poor penetration into the lung tissue, e.g., vancomycin; and (iii) inadequate dosing.
2. Development of resistance by the causative organism.
3. Infection by an organism that was not identified and hence is not being treated. There is a known false negative rate for BAL in which a causative organism is not identified in the BAL fluid. In such cases, especially if the organism is one of the difficult to treat ones, the antimicrobial therapy may not be targeting the organism [49].
4. Development of another infection, either within the pulmonary system or elsewhere.
5. A possible extra-pulmonary source that has been present from the beginning but not identified.

If it is determined that there is a failure of therapy, a systemic search should be performed with a thorough physical examination and appropriate imaging studies. From a pulmonary standpoint, consideration should be given to all the above factors and also to the possibility that the patient has developed an empyema. For empyema a diagnostic tap of the pleural fluid and examination for evidence of empyema should be considered and if diagnostic of empyema, appropriate therapy pursued (see above). Additionally, to account for the possibility of a false BAL, a repeat BAL should be performed, and after obtaining the specimen, strong consideration should be given to broadening of the antimicrobial coverage. Once again after the culture and sensitivity results are available, antimicrobial therapy should be de-escalated based on the results.

Assistance with Ventilation If Required

Assistance with ventilation is required when a patient is unable to maintain adequate oxygenation (primary indication) or remove carbon dioxide (secondary indication) by himself/herself despite the use of supplemental oxygen. Ventilatory assistance may be provided by noninvasive or invasive methods as discussed in the following sections.

Noninvasive Ventilation

Noninvasive ventilation usually consists of a tight mask around the nose + mouth, with assistance provided by the apparatus (ventilator) usually in the form of a continuous positive airway pressure (CPAP). It is possible to also provide some degree of pressure support with each patient-initiated breath. Since the mask can be uncomfortable, and the seal unable to tolerate pressures greater than 10 mmHg, the device has limited use. It should only be considered as a temporizing measure. However, despite these limitations, the device can be used where only short-term support is required: (i) as preparations are being made for formal intubation, (ii) immediately after extubation to decrease the chance of re-intubation, and (iii) in patients where a therapy or intervention can improve the respiratory status over the next few hours – use of diuretic for pulmonary edema, etc. Attempts to use the device long term for frank respiratory failure have not met with success. If noninvasive ventilation is utilized for one or more of the above three indications, the lowest CPAP (<10 mmHg) that provides adequate oxygenation (SaO2 >90 % with respiratory rate <30/min) and is comfortable for the patient should be utilized. If after few (usually four) hours there is no improvement in the status, the patient is best intubated and ventilatory support provided through the endotracheal tube.

Endotracheal Intubation and Assisted Ventilation

Respiratory failure after trauma and the need for invasive ventilation is one of the most common reasons for an elderly patient to be admitted to a surgical intensive care unit. However, it is increasingly recognized that the therapy itself, mechanical ventilation, may result in or, if already present, worsen the acute lung injury – ventilator-induced lung injury (VILI). Hence the aim of mechanical ventilation is to provide ventilatory support to the patient without causing or worsening acute lung injury. To achieve this goal some principles should be kept in mind:

1. Avoidance of atelectrauma or shear stress: In the normal state, alveoli do not completely collapse during expiration just reduce in volume. The complete closure of alveoli and subsequent reopening with inspiration lead to shear stress of the alveolar wall resulting in damage to type I

pneumocytes that are essential for gas exchange and the production of surfactant.
2. Avoidance of volutrauma and barotrauma: In elegant animal experiments, it has clearly been demonstrated that lungs get damaged by both overstretching even if the airway pressures are low (volutrauma) and by overpressure even if the volumes are kept low (barotrauma) [50, 51]. Interestingly as the mean tidal volume has decreased over the past decades, the mortality from acute lung injury has fallen as well. Since so many other changes in critical care have also taken place, it is difficult to ascribe a cause and effect, but the association is certainly present.
3. Avoidance of toxic levels of oxygen within the alveolus: It is well established that 100 % oxygen is toxic to type I pneumocytes, and prolonged periods (>24–48 h) of 100 % oxygen within the alveolus would lead to or worsen acute lung injury. What is less clear is the safe upper limit of alveolar oxygen levels. The commonly accepted value is 60 % [52].

While a detailed discussion of ventilation is beyond the scope of this chapter, some basic terms and principles are presented below:

1. Mode (volume- vs pressure-limited ventilation): There are two methods of forcing oxygen-rich air into the lungs. In volume-limited mode, the ventilator delivers a set volume, irrespective of the pressure created within the airways (in reality a maximum pressure is set that limits the volume and also triggers an alarm; if the pressure is too high – possible obstruction – or too low, possible circuit disconnection). In the pressure limited mode, the ventilator increases the pressure within the breathing circuit that causes the oxygen-rich air to move into the lungs, irrespective of how little or how much volume is delivered (again in practice, there are alarms to warn that the volume is too low – possible obstruction – or too high, possible circuit disconnection).
2. Modality (assist control (AC) vs synchronous intermittent mandatory (SIMV) vs CPAP): In AC the ventilator delivers a set number of breaths to the patient. In addition, when the patient initiates a breath, the ventilator provides the full support (volume or pressure depending on mode) for the patient. In SIMV, the ventilator again delivers a set number of breaths, but the patient-initiated breaths do not get the full support; rather, they are supported at another set parameter – pressure support (see following in CPAP). In the CPAP modality, there are no ventilator breaths. All breaths are initiated by the patient. All breathing is in a constant pressure environment (CPAP pressure) set by the provider. Another parameter utilized in conjunction with CPAP is pressure support (PS). This is the amount of pressure generated by the ventilator within the respiratory circuit to support each breath initiated by the patient. With PS, as the patient initiates the breath, the volume of air moved will increase due to the additional support provided by the ventilator. PS is also utilized with SIMV to support the patient-imitated breaths that are over and above the ventilator set breaths.
3. Positive end-expiratory pressure (PEEP): PEEP is the lowest pressure in the breathing circuit at the end of expiration. The use of PEEP increases residual volume in the lung thus increasing functional residual capacity. This in turn leads to improvement in oxygenation by not allowing complete alveolar collapse during expiration while at the same time preventing atelectrauma. PEEP can have a negative impact on venous return and thus cardiac output. Hence the lowest level of PEEP (usually 5–10 mmHg but sometimes higher) consistent with adequate oxygenation should be utilized.
4. Inspiration:expiration (I:E) ratio: In normal breathing, the I:E ratio is 1:3. Thus, in comfortable breathing at 15 breaths/minute, for each respiratory cycle of 4 s, 1 s is spent in inspiration and three in expiration. One of the methods of improving oxygenation is to increase the proportion of time spent in the inspiratory phase by altering the I:E ratio. This increases the amount of time available for the individual RBC to be fully oxygenated before exiting from the alveolar capillary. Like PEEP, equalizing or reversing the I:E ratio does have a negative impact on venous return and cardiac output.

Weaning from Ventilator and Extubation

Ventilator weaning begins almost as soon as the patient is intubated. Studies have shown that the process of sedation breaks leads to improved alertness, and mentation is critical towards an efficient weaning process. In this setting, spontaneous breathing trials have been implemented in ICUs as an effective means of predicting which patients would successfully be extubatable. One of the most widely accepted, the rapid shallow breathing index (RSBI), was developed by Yang and Tobin and is calculated as the respiratory rate (F as breaths/min) divided by tidal volume (VT in liters) – f/VT (Yang & Tobin). Most ICUs utilize RSBI <105 as predictive of successful extubation and proceed to a spontaneous breathing trial [53]. However, in the elderly, some have suggested that the <130 may be more appropriate [54, 55].

Role of Tracheostomy

Patients requiring long-term ventilation often undergo tracheostomies. It is felt by many that tracheotomy as opposed to endotracheal tube is safer for the long-term ventilated

patient and it may also hasten weaning of the ventilator by reducing the amount of dead space ventilation [56, 57]. However, data supporting this widely held belief is difficult to come by. There are some small studies that demonstrate that performance of tracheostomy was associated with improved outcomes in the form of ICU and hospital lengths of stay and possibly reduced incidence of pneumonia; meta-analysis of these studies failed to demonstrate any benefit [58, 59]. On the flip side, tracheostomies can be associated with significant short- and long-term complications [60]. Despite this in most institutions, any patient requiring intubation and ventilation for longer than 10 days usually undergoes a tracheostomy. As critical care has advanced and more elderly patients are surviving the initial phase of ICU care, the number of tracheostomies performed on elderly patients is steadily increasing. The decision to perform a tracheostomy on an elderly patient has to be taken with some thought especially about the ultimate goals of therapy – cure or palliation.

Ethical Considerations and End-of-Life Care

Mechanical ventilation is associated with significant hospital and medical costs. The outcome of prolonged mechanical ventilation in elderly patients has been shown to be dependent on diagnoses at time of admission and acute physiologic derangements rather than age [61]. Our ability to provide prolonged ventilatory support may not constitute a reasonable quality of life to many people. Many geriatric patients have their specific medical wishes reflected in a living will. When not available or if the patient is unable to participate in a direct discussion of their care, it is important to have a multidisciplinary approach to define the goals of care and determine if these are consistent with the patient's beliefs and values. Family members and health-care providers alike must account for long-term outcomes, quality of life, and baseline functional status. If appropriate, palliative care providers may provide insight into treatment alternatives.

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Renal Replacement Therapy

37

Brian K. Yorkgitis and Zara R. Cooper

Abbreviations

ADH	Antidiuretic hormone
AKI	Acute kidney injury
ATN	Acute tubular necrosis
BUN	Blood urea nitrogen
CIN	Contrast-induced nephropathy
CKD	Chronic kidney disease
CRRT	Continuous renal replacement therapy
CVVD	Continuous veno-venous dialysis
EDD	Extended daily dialysis
ESRD	End-stage renal disease
GFR	Glomerular filtration rate
IAP	Intra-abdominal pressure
ICU	Intensive care unit
IHD	Intermittent hemodialysis
KDIGO	Kidney Disease: Improving Global Outcomes
NAC	N-acetylcysteine
NSAID	Nonsteroidal anti-inflammatory drug
PD	Peritoneal dialysis
PPV	Positive pressure ventilation
RCA	Regional citrate anticoagulation
RIFLE	Risk, Injury, Failure, Loss of kidney function, and End-stage kidney disease
RRT	Renal replacement therapy
SCr	Serum creatinine
SLED	Sustained low-efficiency dialysis
UF	Ultrafiltration
UO	Urine output

Bullet Point Summary

- Elderly patients are at increased risk for acute kidney injury with higher severity than younger patients.
- Early identification of at-risk patient for AKI is essential to mitigate AKI when able.
- Creatinine is a poor marker of renal dysfunction in elderly due to decreased muscle mass.
- Comorbid medical disease and medications used to treat these illnesses can have a dramatic effect on elderly trauma patient's renal function.
- Failure to recover renal function is more common in older patients with AKI.
- Prior to initiation of renal replacement therapy (RRT), discussion with the patient and/or surrogates should be undertaken informing them of the diagnosis, prognosis, and all treatment options.
- RRT modality in AKI is dictated by local resources and physician experience; studies have not clearly defined a superior modality.
- Renal replacement therapy.

Introduction and Epidemiology

Geriatric patients are at higher risk for acute kidney injury (AKI) than their younger counterparts, because age-related changes in renal function impair their ability to tolerate physiologic insults including hypotension, hypovolemia, and nephrotoxic agents that are routinely used in medical care [1, 2]. As a consequence, elderly patients have a three- to eightfold greater incidence of AKI, and older patients with AKI have the greatest risk for developing the most severe form, requiring renal replacement therapy (RRT) [1]. This leads to longer length of hospitalization and increased morbidity and mortality.

Elderly trauma patients often require intensive care admission for management of their injuries and comorbidities or for clinical deterioration. Although there is a paucity of data specific to geriatric ICU trauma patients with AKI, among all adults

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Table 37.1 Hospital-acquired AKI

Increase in serum creatinine level (mg/dL)	Multivariable OR (95 % CI)	Area under ROC curve	Increase in total cost
0.3	4.1(3.1–5.5)	0.84	$4886
0.5	6.5(5.0–8.5)	0.86	$7499
1.0	9.7(7.1–13.2)	0.84	$13,200
2.0	16.4(10.3–26)	0.83	$22,023

Himmelfarb [12]. Reprinted, with permission from Elsevier Limited
OR odds ratio, *CI* confidence interval, *ROC* receiver operating characteristics

admitted to the ICU, rates of AKI range between 5 % and over 60 %, and mortality is as high as 60 % [3–5]. Approximately 70 % of all ICU patients with severe AKI will require RRT [6]. The VA/NIH Acute Renal Failure Trial Network (ATN) study revealed an all-cause mortality of over 50 % by 60 days among critically ill patients with AKI requiring RRT. Of these patients, just over 15 % had complete renal recovery by day 28 [7]. Long-term studies of adult ICU patients, with even mild AKI, had significantly lower survival rates [8].

Acute kidney injury is also associated to considerably higher healthcare costs. Chertow et al. reported in 2005 that adult patients who had any increase in serum creatinine by 0.3 mg/dL had at least four times the odds of death and an increase in hospital costs of at least $4886 [9] (Table 37.1). In a review of 50,314 postsurgical patients, the cost for care almost doubled for patients with AKI, and the mortality was markedly greater at 90 days [10]. A study done on 1033 adult trauma patients found that renal impairment occurred in at least 23.4 % of the patients, of those over 10 % required renal replacement therapy. For every 1 mg/dL increase from presenting creatinine, the length of stay increased by 2.21 days, ventilator days increased by 1.09 days, and mortality increased by 1.83 times. For patients with any degree of acute renal dysfunction, the risk of mortality was 7.19 times higher [11]. Therefore, the cost of renal failure, in terms of lives and dollars, is a major problem in the USA and especially in the growing population over the age of 65 [12].

Definitions

Historically, acute decline in renal function was known as acute renal failure. This term has been replaced with "acute kidney injury "as a simple and direct description of the process, one that patients can readily understand and can be interpreted as a spectrum of disease, including mild or moderate dysfunction along with outright failure. The term injury is thought to better represent the pathologic changes occurring in the kidney parenchyma [12]. Unfortunately, AKI has over 35 definitions, many of which are complex and confusing. This lack of standardization has greatly impeded the understanding of the epidemiology of kidney dysfunction. Many attempts have been made to provide clinicians a standardized definition; unfortunately, with complexity of the disease, there are pitfalls to each definition [12].

One commonly accepted definition is the RIFLE criteria. It was developed by a multidisciplinary group to address the issue of a uniform definition of AKI. The acronym RIFLE represents three severity levels of renal dysfunction (*R*isk, *I*njury, and *F*ailure) and two outcome classifications (*L*oss of kidney function and *E*nd-stage kidney disease) based on measurements of creatinine and urine output (UO). The impairment must be sudden and sustained (>24 h). The dysfunction criteria are derived from the relative increase in serum creatinine, the absolute level of UO, or both. The failure category uses serum creatinine (SCr) ≥4 mg/dL to account for the severity of acute renal disease in patients with chronic renal disease whose relative increase in creatinine may not otherwise reflect AKI (Table 37.2). Unfortunately, the RIFLE criteria are most useful when the baseline SCr is known, but, in trauma patients, this may not be available [13].

To address some of the shortcomings of the RIFLE criteria, the Kidney Disease: Improving Global Outcomes (KDIGO) examined several definitions of AKI and developed an easy, clinically applicable definition for AKI. Criteria include an increase in SCr >0.3 mg/dL within 18 h or an increase in SCr to > 1.5 times baseline, which is known or presumed to have occurred within the past 7 days or UO of <0.5 mL/kg/h for 6 h.

To grade the severity of AKI, three levels of dysfunction were identified. Stage 1 includes a SCr increase of 1.5–1.9 times baseline or ≥0.3 mg/dL or UO <0.5 mL/kg/h for 6–12 h. Stage 2 is defined by any of the following, an increase in SCr of 2.0–2.9 times baseline, an increase of SCr ≥ 4 mg/dL, or UO <0.5 mg/kg/h for ≥ 12 h. Stage 3 includes any of the following, an increase of SCr over 3.0 times baseline, initiation of RRT, estimated glomerular filtration rate (eGFR) decrease to <35 mL/min per 1.73m^2 in patients less than 18 years, or anuria for ≥ 12 h (Table 37.2) [14].

Risk Factors

The etiology of AKI is often multifactorial in geriatric patients. Age-related changes of the kidney make the elderly more susceptible to AKI at baseline [15]. In the trauma setting, hypovolemia from pre-existing medical problems, under-resuscitation, and shock from hemorrhage play important roles in increasing the risk of AKI. Comorbidities such as diabetes, hypertension,

Table 37.2 Acute kidney injury criteria: RIFLE and KDIGO

	RIFLE	Laboratory criteria	UOP criteria	KDIGO stage	Laboratory criteria	UOP criteria
Increased AKI	Risk	Cr 1.5× baseline or GFR decrease >25 %	<0.5 mL/kg/h ×6 h	*1*	1.5–1.9× baseline or >0.3 mg/dL increase	<0.5 mL/kg/h ×6–12 h
	Injury	Cr 2× baseline or GFR decrease >50 %	<0.5 mL/kg/h ×12 h	*2*	2.0–2.9× baseline	<0.5 mL/kg/h for >12 h
	Failure	Cr 3× baseline, Cr >4 mg/dL or GFR decrease >75 %	<0.5 mL/kg/h ×12 h or anuria ×12 h	*3*	3.0× baseline or serum Cr >4.0 mg/dL or initiation of RRT	<0.3 mL/kg/h for >24 h or anuria for >12 h
	Loss	Complete loss of renal function for >4 weeks				
	End-stage renal disease	Complete loss of renal function for >3 months				

Refs. [13, 14]
AKI acute kidney injury, *Cr* creatinine, *UO* urine output, *h* hour

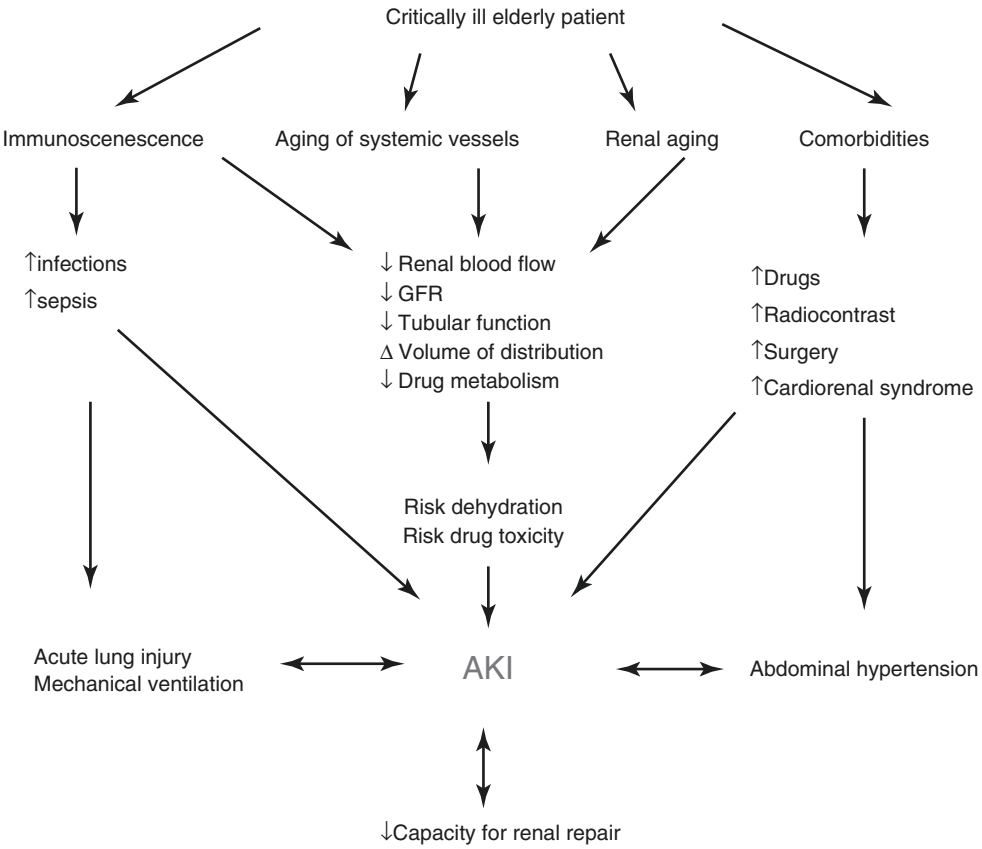

Fig. 37.1 Factors contributing to AKI (Adapted from Chronopoulos et al. [16]. Reproduced, with permission from Springer Science + Business Media)

cardiovascular disease, congestive heart failure, and especially baseline chronic kidney disease (CKD) are additional independent risk factors for developing, and not recovering from, AKI. Furthermore, many patients with comorbid medical conditions are treated with agents that may be nephrotoxic and predispose the elderly trauma patient to AKI (Fig. 37.1) [16].

Age-Related Changes of the Kidney and Risk of AKI in the Elderly

As patients age, there are structural alterations to the kidney. These include atherosclerotic and mesangial matrix changes which alter blood flow. Starting at the age of 40 years, renal blood flow can decrease by approximately 10 % per decade.

The vascular tone of the kidney is maintained by renin-angiotensin-aldosterone system and vasodilatory prostaglandins. There is a reduction of these vasodilatory prostaglandins that can lead to changes in renal vascular tone and exaggerated response to vasoconstrictive stimuli. This can lead to increased vulnerability to stressors such as hypovolemia, low-flow states, or medications that affect the hormonal regulation of the kidney [1, 2].

Structural changes inside the functional renal parenchyma occur as a part of the normal senescence process. Fibrous tissue replaces normal glomerular tissue over time, resulting in a 30–50 % loss of cortical glomeruli by the age of 70 years. Tubular atrophy, reduced tubular number and length, fatty degeneration, and fibrosis lead to fragility of the tubule making them less tolerant to injury caused by toxins or hypoxia. Aging and cellular senescence lead to a loss of 4500 nephrons per kidney per year. The result is a decreased renal mass; by the age of 80 years, 25–30 % of mass is lost [2].

Due to the process of aging, renal function declines, often starting after the third decade of life. The normal loss of glomerular filtration rate (GFR) is estimated at 0.8–1.0 mL/min/1.73 m^2 per year. With age comes loss of skeletal muscle or sarcopenia estimated at 0.5–1% per year starting at the age of 25 years. The process of sarcopenia results in a decrease production of creatinine. The progressive decrease in GFR is not necessarily reflected in a concomitant increase in serum creatinine due to the loss of creatinine production; thus, creatinine is not an ideal marker for renal functional decline [2].

An important function of the kidney is maintaining electrolyte and water homeostasis. As the kidney ages, there is a reduction in its ability to regulate these important processes through changes in the loop of Henle and other structures. Sodium regulation is greatly affected due to a blunted response to large sodium loads and a decrease ability to compensate for sodium loss. Approximately 85 % of elderly persons have decreased ability to reabsorb sodium. The normal countercurrent exchange in the kidney is gradually lost, resulting in renal medullar hypotonicity. The hypotonic state causes reduced ability to maximally concentrate urine which can lead to dehydration. This leads to decreased responsiveness to antidiuretic hormone (ADH) leading to a reduction of water absorption. Senile sodium leakage and water disequilibrium due to a reduction in free water excretion can lead to chronic hyponatremia. Water equilibrium is altered through a decreased response of ADH release and thirst regulation. Due to declining number of urea channels in the tubules, reduction of urea reabsorption occurs, which can lead to a loss of water through osmotic diuresis. Additionally, decreased aldosterone production and developing resistance to aldosterone in the tubule impair potassium regulation. Thus, elderly patients become more susceptible to the development of hyperkalemia [1, 2].

Chronic Kidney Disease and Risk of AKI in the Elderly

CKD is described by a sustained eGFR less than 60 mL/min/1.73 m^2 [2]. Patients with AKI, superimposed on CKD, have a 41-fold increase risk to progress to end-stage renal disease (ESRD) compared to a 13-fold increase in patients with AKI without CKD. Age older than 65 is a risk factor for failure to recover from AKI and even progression to advanced-stage CKD [17, 18]. Critically ill surgical patients that recover from an initial episode of AKI are at a higher risk for subsequent AKI, which carries higher mortality and a decline in renal function at the time of subsequent discharge [19].

Volume Status and Risk of AKI in the Elderly

Intravascular hypovolemia leads to renal under-perfusion from decreased effective arterial blood volume and can subsequently cause AKI. Prerenal etiologies account for approximately one-third of AKI in the elderly [1]. Baseline intravascular hypovolemia from congestive heart disease or liver disease increases the risk of ischemic and nephrotoxic insults in elderly patients who already have physiologic age-related changes as outlined above [15]. Traumatic hemorrhage, third spacing of fluids after operative interventions, and sepsis may result in intravascular volume depletion and thus also increase the risk of AKI. Medications such as diuretics, NSAID, and angiotensin-altering medications and changes in nephron sodium handling may alter the kidneys' autoregulatory responses in the setting of volume loss [1]. For example, Kim et al. showed that among 153 adults who received treatment for intracranial hypertension from TBI, high doses of mannitol (≥1.34 g/kg/day) were associated with more frequent and severe AKI. This was particularly evident in patients over 69 years and pre-existing renal dysfunction [20].

When treating hypovolemia, the goal should be euvolemia, as overly aggressive fluid resuscitation can be harmful [21]. The neurohormonal effects of trauma including catecholamine release and sympathetic activity stimulation result in sodium and water retention which persists after the inciting stressor resolves, leading to excessive volume accumulation [22]. Fluid overload results in tissue edema. This impairs oxygen and metabolite diffusion, distorts tissue architecture, obstructs capillary blood flow and lymphatic drainage, and disturbs cell-cell interactions that may then contribute to progressive organ dysfunction, including AKI. Cardiogenic edema can worsen forward flow, altering renal blood flow and risking injury to the kidney. Additionally, hypoxia induced by pulmonary edema can result in inadequate kidney oxygenation causing further injury [22, 23].

Hypervolemia associated with resuscitation can predispose a patient to intra-abdominal hypertension (IAH). It is defined as repeated or sustained intra-abdominal pressure (IAP) ≥12 mmHg. This is thought to be due to large volumes during resuscitation, and capillary leak leads to visceral edema and IAH. The increase pressure decreases renal perfusion pressure, inducing a "renal hypovolemic state," and has been shown to decrease renal artery resistive index and UO. An IAP of 20 mmHg can reduce the renal blood flow by 20–25 %. Another pressure phenomenon that affects renal perfusion through the same "renal hypovolemic state" is positive pressure ventilation (PPV). PPV can reduce cardiac output by decreasing preload and activate renin-angiotensin axis. One study revealed that invasive mechanical ventilation was associated with a threefold increase in the odds of developing AKI in critically ill patients [24].

Infection

Elderly are at increased risk for healthcare-associated infections, and they also have an increased risk of developing AKI from sepsis [16, 25]. The BEST Kidney investigators reported in their prospective observational study of over 29,000 ICU patients that nearly half of the 5.7 % who developed AKI had septic shock as a likely etiology [26, 27]. Septic AKI is emerging as a separate entity with distinct pathophysiology and outcomes [28]. White et al. examined 246 septic surgical patients and found AKI (defined by RIFLE criteria) occurred in 67 % of the patients, with higher rates among those with septic shock (88 %). Patients with AKI had statistically significant longer ventilator and ICU days and increased hospital mortality and were less likely to be discharged home [29].

Nephrotoxins and the Risk of AKI in the Elderly

Drug-induced nephrotoxicity is another major cause of AKI in the elderly [15, 17]. Diuretics and angiotensin-altering drugs used to treat hypertension and congestive heart failure deplete volume which can cause AKI. NSAIDs are associated with acute tubular necrosis or acute interstitial nephritis. New NSAIDs used in patients over 65 years double the risk for AKI. Additionally, they have a longer half-life in the elderly, further increasing their risk of acute kidney injury [17]. Hypersensitivity to medications causes acute interstitial nephritis, a less common cause of AKI. Antibiotics, especially penicillins, cephalosporins, and sulfonamides, are often implicated [1, 30].

Contrast-induced nephropathy (CIN) has been implicated as a major cause of AKI in hospitalized patients [1, 31]. Several factors increase this risk including hypotension, sepsis, coadministration of other nephrotoxic agents, diabetes, pre-existing renal dysfunction, and higher injury severity score in trauma patients [1, 32–34]. A retrospective study of 1371 trauma patients done by McGillicuddy et al. showed that receiving IV contrast did not increase the rate of AKI [35]. Many of the previous risk factors for AKI were not accounted for in this study. The body of evidence does suggest contrast agents can contribute to the development of AKI. It is likely that AKI in the setting of IV contrast administration is multifactorial, given many different patient factors that can predispose a patient to develop AKI rather than the contrast agent alone [36–38]. It is important to realize the potential for CIN among elderly trauma patients; using these agents judiciously is responsible medicine.

Trauma patients are at risk for rhabdomyolysis. Myoglobin release from ischemic muscle induces renal vasoconstriction, formation of intratubular casts, and the direct toxicity of myoglobin to the kidney tubule [39].

Anatomic Causes of AKI

Postrenal obstruction occurring proximal to the level of the ureter, the bladder, or at the bladder outlet/urethra causes up to 10 % of AKI. Postrenal obstruction AKI typically occurs in men from benign prostatic hypertrophy or prostate cancer. In women, retroperitoneal and pelvic malignancies are the most important causes. Neurogenic bladder and medications such as anticholinergics can lead to obstructive uropathy. Obstruction related to trauma can be due to a direct injury to the genitourinary tract (i.e., bladder hemorrhage with clot); space-occupying retroperitoneal lesions such as hematomas or abscesses can also cause ureteral or bladder obstruction in trauma patients [1]. The kidney can be directly injured by the traumatic insult. In trauma to the kidney, renal dysfunction has been directly correlated to the severity injury [40].

Preventing AKI

In 2012, KDIGO issued guidelines to prevent AKI in adults based on a systematic review of renal-protective strategies in the literature (Table 37.3). Some of their key recommendations include (level of evidence):

Volume expansion: KDIGO recommends controlled fluid resuscitation with isotonic crystalloids in volume depletion (grade 2B) in the absence of hemorrhagic shock. They recommend against the use of diuretics to prevent or ameliorate AKI (grade 1B evidence). Patients at high risk of CIN should receive intravenous volume expansion

Table 37.3 KDIGO prevention and treatment of AKI [14]

Volume status management/hemodynamic support
Controlled fluid resuscitation with isotonic crystalloids in volume depletion (2B)
Use of blood products in hemorrhagic shock
Avoid the use of diuretics to prevent or ameliorate AKI (1B)
Except volume overload states (2C)
Use of vasopressors in conjunction with fluids in patients with vasomotor shock with or at risk for AKI (1C)
Avoid using low-dose dopamine to protect against or treat AKI (1A)
Avoid the use of fenoldopam to prevent or treat AKI or CIN (2C, 1B)
Metabolic/endocrine support
Insulin therapy may be needed to obtain plasma glucose of 110–149 mg/dL in the critically ill (2C)
Adequate nutritional support for all patients at risk for AKI via an enteral route when possible (grade 2C)
Total energy intake of 20–30 kcal/kg/d in patients
Protein restriction should be avoided with the aim being preventing or delaying RRT (2D)
Protein calculations of 0.8–1.0 g/kg/d in non-catabolic AKI patients without the need for RRT (2D)
Protein calculations of 1.0–1.5 g/kg/d in patients with AKI on RRT (2D)
Maximum of 1.7 g/kg/d in patients on CRRT or hypercatabolic patients (2D)
Prevention of CI-AKI
Consider alternative imaging studies in patients at increased risk
Use the lowest possible dose of contrast medium in patients at increased risk (NG)
Iso-osmolar or low-osmolar iodinated contrast media is preferred over high-osmolar (1B)
Intravenous volume expansion with either isotonic sodium chloride or sodium bicarbonate solutions rather no intravenous fluids in patients at increased risk (1C)
Not using oral fluids alone in patients at increased risk (1A)
N-acetylcysteine (NAC) should be avoided to prevent AKI in patients with hypotension (2D) or postsurgical (2D). Oral NAC can be considered in high-risk patients in conjunction with isotonic intravenous fluids (2D)

with either isotonic sodium chloride or sodium bicarbonate solutions, rather than oral fluids alone (1C), or no intravenous volume expansion (1A).

Vasopressors: The group recommends the use of vasopressors in conjunction with fluids in patients with vasomotor shock with or at risk for AKI (1C). They suggest against using low-dose dopamine to protect against or treat AKI (grade 1A).

Vasodilators: The group recommends against the use of fenoldopam to prevent or treat AKI or CIN (2C, 1B).

Metabolic/Endocrine: They recommend insulin therapy to obtain a plasma glucose of 110–149 mg/dL in the critically ill (2C). Protein restriction should be avoided with the aim being preventing or delaying RRT (2D). They suggest adequate nutritional support for all patients at risk for AKI via an enteral route (grade 2C). The use of n-acetylcysteine (NAC) should be avoided to prevent AKI in patients with hypotension (2D) or after surgery (2D). Oral NAC can be considered to prevent CIN in high-risk patients in conjunction with isotonic intravenous fluids (2D).

Evaluation of AKI

A detailed history with particular attention to diabetes, hypertension and vasculitides, baseline renal function, hepatic dysfunction, and potential nephrotoxic medications is essential in assessing the risk for AKI in any given patient. Physical examination should focus on the assessment of volume status and signs of uremia. Diagnostic studies should include standard serum complete blood counts, chemistry panels, myoglobin, urine electrolytes, and urine sediment examination. Renal ultrasound is useful to rule out obstructive causes. UO should be monitored closely and urinary catheter may be necessary. In rare instances, kidney biopsy is necessary to truly establish the diagnosis [15, 41].

Treatment

Treatment for AKI is supportive. Figure 37.2 provides stage-based management recommendations per KDIGO. A critical step in treating AKI is to avoid exposure to nephrotoxins, maintain appropriate hemodynamic parameters, avoid hypoxia, and minimize repeated episodes of AKI, which increase the risk of non-recovery of renal function, especially in the elderly. One of the first steps is to ensure euvolemia in AKI through the use of fluid resuscitation or blood product administration in hemorrhage shock. Isotonic crystalloid fluids over colloid are preferred. Vasopressors may be needed to maintain goal hemodynamics in conjunction with fluids in shock states. Avoiding hyperglycemia is important to prevent osmotic diuresis and infectious complications. Adequate nutrition needs to be ensured, preferably via the enteral route with particular attention to the need for increased protein in patients on RRT or in hypercatabolic states. Table 37.3 provides information from KDIGO for management of AKI [14].

Diuretics in ARF

The physiologic argument to use diuretics in critically ill patients with AKI is that diuretics increase urinary flow and renal perfusion which decreases the risk of ongoing injury. Loop diuretics are also thought to decrease metabolic demand of renal tubular cells and reduce oxygen consumption. Furthermore, some suggest that oliguric AKI is associated with higher mortality than nonoliguric AKI [42].

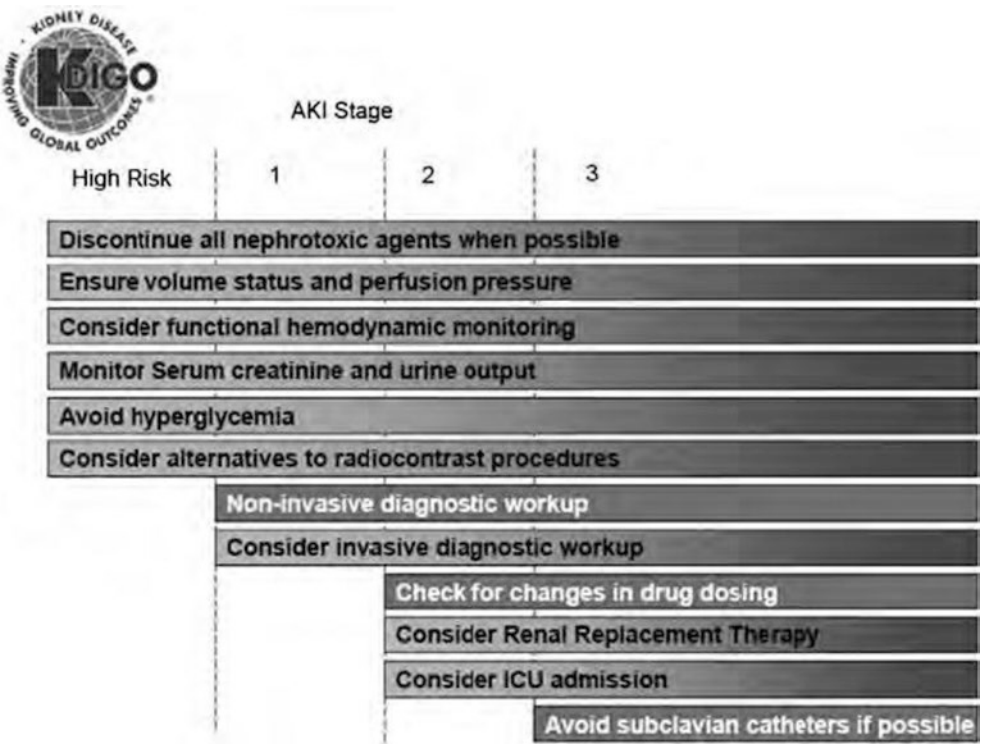

Fig. 37.2 KDIGO AKI stage management (KDIGO [14]. Reprinted with permission from KDIGO)

Karajala et al. conducted a systematic review in 2009 evaluating the role of diuretics in treating AKI and found that diuretics, while useful in managing volume status, do not improve mortality, decrease the use of RRT, or speed recovery from AKI [43]. Diuretics have a role in the setting of oliguric AKI, if systemic complications of volume overload such as pulmonary edema are manifest [43, 44]. According to KDIGO, the use of diuretics should not be aimed at treatment of AKI itself but rather volume overload associated with the disease [14].

Indication for RRT

There are two potential indications for RRT in critically ill patients: renal replacement and renal/multi-organ support. RRT can correct electrolyte imbalances and acid/base disturbances and improve volume status and uremic complications [45]. Examples of conditions that may improve with renal support include congestive heart failure, respiratory acidosis from adult respiratory distress syndrome, liver failure, pancreatitis, fluid management in multi-organ failure, lactic acidosis, crush injury, tumor lysis syndrome, and, potentially, cytokine removal in sepsis [46, 47].

Initiation of RRT in an oliguric patient generally requires evidence of severe hyperkalemia, severe pulmonary edema, severe academia, uremic complications, and intoxication of dialyzable substances, although specific guidelines for thresholds are lacking [48]. Continuous renal replacement therapy (CRRT), rather than intermittent hemodialysis (IHD), is often preferred for critically ill patients with hemodynamic instability [24].

Principles of Renal Replacement Therapy

RRT modalities are categorized by the intermittent or continuous and the mechanisms of fluid and solute removal (Table 37.4). Given the lack of definitive outcome data for RRT modality in AKI, current practice is largely dictated by local resources and physician experience.

Vascular access is typically accomplished via a double-lumen venous catheter in the acute setting introduced in a central vein. Infectious complications have been found to be equivalent in the jugular and femoral sites. The left jugular vein has been implicated in higher rates of catheter dysfunction compared to the right or femoral veins. Deep insertion of jugular catheters in the right atrium has an advantage in terms of filter life and may be associated with better performance. The use of ultrasound guidance is encouraged. The subclavian veins are largely avoided due to the risk of thrombosis and stenosis that may jeopardize future fistula placement in the event of non-recovery. Ideally, the catheter diameter should be about one-third the vein diameter to decrease the risk of vessel thrombosis [49].

Fluid Removal: Ultrafiltration Fluid removal is accomplished through ultrafiltration (UF) in all RRT methods with

Table 37.4 Renal replacement therapy comparison [46, 48]

	CRRT	Standard IHD	SLED
Time of run	Continuous	3–6 h	8–12 h
Blood flow rate	100–300 mL/min	200–300 mL/min	100–200 mL/min
Replacement fluid	1000 mL/h	None	None
Fluid removal	0–96 L/day	0–4 L/day	0–4 L/day
Anticoagulant	RCA or heparin	None	None

CRRT continuous renal replacement therapy, *IHD* intermittent hemodialysis, *SLED* sustained low-efficiency dialysis, *RCA* regional citrate anticoagulation

the exception of peritoneal dialysis (PD). UF uses a pressure gradient to drive fluid across a semipermeable membrane. Factors affecting the UF rate are the transmembrane pressure gradient, membrane water permeability, and membrane surface area [24].

Solute Removal The two primary mechanisms of solute removal are diffusion and convection. In hemodialysis, solutes are cleared by diffusion. Diffusion is the movement of a solute from a higher to a lower concentration across a semipermeable membrane. Diffusion is most effective with small molecular weight molecules (<500 Da). The dialysate fluid, which generally contains sodium, bicarbonate, chloride, magnesium, and calcium, runs countercurrent to blood flow, thus maximizing the concentration gradient. The factors affecting the rate of solute clearance are solute molecular weight, flow rates of blood and dialysate, dialysis duration, concentration gradient across the membrane, membrane surface area, and membrane permeability. Convection, the primary mechanism of solute clearance in hemofiltration, occurs when solutes are "dragged" with water during ultrafiltration. Solutes eliminated by convection include both small molecular weight molecules, such as potassium, phosphates, creatinine, and blood urea nitrogen (BUN), and medium molecular weight molecules up to 40,000 Da. Solute clearance is primarily dependent on the ultrafiltration rate, the ultrafiltration coefficient of the membrane, and the sieving coefficient of the solute that is inversely proportional to the molecular weight [24, 48].

Intermittent Versus Continuous RRT

Intermittent RRT Intermittent renal replacement modalities are the intermittent hemodialysis (IHD), the standard therapy in ESRD, and the sustained low-efficiency dialysis (SLED), also referred to as extended daily dialysis (EDD). IHD uses diffusion for solute removal and ultrafiltration for volume removal. In AKI, it is generally performed several times per week, around 4 h per session, with blood flow rates of 200–300 mL/min and dialysate flow rates of 500–800 mL/min [50]. The advantages include swift solute and volume removal, relatively low cost and complexity, and relatively small, if any, anticoagulation requirements due to rapid flow rates. Its primary disadvantage is the risk of hypotension which may be seen in as many as 20–30 % of patients receiving IHD. The rapid movement of solutes to the extravascular space can also cause cerebral edema; thus, IHD is contraindicated in patients with head trauma or hepatic encephalopathy [51].

SLED/EDD can use the same hemodialysis machines as IHD but runs for longer periods at slower rates. A usual treatment runs for 8–12 h, with blood flow rate of 200 mL/min and dialysate flow rate of 300 mL/min. It combines many of the advantages of IHD and continuous renal replacement therapy (CRRT). It is relatively low cost and low complexity since it uses the same technology as IHD; however, it also has the advantages of gradual fluid and solute removal and high total solute removal. In addition, because it is not continuous, other diagnostic and therapeutic procedures can occur between treatments [48].

Continuous RRT The continuous modalities are peritoneal dialysis (PD) and CRRT, which exist in various forms using ultrafiltration, hemodialysis, hemofiltration, hemodiafiltration, and combinations of these. The three primary modalities of RRT used to treat AKI are IHD, CRRT, and SLED [50]. PD, a common modality in ESRD, is generally not used in the acute setting as it carries an increased risk of peritonitis, catheter malfunction and leakage, contraindicated in patients with recent abdominal surgery or abdominal sepsis, insufficient solute clearance in catabolic patients, and reduces respiratory function through impedance of diaphragmatic excursion [48].

CRRT includes a variety of modalities that use ultrafiltration and may use convection, diffusion, or both. Treatment is 24 h per day with a blood flow of 100–300 mL/min and a dialysate flow of 17–34 mL/min in the case of diffusive technologies [50]. Although solute clearance is lower per unit of time compared to IHD, over 24 h it may exceed IHD. The advantage is a slow shift in both fluid and solutes allowing for better hemodynamic stability including less renal and intestinal ischemia and more precise solute concentration control mimicking the native kidney by its continuous nature [24]. The gradual solute removal in CRRT makes it less likely to cause cerebral edema [51]. Body core temperature may decrease with CRRT [24].

Replacement solution supplants the ultrafiltrate continuously removed by hemofiltration and hemodiafiltration. Buffers used as the replacement solution are lactate, bicarbonate, or citrate. Lactate and citrate are metabolized by the liver and muscles to produce bicarbonate, which is easily tolerated, but can be unstable in the solution. Commercially available bicarbonate solutions are manufactured with a two-compartment bag to prevent carbonate precipitation during storage. Lactate is stable in replacement solution; however, it may contribute to an existing lactic acidosis in patients with sepsis or liver failure [52]. The choice of parameters within CVVH offers some flexibility for patients with differing underlying processes [46]. Citrate is successfully used in patients at risk of bleeding, while bicarbonate-based replacement solution is preferred in those with lactic acidosis or liver failure [53].

The primary disadvantage of CRRT is the possible need for continuous heparin anticoagulation to delay hemofilter clotting which increases the risk of bleeding complications. As an alternative, regional citrate anticoagulation (RCA) has higher efficacy and safety than systemic heparin while prolonging the filter's life span. Citrate is infused pre-filter and works by extracorporeal chelation of calcium ions to decrease their availability for calcium-dependent steps in clot formation. Systemic anticoagulation does not occur as the ionized calcium level is restored when blood returning from the machine is mixed with venous blood. Rapid metabolism of citrate by the kidney, liver, and muscle restores bicarbonate levels and releases calcium [54]. RCA may add complexity to CRRT because it can require customized dialysate solutions or replacement fluids and frequent laboratory monitoring, including electrolytes, ionized calcium, and acid/base status [50, 54]. Patients with mild liver dysfunction and decreased citrate metabolism do not require emergent treatment since these perturbations are generally not life-threatening and are easily corrected with pharmacologic intervention. Patients with severe liver failure and lactic acidosis may develop citrate toxicity which is characterized as low ionized calcium, elevated total serum calcium, exacerbation of serum acidosis, and an elevation of the anion gap [55].

RRT Dose

While standard dosing targets in ESRD have been developed, dosing targets in AKI are not clear. Studies on dose and schedule of RRT have shown variable results. The Randomized Evaluation of Normal Versus Augmented Level (RENAL) replacement therapy study was a multicenter trial enrolling 1508 AKI patients in 35 ICUs randomly assigning patients to CRRT at a high (40 mL/kg/h) and low intensity (25 mL/kg/h). The primary outcome of 90-day mortality was the same in each group (44.7 %). Similar rates of renal recovery among survivors were noted in each group at 90 days [56]. A study of 160 AKI patients treated with IHD randomly assigned patients to a daily or alternating-day therapy showed that the daily group had lower 14-day mortality after the last IHD treatment and improved renal recovery. This study also showed the alternating-day group had higher rate of uremic complications, sepsis, gastrointestinal bleeding, and alterations in mental status [5].

The VA/NIH ATN study, a multicenter, prospective, randomized, parallel-group trial, attempted to definitely answer whether high-intensity or low-intensity RRT in critically ill patients resulted in better outcomes as measured by an evaluated 60-day all-cause mortality. The study included 1124 patients randomized to receive either intensive (IHD and SLED six times per week, CRRT at a flow rate of the total effluent of 35 mL/kg/h) or conventional therapy (IHD and SLED three times per week, CRRT at a flow rate of 20 mL/kg/h). The primary end point was death from any cause by day 60 and they found no difference between the two groups [7]. Intensive therapies do carry risks of electrolyte disturbances including hypokalemia and hypophosphatemia in addition to increase loss of important nutritional building blocks [5].

RRT Modalities and Outcomes

Outcomes for AKI when RRT is initiated early in the course of the injury have shown benefit. One study revealed that a higher degree of azotemia (BUN>76 mg/dL) prior to initiation of RRT had higher mortality [57]. The BEST Kidney study showed that early initiation of RRT was associated with lower mortality, shorter hospital stay, and shorter duration of RRT [24, 26]. Additionally, a study looking at 100 trauma patients with AKI treated with CRRT found that starting RRT at a BUN <60 mg/dL had a survival advantage [58].

Data comparing the outcomes of different RRT modalities in AKI continues to be inconclusive, although what is available points to similar survival rates for IHD and CRRT [24, 49, 59]. Bagshaw et al. recommend the ideal modality be directed to patient-specific (i.e., diagnosis, illness severity), clinician-specific (i.e., RRT prescribing service), and hospital factors (i.e., availability of RRT machines and support staff) [60].

Discontinuing RRT Many studies have looked at proper timing of when to discontinue RRT. Two factors that are closely examined include UO and SCr. It appears that UO > 400 mL/day and evidence of SCr decline are helpful in determining the discontinuation of RRT. In the BEST Kidney study, age <65 years, shorter duration of RRT, lower sequential organ failure assessment (SOFA) score, and UO ≥100 mL/8 h were independently associated with the ability to remain RRT-free at 7 days [61]. Additionally, the use of diuretics negatively impacted the predictive value of UO to predict successful RRT discontinuation [6].

RRT may be discontinued without specific weaning protocol. If symptoms arise that can best be treated with RRT, it can reinitiated on an as-needed basis for symptom management. It

may be helpful for patients that exhibit only partial recovery to undergo prolong RRT with decline support times and modalities to assist in symptom management [6].

Prognosis and Ethical Issues of Treating AKI in the Elderly

The relationship between age and recovery of renal function after AKI is well studied. One meta-analysis of 17 studies showed that 31 % of older patients failed to recover renal function compared to 26 % of a younger cohort ($P < 0.05$) [62]. For Medicare beneficiaries over 67 years in a retrospective study, the hazard ratio of developing ESRD was 13.0 after AKI with no history of CKD and 41.2 in those suffering AKI in the presence of CKD compared to patients with no AKI or CKD [63]. Another study of AKI in Medicare beneficiaries showed that the inhospital mortality of patient requiring RRT was 32.9 % and 27.5 % with AKI not requiring RRT. The 90-day death rate after discharge was 13.1 % without AKI and 34.5 % when AKI was the principal admitting diagnosis and 48.6 % when AKI was a secondary diagnosis [64]. In a prospective study, the inhospital mortality of elderly AKI patients of 99 subjects was 42 % [65]. With these facts, AKI should be looked at not as a self-limiting disease in which most recover but a risk factor for long-term morbidity, mortality, and hospitalization [66]. Unfortunately, many patients are not informed about the associated morbidity and mortality with dialysis [67].

Almost one-third of elderly patients with ESRD have four or more chronic health conditions when they are diagnosed with ESRD and are therefore ineligible for renal transplant. Among older patients in whom dialysis is initiated during hospitalization, the median survival is approximately 8 months. For patients over 85 years, the median survival was 5 months with approximately 2–5 months of that time spent in the hospital [68]. Older patients on RRT, who also have cardiovascular disease or diabetes, have lower survival than other dialysis patients [69]. While on dialysis, many patients report inadequate pain control, cognitive impairment, missed social experiences, and decreased functional status [70].

Given the high mortality rates associated with RRT in the elderly, the use of RRT in geriatric trauma patients can present ethical challenges. The initiation of RRT and the withdrawal of RRT in this population can be controversial. In patients who have a limited life expectancy from underlying serious illness or who expect a poor quality of life, focusing on comfort rather than longevity, including considering hospice, may be a better alternative to initiating RRT [70]. In patients where renal recovery remains uncertain, clinicians could consider offering a time-limited trial [71].

Making the transition to a permanent dialysis is not straightforward in elderly patients. The Renal Physicians Association and the American Society of Nephrology have published a clinical practice guideline: *Shared Decision-Making in the Appropriate Initiation of and Withdrawal from Dialysis*. It provides ten recommendations for the dialysis of patients with AKI and ESRD (Table 37.5). This guideline provides a systematic approach to aiding decision-making and resolving ethical conflicts related to renal support and palliative care [72].

Table 37.5 Shared decision-making in the appropriate initiation of and withdrawal from dialysis [72]

1. Develop a physician-patient relationship for shared decision-making
2. Fully inform AKI, stage 4 and 5 CKD, and ESRD patients about their diagnosis, prognosis, and all treatment options
3. Give all patients with AKI, stage 5 CKD, or ESRD an estimate of prognosis specific to their overall condition
4. Institute advance care planning
5. If appropriate, forgo (withhold initiating or withdraw ongoing) dialysis for patients with AKI, CKD, or ESRD in certain, well-defined situations
These situations include the following:
Patients with decision-making capacity, who being fully informed and making voluntary choices, refuse dialysis or request that dialysis be discontinued
Patients who no longer possess decision-making capacity who have previously indicated refusal of dialysis in an oral or written advance directive
Patients who no longer possess decision-making capacity and whose properly appointed legal agents/surrogates refuse dialysis or request that it be discontinued
Patients with irreversible, profound neurological impairment such that they lack signs of thought, sensation, purposeful behavior, and awareness of self and environment
6. Consider forgoing dialysis for AKI, CKD, or ESRD patients who have a very poor prognosis or for whom dialysis cannot be provided safely
7. Consider a time-limited trial of dialysis for patients requiring dialysis, but who have an uncertain prognosis, or for whom a consensus cannot be reached about providing dialysis
8. Establish a systematic due process approach for conflict resolution if there is disagreement about what decision should be made with regard to dialysis
9. To improve patient-centered outcomes, offer palliative care services and interventions to all AKI, CKD, and ESRD patients who suffer from burdens of their disease
10. Use a systematic approach to communicate about the diagnosis, prognosis, treatment options, and goals of care

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Nutrition Support

38

Michael Pasquale and Robert D. Barraco

Introduction

The Current State

The American population continues to age as confirmed by the Federal Interagency Forum on Aging-Related Statistics [1]. They noted that in 2010, 40 million people in the USA were over the age of 65, comprising approximately 13 % of the population. Additionally, 5.5 million Americans were over the age of 85. Advances in medicine have increased the average life expectancy, and current information suggests that if a person lives to the age of 65, they can be expected to live another 18.5 years. However, one of the "side effects" of this aging process is the increased prevalence of chronic health conditions and the decline in function of our elderly (>65 years). Twenty-five percent of the elderly population has difficulty with at least one activity of daily living (bathing, dressing, getting in/out of a chair, walking, using a toilet), and 42 % report at least one functional limitation, which includes the ability to feed oneself. In nursing care facilities, 15 % of the elderly patients require assistance with feeding [3]. In general, elderly Americans met or exceeded federal dietary quality standards for only 3 of 12 nutritional components (whole fruit, total grain, meat and beans) as determined by the Healthy Eating Index – 2005 [1]. Protein-energy malnutrition occurs in up to 10 % of elderly living at home and up to 70 % of hospitalized elderly [2]. Based on the aging of our population and the limitations associated with this aging, efforts must be focused on improving nutritional support.

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Nutritional Assessment

Nutritional Scales (Walker Review Article)

Over 200 equations predictive of resting energy expenditure currently exist in the literature. The original equations for resting energy expenditure in humans were derived from healthy human subjects at rest and were subsequently adjusted for illness. Due to a number of confounding factors which include but are not limited to obesity, cachexia, edema, and surgery, calculated values are inaccurate by as much as 55 % when predicting daily needs [4].

Indirect calorimetry is the most accurate method to determine resting energy expenditure and caloric needs in the ICU patient [5]. In 1919, the Harris-Benedict equation, which utilizes the variables of height, weight, age, and gender, was derived using data from indirect calorimetry that had been performed in healthy subjects. Once the resting energy expenditure is determined, an illness-based variable multiplier is used to approximate the patient's caloric needs. This equation has been shown to be unreliable when applied to malnourished and critically ill patients and frequently underestimates the caloric requirements when compared to indirect calorimetry [5]. The available evidence suggests that the Harris-Benedict equation should not be used for patients in an ICU setting.

The Ireton-Jones equation, published in 1992, was derived from a multivariate regression analysis including the variables age, weight, sex, and the presence/absence of trauma or burns. The original equation appeared to overestimate needs and was revised in 1997 in an attempt to increase its accuracy compared to indirect calorimetry. The 1997 revision performed poorly in younger and obese patients and in general was felt to underestimate caloric needs. While the original equation is generally the preferred of the two, neither has been shown to be very accurate when compared to indirect calorimetry [6].

Swinamer et al. derived an equation using variables that contribute >3 % of energy expenditure: total body surface

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area, age, respiratory rate, tidal volume, and temperature. While the accuracy of this equation is better than others (45–55 %), it is not utilized frequently because it is cumbersome and not user-friendly [4].

A group at Penn State University developed an equation using data from mechanically ventilated, medical/surgical critical care patients in 1998 [7]. The original equation utilized the patient's adjusted body weight in the setting of obesity; however, a modified version was derived in 2003 specifically for obese patients, which led to improved accuracy in that population. The accuracy of the PSU [m] equation is 93 % in the nonobese elderly and 67 % in the obese elderly mechanically ventilated medical/surgical/trauma patient. No stress factor adjustment is necessary for either of these equations, and they are more user-friendly than the Ireton-Jones equations [7].

Modified equation:

$$\text{RMR(kcal/d)} = \text{Mifflin - St Jeor}(0.71) + T_{\max}(85) + V_e(64) - 3085$$

Original equation:

$$\text{RMR(kcal/d)} = \text{MSJ}(0.96) + T_{\max}(167) + V_e(31) - 6212$$

Mifflin-St Jeor [6]:

$$\text{Male}: 10(wt) + 6.25(ht) - 5(age) + 5$$

$$\text{Female}: 10(wt) + 6.25(ht) - 5(age) - 161$$

(*RMR* resting metabolic rate, $T_{\max}$ maximum body temperature, V_e minute ventilation, *wt* weight in kilograms, *ht* height in meters) [6]

The American College of Chest Physician (ACCP) consensus statement in 1997 recommends 25 kcal/kg of usual body weight for calculating resting energy expenditure to avoid overfeeding. The calculation for obese individuals (BMI >25 using ACCP definitions) should utilize ideal body weight (male IBW = 50 + 2.3 kg for each inch >60 inches, female IBW = 45.5 + 2.3 kg for each inch >60 inches). Underweight patients (BMI <16) are at increased risk for refeeding syndrome. The calculation for REE in this setting should utilize the actual body weight for the first 7–10 days and then the ideal weight thereafter. For example, a 70 kg male with a BMI of 25 has a resting energy expenditure of 70 kg × 25 kcal/kg or 1750 kcal [8].

Metabolic Requirements

Physiologic Changes

While aging decreases the basal metabolic rate (BMR), physiologic aging does not progress at the same rate in all individuals. It is agreed that between the ages of 30 and 70 years, the BMR decreases by approximately 16 % and body composition changes such that there is increased fat and decreased protein content [9, 10]. Lean body mass for the average 30-year-old is approximately 45 % of total body weight (TBW) and for a 70-year-old is approximately 27 % TBW, while the total body fat is 14 % of TBW for age 30 and 30 % of TBW for age 70 [11].

A number of factors impact appetite as patients' age. The incidence of dysgeusia and dysosmia increases secondary to the decreasing number of taste buds, peripheral olfactory atrophy, and less saliva production. The first taste buds to be lost detect sweet and salt quality with bitter and sour diminishing later. Due to these changes, food begins to taste bitter and not smell appetizing [3, 9, 12]. Additionally, the physiologic regulation of appetite is a complex neural and hormonal network involving the autonomic nervous system, enteric nervous system, and hypothalamic-pituitary-adrenal axis in homeostatic balance. This balance is disrupted with chronic diseases, cancers, inflammatory processes, and polypharmacy resulting in an overall decrease in appetite [12].

Renal function declines with age and 40 % of nephrons are sclerotic by the age of 85. This process is accelerated in patients with diabetes, hypertension, dyslipidemia, and/or atherosclerosis. As renal function declines, the ability to regulate fluid balance and acid-base status deteriorates, and dehydration can occur as the kidney is unable to respond to renal sodium and water losses. This is likely secondary to a decreased responsiveness to ADH and decreased renin-angiotensin system activity, as well as diminished thirst [3, 13].

The gastrointestinal tract also undergoes age-related changes that include esophageal dysmotility from a change in peristalsis, chronic atrophic gastritis, intestinal bacterial overgrowth, and chronic constipation. All of the abovementioned factors, as well as laxative abuse, impact the intake and absorption of nutrients [9, 10]. Dyspepsia frequently occurs in the elderly and is most commonly related to peptic ulcer disease, gastroesophageal reflux, or gastric cancer [13]. Lactase, an essential enzyme in the digestion of dairy products, is produced in lesser amounts in the elderly, which leads to lactose intolerance resulting in stomach cramps and diarrhea. These factors contribute to malnutrition and vitamin/mineral deficiencies in the geriatric population [3]. Malnutrition, in turn, increases the incidence of complications such as wound failure/infection and nosocomial infections when combined with age-related reductions in skin integrity and immunocompetence. In an ICU setting, these complications are associated with negative outcomes and potentially death [9, 10].

Common Deficiencies

The aging population is at risk for deficiencies in many vitamins and nutrients. The decreased appetite, the inability to chew certain foods (e.g., fresh fruits and vegetables), and the

increased incidence of lactose intolerance are contributing factors to these deficiencies.

Vitamin D deficiency in the elderly is multifactorial with decreased consumption of vitamin D-fortified dairy products occurring secondary to an increased incidence of lactose intolerance. Further, less exposure to sunlight disrupts the conversion of vitamin D to the active form. This can be more pronounced in institutionalized patients who have limited exposure to direct sunlight. Finally, as the kidney ages, its ability to convert vitamin D to the active form also decreases. In order to prevent vitamin D deficiency, it should be supplemented (600 IU daily) in the diet, and efforts should be directed at providing the elderly with more exposure to sunlight [11, 13].

Red meat is the primary source of vitamin B12, and deficiencies may be related to food cost, dietary caloric restrictions, and difficulty with mastication due to poor dentition. Twenty percent of the geriatric population is deficient in vitamin B12 [13]. Decreased gastric acid secretion related to aging and/or the use of acid-reducing medications diminishes intrinsic factor production which can lead to atrophy of the gastric mucosa. Intrinsic factor is essential for the release of vitamin B12 from its carrier protein as well as absorption. Signs and symptoms of vitamin B12 deficiency include anemia, neuropathy, and dementia [11, 13].

Vitamin K deficiency is not prevalent in the geriatric population; however, certain medications may lead to inadequate absorption such as anticoagulants, antibiotics, and sulfa drugs. This vitamin should be kept in mind when starting these medications in the intensive care setting [11].

Nutritional Monitoring

There is no standard way to measure malnutrition in the hospitalized elderly patient. There are screening tools to help identify those individuals at risk. Screening is important due to the adverse effects of malnutrition on outcomes. Patients presenting malnourished have increased hospital stays, more complications, and higher mortality rates. In this section, we will discuss risk factors, screening tools, and biochemical markers of malnutrition.

Risk Factors

Risk factors for malnutrition in the elderly include those unrelated to age and those related to age [2]. Factors unrelated to age include cancer, chronic and severe organ failure, gastrointestinal diseases, alcoholism, chronic infectious, and/or inflammatory diseases as well as all factors likely to cause one or more of the following: a reduction in food intake, an increase in energy requirements, and malabsorption.

Risk factors related to age include psychological, social, and environmental factors such as depression, grieving, financial hardship, and admission to a long-term care facility. Oral, dental, and swallowing disorders can contribute to malnutrition. Dementia and other neurological disorders put the elderly at increased risk. Acute problems that result from trauma such as pain, fractures, and surgery increase the risk for malnutrition in the elderly.

Screening Tools

Screening for malnutrition includes evaluating risk factors, appetite, and food intake, comparing weights as possible, and calculating body mass index. These may contribute to the diagnosis of malnutrition but will not be obtainable in the obtunded trauma patient.

The Mini Nutritional Assessment (MNA) has been used as a standard for screening the elderly for malnutrition risk and is recommended in the 2007 evidence-based guideline from France. Questions address various areas and include appetite, meals, and weight loss. It also contains objective measurements of calf and mid-arm circumference. There is also a short form, the MNA-SF, which contains only six items [37].

In the critical care environment, the Nutrition Risk in the Critically Ill (NUTRIC) score has been proposed in an attempt to identify patients who benefit the most from nutrition therapy [38]. The score consists of six elements: age, APACHE II, SOFA, number of comorbidities, days from hospital to ICU admissions, and IL-6 level. The elements of the NUTRIC score are related to the severity of disease not nutritional parameters, which is considered a weakness of the score [39]. The score was found to correlate with mortality rate and duration of mechanical ventilation. In addition, the correlation between the risk score and mortality is reduced in patients who meet their caloric requirements.

Albumin

Visceral protein stores can be assessed by serum albumin concentration. Albumin is a plasma protein that maintains plasma oncotic pressure and a carrier protein for multiple elements and drugs. Testing serum levels is routinely available and the normal range is between 3.5 and 5 g/dl. The half-life of serum albumin is approximately 20–21 days; therefore, loss of protein stores will be reflected in the serum level at that time. Serum albumin is a reliable marker in the absence of liver disease, renal disease, prolonged bed rest, infection/sepsis, and cancer. However, these ailments are frequently comorbidities for many of the geriatric patients that enter critical care units [11, 14].

The assay of C-reactive protein may assist in interpreting the albumin result when an inflammatory process is involved. Serum albumin may distinguish between two forms of malnutrition, that due to a deficiency in food intake (albumin may be normal) and that due to inflammation and a catabolic state, with a rapid fall in serum albumin [2].

Transferrin

Transferrin is a protein that binds iron for transport to the bone. Its levels are affected by total body iron storage [14]. With aging, body tissue iron stores increase leading to a decrease in transferrin levels in healthy individuals. However, malnourished elderly patients with decreased protein and low iron stores may express a normal transferrin level. The 8–10-day half-life makes transferrin a good choice to assess the nutritional status of younger individuals, but should not be used in the geriatric population [10]. Normal serum values are between 200 and 400 mg/dl [14].

Prealbumin

Prealbumin is a visceral protein synthesized by the liver that binds thyroxine. The half-life of prealbumin is approximately 2 days making it a promising biochemical marker of protein storage and ideal for short-term nutritional assessment. Normal serum levels are between 18 and 40 mg/dl [11, 14].

Total Lymphocyte Count

Depressed total lymphocyte count can be a marker of malnutrition as it is used as a measure of immunocompetence. However, the total lymphocyte count can be altered by a wide variety of factors including hypoalbuminemia, infection, chronic comorbid conditions, and malignancy. The normal range is greater than 1500 cells per cubic millimeter [11]. Total lymphocyte count is not an adequate indicator of nutritional status in the geriatric populations as it is affected by the factors mentioned above [15].

Diagnosis of Malnutrition

Per the French guideline on protein-energy malnutrition, the diagnosis of malnutrition is based on one or more of the following criteria [2]: weight loss ≥5 % in 1 month or ≥10 % in 6 months, body mass index <21 (a BMI ≥21 does not exclude the diagnosis of malnutrition), serum albumin concentrations <35 g/l, and MNA score <17.

Severe malnutrition may be diagnosed by one or more of the following criteria: weight loss of ≥10 % in 1 month or ≥15 % in 6 months, BMI <18, and serum albumin <30 g/l. Severe malnutrition requires rapid nutritional management.

Nutritional Requirements

Carbohydrates

Half of the average Western diet consists of calories derived from carbohydrates. The body is able to store approximately 1200 calories in the liver and muscle in the form of glycogen. These stores are immediately available and depleted within 3 days of starvation. This process begins between 8 and 16 h postprandially. Glycogenolysis occurs as insulin levels decrease, mobilizing glucose from hepatic stores. Alanine is also essential for this process in the muscle and is used for gluconeogenesis as the muscle cannot mobilize glucose from glycogen for lack of glucose-6-phosphatase [12]. The ability to metabolize glucose diminishes with age leading to chronically elevated blood glucose levels and the development of advanced glycosylation end products (AGEs). AGEs promote fibrosis, decrease connective tissue flexibility, and change the extracellular matrices of the heart, kidney, skin, and central nervous system. These changes result in many of the common comorbid conditions in the geriatric population: neuropathy, nephropathy, cardiomyopathy, atherosclerosis, etc. [12]. Therefore, it is recommended that elderly individuals consume complex carbohydrates rather than simple sugars [11].

Proteins

The average adult requires 0.8 g of protein per kilogram body weight daily. The body is able to store protein in large amounts. However, only 50 % of the proteins can be utilized without serious consequences. Over 50 % depletion of protein stores is incompatible with life [12]. In the stress state, the body may require up to 1.5 g/kg/day to support wound healing, immune function, etc. Furthermore, patients who are bedbound, or institutionalized, require more than average protein to maintain nitrogen balance. This is not intuitive as one may believe that since lean muscle mass decreases in the elderly population, protein requirements would follow suit. However, the amount of nitrogen retained by the body decreases with decreased caloric intake, and in order to maintain positive nitrogen balance, additional protein must be provided. The average elderly person requires 1.0 g/kg/day of protein in order to maintain skeletal muscle protein metabolism which requires a larger amount of essential amino acids [11, 16]. Finally, only 25 % of undernourished

patients achieve protein and energy requirements by day 4 of their hospitalization [17]. Protein intake is essential and should not be overlooked.

Lipids

Up to 40 % of the calories that make up the average Western diet are from fat. This is 10 % in excess of the daily requirement and is approximately 600 unnecessary kilocalories daily. The greatest amount of energy storage in the body is in the form of fat. During starvation, free fatty acids are released in the normal state; however, in the elderly patient, the mobilization of fat does not occur as readily leading to excess protein breakdown and sarcopenia [11, 16]. Fat is a requirement in every diet, but should not exceed 30 % of total caloric intake. If being administered parenterally, triglyceride levels should be monitored, and elevated levels should prompt a reduction of infusion.

Vitamins and Minerals

Vitamin E, vitamin C, zinc, copper, and selenium are vitamins and minerals that have been shown to improve outcomes in critically ill surgical patients receiving nutritional support. A variety of combinations of the antioxidant vitamins and minerals administered have shown a decrease in mortality. Studies have also shown that adding selenium to the nutritional source reduces mortality in sepsis and septic shock [18, 19].

Calcium

Calcium is used to maintain bone health and structure and to minimize the risk of fractures in the elderly. Osteoporosis is aggravated by age-related hormonal changes, particularly in women. Total bone mass decreases with age and inadequate intake leading to lower vertebral, hip, femoral, and cervical spine fractures. This affects women more so than men secondary to gender-specific hormonal changes, dieting, childbearing, breastfeeding, and life longevity. Calcium requirements increase with age. The recommendation for calcium intake is 800–1200 mg per day with supplementation if levels cannot be maintained with diet [9, 13].

Fluids

Dehydration is a major concern in the geriatric population. Cellular dehydration and hypovolemia are the two main factors involved in thirst regulation. Thirst sensitivity decreases with age leading to high risk for dehydration. The recommended fluid intake is 30 ml of fluid per kilogram of body weight. This amount increases substantially in patients with vomiting or diarrhea and should be based on clinical findings [11].

Glutamine

Glutamine is the essential nutrient used by intestinal epithelium for maintenance of function. Enterocytes, lymphocytes, and macrophages utilize glutamine to maintain intracellular levels of ATP. In critical illness, the gut is susceptible to loss of mucosal integrity increasing the risk of bacterial translocation, sepsis, and death. Adding glutamine (0.3–0.5 g/kg/day) to enteral formulas has been shown to decrease hospital mortality in burn and mixed ICU patients [19, 21]. This has recently been called into question in several studies [40, 42, 43].

Indications for Nutritional Support

All patients admitted to the hospital should be screened for the risk of malnutrition. The rationale for screening all patients stems from studies showing increased complication rate, mortality rate, and length of stay in malnourished patients (ASPEN-1). The goal of aggressive early nutritional support is the maintenance of immunological integrity, preservation of lean body mass, and aversion of metabolic complications [18, 20].

Patients with oral/esophageal obstructions, dysphagia, psychomotor diseases (Parkinson's disease, Huntington's disease, multiple sclerosis, dementia), polytrauma, poor dentition, and xerostomia have difficulty consuming nutrients orally. Patients with loss of appetite, depression, decreased metabolism with aging, and decreased colonic motility lose the desire to eat. Even though patients may eat, the caloric intake may be inadequate. Contributing factors include infections (e.g., urinary tract), polypharmacy, and electrolyte imbalances [11, 18, 21].

"At-risk" patients, as determined by initial screening, should then have their nutritional status assessed. Traditional nutritional assessments include anthropometry and laboratory values such as albumin, prealbumin, transferrin, and total lymphocyte count. The assessed values are valid in "normal" patients outside and can be useful within the critical care arena.

Anthropometric data obtained should include height (cm), weight (kg), body mass index (kg/cm^2), and skinfold measurements to determine fat and protein stores. There is a great deal of variability in these measurements between physicians and even when repeated by the same physician. A

trained technician or physician should obtain these measurements with validity testing performed often. The measurements obtained are more useful in the outpatient setting [11].

Laboratory values are discussed within the nutritional monitoring section of this chapter. The values are more for nutritional monitoring rather than determination of nutritional status as most are acute phase reactants affected by a patients' metabolic state.

Other important nutritional assessment parameters include the patients' normal weight and any recent weight loss, pre-illness caloric intake, the severity of their disease state, comorbid conditions, and gastrointestinal function. Once a patient is identified as being malnourished, interventions should be made in the form of enteral nutrition, parenteral nutrition, or supplementation [18].

Enteral Nutrition

Surgical dogma has dictated, "if the gut works, use it." This simple statement has been backed by many studies throughout the literature. The enteral route of nutrition administration is preferred for multiple reasons. Studies have shown a decreased rate of infectious complications including pneumonia, central venous catheter infection, and abdominal abscess in trauma. Decreased length of stay and cost have also been shown. Other benefits include the preservation of intestinal mucosal integrity [18]. Feeding enterocytes promotes the release of endogenous hormones, blood flow, and secretory IgA immunocytes. Without these factors gut permeability increases leading to a breakdown in the mucosal defense system and the theoretic risk of bacterial translocation, systemic infection, and multi-organ system failure [18]. Enteral nutrition can be delivered via nasogastric or nasojejunal tubes or gastrostomy and jejunostomy tubes.

When should enteral nutrition be initiated? The general answer to this has to do with the patient's nutritional status, the timing of presentation to the hospital, and the procedure to be performed. In the case of elective surgery, if the patient is determined to be protein malnourished, nutritional support should be initiated 10 days preoperatively [22]. However, emergent/unplanned admissions do not have the luxury of extensive preoperative planning, and the answer becomes when the patient is hemodynamically stable and fully resuscitated with a time frame between 24 and 48 h from admission. Feedings should not be initiated if the patient is hemodynamically unstable or under resuscitated secondary to the risk of ischemic bowel. Patients requiring vasopressors to maintain adequate perfusion should not be started on enteral nutrition unless the vasopressor requirement has been stable. Initiating enteral feedings for patients on a stable vasopressor dose warrants close monitoring for intolerance [18].

Old surgical dogma included the presence of bowel sounds as criteria for the initiation of enteral nutrition. The absence of bowel sounds has not been shown to be associated with enteral nutrition intolerance and should not be used as criteria for initiation. Gastric residuals are often checked during the infusion of tube feedings as an indicator of tolerance. The literature has shown that a range of aspirate between 200 and 500 cc is elevated [3, 18]. However, tube feedings should not be held, and interventions to promote gastric emptying and decrease aspiration risk should be initiated unless the patient is showing signs of intolerance (pain, distention, absent flatus). These include administration of a prokinetic agent, elevating the head of the bed, and possibly inserting a small bowel feeding tube. Gastric residuals >500 cc should prompt cessation of enteric feeding with the intent of attempting again in the near future after the initiation of the interventions mentioned above [18].

There are many formulations of enteral nutrition from predigested amino acid-based formulations to immune-modulating formulations. With so many different options and new products coming to the market, what should be used and when? Immune-modulating enteral formulations contain arginine, glutamine, nucleic acids, omega-3 fatty acids, and antioxidants. There is data to indicate that these formulations are beneficial in major elective general surgery, trauma (ISS>20), burn, obese patients (BMI >30), and head and neck cancer patients in the intensive care setting on mechanical ventilation. Benefits included decreased time on mechanical ventilation, infectious morbidities, and hospital length of stay. There was no significant impact on mortality [18]. However, several recent randomized studies show not only no reduction of infectious complications but an increased mortality [40–43]. Therefore, recommendation of such formulas is unclear.

Another subset of patients are those with adult respiratory distress syndrome (ARDS) or acute lung injury (ALI). Enteral formulations with an anti-inflammatory lipid profile are beneficial to this subset. The formulation includes omega-3 fatty acids (eicosapentaenoic acid), fish oil, borage oil, and gamma-linolenic acid. Benefits include decreased ICU length of stay, time on mechanical ventilation, and organ failure. However, no significant impact on mortality was found [19].

Protein is important for wound healing, maintenance of immune function, and maintenance of lean body mass. Supplementation for patients with a BMI <30 should occur to increase the protein consumption to 1.2–2.0 g/kg/day. This is especially beneficial in patients with negative nitrogen balance, which is the preferred method to determine the need for protein supplementation rather than albumin, prealbumin, transferrin, and total lymphocyte count [18].

Complications of enteral nutrition arise from the formulation, infection, or route of delivery. Formulation complications include diarrhea, vomiting, constipation, aspiration, hyperglycemia, and electrolyte imbalance. At times, patients may

have diarrhea secondary to an infectious etiology while on tube feedings; therefore, if a patient develops loose stools, it should be immediately investigated. Possible etiologies include hyperosmolar substances/formulation, recent broad-spectrum antibiotics, and *Clostridium difficile* colitis. Physical exam, fecal white blood cell count, stool quantification, and basic metabolic profile should be obtained [18]. Aspiration is a serious complication and is the most common cause of death after percutaneous gastrostomy tube insertion [3]. Subclinical aspiration can be seen in patients who develop chronic cough with enteral access. In this population changing the nasogastric tube to a nasoenteric tube may decrease the incidence of aspiration.

The mechanics of the route of delivery can also lead to complications. Clogging the tube with inspissated tube feedings occurs in 18–45 % of tubes placed. This complication prompts attempts at flushing the tube or dissolving the tube feeds with warm water, cola, pancreatic enzyme, and meat tenderizer [23]. In the case of percutaneous endoscopically or surgically placed tubes, mechanical obstructions can occur as the bowel may volvulize around the tube, or the balloon may cause a lead point of obstruction at the pylorus or within the small bowel lumen by migration [23, 27]. Also, patients may inadvertently pull the tube out. If the tube has been present long enough for a tract to form between the lumen of the bowel and the exit site (approximately 2 weeks), then reinsertion can be performed. Reinsertion should occur in a timely fashion as the gastrocutaneous tract may obliterate if enough time passes. However, if dislodgement occurs shortly after placement, the tract has not had enough time to form and is likely to act as a small bowel or gastric perforation, which is a surgical emergency.

Parenteral Nutrition

The parenteral delivery of nutrition dates to the late 1960s with the work of Dudrick and Rhoads. Infusion of a hypertonic solution with nitrogen and nutrients was shown to sustain nitrogen balance and stimulate growth and development [24, 25]. In patients who are unable to tolerate nutrients orally or enterally, parenteral nutrition should be considered. Throughout the literature, there is a debate regarding when to initiate parenteral nutrition in those who meet criteria. Evidence has shown that initiation of parenteral nutrition preoperatively in a patient with protein malnutrition and continuation postoperatively is beneficial in elective general surgery. In patients who are well nourished preoperatively or prior to admission to the intensive care unit who cannot receive enteral nutrition, parenteral nutrition should be reserved and initiated after 7 days without enteral nutrition [19, 22]. Furthermore, a patient with a nonfunctional gastrointestinal tract should be started on parenteral nutrition [11].

The goal of parenteral nutrition is to restore nitrogen balance and create an anabolic state. Energy requirements are calculated by the equations discussed in the Nutritional Scales section of this chapter. It is recommended that a goal of 80 % of calculated energy expenditure be used as permissive underfeeding, or hypocaloric alimentation, which is beneficial in the critical care setting. Stated benefits include avoidance of the potential for insulin resistance, decreased infectious morbidity, less time requiring mechanical ventilation, and decreased length of stay. Strict glucose control has also been a popular topic in the literature. Current recommendations to maintain blood glucose between 110 and 150 mg/dl have shown decreased rates of sepsis, ICU length of stay, and inhospital mortality [18].

Parenteral nutrition with hypertonic infusions must be given through a central venous catheter. Insertion of the catheter is not without risk with a complication rate between 5 and 19 % in the literature. Pneumothorax is one of the more frequent complications with a range of 1–1.5 %. The incidence increases with multiple passes of the access needle, insertion of larger catheters, and emergent placement. Malpositioning of the catheter can lead to venous thrombosis or perforation of the vein. Possible vascular injuries include arterial puncture and hematoma, hemothorax, cannulation of the artery leading to stroke or neurologic deficits with infusion, pseudoaneurysms, and arteriovenous fistulas. During insertion, the guidewire can produce cardiac arrhythmias. A small number of the arrhythmias may become symptomatic but most subside with removal of the guidewire. However, complete heart block and sudden death have been described. Infection of an indwelling catheter is a major complication that can lead to sepsis with a mortality rate of 18 %. Thrombosis increases the rate of infectious complications as well. Great efforts have been made to prevent catheter-related bloodstream infections including strict hand hygiene, surgical preparation with chlorhexidine, sterile precautions during insertion, and catheter removal when no longer required. Indwelling catheters can lead to central venous thrombosis ranging between 33 and 59 %; however, only a small percentage are symptomatic. Over time, mechanical forces on the catheter can lead to fracture and embolization of the catheter. This can also occur during removal of the catheter. Other catheter removal complications include air embolism and hemorrhage [26].

Nutrition in Palliative Care and the Terminally Ill

The goals of nutrition in palliative care must be consistent with those of palliative care in general (see Chap. 42). To that end, the use of nutrition must improve the quality of life and

Table 38.1 Differences between starvation and cachexia of terminal illness [30]

	Starvation	Cachexia of terminal illness
Appetite	Suppressed late	Suppressed early
BMI	Not predictive of mortality	Predictive of mortality
Albumin	Low late	Low early
Cholesterol	May be normal	Low
Total lymphocyte count	Low, responds to refeeding	Low, no response to refeeding
Cytokines	N/A	Elevated
Response to refeeding	Reversible	Resistant

palliate symptoms. It may be indicated for those patients who are malnourished or may become malnourished during the remaining course of their disease.

Psychosocial Aspects

Patients and loved ones can become distressed over loss of appetite. Meals are often social events. There are many fears and misconceptions surrounding anorexia and cachexia near the end of life. Education and reassurance can help refocus care. Eating will not reverse the terminal illness. In these cases, the body will only take what it needs. The body's needs and ability to metabolize food are altered by the illness, and this is manifested by decreased intake. This does not shorten life but is a part of the natural process of terminal illness.

Anorexia

In cases of reduced intake, reversible causes should be looked for and treated. These include xerostomia, nausea, constipation, electrolyte disturbances, and psychological conditions such as depression. Altered taste sensation can be addressed by a variety of means. These include altering the temperature or presentation of the food. Using different types of food that are lower in urea and spicing or marinating foods may help. Commercial supplements may actually contribute to suppressing appetite. Where possible, the best appetite stimulant is the patient's preferred foods. Pharmacologic appetite stimulants do not affect prognosis but may improve quality of life [28]. Such stimulants include megestrol acetate and dexamethasone.

The most important intervention the care team can offer is to give permission to the patient to eat less. Reducing the stigma of loss of appetite and altering the way in which food is available and meals are offered can help improve intake. Interventions include smaller, more frequent meals, having food available at all times whenever the patient is hungry and having patients take part in meal planning.

Cachexia

Cachexia is an effect of disease which causes wasting of protein and energy stores. It is not responsive to hyper-caloric feedings. Starvation, on the other hand, is protein and energy deficiency that is not part of a disease process [29]. In cachexia related to terminal illness, of which cancer is the best studied, the process is mediated by cytokines, such as tumor necrosis factor, IL-1, and IL-6 [30–32]. Appetite is suppressed early and hunger pains generally do not occur. Refeeding does not improve functionality or survival. This may not be true of certain subsets of AIDS patients [33] (Table 38.1).

Ethical Decision-Making Regarding Artificial Nutrition

The use of artificial nutrition is controversial at best. Very few of the terminal illnesses most commonly encountered in the geriatric population show a favorable response to artificial feeding. Patients with dementia and most patients with advanced cancer do not show improvement in outcomes [30]. One subset of patients that may show improvement are those with a head and neck or esophageal cancer [34]. Regarding dementia, the National Institute for Health and Clinical Excellence in Britain recommended the following in their clinical guidelines: [35]

- Encourage people with dementia to eat and drink by mouth for as long as possible.
- Do not generally use tube feeding in severe dementia if dysphagia or disinclination to eat is a manifestation of disease severity.
- Consider nutritional support, including tube feeding, if dysphagia is thought to be transient.
- Apply ethical and legal principles to decisions to withhold or withdraw nutritional support.

Feeding may actually worsen quality of life and the dying process. The by-products, namely, ketones, of the malnourished state can produce a euphoric feeling and reduce hunger

pains. Aspiration can lead to pneumonia. Feeding tubes can lead to the use of restraints and the complications related to their use [34].

A Cochrane review in 2008 did not find sufficient evidence to make any recommendations for practice with regard to the use of medically assisted nutrition in palliative care patients [36]. Therefore, decisions regarding artificial nutrition must be approached with careful consideration of the clinical situation, the underlying disease, the patient's wishes, and the artificial nutrition's possible benefits or burdens.

Summary

The risk of malnutrition rises dramatically in the hospitalized elderly. There are many risk factors related to age and are listed in the table in this section. Nutritional deficiencies need to be addressed and requirements maintained. Assessment must be a routine part of the care of the hospitalized elderly. The tables in this section will function as a quick reference for practitioners taking key points from the chapter and placing them at your fingertips.

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Common Pharmacologic Issues

39

Jason P. Hecht and Wendy L. Wahl

Introduction

Prescription of drug use in the elderly population is an ever-growing trend, with nine out of ten older Americans reporting the use of at least one prescription drug and 64 % using at least three prescriptions [1]. This trend is especially concerning as the elderly are seven times more likely to have an adverse drug event resulting in hospitalization with an estimated 100,000 hospitalizations in 2011 [2, 3]. These agents not only can result in hospitalizations but can have significant implications for the inhospital management of acute trauma. Many medications used in the emergency or intensive care setting have altered pharmacokinetic properties in the aged population and may also interact with other prescribed drugs taken by the patient. This chapter will describe the alterations in drug metabolism, provide an overview of drugs that may affect trauma management, and discuss the management of pain and delirium in the elderly patient.

Pharmacokinetic and Pharmacodynamic Alterations in the Elderly

Significant alterations in pharmacokinetics accompany aging and must be considered when selecting and optimizing medication therapy in the elderly patient. Enteral absorption is minimally affected by the process of aging alone, but subcutaneous and intramuscular absorption may be affected by decreases in total body water and muscle mass in the aged [4]. Gastric emptying time, however, is increased in the elderly population, so medications administered by the enteral route may have a delayed effect [5]. Decreases in total body water and alterations in plasma protein concentrations change volumes of distribution for many commonly used medications. Elderly patients may require lower doses of hydrophilic agents such as heparin, insulin, and morphine to account for this change in drug disposition. Hepatic drug metabolism by the cytochrome P450 system is variably affected due to age-related decreases in some isozymes' activity. Drug elimination is the pharmacokinetic process most affected by aging due to age-related decline in some isozyme's activity and as glomerular filtration and renal drug elimination decline with increasing age. Many commonly prescribed medications require dosage adjustment in patients with renal dysfunction, including most antibiotics, antihypertensives, anticoagulants, and analgesics [4].

Anticoagulant and Antiplatelet Agents

Anticoagulant and antiplatelet use is widespread in the elderly population with many indications ranging from stroke prevention in atrial fibrillation to the treatment and prevention of recurrent venous thromboembolisms (VTE). Though these medications offer many therapeutic benefits to this population, there is also a large burden of potential risk. Warfarin, alone, is associated with one-third of all emergency hospitalizations for adverse drug events in the elderly [2]. It is logical that pre-injury anticoagulation therapy would increase the risk of negative outcomes in this population and many recent studies exist to support this notion. Traumatic brain injury patients on pre-injury warfarin have been shown to have higher injury severity, increased need for neurosurgical intervention, and an overall increase in mortality [6, 7]. Studies to classify the risk to patients on the direct oral anticoagulants (DOACs) have not been performed as of yet, but it is reasonable to assume DOACs would have the same deleterious effects.

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Table 39.1 Anticoagulant and Antiplatelet Agents

Anticoagulant agents		
Agent	*Mechanism of action*	*Emergency reversal*
Apixaban	Factor Xa inhibitor	**No antidote** Administer activated charcoal if last ingested within 3 h Consider PCC4 50 units/kg (max dose 5000 units) if bleed is life threatening
Dabigatran	Thrombin (factor II) inhibitor	Idarucizumab 5 g (2.5 mg doses 15 min apart). May administer a second 5 g dose if relevant bleeding continues Renal replacement therapy can be utilized to reduce the duration of bleeding but should not be used for emergent reversal due to time constraints
Edoxaban	Factor Xa inhibitor	**No antidote** Consider PCC4 50 units/kg (max dose 5000 units) if bleed is life threatening
Enoxaparin	Factor II and Xa inhibitor	Administer protamine to partially reverse (~60 %) the anticoagulant effects ≤8 h since last dose: 1 mg protamine for each 1 mg of enoxaparin >8 h since last dose: 0.5 mg protamine for each 1 mg of enoxaparin >12 h since last dose: protamine will not be effective; do not administer
Fondaparinux	Factor Xa inhibitor	**No antidote** Consider rFVIIa 40 μg/kg if bleed is life threatening
Rivaroxaban	Factor Xa inhibitor	**No antidote** Administer activated charcoal if last ingested within 8 h Consider PCC4 50 units/kg (max dose 5000 units) if bleed is life threatening
Warfarin	VKORC antagonist (inhibits clotting factors II, VII, IX, and X)	Administer vitamin K 10 mg IV in all patients where reversal is needed Administer FFP in addition to vitamin K for all life-threatening bleeds besides ICH Administer PCC4 in addition to vitamin K as first line for ICH and if above measures are ineffective for all other bleeds that are life threatening INR 2.0–3.9: 25 units/kg (max dose 2500 units) INR 4.0–6.0: 35 units/kg (max dose 3500 units) INR >6.0: 50 units/kg (max dose 5000 units)
Antiplatelet agents		
Agent	*Mechanism of action*	*Emergency reversal*
Aspirin	Thromboxane A_2 inhibitor	**No antidote** Administer platelet transfusion Consider DDAVP 0.3 μg/kg IV
Clopidogrel Prasugrel Ticagrelor	$P2Y_{12}$ inhibitors	**No antidote** Administer platelet transfusion Consider DDAVP 0.3 μg/kg IV

PCC4 four-factor prothrombin complex concentrate, *rFVIIa* recombinant activated factor VIIa, *FFP* fresh frozen plasma, *ICH* intracerebral hemorrhage, *INR* international normalized ratio, *DDAVP* desmopressin, *IV* intravenous

Warfarin is an inhibitor of the vitamin K epoxide reductase complex (VKORC) which results in decreased activation of clotting factors II, VII, IX, and X. Warfarin has a mean elimination half-life of approximately 40 h and therapeutic effects lasting for 5–7 days. These therapeutic effects can quickly be measured in a trauma situation by looking at the international normalized ratio (INR), a derivative of the prothrombin time (PT). Warfarin is metabolized through the CYP450 system and as a result has many drug interactions that can have a drastic effect on the INR and degree of coagulopathy. Though warfarin is still widely used as an oral anticoagulant, disadvantages such as need for blood test monitoring and dietary changes have led patients and prescribers alike to utilize the newer DOAC agents.

The DOAC agents gained traction in 2010 with the approval of dabigatran, and since then, rivaroxaban, apixaban, and edoxaban have been approved in the United States. These agents now account for over half of all new prescriptions for patients requiring an anticoagulant, so their role in trauma management is an ever-growing concern [8]. DOACs differ from warfarin in that they directly inhibit a single activated clotting factor and exhibit more predictable pharmacokinetic and pharmacodynamic properties [9], Table 39.1. Though it is beneficial in most cases that these agents do not require monitoring for therapeutic efficacy, in a trauma situation, there is no routine coagulation test to determine the degree of anticoagulation. Spontaneous major bleeds have been shown to be significantly reduced with DOACs as opposed to traditional treatments, but the lack of reliable reversal agents complicates a situation in which a major bleed has occurred [10].

The first approved DOAC, dabigatran, is an oral selective direct thrombin inhibitor. Dabigatran has a mean elimination half-life of 12–17 h with peak effects occurring 2 h after a dose is given [11]. Like all direct thrombin inhibitors, dabigatran will have noticeable effects on common coagulation

tests like prolonging the PT and aPTT [12]. However, these tests are unreliable in providing quantitative assessments of anticoagulation [11]. In clinical trials, dabigatran was associated with similar rates of clinically relevant bleeding as warfarin, but rates of major gastrointestinal bleeding may be higher with dabigatran [13, 14]. Dabigatran's pharmacodynamics effects depend primarily on age and renal function. It is removed primarily through renal elimination as an unchanged drug and, as a result, requires a dose adjustment in renal insufficiency [15]. A study in elderly subjects aged 65–87 years receiving dabigatran showed that the area under the concentration curve doubles in this population as compared to younger adults with more pronounced effects seen in elderly women [11].

Rivaroxaban is a direct oral factor Xa inhibitor. It is metabolized via the cytochrome P450 system with approximately 66 % of the drug then excreted through the kidneys [16]. However, renal function appears to have only a moderate effect on elimination half-life most likely due to alternate clearance pathways [17]. The elimination half-life is also shorter than dabigatran at 6–7 h with peak effects occurring 2 h after administration [18]. Phase III clinical trials with rivaroxaban found no difference in major bleeding events or clinical relevant bleeding as compared to existing anticoagulants [19, 20]. There appears to be less significant pharmacokinetic differences in the elderly associated with rivaroxaban and with no reported gender differences [21, 22]. Rivaroxaban has dose-dependent effects on the PT and aPTT, but the tests are not validated for quantitative use because of variability in testing materials [22, 23].

Apixaban is another direct oral factor Xa inhibitor that was recently approved for use in the United States. It is the only DOAC agent that has proven superior to warfarin in the incidence of spontaneous major bleeding and clinically relevant bleeding [24]. Apixaban has an effective half-life of about 12 h, and due to slower absorption, it takes longer for a peak effect to occur at 3–4 h after the dose [25]. As is the case with all DOAC agents, the anticoagulant effect of apixaban cannot be quantified using traditional laboratory measures like the aPTT or INR. Chromogenic anti-Xa assays do exist to measure the concentration of Xa inhibitors, but they are not readily commercially available [26]. Apixaban is primarily cleared through renal elimination and requires a dosage adjustment in renal insufficiency. Age- and sex-related differences also exist with the pharmacokinetics of apixaban with the elderly and female population having a moderately increased exposure [27].

Edoxaban, a direct factor Xa inhibitor, is the most recently approved DOAC agent in the United States. This agent is unique in that it has a rapid time to peak effect of 1.5 h while also displaying a long elimination half-life of 10–14 h [28]. Edoxaban displays major bleeding rates similar to that of warfarin and other DOAC agents despite being more effective at reducing some coagulation markers [29–31]. A small phase I trial was able to show that traditional laboratory measures like the PT, INR, and anti-FXa activity correlate closely with edoxaban plasma concentrations, but further validation of this result is needed before it should be relied upon in clinical practice [32]. The elimination half-life of edoxaban is prolonged in patients with renal failure, but no other altered pharmacokinetics have been reported in the elderly population. Pharmacokinetic studies have shown that hemodialysis is not effective at removing edoxaban from the blood and it should not be used as a means of reversal in a trauma scenario [33].

Antiplatelet Agents

Aspirin, clopidogrel, prasugrel, and ticagrelor are commonly used agents which decrease platelet activation and aggregation via glycoprotein IIb/IIIa. The effect of pre-injury antiplatelet agents on mortality in TBI patients has been studied with varying results. A recent retrospective analysis of 1552 patients found that pre-injury use of aspirin alone, clopidogrel alone, and a combination of the two did not result in increased mortality as compared to patients on no antithrombotic agent [7]. This result has been reinforced with a large meta-analysis showing only a minor effect on survival with pre-injury antiplatelet agents that did not meet statistical significance [34]. The effect of these agents on other outcomes such as the severity of bleeding and need for neurosurgical intervention is not as well defined. Thus, reversal is still warranted in many cases as it is unlikely that antiplatelet therapy is completely benign in a traumatic bleed [35–40]. Combination therapy with antiplatelet agents is common, and this has been shown to have an additive effect on the degree of platelet inhibition [41].

There are numerous assays currently marketed that test response to antiplatelet agents. However, current cardiology literature does not support antiplatelet testing to individualize therapy given the variability between assays and lack of established reference ranges. One study in trauma patients examined point-of-care testing for patients with a reported history of taking clopidogrel. The results confirmed previous literature outside of trauma populations, in that large variability between patients exists [42]. Viscoelastic testing is becoming commonplace in the setting of traumatic hemorrhage management, but this also has a lack of sensitivity to detect platelet dysfunction due to antiplatelet agents [43]. To date, antiplatelet testing cannot be used to reliably guide therapy in the management of traumatic hemorrhage.

Reversal of Pre-injury Antiplatelet and Anticoagulant Agents (Table 39.1)

Platelet transfusion is commonly employed in the management of traumatic intracranial hemorrhage in patients on pre-injury antiplatelet therapy, despite a lack of data to support

its efficacy. Both aspirin and clopidogrel bind irreversibly to platelets causing dysfunction for the life of the platelet. If transfusion is to be beneficial, it would only do so by providing additional functional platelets. Two retrospective studies have shown no benefit on either morbidity or mortality [44, 45]. A meta-analysis of intracerebral hemorrhage (ICH) patients was also unable to show that platelet transfusion was beneficial [46]. One explanation for the lack of efficacy with platelet transfusion is that recent ingestion of an antiplatelet agent may quickly inactivate the infused platelets. Ultimately, early platelet transfusion is still recommended in patients with substantial bleeding who are on pre-injury antiplatelet therapy despite the lack of evidence supporting its efficacy.

Extrapolating data from other patient populations, several guidelines and reviews have suggested using desmopressin (DDAVP) to reverse platelet dysfunction although it has not been studied in trauma patients [47]. DDAVP is known to increase concentrations of von Willebrand factor and factor VIII thus enhancing platelet adherence. A meta-analysis of clinical trials found a small reduction in blood transfusion requirements in the postoperative period, though these were not urgent procedures that would be seen in the setting of trauma. It is suggested that DDAVP be used at doses of 0.3–0.4 μg/kg intravenously [48].

Vitamin K is the antidote for warfarin toxicity, and when administered intravenously, reversal effects can be seen within 12–24 h [49]. However, rapid reversal of the anticoagulant effects of warfarin has been shown to decrease progression of ICH and mortality [50]. Administration of fresh frozen plasma (FFP) can begin to reverse coagulopathy by supplying clotting factors II, VII, IX, and X while awaiting the full effects of reversal with vitamin K. While a targeted therapy, FFP use is fraught with limitations: optimal dosing is unknown, clotting factor concentrations are variable, the required volumes of FFP to be infused may be problematic for fluid-sensitive patients, it requires thawing prior to administration, and time to correction of INR is highly variable.

Prothrombin complex concentrates (PCCs) and recombinant activated factor VIIa (rFVIIa) may also be beneficial for the emergent reversal of warfarin. Three-factor PCCs contain factors II, IX, and X with little to no factor VII. Four-factor PCCs contain high concentrations of factors II, VII, IX, and X. PCCs provide replacement of carboxylated clotting factors and appear to be the only available option for immediate reversal of warfarin despite a lack of robust data for their use. Recent guidelines for anticoagulant reversal from the American College of Chest Physicians suggest four-factor PCC for patients with life-threatening warfarin-associated bleeding over plasma infusion [51, 52]. PCC agents and the clotting factors they replace have a significantly shorter half-life than that of warfarin, so combination therapy with vitamin K should still be utilized.

The introduction of the DOAC agents presents the trauma clinician with distinct new challenges in the setting of an emergency. Data from prospective phase III trials and a combined meta-analysis have suggested that there may be a lower risk of bleeding with these newer agents compared to warfarin [53]. However, there are limited options available for reversal of these agents, making a traumatic bleed associated with one of them problematic. Traditional reversal agents such as vitamin K, FFP, protamine, and cryoprecipitate have been proven ineffective. Idarucizumab was recently approved and is the first specific reversal agent for a DOAC agent. It was found to completely reverse the anticoagulant effects of dabigatran in patients with life-threatening bleeding or those requiring urgent surgery [54]. When dabigatran reversal is needed, clinicians also have the option of utilizing hemodialysis as it has been shown to remove up to 62 % of the drug in a 2-h session [55]. Though this is likely not useful in the case of an emergency bleed because of time constraints, renal replacement therapy has been shown to reduce the duration and severity of bleeding [56]. Unfortunately, the more commonly used DOAC agents, rivaroxaban and apixaban, lack a specific reversal agent, so nonspecific agents must be utilized.

It has been suggested that PCCs and rFVIIa may have a role in reversing the anticoagulant effects of DOAC agents in cases of severe bleeding by increasing the plasma concentration of the clotting factors they inhibit. However, studies supporting their use have been limited to animal studies or human studies that were severely limited by sample size and were with healthy volunteers [57–62]. These in vivo and in vitro studies have presented mixed results with no convincing evidence of benefit. Despite this, numerous guidelines still suggest reversal with PCCs in cases of emergent bleeding [63, 64]. Specific reversal agents for factor Xa inhibitors are being investigated and have shown promise in their early stages [65, 66].

Beta-Blocker Therapy

Beta-blockers (BB) are commonly prescribed in elderly trauma patients for blood pressure, heart rate, or arrhythmia control [67–71]. Studies have shown survival benefits for patients receiving BB therapy for cardiac and high-risk vascular procedures [68, 69]. For nonvascular operations, the data for BB use is mixed, where the cardiac events are less, but the mortality rates are not improved compared to those treated perioperatively for cardiac or vascular procedures [67–71].

Nonrandomized, cohort controlled studies in both adult burn and trauma patients have suggested potential benefits [72–77]. Effects of BB include decreased cardiac oxygen consumption and hypermetabolism [74]. BB also can

decrease systemic and cerebral perfusion pressure [78]. Theorized mechanisms for BB effects may be secondary to suppression of IL-6 which has been associated with increased mortality for trauma and sepsis patients. A small, randomized trial of patients treated with BB found lower IL-6 levels [76]. In a study comparing older patients who were case matched for age, Injury Severity Score, Glasgow Coma Scale score and mechanism of injury, BB use decreased mortality [73]. A similar study in adult burn patients showed faster rates of healing and time to discharge for those on BB [72]. Patients in these studies who arrived to the hospital on BB were older and more severely injured [72, 73].

A subsequent retrospective study, which did not include cohorts or the use of case matching in the study design, found that patients admitted on BB without head injury had higher mortality than those admitted without BB therapy [79]. While for the overall patient population admitted on BB there was no difference in mortality, those admitted on BB appeared to have more warfarin use and vascular disease [79], suggesting that BB therapy may have been beneficial for those with head injury since mortality was not higher. Another group studied the use of BB in trauma patients with severe traumatic brain injury (TBI) and found a survival benefit. While not all patients in the severe TBI study were elderly, the mean age of the BB group was 50 compared to 36 years in those without BB use. Despite the significantly older age of those receiving BB therapy during hospitalization, the BB-treated TBI patients had improved survival compared to patients not treated with BB [80].

The former studies posed the question that BB may have caused injured patients to appear less ill due to less tachycardia at presentation and that this may have affected their subsequent resuscitation. Alternatively, BB use in the elderly may have been a marker for patients with more systemic illness at baseline, which would make the findings of lower mortality even more compelling [79, 80]. In a subsequent study, which looked at patients with isolated TBI, researchers found that patients admitted on BB were older, had more severe TBI, had more skull fractures, and required operative intervention more frequently, but had lower mortality than those who did not receive BB therapy [81]. Beta-blockade was independently associated with improved survival [81].

Despite the positive findings in retrospective, nonrandomized studies, there is still concern over the potential side effects of BB therapy from vasoconstriction and bradycardia due to antagonism of beta-mediated vasodilation and increased risk of vasovagal reaction. Early in hemorrhagic shock, the effects of BB may mask early recognition of shock, and the provider should seek other signs of poor perfusion such as acidosis, decreased urine output, and altered mentation since hypotension is a later manifestation of shock. One retrospective study which looked at the use of pre-injury BB, angiotensin-converting enzyme inhibitors (ACE-I) or angiotensin receptor blockers (ARB), calcium channel blockers, or amiodarone found no demonstrable effect on systolic or diastolic blood pressures in trauma patients presenting on these individual medications. However, patients who received the combination triple therapy of a BB, ACE-I/ARB, and calcium channel blocker had higher mortality and inhospital complications despite only mild changes in the initial hemodynamic profile at admission [82]. The need for triple therapy may be a marker for more severe underlying comorbidities in the patients requiring these medications, given that 22 % of complications in these patients were cardiac in nature [82].

Delirium and Management in the Elderly

Unlike dementia which is a chronic confusional state, delirium is an acute confusional state which occurs most commonly in older, hospitalized patients [83]. Acute brain dysfunction, or delirium, occurs in up to 70 % of mechanically ventilated patients in the surgical ICU [85–87] and recently has been reported in a similar proportion of trauma ICU patients [83–85]. Delirium has been identified in 15–53% of older patients undergoing operation [88, 89] and is associated with mortality rates of 22–76% [90], rivaling mortality rates of sepsis and acute myocardial infarction [84, 91]. The clinical manifestations of delirium vary from hypoactive with withdrawal and decreased motor activity to hyperactive with agitation, increased arousal, and aggression. Delirium is reportedly underdiagnosed in more than half of cases largely due to the under-recognition of the hypoactive form and attributing symptoms to dementia [92].

Evidence suggests that delirium may be secondary to altered neurotransmission, inflammation, and even chronic stress [93]. Administration of anticholinergic drugs has been shown to cause delirium in both animals and humans. Excess dopaminergic activity may also contribute to delirium as a regulator of acetylcholine, which supports the use of antipsychotic agents for treatment of delirium symptoms [83, 93].

With the potential for inflammation and alterations in neurotransmitters contributing to delirium, it is not unexpected that surgical procedures would potentially increase the incidence of delirium. In a Canadian study looking at over 19,000 patients aged 65 years or older undergoing elective surgery, 16 % of the elderly patients developed delirium. The biggest predictor for development of delirium was the duration of surgery, which accounted for about 44 % of the risk, but unique to this study was the finding that preoperative statin use accounted for a 28 % increase in delirium [94]. Other contributing factors to delirium are common in the postoperative setting. Multiple studies have concluded that exposure to sedatives and analgesics is associated with delirium [85–87, 95–97]. Not only are continuous sedative

infusions contributors to higher rates of delirium, but they are also associated with increased mechanical ventilator days and intensive care unit lengths of stay [96]. In a study of patients with a hip fracture and an average age of 81 years, patients treated with fracture fixation under spinal anesthesia and a light level of sedation had 50 % less postoperative delirium than those managed at a deeper level of sedation during the procedure [98].

To confront the issues of continuous sedation increasing the risk of adverse outcomes, some recent studies have looked at changing how ventilated patients are managed, addressing pain first [85, 87]. If after treating with pain medications, a patient is still agitated, then delirium is addressed. Sedative medications should only be added if a patient is unable to be maintained safely on the ventilator or is at risk of removing other vital tubes or drains without sedation. This approach has gained significant traction in critical care organizations [99] and requires objective evaluation of patients with standardized tools which assess for pain and delirium screens such as the Confusion Assessment Method for the Intensive Care Unit (CAM-ICU) score [100]. If patients screen positive for delirium, non-pharmacologic treatment should be attempted. Review of medications which may have sedative properties or cognitive side effects should be eliminated or the dose minimized, if possible. Metabolic causes for delirium should be corrected such as hypoxia, electrolyte disturbances, and hypothyroidism. Underlying infection should be considered and appropriate testing done to exclude this possibility. If the patient has hearing or visual aids, these should be in place to improve the ability to communicate and orient the patient. Non-pharmacologic methods such as relaxation, music, restoration of the normal sleep-wake cycle with avoidance of loud noise, and bright lights during sleep should be employed as much as possible [84, 87, 97, 101].

If the patient remains with symptoms of delirium and exhibits severe agitation with potential for self-harm, pharmacologic therapy should be given. Generally, antipsychotic and atypical antipsychotic agents are the first-line agents for acute delirium not responsive to alternative treatment and should be started at the lowest effective dose for the shortest possible duration [101]. Low doses, given 2–3 days for maximal effect, should be started [83]. The possibility of alcohol or benzodiazepine withdrawal should be considered, and in those cases a benzodiazepine would be appropriate, but in general should be avoided [101]. Haloperidol can be given enterally or intramuscularly (IM) starting at doses of 0.5–1 mg, repeating enteral doses every 4 h as needed or every 30–60 min for IM dosing, until desired effect. Monitoring for extrapyramidal symptoms and prolonged QT intervals should be done with a baseline EKG. Haloperidol should not be used for those with a history of neuroleptic malignant syndrome, QT prolongation, or significant liver dysfunction [83, 100, 102].

Atypical antipsychotic agents such as risperidone and quetiapine are now commonly used in many intensive care settings for agitation. Unlike haloperidol, these agents have only been tested in smaller, uncontrolled studies [103]. The attraction for use is the potentially safer profile related to extrapyramidal motor side effects. The same cautions apply for QT prolongation, and there have been reported increases in mortality for the generalized use of these agents in elderly patients with dementia [101].

Pain Medications and Management

It is common for older patients to suffer from sight and hearing loss and cognitive and memory loss either from pathology or medication side effects. These functional alterations may lead to the under- or overtreatment of pain which in turn may cascade into other adverse events such as pneumonia and falls [104]. Some studies support that there are age-related differences in how pain is perceived [105]. Older patients may have reduced responses to mild pain, while the response to severe pain may be exaggerated [106]. These alterations in pain perception make pain management in the elderly more challenging than in younger patients. Higher pain thresholds for less severe pain may lead to delays in diagnosis or missed diagnoses. In addition, heightened responses to severe pain may lead to overtreatment [105, 106]. The presence of pain is associated with worse functional impairment, falls, depression, sleep, and appetite in the elderly [107, 108].

The World Health Organization's three-step pain ladder was initially designed for treatment of cancer-related pain, but has been generalized as a guide for choosing analgesics [104, 107, 108]. The first step addresses mild intensity pain and targets the use of acetaminophen, nonsteroidal anti-inflammatory drugs (NSAID), or both. The next level, step 2, corresponds to moderate pain and advocates the use of "mild opioids" generally combination products of acetaminophen or an NSAID added to an opioid agent or tramadol. Step 3 is reserved for severe pain and suggests the use of stronger opioids such as morphine, hydromorphone, or oxycodone. The key to dosing is "start low and go slow" [108]. Adverse reactions with opioids are common in the elderly and may have much more dire consequences than in the younger population. Drowsiness, motor instability, and dizziness often are poorly tolerated in the older patient population. Common side effects of opioids in the elderly include constipation, nausea and vomiting, impaired judgment, sedation, reduced psychomotor function, and respiratory depression [104]. For all opioids, these factors can be reduced by smaller starting doses, longer intervals between doses, and slower upward titration of doses [104].

There are no well-controlled studies addressing which opioids treat pain most effectively in the elderly population

and more specifically for elderly trauma patients. The route and dose of narcotic should be selected based on patient's baseline renal and hepatic function, severity of pain, location in the hospital, and response to treatment. The only guidelines which address pain management in the elderly were published by the American Geriatric Society in 2002 and were targeted to those with chronic pain, but many of the recommendations are still valid for acute pain management [107]. Pain medication should be administered through the least invasive route which controls the pain. Introduce only one agent at a time at a low dose before titrating to higher dosing. Allow sufficient timing between doses given changes in drug availability and metabolism. Provide adequate monitoring to ensure adequate pain control without overtreatment. Alternatives to opiate administration should be considered where possible [107]. An example would be placement of an epidural catheter or regional block for management of rib fracture pain rather than treatment only with narcotics.

Summary

There are very few pharmacologic studies which specifically address treatment considerations for elderly trauma patients. For any medication administered in the elderly population, knowledge of potential drug-drug interactions, reduced metabolism, and the potential for accentuated side effects should be monitored. Consideration for geriatric consultation, particularly for those with delirium and dementia, and participation of clinical pharmacists on rounds may aid the trauma surgical team in the complex pharmacologic management of these patients.

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Nursing Consideration

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Alice Gervasini

Introduction

Older adults are emerging as the fastest-growing population in the USA. Population aging is expected to continue to increase with a doubling of older adults from approximately 40 million in 2010 to an estimate of 80 million in 2050 [1, 2]. Currently, more than half of the ICU beds in the USA are filled with patients over the age of 65 [3]. With an escalation in the number of elders, the impact on the critical care unit will almost certainly be daunting. The environment of care for the critically ill adult has been challenged over the years to manage increasingly complex patients in the face of advancements in technologic and diagnostic opportunities. There has also been an expansion in the research efforts to assist clinicians in the development of best practice and ultimately resulting in better outcomes. Unfortunately, the host response to critical illness is exceedingly complex and not all treatment protocols and practices have proven to be beneficial [4]. The aging critically ill adult will add another layer of complexity to these efforts.

The establishment of interdisciplinary teams in the critical care environment has been shown to impact the recovery of critically ill patients. The team approach has resulted in improved outcomes, by decreasing mortality [5] and adverse events. Interdisciplinary teamwork reflects a complex process of bringing staff together who share their expertise, knowledge, and skills to accomplish the task of taking care of a specialty population. The aging population with complex needs associated with chronic illness has been identified as one patient cohort that would benefit from this approach [6, 7]. Critically ill older adults may have an atypical presentation of common ICU conditions based on their anatomic and physiologic changes associated with aging and the presence of comorbidities. They may also be at increased risk for ICU related complications [8, 9].

The critical care nurse is an integral member of the interdisciplinary team. The foundation of critical care nursing represents a specialized body of knowledge, skills, and experience, to provide care to patients and families and create environments that are healing, humane, and caring [10]. The value of the interdisciplinary team and the critical care nurses role on that team is essential to the successful management of the older adults in the ICU. The critical care nurse will not only need to maintain their knowledge and skills of critical care theory but also to expand this to include a focus on the older adult. Establishing a knowledge base inclusive of the uniqueness of the older adult in the presence of critical illness is imperative for the nurse to remain competent in the delivery of care and in providing a meaningful contribution to the interdisciplinary approach to the successful management of this patient population.

Knowledge Development

The care of the older adult requires extensive knowledge of both nursing and geriatrics to manage the complexity that influences quality outcomes [2]. In 1996, the Hartford Foundation funded the Hartford Institute at New York University for the primary purpose of promoting geriatric nursing. The institute was funded in response to an inconsistency within nursing practice that impeded the delivery of excellent care to the geriatric patient population [11]. This initiative not only looked at the care delivery but established a project known as Nurses Improving Care for Healthsystem Elders (NICHE) that now incorporated a guide for hospitals to provide a better environment of care for the older adult. This program includes an institutional assessment profile, evidence-based clinical practice guidelines, tools to establish nursing expertise, and unit-based interdisciplinary teams [12]. All of these initiatives focus on the nurse acquiring the

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knowledge base and skills to provide competent care to the older adult in the critical care environment [13, 14]. Although there are many educational tools and resources available, there still remains a knowledge gap for many clinicians [15].

In order to deliver excellent care, the hospital environment as well as the ICU environment needs to value and be supportive of the critical care nurses' initiatives in managing the critically ill older adult. A geriatric-focused educational program for the nurses is needed. The establishment of a unit-based geriatric resource nurse to provide advanced knowledge to the staff through bedside consultation and coaching through evidenced-based guidelines is beneficial. The traditional critical care interdisciplinary team may want to expand to include a nurse or physician and pharmacist with geriatric expertise to contribute on daily rounds. Increased involvement of palliative care, case management, and social work consults at the beginning of the patients' ICU experience should be expected. These actions require a commitment from the institution and a buy-in to the philosophy that the critically ill older adult is a different patient than a younger critically ill adult. Through these activities, the care delivery model should enhance the patient and family experience with a goal to decrease complication rates and adverse events, and ultimately lead to an optimal outcome.

The generic environment of an ICU may contribute to poor outcomes for the older adult. The constant 24-h care delivery model that may include periods of continuous bedside attention contributes to disrupted sleep patterns and sleep deprivation. Noise and ambient light levels in ICUs from monitors, room and/or hall lights, normal staff conversations, and televisions also significantly impact the older adult. Establishing an environment of respect for the patients' need for undisturbed rest within the goal of patient safety is challenging but attainable when supported by the unit and team members. The care delivery model should also be reviewed. Unit-based nursing leadership should make conscious choices regarding general staffing and the nurse/patient ratio. Not every ICU patient is the same nor requires the exact same delivery of care. The demands of caring for a critically ill older adult should be taken into consideration when making assignments. The initial management of the critically ill older adult will often require more time to establish not only a baseline of hemodynamic and cognitive status upon arrival in the unit but to also investigate the details of the patient's baseline functionality and response or coping strategies used to manage their chronic illness or comorbidities [9]. The nurses' assessment of the preexisting functionality or frailty of the patient as well as a detailed description of their medical history will be pivotal in their ability to provide optimal care to this complex patient population.

Frailty

Generic hospitalization of older adults has been linked with functional decline that is often difficult to recover from and does not always return the older adult to pre-hospitalization baseline function [16–18]. Identification of baseline parameters is essential. When assessing the critically ill older adult, the critical care nurse needs to not only acknowledge the chronologic age of the patient but also their physiologic age. When obtaining a history from a family member, they will often describe the patient not only by the chronologic age but will use a qualifier to help the clinician understand the patient better. Words like healthy or robust describe the individual that may be perceived by the family member to be more active than what they would expect of an aged adult, while words like frail or failing depict a much older than stated aged individual [19]. The critical care nurse must identify the challenges in the critically ill older adult's past medical history that has potentially moved the aging qualifier from robust to frail. The impact that a chronic illness has on an individual is unique but factors into the concept of frailty. The concept of frailty is complex and goes beyond chronological age to include the anatomic and physiologic changes of aging, the functional reserve of the individual, and the observed response the individual demonstrates when faced with minor to major illness [19–22]. The vulnerability of the critically ill older adult can be related to decline in reserve of any physiologic system. The clinical syndrome of frailty puts the critically ill older adult at risk of increased adverse events, increased mortality, and generally poor outcomes [21, 22].

The degree of frailty of a critically ill older adult should be factored into the interdisciplinary teams' approach to care. A frailty index can be calculated based on information shared by the patient or a surrogate, including information obtained from existing medical records. The index takes into account deficits in the health of the older adult and is either represented in a sum total or as a ratio of the identified concerns over the total deficits screened for. Deficits reflect signs and symptoms of illness as well as functional and cognitive decline and laboratory and radiographic abnormalities [23, 24]. There are many scoring tools available that can be incorporated into the nurses' assessment that can assist the clinician in identifying the degree of frailty. The screening process is not without its own inherent difficulties. Often the patient is not able to provide information as a result of their illness or injury, and the clinician will need to rely on surrogates to complete the assessment. In 2015, Maxwell et al. [25] demonstrated it is feasible to assess preexisting frailty among hospitalized injured older adults. This study utilized three surveys that targeted self-report of health, ability to accomplish activities of daily living, and the assessment of

the patients' movement within the community, along with two questions aimed as measuring the patients' degree of vigorous physical activity. A significant percentage of patients were identified with preexisting frailty. Bellal [22] utilized the 50 variable Frailty Index (FI) [24] to demonstrate frailty verses chronological age as a better predictor of outcomes among geriatric trauma patients. Univariate analysis identified the FI as well as age, systolic blood pressure, heart rate and Injury Severity Score, as all being associated with in-hospital complications. After controlling for these variables in a multivariate regression analysis, the FI was an independent predictor of in-hospital complications. The FI was also a predictor of discharge placements to skilled facilities or in-hospital mortality. Building on their research, this group developed and validated a 15-variable modified trauma-specific frailty index [26]. The outcome measure was defined as a favorable (discharge to home or rehabilitation center) or unfavorable (discharge to skilled nursing facility or death) discharge. The score successfully predicted those patients that would have an unfavorable discharge.

Although there is no one definition of frailty and many tools to help establish a degree of frailty, there is certainly enough data to support the need for a comprehensive assessment of the critically ill older patients past medical history, functional reserve, and current functional and cognitive abilities. The critical care nurse is strategic in this process. Establishing preexisting frailty should help guide strategies for addressing the immediate needs of the critical illness and be factored into the plan of care to minimize overall functional decline. Physical and cognitive decline is often part of the preexisting degree of frailty but is exaggerated secondary to stress of critical illness and hospitalization.

Focused Assessment

A focused assessment for the critically ill patient is an acuity-based organ system approach to assess the most critical components impacting the patient at one point in time. When assessing the critically ill older adult, the nurse will need to expand this approach to include the detail of any chronic illness and its impact on the patient, as well as baseline changes in cognitive responses or mobility, or functionality within their environment [8, 9]. Some or all of this information may need to come from the patients' surrogate. The nurses' ability to meet the needs of the critically ill older adult involves the initial comprehensive assessment with appropriate interval reassessments based on the patient response to planned interventions [27].

Assessment tools and documentation standards can focus the clinician to ensure that all aspects of the critically ill older adults' baseline information are captured and incorporated into the medical record. The use of standardized tools provides the caregivers with a shared language when discussing the implications of the assessment. Unit-based strategies encompassing assessment scores or tools need to be consistent in their application and utilized to enhance the delivery of care. The interdisciplinary team should review their expectations for how information is synthesized for the critically ill older adult. There are numerous scoring systems in the literature that have contributed to the ICU total assessment of the patient, but it is not always clear that this additional information is critical to the delivery of care. For example, the APACHE II [28] and SOFA [29] scores are both used widely to assess the patients' clinical status over time, as scores to assess pain, sedation, and agitation [30, 31] are generally time sensitive and clinically applicable to direct care. Decisions regarding the use of standardized scores, tools, or guidelines need to be established by the interdisciplinary team with expectation for unit compliance. The unit-based environment to support the critically ill older adult encompasses the standardization of practice and the utilization of evidence-based guidelines [12].

ICU Triad

Clinically, when we refer to the "triad of death" for critically ill trauma patients, many clinicians immediately reflect on the concepts of acidosis, coagulopathy, and hypothermia [32, 33]. Three interrelated codependent physiologic cascades, which when left unchecked, caused significant cell dysfunction that often culminated in an irreversible condition resulting in death. Fortunately, we have employed best practices to help avoid this catastrophic combination of insults, and the incidence of this triad has significantly decreased. A different sort of challenge has emerged in the critically ill patient population that requires a balanced approach that capitalizes on the strengths of the interdisciplinary team to minimize the impact. The "ICU triad" of pain, agitation, and delirium [34] has emerged as the interrelated, codependent cascade of events that significantly impacts the critically ill patient and if poorly managed results in increased adverse events, major functional decline, and general prolonged illness and hospitalization. It is also linked to increased mortality. The critical care nurse plays a major role in the identification of each physiologic component of the triad and in the balancing act of recognizing the appropriate therapy to address each while minimizing the interdependent impact. In 2013, Critical Care Medicine published the *Clinical Practice Guidelines for the Management of Pain, Agitation, and Delirium in Adult Patients in the Intensive Care Unit* [31]. These guidelines

provide the supportive information to assist interdisciplinary teams to establish unit-specific evidenced-based protocols to manage pain, agitation, and delirium.

Pain

Pain is an intrinsic protective mechanism with acute pain being a symptom of injury or illness. The prevalence of pain in the critically ill population is pervasive. There is extensive literature related to the concept of pain, and there is some controversy regarding the differences in pain perception between older and younger critically ill adults. Assessment of pain can be hindered by age-related limitations or by the clinical therapies currently used to treat the patient, while measurements of pain represent the difficult task of quantifying the experience [35]. As the direct care provider, the critical care nurse should be able to identify patterns in the patients' response to "normal" ICU activities and procedures. This subjective awareness should be coupled with an objective measurement to begin to quantify the impact these activities have on the individual patients' pain threshold. There are numerous pain scales available, and each critical care unit should standardize their approach to assessment and measurement of pain. Popular measurements include self-report tools like the Visual Analogue Scale or the Verbal Descriptor Scale [36] employed when patients are more interactive, or the Behavioral Pain Scale [37] and the Critical Care Pain Observation Tool [38] predominately used when measuring pain in sedated patients. Pain management represents a balance of tolerance and relief. Under- or overtreating the critically ill older adult with analgesia can result in adverse events. The knowledge of the individual patients' pattern of response to stimuli and physiologic response to analgesia should help achieve balance. Although achieving pain management is a major task for the critical care nurse, the plan should not be formulated in a vacuum. Interdisciplinary team resources, such as the geriatric resource nurse and geriatric-focused pharmacist, should be intricately involved to work with the nurse to devise a plan that is dynamic and flexible to respond to the challenges a critically ill older adult experiences in the unit. As the critical illness changes, the plan for pain management should also change. Overriding principles in this process include the concept of starting with lower doses and slowly titrating to achieve the target goal, and only introducing one intervention at a time. The success of this approach is dependent on the comprehensive assessment and reassessment by the critical care nurse. When pain management is not adequately achieved, the patient is often more likely to experience exacerbation of agitation and demonstrate episodes of delirium.

Agitation

Agitation refers to a variety of behavioral disturbances that occur in response to physiologic and environmental triggers. The range of behaviors includes combativeness or aggressive behavior toward the caregiver, uncooperativeness with necessary care, or demonstration of general frustration and fear. The critically ill older adult is often more susceptible to agitation due to age-related sensory impairments. Noise levels, background distractions, constant bedside attention, and hospital lighting are all contributing factors to the critically ill patients' level of agitation. Physiologic triggers that can contribute to agitation include unrelieved pain, fatigue, fear, inability to communicate, and a sense of helplessness. The illness itself can contribute to agitation as well as new onset of infection. Being aware of triggers and establishing a plan of care to minimize the triggers is important. Modifying the environment to provide rest periods and undisturbed sleep is beneficial to combat fatigue, weariness, and overstimulation. Repeated reassurances to the patient that they are in a safe place, as well as frequent reorientation, and providing them an opportunity to communicate their concerns are helpful. Adequate pain management, prevention of infectious complications, as well as accurate diagnosis and management of the presenting critical illness all help minimize the degree of agitation experienced. Agitation can also be the result of polypharmacy and drug to drug interaction. The critically ill older adult is at high risk for medication interactions due to the complexity of the management strategies of their chronic illness and the interaction with the management strategies for their current acute illness. This highlights the need for not only the initial comprehensive assessment but reinforces the value of the geriatric-focused pharmacist as part of the interdisciplinary team. Immediate review and reassessment of the home medication plan to identify possible drug interactions as well as the ongoing review as new medications are added in response to changes in the clinical situation is critical.

The use of sedatives to treat agitation in the critically ill older adult should be in response to a specific indication and only after pain is adequately treated [34]. Clinical situations that benefit from the use of sedatives include, but are not limited to, patients who are in respiratory failure to optimize the benefits of ventilator support, those receiving neuromuscular blocking agents, and those with severe anxiety and/or delirium. It is recommended that the team make conscious decisions around the depth and duration of sedation, with scheduled times for objective assessment, and planned interruption in drug delivery to allow the patient to be awake [34, 39]. The use of sedatives, like analgesia, in the critically ill older adult requires a balanced approach and should

be synergistic with non-pharmacologic measures. Nurse-driven evidenced-based protocols are beneficial when trying to achieve this balance.

Delirium

The *Diagnostic and Statistical Manual of Mental Disorders*, *5th Edition*, defines delirium as an acute, fluctuating syndrome of altered attention, awareness, and cognition precipitated by an underlying condition or event in vulnerable persons [40]. The critically ill older adult is at high risk for experiencing episodes of delirium. Preexisting chronic disease, current critical injury or illness, and necessary clinical interventions, along with the use of sedatives and analgesics can all contribute to the onset of delirium. The range of symptoms can often result in mislabeling the disease and in the older adult be inappropriately attributed to advanced age [41]. Hyperactive delirium can resemble episodes of agitation or can be described as delusional, while hypoactive delirium can be consistent with confusion and resemble general fatigue or lethargy [31, 34]. Patients may experience fluctuating symptomatology and episodes of lucidness over hours or days that can coincide with how they are responding to their critical illness, changes in medications, or the onset of an infectious process. Critically ill older adults who experience episodes of delirium during their critical care course are at higher risk for continuing cognitive impairment, a decrease in their quality of life post hospitalization, and higher mortality [42, 43].

The primary strategy for addressing delirium is prevention. A group in Europe developed a delirium prediction model for ICU patients "PRE-DELIRIC" that utilized common ICU data elements obtained during the first 24 h of care [44]. Recognizing that patients are at risk for developing delirium during that first 24 h of ICU care, they built on this work and developed a model that will provide early, during the initial assessment period, predication of delirium [45]. The E-PRE-DELIRIC model results in a risk stratification of high, medium, or low risk of developing delirium during their ICU course. This work is valuable and attempts to impact the development of delirium by identifying those patients that may benefit from preventative measures. The researchers do recognize that the model is static and does not account for clinical changes that can impact the patient's risk for development of delirium. A secondary outcome of this study did compare the prediction model to the clinician (RN and MD) ability to predict the development of delirium during their ICU course based on the same data points and clinical experience. The clinicians performed significantly worse than the model [44].

Having an index of suspicion for the development of the syndrome is critical to the process. Knowledge of the high-risk parameters, along with focused assessment skills and tools, should help the bedside clinician employ interventions to minimize or prevent episodes of delirium. Utilizing a geriatric resource nurse or clinical nurse specialist to assist with delineating the specifics of a delirium-focused assessment is advantageous [46]. There are many delirium screening tools available, and each critical care unit should standardize their approach to assessment and management of delirium. Two tools that are designed for use in the intensive care setting include the Confusion Assessment Method-ICU (CAM-ICU) [47] and the Intensive Care Delirium Screening Checklist (ICDSC) [48]. The interdisciplinary team needs to standardize the unit approach to the prevention, assessment, and management of delirium. Studies have shown that utilization of assessment tools for delirium and sedation [49] is reliable and sustainable in clinical practice. Education and training around the tools themselves and integration of the information obtained from the assessment are extremely important. The critical care nurse is an integral component of this process. The addition of more assessment tools can increase the workload of the bedside clinician, but it has been shown that the dedication to accurate utilization, documentation, and integration into the standards of care may be the result of the perceived clinical value of this information [49].

There is no standardized pharmacologic approach to treat delirium, and the only non-pharmacologic therapy that has been shown to impact the incidence of delirium is early mobilization. In studies investigating the impact of mobility on functional decline of the critically ill patient, the incidental benefit of mobility on the decrease in the incidence of delirium was identified. Early and frequent movement of patients out of bed is not a new concept, but it now takes on a different implication in the critically ill older adult. Mobility should not be limited to only those that it is convenient to get out of bed. The expectation should apply to ventilated patients as well. The critical care nurse must work with the physical and respiratory therapist to maximize the timing and duration of this activity and factor in the degree of pain and agitation associated with the movement. This activity usually requires physical and mechanical resources to help get a patient out of bed. The unit environment needs to be conducive to support this clinical initiative.

The emphasis on the critical care nurse role in these strategies is impressive. Unit-based leadership needs to evaluate the environment to determine if the appropriate resources and supports are in place to ensure competency with practice expectations. There is still a perceived knowledge gap of the implications of aging and the critically ill older adult. Available resources with geriatric expertise and ongoing

education focusing on the critically ill older adult are essential. As research recommendations impact daily expectations of care, ICU leadership and the interdisciplinary care team need to provide thoughtful review and conscious application of changes to practice.

Management Strategies: The "ABCDE Bundle"

Critically ill older adult patients are at high risk for the development of significant adverse events and mortality from a cascade of intrinsic and extrinsic events that interfere with their clinical response to therapies and interventions designed to treat their illness or injury. There is extensive data that supports the need for comprehensive assessment strategies along with the application of protocol-driven pharmacologic and non-pharmacologic interventions to significantly impact this cascade and minimize negative outcomes. In 2010, Vasilevskis et al. published a new approach to combating the risks of ICU-acquired delirium and functional decline. Recognizing there were established validated assessment tools and evidenced-based protocols to address these issues, they sought to unify these strategies and move from silos of care to an integrated approach. The "Awakening and Breathing Coordination, Delirium Monitoring and Management, and Early Mobility" (ABCDE) bundle represents this strategy [50].

The coordination of efforts to carry out the ABCDE bundle highlights the need for unit-based buy-in and commitment from the interdisciplinary team. The essence of the bundle relies on nursing implementation of evidenced-based algorithms. The plan requires communication between disciplines and coordination of services to achieve maximum effect. If adopted, the unit should establish standardization of assessment tools for pain, sedation, agitation, and delirium with unit-based expectation of assessment schedules. This establishes a common language across disciplines when discussing assessment outcomes and necessary clinical interventions. Algorithms to direct the use of analgesia and sedation should be linked to the assessment parameters and be endorsed by the interdisciplinary team. The expectation of compliance with the standards and ongoing reassessment of the response to treatments is critical to the success of this program. Although it is not a mandate, each unit should establish a standard approach to include the application of the bundle on all patients during daily rounds. No one approach to care is universal across all patient types or clinical situations, but the expectation should be that all ventilated patients in the unit are reviewed for the application of the bundle.

A brief review of the components of the ABCDE bundle [39] includes:

1. Awakening and Breathing Coordination (ABC)
   (a) Relies on a coordinated approach between the critical care nurse and the respiratory therapist.
   (b) Utilizes safety screens to determine if the patient can tolerate each process.
   (c) If it is determined to be safe, the nurse will carry out a Spontaneous Awakening Trial (SAT).
   (d) If it is determined to be safe, the respiratory therapist will then carry out a spontaneous breathing trial (SBT).
   (e) Both trials include nursing implemented evidence-based guidelines for specific decision-making regarding timing and changes in dosing of sedatives.
   (f) The outcome of both trials needs to be communicated to the interdisciplinary team and incorporated in the decision-making/planning for next steps related to the continuous use of sedation and mechanical ventilation.
2. Delirium monitoring and management (D)
   (a) There is an expectation for nursing assessments for sedation/agitation and delirium.
   (b) The team should establish target sedation scores and goal-directed titration of these medications.
   (c) Input from these assessments should guide the nurse in implementation of pharmacologic and non-pharmacologic interventions.
3. Essential elements of early mobility (E)
   (a) Early mobilization is one therapy that has the potential to impact all aspects of the bundle:
      (i) Improved oxygenation
      (ii) Decreased incidence of delirium
   (b) Relies on coordinated approach between the physical therapist, critical care nurse, and the respiratory therapist:
      (i) The physical therapist determines the patients' ability to participate in the activity.
      (ii) The critical care nurse assesses the overall physiological state and determines if the patient is able to participate in the activity.
      (iii) The respiratory therapist assesses the stability of the patients' airway and determines if the patient is able to participate in the activity.

The bundle is centered on established evidence-based guidelines and has worked to unify these practices into one strategy [50]. The decision to adopt the concept of the ABCDE bundle requires input from every member of the interdisciplinary team as well as unit leadership. Successful implementation relies on standardization of evidence-based protocols, clear role delineation, establishment of strong communication patterns, and support from both the physician and nursing unit-based leadership. The critical care nurse plays a major role in the success of this application.

Nurse-driven evidence-based protocols are involved in each step of the process.

Conclusion

The number of critically ill older adults is increasing at startling rates. The unique concerns of this patient population present challenging opportunities for the ICU interdisciplinary team. The need for focused education, geriatric resources, and the realization that this patient population is different than younger critically ill patients is essential to successful management and optimal outcomes. There is evidence that coordination and collaboration from an interdisciplinary team as well as standardized assessment and treatment protocols influence patient outcomes and minimizes the incidence of adverse events and mortality. The critical care nurse is fundamental to the entire process. Nurse-driven evidence-based algorithms for assessment and management of pain, agitation, and delirium should be considered as part of a comprehensive plan of care. Optimal care for the critically ill older adult should strive to help them stay calm, lucid, pain free, interactive, and cooperative with their care [34].

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Rehabilitation Concerns in Geriatric Trauma

41

Bellal Joseph and Ahmed Hassan

Introduction

The US population aged 65 years and older has increased significantly by 21 % in the United States since 1980 [1, 2]. This group of elderly Americans is anticipated to grow from 12 % of the entire populace in 2000 to 20 % in 2030. This represents an increase from 35 million to 72 million elders. Moreover, the fastest-growing cohort among older adults is the 85-and-older group, increasing at three to four times that of the general US population. The rapid increase in the geriatric population has a significant impact on our health system. Clinical and ethical issues related to the care of seniors, particularly in trauma care, will become more prominent as the population ages. The financial burden of geriatric trauma is about 30 % of all trauma costs in America. In 2009 the estimated cost for geriatric trauma care was approximately $9 billion and more increases are expected in the coming years [3]. This increase is likely to arise from an increasing proportion of the geriatric population living an active lifestyle that is likely to result in trauma and disability.

Understanding Rehabilitation

Disability is a matter of permanent physical or mental impairment due to disease or injury [4]. Rehabilitation is a set of measures that assist individuals with physical impairments or disabilities through promotion of mobility, functional ability, and quality of life [5]. Rehabilitation medicine is designed to enhance functional status through the diagnosis and treatment of health conditions, reducing impairments, and prevention or treatment of complications. Rehabilitation is a multidisciplinary intervention that considers the disabled person as a patient and accepts the permanent impairment and attempts to overcome, adapt, and compensate for it. Physicians with specific expertise in medical rehabilitation are referred to as physiatrists, rehabilitation doctors, or physical and rehabilitation specialists. Medical specialists such as psychiatrists, geriatricians, ophthalmologists, and trauma surgeons can be a part of the rehabilitation team.

Rehabilitation and the Need for a Different Approach

Injury-related disabilities are dynamic processes over time. The size and strength of challenges and difficulties can be different across the course of sickness and disability. So timing is a crucial factor for the rehabilitation team to design an appropriate intervention that can fit the time of delivery [4, 6].

Rehabilitation has usually been a separate, second-stage process, carried out after the initial medical treatment when recovery remains incomplete. That approach is inappropriate for common health problems and disabilities as the main challenge for recovery is usually psychosocial in nature rather than the disability itself. [7] Planning for rehabilitation needs should ideally begin at the time of admission. Ideally rehabilitation specialists should evaluate the patient's pre-injury state of wellness at an early stage to consider all of the options available to the patient and identify the health, personal/psychological, and social/occupational obstacles to recovery [8].

This implies that rehabilitation can no longer be a separate, second-stage intervention after treatment is complete. The evidence shows that individuals who receive an early

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rehabilitation intervention have higher rate of recovery and return to work and individuals with late rehabilitation intervention tend to have more complex and challenging obstacles to overcome. Furthermore, participation with therapies is more difficult and costly with a lower rate of achieving the goals of the treatment plan [9]. Therapeutic intervention should be an integral part of good clinical and occupational management to achieve the maximum benefits for the patients and minimize the number with long-term disability.

Rehabilitation Assessment

The elderly develop unique characteristics that make them differ significantly from their younger counterparts including more comorbidities, vulnerability to develop complications, and a protracted time to achieve full recovery. There is a substantial need for accurate assessment in this population as it can have a significant impact on older patients' care planning and quality of life. Rehabilitation intervention targets body functions and structures, activities and participation, environmental factors, and personal factors. It aims to enhance the individual's ability to achieve and maintain an optimal functional status in interaction with their environment.

Rehabilitation Outcomes

Rehabilitation outcomes are the benefits and changes in the functional status of an individual over time that are attributable to a single measure or set of measures [5]. Usually, rehabilitation assessment tools focus mainly on the individual's impairment level as a primary outcome. More recently, outcome assessment tools have been extended to include individual activity and participation outcomes. Measurements of activity and participation outcomes assess the individuals' communication, mobility, self-care, education, work and employment, and quality of life [10].

Rehabilitation outcomes include:

- Prevention of the loss of function
- Slowing the rate of loss of function
- Improvement or restoration of function
- Compensation for lost of function
- Maintenance of current function

Assessment Instruments

- Activities of daily living
- An older adult's functional status can be assessed at three levels [11]:
  - Basic activities of daily living (BADLs)
  - Instrumental or intermediate activities of daily living (IADLs)
  - Advanced activities of daily living (AADLs)

  BADLs refer to self-care tasks which include:
  - Bathing
  - Dressing
  - Toileting
  - Maintaining continence
  - Grooming
  - Feeding
  - Transferring

  IADLs refer to the ability to maintain an independent household which include:
  - Shopping for groceries
  - Driving or using public transportation
  - Using the telephone
  - Performing housework
  - Doing home repair
  - Preparing meals
  - Doing laundry
  - Taking medications
  - Handling finances

  AADLs vary considerably from individual to individual. These advanced activities represent physical and social abilities such as employment, traveling, hobbies, and involvement in family roles as well as participation in occupational tasks [12]:
- Functional Independence Measure (FIM)

  The Functional Independence Measure (FIM) is a global measure of disability used for assessing basic functional activities of patients during hospitalization and their progress during inpatient rehabilitation. FIM measures how independent a person is on a scale from 1 to 7 (Table 41.1). A FIM score of 7 is categorized as "complete independence," while a score of 1 is categorized as "total assistance." Each dimension is then added, yielding a possible total score between 18 (complete dependence) and 126 (complete independence). These scores are used for initial assessment and upon discharge may be used as a measure of progress [13].
- Gait speed

  Physical performance measurements such as gait speed can reflect health and functional status and are one of the components in Fried's model of frailty. Gait speed has been recommended as a potentially useful clinical indicator of well-being among the older adults allowing clinicians to make more individualized estimates and identify patients who need further evaluation, such as those at increased risk of falls.
- Gait instability or fall

  Walking disability increases with age, from an incidence of 6 % for people aged 65–69 years to approximately

Table 41.1 Functional Independence Measure™ instrument: developed by the University of Buffalo, a proprietary, subscription-based instrument to measure and document function

Contains 18 items composed of: 13 motor tasks Five cognitive tasks (considered basic activities of daily living)
Dimensions assessed include: 1. Eating 2. Grooming 3. Bathing 4. Upper body dressing 5. Lower body dressing 6. Toileting 7. Bladder management 8. Bowel management 9. Bed to chair transfer 10. Toilet transfer 11. Shower transfer 12. Locomotion (ambulatory or wheelchair level) 13. Stairs 14. Cognitive comprehension 15. Expression 16. Social interaction 17. Problem solving 18. Memory
Tasks are rated on a 7-point ordinal scale: 7 – Independent: able to perform task independently 6 – Modified independent: able to perform task independently but requires extra time 5 – Supervised: able to perform task with setup, may need verbal cues for safety and sequencing 4 – Minimal assistance: requires assistance for up to 25 % of the task 3 – Moderate assistance: requires assistance for 26–50 % of the task 2 – Maximal assistance: requires assistance for 51–75 % of the task 1 – Total assistance: requires assistance for greater than 76 % of the task
Scores range from 18 (lowest) to 126 (highest) indicating level of function
Scores are generally rated at admission and discharge

40 % among those aged 85 and older. In the elderly with diseases such as arthritis, 35 % admit to difficulty when walking one-quarter mile. Approximately one-third of frail persons aged 65 years and one-half of those over 80 years of age fall each year [14]. Patients who have fallen or have a gait or balance problem are at higher risk of having subsequent falls and losing independence [15]. An assessment of fall risk should be integrated into the history and physical examination of all geriatric patients.

- Cognition
  The incidence of dementia increases with age, particularly among those over 85 years, yet many patients with cognitive impairment remain undiagnosed. The value of making an early diagnosis includes the possibility of uncovering treatable conditions. The evaluation of cognitive function can include a thorough history and several rapid screening tests that may require less than a minute to complete [14]:
  - Mini-Cog
  - 3-item recall at 1 min
  - Serial 7's
  - Clock-drawing test

Patients with suspected cognitive impairment should be screened for delirium and depression. Delirium is a reversible disorder of attention and should be considered in patients with decreased level of consciousness or inattention. Delirium is associated with reduced function and independence, increased short- and long-term mortality, and prolonged cognitive impairment in elderly. Delirium is a common side effect of medications (benzodiazepines, barbiturates, opioids) and often unrecognized by clinicians.

- Mood disorders
  Depressive illness in the elderly is a serious health concern leading to unnecessary suffering, impaired functional status, increased mortality, and excessive use of healthcare resources. Depression in the geriatric population may present atypically and may be masked in patients with cognitive impairment. Approximately 6–10 % of older individuals seen in ambulatory primary care settings have major depression. People aged 65 and above represent less than 13 % of the populations but account for 25 % of suicides. More than 75 % of elder who commit suicide were also suffering from a major depression. Risk

factors for late-life suicide include depression, comorbid physical illness, living alone, male gender, and alcoholism [14].

Functional Status and Frailty

Functional status refers to the ability to perform activities necessary or desirable in daily life. Measurement of these activities can be valuable in monitoring response to treatment and can provide prognostic information that assists in planning for long-term care. Development of valid and reliable outcome measures for use with older adults is complicated by frailty, comorbidities, and heterogeneity in this population.

Geriatric patients are different from their younger counterparts as they tend to have lower functional status on admission and higher clinical complexity due to multifactorial disability and concurrent medical conditions. Differences exist in geriatric trauma patients based on their frailty rather than their age [16]. Frailty has a significant impact on hospital discharge disposition for trauma patients even after a relatively minor event such as ground level falls as frail patients are more likely to be overwhelmed by devastating complications and discharged to an institutional facility compared to non-frail patients [17].

According to recent studies, frail trauma patients are less likely to recover to their baseline functional status compared to non-frail patients. Early focused intervention in the frail elderly patients is warranted to improve functional recovery.

Function Restoration

Rehabilitation usually requires a combination of therapeutic and social interventions that address the clinical problem and issues in the individual's physical and social environment. Therapeutic plans are focused on restoring or compensating for the loss of function and preventing or slowing deterioration in function for all daily activities [18]. Therapy measures include:

- Training, exercises, and compensatory strategies
- Education
- Support and counseling
- Modifications to the environment
- Provision of resources and assistive technology

General Principles for Rehabilitation Intervention Therapy

1. Establishment of a relationship between the patient and their rehabilitation team.
2. Sensitive and objective measurement of functional impairment before/during treatment.
3. Determine whether the aim of intervention is to restore function or to adapt to its loss and the prognosis after the intervention.
4. Determine the type and amount of therapy to be provided over what time period.
5. Provide the best available resources and most effective and cost-effective services.
6. Provide research-based information which is essential for strengthening rehabilitation systems while reducing cost for services and better outcomes.

Functional Restoration Team

The rehabilitation team includes occupational therapists, trauma surgeons, orthopedic surgeons, physiotherapists, prosthetists, psychologists, rehabilitation and technical assistants, social workers, and speech and language therapists. Physical therapists determine the physical disability and impairment and provide therapy to improve the associated dysfunction or minimize it. Occupational therapists focus on improving the participation in daily activities such as participation in home, school, college, and at work. Social workers determine the resources available to the patient based on their insurance and financial situation. Speech and language therapists help improve the language, speech, and swallowing impairments. In summary, rehabilitation is a multidisciplinary profession that requires coordination between providers to ensure the continuity of care and focus on every aspect of recovery and rehabilitation. The aim of coordinated rehabilitation is to improve functional outcomes at an affordable cost.

Inpatient rehabilitation consultation has been shown to play a beneficial role during the acute care of older trauma patients. For example, collaboration between orthopedic surgeons and geriatricians on an acute orthopedic floor produced significant benefits such as reducing patient mortality, hospital length of stay, and cost of care [19]. Consultation is also more effective if the physiatrist has an opportunity to discuss patient care issues with the trauma surgeon and have face-to-face verbal acknowledgment of the issues and therapeutic recommendations. The rehabilitation team should incorporate knowledge of the trauma care system as the trauma service integrates geriatric principles into their care processes. Occasional meetings between the two services should be held to discuss to continually improve the integration of treatment plans that will optimize outcomes for each patient.

Rehabilitation Settings

Hierarchy of care exists for the provision of rehabilitation services similar to which exist for trauma centers depending

on the needs of the patient. Very often the patient begins their rehabilitation at one level and is gradually transitioned through different levels of rehab facilities as their needs change [20] (Table 41.2).

Acute Inpatient Rehabilitation Facility (IRF)

The Acute Inpatient Rehabilitation program helps patients with disabilities following trauma to become as independent as possible in the activities of daily living and return home and reenter the community. There are strict requirements that should be met before a patient is eligible for admission to an Acute IRF which is determined during a preadmission screening.

The patient must demonstrate that they are:

- In need of at least two skilled rehabilitation services (services include physical, occupational, or speech therapy)
- Able to participate in at least 3 h of therapy per day, 5 days a week
- Medically and psychologically stable
- Mentally alert enough to participate in rehabilitation
- Expected to improve based on measurable program goals

Skilled Nursing Facilities (SNF)

Those patients who have limited ability to learn skills compatible with safe, independent living are referred to nursing homes. Once sufficient functional recovery has taken place, the patient is then transferred for either inpatient or outpatient therapy. A patient may qualify for SNF services if the

Table 41.2 Overview of typical settings for continued rehabilitation efforts

Rehabilitation option	Typical length of stay	Services/requirements	Insurance coverage
Inpatient rehabilitation facility (IRF)	~10–14 days on average; model systems can provide longer stays	Require and are able to tolerate high-intensity therapies at the rate of at least 3 h/day or 15 h/week Must require at least two therapy modalities: PT, OT, and/or SLP Must require rehab nursing Must have completed all medical and surgical procedures, be medically stable, and require continued medical supervision Demonstrate high likelihood of significant functional improvements Must have viable discharge plan upon completion of IRF stay	Medicare: covers 14 CMS diagnoses Commercial: varies by plan, requires pre-authorization Medicaid: no
Model systems IRF	Individually assessed during stay	National Institute on Disability and Rehabilitation Research (NIDRR)-funded facilities that receive funding for establishing models for treatment of certain diagnoses (i.e., TBI, SCI) Maintain databases on patient treatments and outcomes for the purposes of research and innovative outcomes	Medicare: covers typical diagnoses Commercial: varies Medicaid: no
Skilled nursing (SNF)/subacute rehabilitation	~20 days but can be up to 100 days	Require and are able to tolerate some therapies up to 180 min/week Many SNFs will work more with patients who are preparing for IRF stay PT, OT, +/− SLP usually available at most facilities	Medicare: covers most diagnoses Commercial: varies by plan, requires pre-authorization Medicaid: varies by state
Long-term acute care (LTAC)	Depends on pathology; most take ventilated patients	No therapy requirements, although many offer it in preparation for IRF/SNF Requires continued physician supervision with 24-h nursing	Medicare: covers most diagnoses Commercial: varies by plan, requires pre-authorization Medicaid: typically no
Home health Outpatient therapies	Depends on progress and prognosis Depends on progress	Patients must be homebound and willing to receive care and/or therapies in their home Goal is to restore function to baseline including requirements for employment	Medicare: covers most diagnoses Commercial: varies Medicaid: typically covers Medicare: covers Commercial: varies Medicaid: no

patient's care involves one or more of the following conditions:

1. Requirement for dressing of postsurgical wounds, decubitus ulcers, leg ulcers, tracheostomy care, nasal catheter maintenance, gastrostomy feeding or other tube feeding, or colostomy care
2. Need for medication administration which cannot be self-administered and requires skilled nursing services
3. A physical or mental functional limitation
4. A medical condition that requires continuous skilled nursing observation of blood pressure, pulse, and respiration, as indicated by the diagnosis or medication ordered by the physician, or observation of skin for conditions such as decubitus ulcers, edema, color, and turgor

Long-Term Acute Care (LTAC)

A long-term acute care facility is a specialty care hospital designed for patients with serious medical problems that require intense, special treatment for an extended period of time—usually greater than 25 days as opposed to an acute care hospital where a patient receives active but short-term treatment. Many of the patients in LTACs are transferred there from a critical care unit. LTACs specialize in treating patients who may have multiple serious conditions but who may improve with time and care and return home. LTACs generally give services like ventilator care, TBI, and pain management. The motivation for transferring patients to LTACs appears to be purely financial, because Medicare rules limit payment for long-term inpatient care.

Home Health Services

Home health services provide services and assist patients who are recovering after discharge from a hospital or other facilities but have ongoing needs for additional therapy. The patient needs may be provided by registered nurses, physical therapists, occupational therapists, speech language pathologists, and social workers through multiple weekly visits. Home health services are typically covered by Medicare and Medicaid.

Outpatient Therapy

These services are more intense than the home health services and are available to patients who are ambulatory.

Telerehabilitation

Telerehabilitation is a term used to describe the provision of rehabilitation services at a distance using telecommunications technology as the service delivery medium [5]. It is a subgroup of telemedicine which is an umbrella term denoting all healthcare services, whether clinical or educational, which are delivered via telecommunications means. Telerehabilitation technologies include:

- Video and teleconferencing technologies
- Mobile phones
- Computers
- Remote data collection by tele-monitoring and sensors

The use of information, communication, and related technologies for rehabilitation is an emerging resource that can enhance the capacity and accessibility of rehabilitation measures by providing interventions remotely. Potential benefits of telerehabilitation include:

- The potential transportation cost and time savings from the perspective of both the healthcare system and the patient
- The continuity of patient care that can be achieved through the remote provision of services
- The heightened ability to control the timing, intensity, and sequencing of intervention
- The potential environmental impacts of reducing travel
- Other benefits such as the positive effects of rehabilitating a patient in their own social and vocational environment

Assistive Technologies

An assistive technology device can be defined as "any item, piece of equipment, or product, whether it is acquired commercially, modified, or customized, that is used to increase, maintain, or improve the functional capabilities of individuals with disabilities" [5]. Rehabilitation systems should provide assistive devices that are appropriate, sustainable, affordable, and accessible.

Common examples of assistive devices are:

- Crutches, prostheses, orthoses, wheelchairs, and tricycles for people with mobility impairments
- Hearing aids and cochlear implants for those with hearing impairments
- Canes, magnifiers, ocular devices, talking books, software for screen magnification, and reading for people with visual impairments
- Communication boards and speech synthesizers for people with speech impairments
- Devices such as day calendars with symbols and pictures for people with cognitive impairment

Assistive technologies when appropriate to the user and the user's environment have been shown to be powerful tools to increase independence, improve participation, and possibly reduce cost of care.

Challenges and Barriers to Rehabilitation

Many of the challenges in assessing the aging patient for rehabilitative care are related to the ever-changing guidelines, rules, and regulations. The barriers to rehabilitation service delivery can be overcome through a series of actions including modification of policies, laws, and delivery systems; development of resources for financing of rehabilitation including rehab loans and government programs; expansion in rehabilitation professional recruitment, including training and retention of rehabilitation personnel; decentralization of rehabilitation delivery and seeking new ways of service delivery by the use of telerehabilitation; and increasing the use of appropriate, sustainable, affordable, and accessible assistive devices.

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End-of-Life Care

42

Mary Condron and Karen Brasel

Summary

- Because of the high mortality rate in elderly patients with unplanned ICU admissions, practitioners need to have the skills to provide optimal end-of-life care. A cultural shift toward including basic palliative care in routine surgical ICU care may improve our ability to effectively care for our patients.
- End-of-life care is broad in scope and can only be done successfully with defined goals of care, familiarity with symptom management, and comfort in addressing personal and professional ethics. Understanding the differences between healthcare power of attorneys, advanced directives, and do-not-resuscitate orders—as well as the roles of palliative and hospice care—is key to engaging in discussions with patients and families.

Epidemiology

Given the severity of illness of patients arriving to the intensive care unit (ICU), it is not surprising that mortality of patients admitted to the ICU is high. Approximately 20 % of all deaths in the United States occur each year in the ICU or within days after transfer from the ICU [1–3]. Furthermore, most of these deaths are a result of the decision to withdrawal or withholding life-sustaining therapies [4–8].

When considering geriatric trauma patients, trauma is the fifth leading cause of death in patients over the age of 65 [9]. Furthermore, though geriatric patients represent only 12 % of the overall trauma population, they account for 28 % of the deaths due to trauma [10]. The effects of age begin to impact mortality at age 45, but for each year over age 65, mortality increases by 6 % [1, 11]. Emergency general surgery is also associated with a high risk of death in geriatric patients, with a mortality of two to three times that of nonemergent surgery [12]. Similarly, when compared to younger cohorts undergoing emergency general surgery, mortality of geriatric patients is two to three times greater [13, 14]. Of note, more than 10 % of Medicare decedents have surgery during their last week of life, and more than a third of Medicare patients in hospice were transferred there from an ICU [15].

Given the challenges in management of elderly surgical patients, it is clear that during a surgeon's career, he/she will encounter many patients with end-of-life needs. Despite the ubiquity of these issues, there is tremendous evidence that quality of care at the end-of-life, as perceived by patients and their families, needs to improve [3, 16]. Table 42.1 lists common barriers to institution of palliative care measures in surgical ICUs. Some of these barriers to satisfaction and high-quality end-of-life care include inflated expectations of outcomes held by clinicians and families, uncertainty regarding prognosis, delay in attention to palliative needs, and the lack of an integrated approach to end-of-life care [17]. An understanding of palliative care methods and the ethical management of patients at the end of life as well as the needs of their families is necessary to improve the care of the dying patient.

Surgical Buy-In

Several barriers hinder a timely and adequate approach to end-of-life care; one of the most difficult to overcome is that of surgical culture. The historical approach in the surgical or trauma ICU has been a culture of rescue. This frames the surgeon as a warrior against disease carrying an absolute responsibility to save the patient's life [18]. This culture can

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Table 42.1 Surgical ICU culture and barriers to palliative care

Surgical ICU characteristics	Barrier to palliative care
Structure and process "Open" ICU Multiple consultants No interdisciplinary team rounds or processes of care Surgical hierarchy prevails Surgeon has primary relationship with family, not ICU team	No leadership to drive change No standard processes in place No one person has responsibility for end-of-life decisions or communication Interdisciplinary team undermined or devalued Communication in silos leads to conflict and delays in decision-making Delay in palliative care consult
Surgical patients and disease Different disease trajectories: trauma, transplant, surgical oncology, and neurosurgery Lack of clear prognosis for mortality Lack of quality of life or functional outcome data	One palliative care approach does not fit all ICU patients Triggers for palliative care evaluation need to be disease specific Can't tell who is dying, and then can't do palliative care until very late in course Difficult to predict if patient's quality of life will be acceptable to patient's wishes
Families Sudden or catastrophic illness High expectation for life-saving surgery (transplant, cardiovascular) No knowledge of patient's wishes	Lack of readiness for end-of-life decisions Unwillingness to accept poor outcome Family burdened by decision-making Intensive need for family support
Surgeons' attitudes Palliative care = end of life care, only for dying Death is a failure Fear of abandonment Fear of destroying hope Lack of skill or expertise in communication, pain management	Palliative care delayed until death imminent Avoidance and delay of family meetings and end-of-life decisions Refuse palliative care consultation Avoidance of discussion of bad prognosis

From: Mosenthal et al. 2012 [37]

interfere with open discussions and decision-making. "Admitting defeat" by withdrawing or withholding life-sustaining treatment and allowing a patient to die is an emotional challenge that many surgeons are unwilling to face. As a result, surgeons frequently delay end-of-life discussions and palliative care treatment despite patient or family member requests for these measures. In 2008, Morrell et al. found that surgical services took nearly twice as long as their medical colleagues to establish DNR status in a single-institution review of the management of patients with life-threatening illnesses [19]. Moreover, many patients and families find that continuation of therapies often proceed beyond a time when they feel it is wanted or even acceptable [20].

The relationship between the surgeon and patient has been described as both a covenant and an implicit contract made preoperatively between a patient and their physician [18]. In an analysis of physicians' opinions regarding the contract between patient and physician, Schwarze et al. found that important negotiation about postoperative participation occurred during preoperative surgical planning and discussion. It is during this time that an implicit contract is created that has important consequences in the postoperative time period [21].

It is important to note that during these preoperative discussions for planned procedures, the person who would be the patient's surrogate decision-maker may not be present. This has significant implications for end-of-life decision-making. It has been reported that 64 % of surrogates of critically ill patients did not believe physician predictions that ongoing treatment was futile [22]. Rather than relying on the medical team for prognostic information, 98 % relied on nonmedical sources (including patient character and will to live, as well as spiritual beliefs) to determine prognosis [22]. The arrival of a surrogate who was not part of preoperative discussions, and who has a vision for goals of care different from the surgeon, can lead to feelings of betrayal and create conflict [21]. Thus, it is well advised to encourage the participation of family in preoperative planning for high-risk procedures.

It is encouraging to note that structured interventions tailored to individual surgical ICUs can successfully effect cultural change with resultant changes in patient outcomes. Mosenthal et al. reported such a program that resulted in earlier DNR orders (without an associated change in death rate) [23]. This allowed family members and loved ones more time to say goodbye and increased the ICU team's focus on pain control.

30-Day Mortality

Vignette: The surgeon on call at a tertiary care facility is paged by a rural hospital requesting transfer of an 85-year-old demented man with a small bowel obstruction. The patient has emesis not controlled by nasogastric tube and systemic inflam-

matory response syndrome (SIRS). The surgeon accepts the patient, who upon arrival is tachycardic and having feculent emesis. The patient's son (who is his medical decision maker) advocates for surgical exploration. In the operating room the obstruction is relieved, but the patient is found to have a non-survivable amount of infarcted small bowel. Goals of care are adjusted, the patient is made comfortable, and the following morning life-sustaining treatment is withdrawn in ICU after the patient's family has arrived and said good-bye.

Does 30-day mortality capture patient safety in this case? Does it capture the surgical team's efficacy at meeting goals of care?

30-day mortality is a publically reported, commonly cited quality metric used across the country. These data are intended to provide patients and community members with valuable information about safety of operations at a given institution or with a particular provider. While these data are easy to capture, they can be misleading when the patients or procedures involved are particularly high risk. Recent work by Talsma et al. showed that 30-day mortality significantly underrepresented risk of death when compared with 90-day mortality. Further, they found that 90-day mortality was better at capturing deaths related to the surgical procedure, rather than patient comorbidities [24]. A desire to keep 30-day mortality measures low may motivate providers to continue futile or unwanted interventions that keep patients alive for the duration of this measure [25]. Similarly disturbing, it may prompt discriminatory practices where high-risk patients are avoided. 30-day mortality also fails to capture important information regarding palliative procedures; relieving an obstruction in the face of non-survivable cancer may be aligned with the patient's goals of care and may be quite effective at alleviating suffering [25].

Frailty vs. Age

Although age has a well-described impact on outcomes in the surgical and trauma ICU [12–14], frailty may be more informative about prognosis. Frailty can be understood as a decreased physiological reserve and resistance to stressors that results in increased vulnerability to poor outcomes [12]. Joseph et al. showed that in trauma patients older than 75 years, frailty index was a better predictor than age for mortality, adverse discharge, pneumonia, and urinary tract infection [26]. There are many competing validated frailty indices; unfortunately most require the input of too many factors to be calculated easily or routinely in clinical practice. Easy to assess metrics that may provide an admittedly incomplete measure of frailty include unintentional weight loss >10 lbs in the past year, slowed walking speed (>7 s to walk 15 ft), and degree of independence prior to hospitalization [27, 28].

Establishing Goals of Care

The transition of care from curative to palliative does not need to be a dramatic shift in strategy [29] (Fig. 42.1). A patient-centered approach to care should include early discussions with the patient and family regarding goals of care and treatment limitations. These discussions should occur prior to the acute situation when decisions are difficult to make and the patient frequently is no longer able to voice his or her opinions. In situations where the admission to the hospital or ICU is the initial acute situation, the discussion should occur as soon as possible—ideally, during the first conversation with the patient and/or family [30]. Communicating clearly and establishing an open dialogue are critical to setting expectations and allowing those with the most at stake to be active participants in healthcare decisions. This approach also ensures that no matter the goals of treatment, care will not be withdrawn. Certain treatments may change, but the patient and family are provided care and support throughout their illness.

One of the first steps is clearly delineating goals of care. Goals of care include the expectations of the patient and surgeon if everything goes as planned as well as if there are significant complications encountered. These goals should include discussions regarding optimal treatment outcomes and what the patient would consider unacceptable outcomes. Many patients have opinions regarding quality of life limitations that they have considered privately but never spoken about to family or healthcare providers. This conversation should include not only goals of care for while in the hospital but also opinions about disposition. In particular, it is important to identify patients for whom a skilled nursing facility (SNF) would be unacceptable either as a short-term discharge destination or as a long-term disposition.

Treatment limitations include setting limits on the aggressiveness with which to sustain life. These limitations may be made considering both the potential for survival and/or the subsequent quality of life. Treatment limitations might

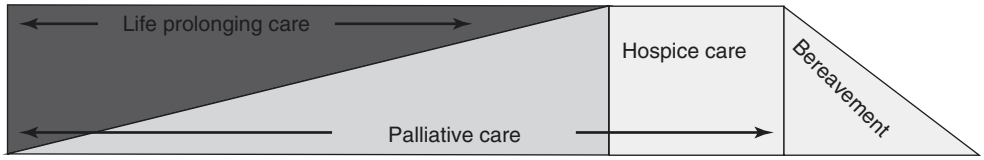

Fig 42.1 Trajectory of illness and provision of palliative care [29]

include any number of treatment modalities. These limitations are best set while the patient is lucid and able to rationally consider all treatment options.

Terms and Definitions

Advance Directives

Advance directives, advance healthcare directives, medical directives, and living wills fit into this category. They are defined as "written expression of how you want to be treated in certain medical circumstances." They can address any number of scenarios in specific or general terms. Examples include use of feeding tubes, mechanical ventilation, discharge to nursing facilities, and desire for cardiopulmonary resuscitation.

Do Not Resuscitate (DNR)

A DNR is a physician order regarding the implementation of therapy if the patient were to suffer a cardiopulmonary arrest. On the surface, DNR seems simple to understand and implement; however, there are many nuances to the DNR order that complicate execution of the wishes of the patient. Frequently, DNR orders are not discussed during the preoperative stages of care. Furthermore, most hospitals have rules informed by the American College of Surgeons and American Society of Anesthesiologists' guidelines regarding DNR order holding while the patient is in the operating room. Highlights of these guidelines are as follows:

- Institutional policies that automatically enforce or cancel pre-existing DNR orders do not sufficiently support a patient's right to self-determination.
- Physicians should discuss and document DNR status with the patient or surrogate decision-maker prior to proceeding with a planned operation.
- Options include suspending the DNR for a defined amount of time in the perioperative period, continuing DNR in the perioperative period, and limiting specific interventions (such as chest compressions but not intubation) in the perioperative period.
- If a healthcare provider has an ethical or professional conflict with the patient's advance directive, an alternative provider should be recruited [31, 32].

DNR orders may be complicated to understand as many individuals do not want a portion of resuscitation but would allow other treatment modalities if necessary. For example, a patient may not want chest compressions but would allow intubation or performance of electrical defibrillation. There are stigmata surrounding various resuscitation treatments held by healthcare providers as well as patients. Most patients do not understand the risks and benefits of undergoing CPR in the hospital setting. Similarly, many healthcare providers are uncomfortable "allowing" a patient to die without intervention through heroic measures despite data showing poor outcomes in patients who suffer a cardiorespiratory arrest during hospitalization.

The use of these "partial DNR" orders should be discouraged [33]. These orders are intended to provide a tailored approach to anticipated patient needs and desires; however, because it is impossible to predict all potential patient scenarios, these types of orders frequently lead to non-beneficial or harmful interventions [33]. For example, a patient may not want chest compressions, but the use of medications without chest compressions during an arrest is extremely unlikely to be of any benefit to that patient. Patient education and physician response to patient emotions and questions are critical [34]. It is up to the physician to provide a recommendation based on medical evidence and patient priorities when establishing code status [34].

Further complicating the implementation of DNR orders is the poor understanding of CPR outcomes seen in surrogate decision-makers. Although many decision-makers have taken CPR classes, it is common for their understanding of the outcomes of CPR to be based on depictions in TV or movies. In a recent study, more than 70 % of surrogate decision-makers thought that survival after CPR was >75 %, 20 % understood that brain damage could be present afterward, and only 2 % understood that the patient could be dependent on life support afterward [35]. This knowledge gap is a significant source of unrealistic expectations.

Healthcare Power of Attorney

These are defined as "durable power of attorney specifically designed to cover medical treatment." These designate a person who will make decisions on the patient's behalf, although they do not specify what decisions should be made. State laws will dictate the hierarchy of designating medical decision-makers if this person has not been appointed. If no person exists, a court-appointed designee may be necessary. Involvement of an institution's ethics board may be helpful in this situation.

Futility

There will be times when despite open conversations with patients and their family members, there will be disagreement over the use of certain life-sustaining therapies. Medical futility is a concept that refers to the appropriateness of medical treatment when the expected success of that intervention in poor. Quantitative futility defines a situation in which

there is a <1 % expected chance that the intervention will be success. Texas and California have statewide futility policies, but the majority of the country relies on individual institutional policies. Physicians are not legally, ethically, or professionally required to provide any medically futile therapy as defined by the standard of the medical community.

Planned vs. Emergent Admission ICU

> Vignette: A frail 76-year-old woman with terminal colon cancer presents with cholangitis. She is in severe pain and has an associated mental status change. She wrote an advance directive in the past specifying her wish for limited intervention in the event of terminal disease. Her husband, who is her surrogate decision maker, is unsure if they should proceed with surgical treatment of her biliary tract disease: he wonders if this should be seen as acute and reversible or as a fatal event.
>
> How does the utility of an advance directive vary between planning for the management of a known, progressive condition and managing an unexpected emergent condition? What are the differences in prognostic accuracy between outcomes of elective and emergent procedures?

Emergent admission to the ICU presents different patient care challenges than planned postoperative admission. Patients admitted emergently generally have less predictable trajectories, and their prognosis is more uncertain. Elderly patients who have undergone emergent surgery or who are recovering from significant trauma experience a compressed time frame for decline. These abrupt changes often make decision-making harder as their wishes may not have been expressed, leaving their families, who generally are already understandably emotionally distraught, unprepared to determine what the patient would have wanted.

Advance directives also play a different role in this patient population. They often specify preferences for how aggressive treatment should be if illness is considered irreversible or terminal. Because trauma and emergency surgical problems have less clear prognoses, it can be difficult to know if the treatment strategy outlined in the advanced directive applies. Further, it is rare for an advance directive to provide useful guidance on what to do when the underlying condition is terminal, but the acute problem is reversible [36].

Palliative Care Models

There are several models of palliative care that have been successful within various institutions and settings. The optimal model depends upon institutional resources and culture.

Consultative

A consultative model describes the use of a consultant palliative care service to provide all or a majority of palliative care needs within an institution [17, 34]. This model works well in settings where few physicians are familiar, adequately trained, or sufficiently engaged in palliative management. A consultative service can provide needed resources for patients, families, and their physicians. There are limitations to the ability of a consultative service to provide sufficient coverage for an institution depending upon the size of the organization and the number of healthcare providers on the consultative service.

Triggers

Another model of palliative care similar to and building upon a consultative model is the use of triggers to prompt consultation of a palliative care team. The use of triggers such as number of days spent in the ICU, presence of dementia, and other poor prognostic indicators can be used to triage and prompt appropriate resource utilization of the palliative care service [34]. Triggers have, in general, worked better in medical ICUs rather than surgical ICUs, where they have failed to increase the rate of palliative care consultation [17, 37].

Team Based

Lastly, the most inclusive approach to palliative medicine is to create a culture of team-based palliative management whereby multidisciplinary and interprofessional healthcare teams interact to incorporate palliative care practices into daily patient care services [34]. Similar to the approach taken by the specialty of geriatrics, palliative care leaders recognize the limitations of a consultative palliative care service and encourage a palliative care approach within all appropriate specialties [17, 34]. Utilizing set orders and care plans or so-called palliative care "bundles" in the delivery of care can prevent the delay often seen when consulting a new service. Many of these bundles emphasize addressing basic needs important in both palliative care and ICU care—have goals of care been addressed, is pain management optimal, is the patient having respiratory or GI distress, and have the patient's and family's spiritual needs been addressed. Incorporating these bundles on a daily basis for all patients in the ICU, regardless of whether they are at the end of life or not, helps establish a culture where optimal palliative care can be delivered [38].

Communication and Family Meetings

One of the most important aspects of care during the end of life is communication between caregivers and patients and their families. The emotional toll experienced by all is significant and confusion or unclear messages only worsen this

aspect. Families frequently want to know how long the patient has to live, but prognostication is notoriously inaccurate in most situations [38]. There are prognostic tools available that will allow for better informed discussions with patients, recognizing that no prognostic tool is perfect and that for an individual patient or family, the outcome is either 0 % or 100 %. Regardless of the prognosis, frequent scheduled meetings with patients and their loved ones have the effect of decreasing the fear of the unknown and the frequently lamented feeling that they are being left in the dark [39]. The transition to end-of-life care is made more easily if frequent meetings have been carried out, and a level of familiarity and trust has been developed between the healthcare team and the family.

A structured approach to family meetings can ease the delivery of unfavorable news. One approach uses six steps to run a family meeting: (1) select an appropriate setting with appropriate seating capacity, (2) determine what the family already knows, (3) determine what the family wants to know, (4) deliver information, (5) express empathy, and (6) establish expectations and plan for next steps [40]. A critical aspect of delivery of bad news is for the physician to express and appear empathetic. This requires the healthcare provider to be able to recognize and understand the emotions of the patient and family. A proposed algorithm for conducting family meetings is depicted in Fig. 42.2.

Particularly in the surgical ICU, family meetings directed by intensivists may be perceived as threatening by the primary team. Although specific diagnoses are often used to determine when family meetings should be held in the medical ICU, a time-based approach works better in the surgical ICU. Patients who remain in the ICU for >72 h are likely to have prolonged ICU stays; often, it is these patients in whom goals of care have not been adequately or appropriately addressed [34]. It is important to emphasize that the reason for family meetings is not to take communication out of the hands of the primary surgeon, but to ensure that all healthcare providers and all family members hear the same thing at the same time. It is also important to ensure that the conversation and outcome of the family meeting is documented in the medical record so that it is available to all current and subsequent healthcare providers.

Symptom Management

One common fear for patients and families is that patient treatment will end upon palliative care implementation, hence, the important distinction between withdrawal of care and withdrawal of life-sustaining treatment. This misconception must be addressed early and often during discussions regarding care plans. The hallmark of palliative care is the management of symptoms in order to provide greater patient comfort and quality of life, particularly during a patient's final days. There are a host of options for management of the common symptoms encountered during the stages of death.

The most common symptoms encountered and managed by palliative measures include pain, respiratory distress, gastrointestinal symptoms, and cognitive failure. Basic principles of symptom management include anticipating needs prior to their development, minimizing interventions, and planning alternative routes for administration of medications when oral routes are not feasible. An algorithm for approaching symptom management is presented in Fig. 42.3.

Pain

Patients and families commonly worry about whether the patient will suffer from pain during the dying process; therefore, allaying fears may be as important as the actual pharmacologic intervention when treating pain. The pharmacologic treatment of pain should follow a "step ladder" approach with escalation of therapies until pain is controlled.

The first step in pain control requires an assessment of the pain and discomfort experienced by the patient. The assessment should include the location, duration, temporal pattern, and modifiers of pain as well as the quality (somatic, visceral, neuropathic), intensity (0–10 visual analog scale, 0 = no pain; 10 = worst possible pain), and patient's goal for pain management (0–10 scale, functional, sleep).

Basic recommendations for pharmacologic treatment based on quality of pain are shown in Table 42.2. Anticipate the possibility that the patient may lose the ability to take medications orally and have a plan for pain control that utilizes alternate routes of administration (such as sublingual or transdermal). If the patient is expected to survive more than 2 weeks, there may be a role for selective serotonin reuptake inhibitors (SSRIs) as an adjunct in achieving pain control. SSRIs can take several weeks to have an effect but have been shown to act synergistically with other pain medications [41]. Palliative procedures ranging from regional nerve blocks to operative intervention can be considered as approaches to pain control; however, a careful consideration must be given if an invasive intervention is consistent with goals of care. Non-pharmacologic treatment of pain may include physical modalities, such as massage, heat, cold, stretching and physical therapy, and acupuncture, or behavioral treatments such as relaxation, meditation, music therapy, psychotherapy, reframing, and biofeedback education. Regardless of the treatment strategy employed, frequent reassessment and adjustment is needed.

The ethical principle of double effect is important when pain becomes difficult to control. Escalating doses of narcotics may have the unintended side effect of respiratory

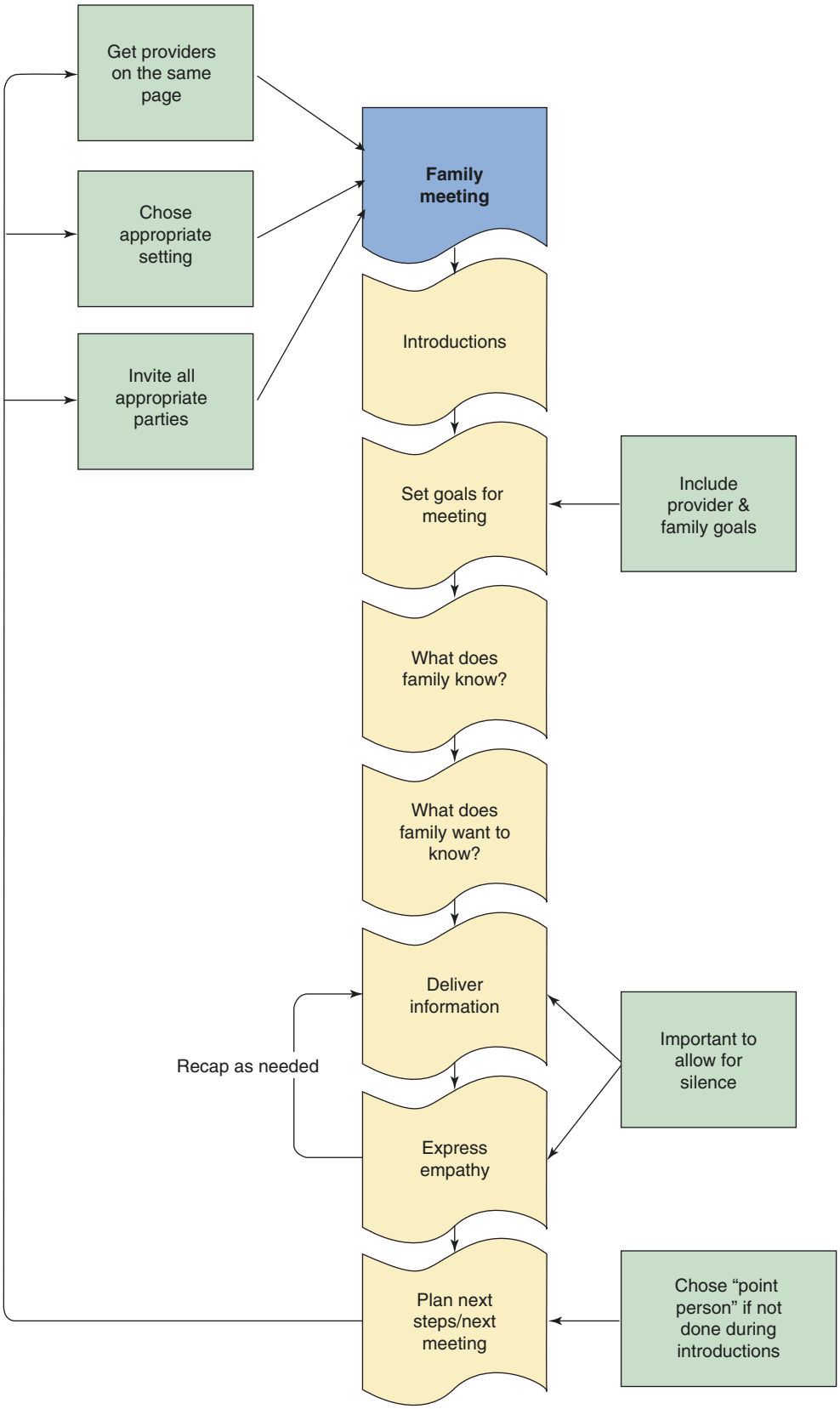

Fig. 42.2 Steps in conducting a family meeting

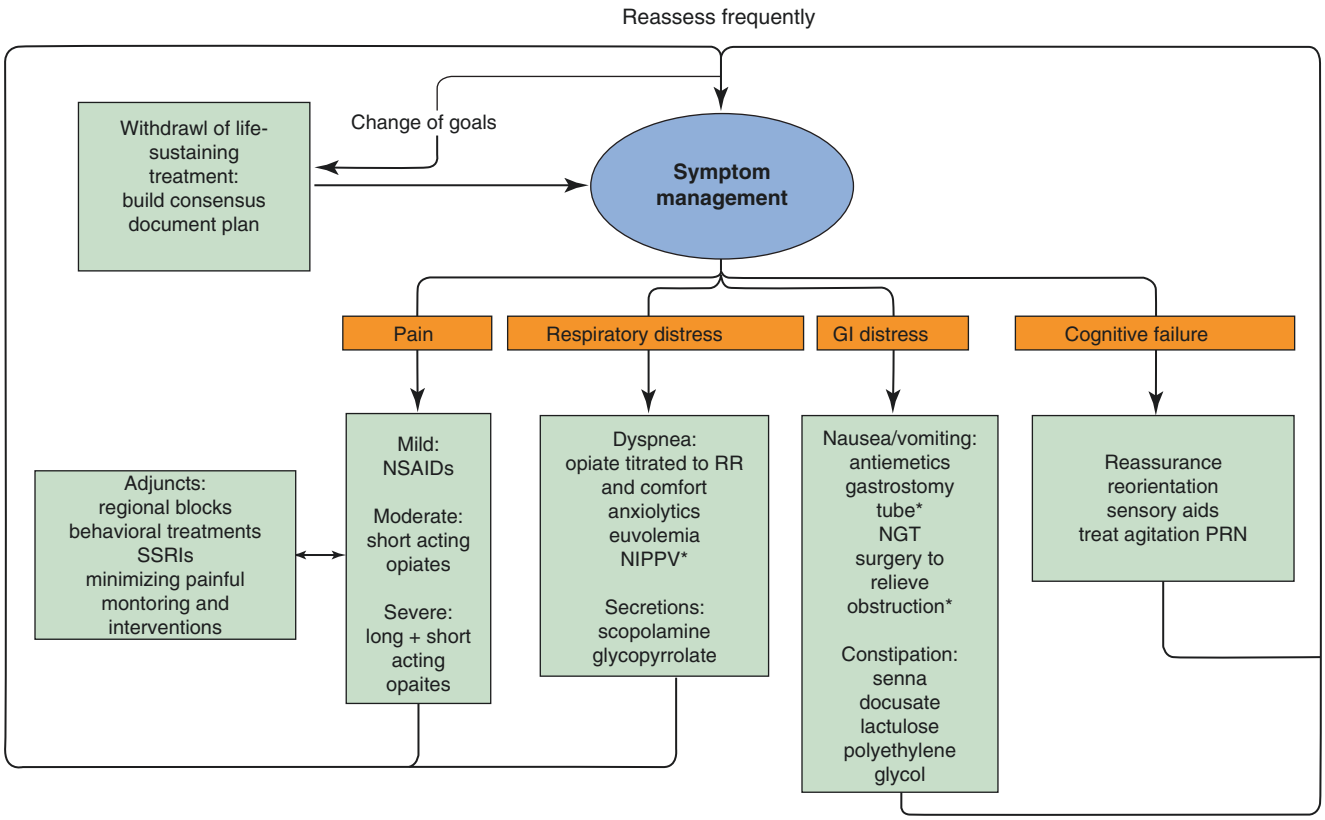

Fig. 42.3 Algorithm for symptom management

depression, occasionally to the level that they precipitate expected death albeit perhaps sooner than otherwise anticipated. Administration of these medications with the intent of causing respiratory depression and hastening death is inappropriate; the occurrence of respiratory depression as a side effect of treating pain is not.

Respiratory Distress

Air hunger or dyspnea in the last stages of dying is common and may be psychologically troubling for family members to witness. The primary treatment of dyspnea in this situation is titration of opioids to increase the patient's comfort. Supplemental oxygen may provide some relief and should be humidified if used. Oxygen should not be titrated to achieve a pulse oximetry cutoff, as oxygen saturation is not a good proxy for the patient's subjective experience. Noninvasive positive pressure ventilation has a very limited role in this setting, as it can cause more discomfort than the dyspnea it would be treating. Maintaining euvolemia can minimize dyspnea caused by heart failure or pleural effusions. If symptomatic pleural effusions are not controllable in this manner, it is worthwhile to consider placing a pigtail catheter for drainage (again considering if the pain and risks associated with this procedure are consistent with goals of care) [41]. Anxiolytics such as diazepam or lorazepam may be of benefit to patients who are also experiencing anxiety or panic as a result of dyspnea. Many dying patients exhibit the "death rattle" due to large amounts of thin, watery respiratory secretions. These secretions should be treated with anticholinergic agents such as centrally acting scopolamine or peripherally acting glycopyrrolate.

Gastrointestinal Symptoms

Nausea and vomiting may occur during the end of life due to a variety of causes. Many surgical patients have bowel obstructions due to functional or anatomic obstructions; therefore, control of nausea and vomiting becomes a challenge for the treating physician. Preventing constipation, which in addition to causing pain can worsen nausea and vomiting, is paramount. An aggressive bowel regimen may be necessary to counteract the constipating action of narcotics. Senna and docusate should be considered for all of these patients. Lactulose and polyethylene glycol may be useful in cases of refractory constipation. Treatment of nausea and vomiting may include pharmacologic and non-pharmacologic therapies. Pharmacologic treatment may include a trial and

Table 42.2 Tiered pharmacologic treatment of pain

Pain severity	Drug	Initial dosing (adult >60 kg)
Mild (VAS 1–3)	Acetaminophen	Maximum = 3200 mg/24 h
	Aspirin	600–1500 mg PO qid
	Ibuprofen	Maximum = 3200 mg/24 h
	Naproxen	250 mg PO bid, maximum = 1300 mg/24 h
Moderate (VAS 4–6)	Codeine	30–60 mg PO q 4 h
	Oxycodone	5 mg PO q 4 h
	Tramadol	50–100 mg PO q 4 h
Severe (VAS 7–10)	*Short acting*	
	Morphine	10 mg PO q 2 h, 2–4 mg IV q 2 h
	Hydromorphine	1–3 mg PO, PR q 4 h, 1 mg IV, SC q 4
	Oxycodone	5 mg PO q 4 h
	Oxymorphone	10–20 mg PO q 4 h
	Long acting	
	Morphine SR	15–30 mg PO q 8–12 h
	Oxycodone SR	10 mg PO q 12 h
	Oxymorphone SR	5–10 mg PO q 12 h
	Transdermal fentanyl	12 mcg/h

VAS visual analog scale, *SR* sustained release

error approach using any number of available antiemetics from various drug classes such as ondansetron, metoclopramide, prochlorperazine, or dronabinol. Nondrug treatment should take into account the acuity and severity of the symptoms. Refractory or severe long-term gastric stasis symptoms may benefit from percutaneous gastrostomy tube placement. Nasogastric tube drainage may suffice for treatment of acute bowel obstruction symptoms but must be weighed against the tube irritation and discomfort.

Cognitive Failure

Cognitive failure during the last stages of dying typically is manifested by worsening delirium or increasing somnolence. Frequently, patients become progressively confused but are typically not mobile or physically active. Therefore, most attention can be directed toward reassurance of both patient and family members. If agitation must be treated, sedatives or anxiolytics may be used to provide sedation and relaxation. Of course, the physician must be aware that escalating doses of opioids or anxiolytics can exacerbate delirium or somnolence [13].

Withdrawal of Life-Sustaining Treatment

The process of withdrawal of life-sustaining treatment should take into account the above management of symptoms that frequently occur during the final stages of dying. In the ICU, withdrawal of life-sustaining treatment may also include removal of mechanical ventilation as well as withdrawal of artificial hydration and feeding, blood pressure support, antibiotics, blood products, and invasive as well as noninvasive monitoring. Often, the decision to withdraw all life-sustaining treatment may be difficult for the family, and an intermediate step of withholding further life-sustaining treatment may be appropriate. Ethically, these two approaches are no different. The goal should be to establish a quiet, peaceful, and supportive environment for both the patient and the family. Once the decision to transition to palliative treatment has been made, the physician should clearly document discussions and plans in the chart.

Removal of mechanical ventilation should be a planned, well-orchestrated event with the presence of physician, respiratory therapist, and nurse in order to assure appropriate symptom control is achieved. Patients should be off of paralytics, but premedication with sedatives and opioids is appropriate to manage dyspnea that may occur upon extubation. Alarms should be silenced prior to extubation. In general, family members should also be offered an opportunity to be present during the extubation process.

Bereavement and Grief

When death occurs after trauma, emergency general surgery, or an unanticipated ICU stay, it is obviously unexpected. This unexpected nature is a risk factor for complicated grief [42]. Other risk factors include recent loss of another family member, strained relationships or distance between family and the one who died, and separation of the family from their loved one at the time of death. Obviously, much of that is out of the control of the healthcare team.

One factor that is more under the control of the healthcare providers is the ability for families to be present at the time of death. This includes facilitating family presence during resuscitative events and ensuring that families have the option to be present throughout the process of withdrawal of life-sustaining therapy if they desire [40].

Another factor that mitigates complicated grief is a formal bereavement program. Services provided through a hospital-based program include physical comforts during the dying process, follow-up from a bereavement coordinator, and cards on major milestones during the first year after death and on the anniversary of the death.

Conclusion

Elderly patients with traumatic injury, emergency general surgery, and unplanned ICU admissions have a much higher mortality than younger patients with the same conditions. Practitioners should have the basic skills to provide optimal end-of-life care to these patients. High-quality care begins with early, open, and honest communication about goals of care and concludes when those goals are met to the best of everyone's ability.

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Ethics in Geriatric Trauma

43

Christine S. Cocanour and Kathleen S. Romanowski

Case Vignette 1

A 75-year-old man presents to the emergency department following a fall down ten stairs. On arrival, the patient has a GCS 8 and is intubated for airway protection. He undergoes a CT scan of the head which reveals a right subdural hematoma and an intraparenchymal hemorrhage. He is transferred to the ICU. Over the next several days, he fails to have any recovery of mental status. The patient's wife is deceased and he has two adult children. His children are unaware of what his wishes would have been in this situation. What are the principles that govern the decision making in this situation? Who are the decision makers? What happens if these decision makers disagree?

Introduction

All societies have developed ethical codes governing the interaction between healers and their patients that reflect the social values in which they are framed. These codes followed the evolution of medicine as it journeyed from a vocation in the pre-Christian era to religious vocation in Judaism, Islam, and Christianity to the medieval European guilds which began the transformation of medicine to a paid profession. Thomas Percival's treatise on *Medical Ethics, or a Code of Institutes and Precepts Adapted to the Professional Conduct of Physicians and Surgeons* in 1803 provided a modern foundation for medical ethics in North America [1]. Using Percival's treatise as a basis, the American Medical Association produced its Code of Medical Ethics in 1847 which defined the relationship between the doctor, the patient, and the public trust [2]. The unprecedented scientific and medical advances that occurred in the nineteenth and twentieth centuries opened a Pandora's box of potential ethical issues, especially for the elderly. In the elderly, morbidity and mortality are magnified by their comorbidities [3]. Ethical issues, present in any age group, attain much greater significance in the geriatric population. The ability to prolong life may be positive for the community but may increase suffering in an individual.

Surgical ethics in Western medicine are governed by four basic principles: non-maleficence, beneficence, autonomy, and justice. The principle of double effect is also of utmost importance in the geriatric patient. Non-maleficence and beneficence, along with confidentiality, date back to the Hippocratic oath. While the advances in medicine over the past 150 years were beneficial to society as a whole, they were not always beneficial to the individual patient. In 1972 the Patient's Bill of Rights formalized the concept of informed consent. Medicine shifted away from a paternalistic model, and autonomy was embraced as a guiding principle in American health care [4]. In recent years, the allocation of health-care resources, access to care, and disparities in care have become increasingly important as health-care resources are stretched thin. The principle of justice or equal distribution of care becomes important as we balance our surgical decision making not just on the individual patient but on the population at large.

The elderly trauma patient is a classic example of the balance that must be achieved between the conflicting ethical priorities that occur in the face of advances in surgical care that may or may not translate into better outcomes. How this

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affects the surgical decision making for the geriatric trauma patient, and the ethical principles that guide it, is the subject of this chapter.

Basic Principles of Medical Ethics

Non-maleficence

Primum non nocere: first, do no harm. This principle is at the core of all medical ethics and dates back to antiquity. The guiding principle of non-maleficence is that the physician must avoid doing harm. Any procedure has the possibility of benefit or cure, but it may also cause harm or even death, especially in the elderly. The physician must understand the potential risk of harm of any treatment which is offered to a patient. In the geriatric trauma population, the overall mortality is 8 % [5]. For each 1-year increase in age beyond 65, the odds of dying following trauma increases by 7 % [5]. Operative mortality is two to three times greater in those over age 65 compared to younger patients [6]. Beyond the implications of age alone on mortality in elderly trauma patients, frailty is increasingly recognized as a predictor of poor surgical outcomes in older patients [3, 7, 8]. Many of the commonly used preoperative risk assessment tools do not take into account a patient's physiologic reserve, nor are there easy ways of measuring frailty in the acute injury setting. Although surgeons' accuracy in prognostication of complications and mortality improves when using these tools, the overall outcome must be considered when seeking invasive interventions as there is the potential to do more harm than good as there is most certainly an age-dependent survival decrement [8].

Beneficence

The second principle of modern medical ethics is beneficence. Beneficence refers to the relieving of pain and suffering and fostering the well-being of other persons and society. Beneficence is also rooted within the Hippocratic oath and goes hand in hand with non-maleficence. Beneficence requires that a surgical procedure is done with the intent of doing good for the patient and promoting their overall well-being. At the same time, the surgical procedure entails risks and the principle of non-maleficence comes into play. This is the principle of double effect which is discussed later in this chapter. It becomes a risk-benefit ratio and it is critical that it is patient centered. Deciding what is beneficial to the patient and what is harmful can be fraught with difficulty.

Beneficence also demands that health-care providers develop and maintain their skills and knowledge such that they may provide the best possible care for their patients. As the population of elderly patients in this country increases, all physicians must become familiar with the issues that affect their elderly patients.

Autonomy

Autonomy refers to the ability of competent individuals to make decisions about their lives or self-determination. It requires that decisions made by competent individuals must be respected even if those decisions conflict with what others deem reasonable. In the United States, it is supported legally by the Patient's Bill of Rights (American Hospital Association 1974) [9] and the Patient Self-Determination Act enacted by Congress in 1991 [10]. Autonomy is at the heart of the informed consent process. It requires that the surgeon must give the patient as accurate and complete information as possible regarding their condition, the possible options for treatment, the associated risks and benefits, and the likelihood of success or failure. Information must be given clearly so that the patient is not overly burdened by incomprehensible medical jargon. The surgeon must avoid using his or her own value system in judging what is best for the patient. Patients may choose among all of the treatment options or refuse care altogether, even if the recommended treatment is lifesaving. The surgeon must respect the patient's choice even if it conflicts with the health-care team's advice.

The elderly are often more susceptible to erosion of autonomy. The physical and mental illnesses associated with aging may diminish their decision-making capacity. They may also make the elderly patient's decisions more susceptible to influence by family, friends, or the health-care team. Creating an advance care directive or living will can allow the elderly to continue to direct their health care through designation of a surrogate decision maker even after they are incapacitated. Unfortunately, these documents are general guidelines and do not specifically cover every possibility so that the surrogate decision maker must make decisions on behalf of the patient to the best of their knowledge of what the patient would have wanted.

Justice

The fourth and final basic principle of medical ethics is justice. Justice refers to the impartial and fair approach to treatment and distribution of scarce resources. It addresses how the needs of the individual patient must be balanced against the medical needs of society in general. Justice demands that the burden and benefits of treatments, including new or experimental, must be equally distributed among all groups. The ethical concept of justice provides protection for vulnerable populations and seeks to avoid discrimination. The elderly, through the physiologic and social changes that occur with aging, become increasingly vulnerable as they age.

Treatment decisions by surgeons should never be based solely on age. Other factors such as functional status, frailty, underlying comorbidities, quality of life before illness or injury, and the potential outcome after surgery are much more important in making treatment decisions. The health-care team must consider four main areas when evaluating justice: fair distribution of scarce resources, competing needs for those resources, rights and obligations, and potential conflicts with established legislation.

Principle of Double Effect

Thomas Aquinas is credited with introducing the principle of double effect in the *Summa Theologica*. The principle of double effect occurs when a morally grave harm (maleficence) occurs as a side effect of pursuing a good end (beneficence). It is a clash between beneficence and maleficence. The classic example in health care is giving medication to relieve pain (beneficence) even if it hastens death (maleficence). It is distinctly different from causing a morally grave harm to achieve a good end. A surgeon attempts to do good and promote the welfare of the patient yet causes pain, suffering, and even death.

An example in the trauma setting occurs when a patient undergoes surgery for repair of perforated bowel but complications from the procedure lead to death. The principle of double effect allows the surgeon to repair an injury in an attempt to restore the patient to their previous functional status; doing good and promoting the welfare of the patient, realizing that in doing so, will cause pain and even death if complications occur.

Case Vignette 2

A 91-year-old woman lives alone and is very active both at home and in the community. She has severe right hip osteoarthritis but is otherwise in excellent health. She presents to the orthopedic surgeon to discuss the possibility of hip replacement as her pain is limiting her ability to participate in the activities that she enjoys. The surgeon thinks she is a good candidate for the surgery, but has reservations about the amount of benefit that this patient would receive given the realistic limits on the number of years of benefit that the patient would receive and the limited health-care dollars available. Should these be considerations for the surgeon? How should limited resources be distributed? What factors should go into these decisions and should age be one of these factors?

Scarce Resources and Access to Care

The resources available in health care are not unlimited, and often difficult decisions must be made concerning how these resources should be allocated. Not every patient can be treated to the fullest extent possible, and not all of the country's health-care desires or expectations can be fully met due to limited financial resources, insufficient numbers of health-care providers, and the expense and scarcity of medical products. Justice is the crucial principle when addressing issues related to the allocation of health-care resources. As previously discussed the principle of justice suggests that individuals should have the opportunity to obtain a share of the benefits that society provides. However, although each individual is entitled to benefits, the benefits of an individual patient must be balanced against the medical needs of society in general. In the case of elderly trauma and other areas where resources may be limited, the question arises whether there are any circumstances where it is morally appropriate to set priorities for health care [11]. When setting priorities there are two views on how resources should be distributed. One view is that the sickest patients should receive treatment first. Unfortunately this practice could take away valuable resources from patients who are more likely to survive and who may enjoy a better quality of life. For example, one must consider whether, and at what point, medical procedures can or should be halted when treating patients who suffer from dementia. As these patients suffer from an incurable illness, then some treatments might be "futile" and provide no appreciable benefit to the patient.

As patient life-spans continue to extend, the demand for end-of-life care continues to escalate and results in an alarming rise in health-care costs. The development and use of new drugs, devices, and diagnostic techniques have significantly added to the rising cost of health care, which has placed a heavy burden on patients seeking affordable health insurance. The rising costs in health care have led to the development of the philosophy of managed care. Managed care involves applying business principles and practices, such as market competition, to the health-care arena in order to ensure efficient and cost-effective care. Unfortunately managed care has failed to control costs effectively and is criticized for causing the physician-patient relationship to deteriorate. The failure of managed care has contributed to the significant number of elderly individuals in the United States who have had difficulty getting access to quality health care [12]. The factors that contribute to this lack of access include poverty, homelessness, history of illness, and the lack of health insurance. In principle, economic factors should not interfere with good health-care practices. However, if payment is not received for a patient's care, this can interfere with the ability of a health-care institution to provide care for its other patients or for future patients.

Elderly patients are frequently unable to afford the high cost of hospital stays, medical procedures, and prescription drugs. Unfortunately there are no easy solutions to these issues in our current health-care climate. When looking at the problem of prescription drug costs, the difficulties elderly patients confront are evident. In desperate attempts to find affordable prescription drugs, elderly patients have resorted to seeking medications from outside the United States. These examples indicate that measures are needed in order to assist patients, elderly or otherwise, with the cost of prescription drugs. In 2003, Medicare Improvement and Modernization Act, Public Law 108–173, was signed into law. The Act's Prescription Drug Discount Program took effect in 2006 and we are only now starting to understand the ramifications of this change. The plan currently provides coverage to 39 million patients and has made strides in providing affordable medications for the elderly, but in the future, policy makers face the challenge of slowing spending while protecting beneficiaries' gains in access and affordability for prescription drugs [13].

Case Vignette 3

A 75-year-old woman shows signs of abuse that appears to be inflicted by her husband. As he is her primary caregiver, she feels dependent on him and pleads with you not to say anything. How would you handle this situation? What are your responsibilities as a physician?

Confidentiality and Privacy

Confidentiality refers to the duty to protect privileged information and not divulge that information unless the patient gives permission. The ethics of this principle stems from the notion that a person's wishes, decisions, and personal information should be treated with respect. In fields like medicine, there are explicit, professional obligations to keep personal information in confidence, because trust is the foundation for meaningful professional relationships. As a general rule, health-care providers have a responsibility to avoid disclosing personal and medical information that has been entrusted to them without the patient's consent. In accordance with professional standards, when a patient's private information is shared, there is the expectation that health-care providers will keep the information in confidence. This includes details about a patient's diagnosis, prognosis, history of illness, drug use, family history, and sexual activity.

While confidentiality is of supreme importance to the physician-patient relationship, there are circumstances where concerns for justice and looking out for the common good can supersede the duty to keep information confidential. There are rare circumstances when a physician may be legally obligated to disclose a patient's information without the patient's consent. There are two main exceptions to maintaining confidentiality. The first is concern for the safety of other specific persons and the second is when there is concern for society as a whole. With respect to the concern for the safety of specific persons, we as physicians have the duty to protect identifiable individuals from any serious, credible threat of harm if they have information that could prevent the harm. It must be determined whether there is a good reason to believe that a specific person or group is in serious danger that breaking confidentiality might prevent.

The second exception to confidentiality is when divulging private information is critical for the protection of society as a whole. An example of this is the all too common situation when a physician treats an elderly individual who is unwilling to stop driving a car, but whose physical or mental capacity to do so may be compromised. These are the situations that demonstrate the tension between the obligation to maintain confidentiality and the obligation to prevent the patient from harming others. State laws often require the report of certain communicable/infectious diseases to the public health authorities. In these cases, the duty to protect public health outweighs the duty to maintain a patient's confidentiality. States have an interest in protecting public health and this outweighs individual liberties in certain diseases. Examples of this include diseases such as measles, rabies, anthrax, botulism, sexually transmitted diseases, and tuberculosis.

Elder abuse is another area that requires a break in patient confidentiality. This is a major issue that is often encountered in elderly trauma patients. The elderly are a potentially vulnerable population at risk for abuse. It is not always clear that the trauma that they have sustained is due to an accident versus abuse by a caregiver. Each state defines elder abuse according to its unique statutes and regulations, and definitions vary from state to state [National Center on Elder Abuse Administration on Aging https://ncea.acl.gov/whatwedo/policy/state.html; http://www.cdc.gov/violenceprevention/elderabuse/definitions.html accessed 1/24/16]. The laws in most states require physicians and other helping professions such as home health providers to report suspected abuse or neglect. In at least eight states, any person is required to report a suspicion of mistreatment.

The importance of privacy and confidentiality to elderly patients should not be overlooked. Although health-care teams, family, and friends might assume that these concepts are unimportant to an elderly patient, the patient might not agree. An elderly patient should expect that information shared with their health-care team will be kept confidential regardless of their age. Maintaining their privacy will enable elderly patients to feel that they have an appreciable level of control over their own lives. Physicians should not automatically assume that an elderly patient wants family and friends

to know about their protected health information or to be in the hospital room when personal or medical information is being shared. The desire to maintain one's privacy does not necessarily decline with age.

Case Vignette 4

A 64-year-old man with recurrent strokes is hospitalized. The team feels he may need a feeding tube soon to assure adequate nourishment. They ask the patient about this in the morning and he agrees. However, in the evening (before the tube has been placed), the patient becomes disoriented and seems confused about his decision to have the feeding tube placed. He tells the team he doesn't want it. They revisit the question in the morning, when the patient is again lucid. Unable to recall his state of mind from the previous evening, the patient again agrees to the procedure.

Is this patient competent to decide? Which preference should be honored?

Informed Consent

Informed consent is a relatively new idea in the practice of medicine. Ancient practitioners of medicine adopted a paternalistic approach to patient care and seldom involved the patient in the decision-making process. In the eighteenth and nineteenth centuries, the concept of assault and battery arose from English Common Law and was applied to medicine, establishing the need for authorization by the patient before surgery. Over the course of the twentieth century, the process of informed consent has societally and legislatively evolved to a more patient-centered concept [14].

Under most circumstances, an informed consent must be obtained from a competent individual before a procedure is performed. There are three fundamental criteria for assuring informed consent. (1) The patient must be competent. Determining whether an elderly patient is competent is sometimes challenging. They must be able to communicate choices, understand and assess the information that is given to them, and be able to understand the consequences of a decision. (2) The patient must be adequately informed about the diagnosis, the procedure, and its benefits, risks, and possible complications. They must also be informed of all alternative methods of treatment both surgical and conservative. The information should include the expected results. (3) The third fundamental criterion for assuring informed consent is that the patient should not be coerced into making a health-care decision. The patient's decision must be voluntary. Giampieri has reviewed the communication process for the informed consent process in the elderly patient [15].

The only time that consent is not required is in emergency situations, when a patient is unable to give consent, family members are unavailable, and treatment cannot be delayed. This happens often in the acute care surgery setting. This exception to the formal consent process was created with the assumption that the patient, if able, would consent for the proposed procedure. This exception is only appropriate when the treatment is directed toward a life-threatening condition. After the immediate threat is addressed, further interventions require consent, whether by the patient or if they remain cognitively impaired, a surrogate.

Decision-Making Capacity

The geriatric population poses a particular challenge in determining whether a patient has decision-making capacity. Capacity describes a person's ability to make a decision (such as consenting to health care or changing a will) or perform a specific task (such as driving or living independently). It is fundamental to the ethical principle of patient autonomy. There are at least eight major capacity domains of relevance to the elderly [16]. Independent living and general financial management require a broad set of cognitive and procedural skills, while other capacities such as treatment consent are narrower in scope.

Consent capacity has been defined as the ability to understand significant benefits, risks, and alternatives to proposed health care and to make and communicate a health-care decision [16]. Because capacity requires cognitive skill, any condition or treatment that affects cognition may potentially impair decision-making capacity. Health-care providers often informally ascertain a patient's ability to make decisions. Formal declarations regarding competence are made by the courts. The following criteria may be useful as a guide to determine whether or not an elderly patient has decision-making capacity [17].

There are four generally accepted decision-making abilities that constitute capacity: (1) understanding, (2) expressing a choice, (3) appreciation, and (4) reasoning. These may be useful as a guide to determine whether a patient has decision-making capacity:

1. *Understanding or to know the meaning of information* is a key decisional ability in both medical ethics and the law. The patient must understand their diagnosis and treatment plan.
2. An individual should be able to clearly *express a choice* when presented with multiple treatment options. Frequent changes in choice may signal a lack of capacity, as well as when a patient says "yes" to every treatment option. Stability of a choice over time adds additional confirmation that the choice is being made with capacity. A patient

may change their mind but should be able to provide a meaningful reason for that change.
3. *Appreciation* refers to the ability to take information and recognize how it is relevant to themselves. The patient must be able to understand their illness or injury and how it will impact their life.
4. *Reasoning* is the ability to compare between options. The patient must be able to give reasons for their views or conclusions. While occasionally a patient's view may be the consequence of delirium, dementia, or other disorders, most often their specific views or beliefs are related to their premorbid beliefs. If the patient comes to a decision that is at odds with a physician's recommendation, this is acceptable as long as the decision was made in a logical fashion. If the decision that the patient makes is based in delusion or delirium, decision-making capacity may be inadequate.

Dementia is the most common cause of impaired capacity in the elderly. Adults with dementia are most impaired on measures of understanding, followed by reasoning and appreciation. As dementia progresses, consent capacity declines. Decision-making capacity is also affected by reversible factors such as delirium or medication side effects. Treatment of the underlying cause can improve decision-making capacity. Decision-making capacity often declines near the end of life. A study of more than 3700 adults 60 and older found that capacity was impaired in 70 % [18].

Determining whether a patient has adequate capacity requires striking the correct balance between respecting autonomy and acting in the patient's best interests (beneficence). When patients are judged to lack capacity to make decisions, a surrogate decision maker should be sought.

Case Vignette 5

An 84-year-old woman presents to the emergency room following a motor vehicle collision. She has a large subdural hematoma with significant midline shift. She is intubated for airway protection and has a GCS score of 5. The neurosurgeons meet with the family to discuss the patient's poor prognosis given her age and injury. The patient has an advance directive that states she would not want heroic measures if she did not have a reasonable chance of a good quality of life. She does not want to be ventilator dependent or have artificial nutrition. Her family states that they know her wishes but that they would like everything done in spite of this. What are your responsibilities as a health-care provider to this patient? To her family?

Advance Directives

Living wills were first suggested in 1967 to facilitate the rights of dying people to control decisions about their own medical care, but it was not until 1976 that California became the first state to recognize living wills. In that same year, the New Jersey Supreme Court validated advance directives in the Karen Ann Quinlan case [19]. By 1992, all states had passed legislation to legalize some form of advance directive. The Patient Self-Determination Act enacted in December 1991 required that health-care providers, predominantly hospitals, nursing homes, and home health agencies, give patients information about their rights to make advance directives [10]. Advance care planning allows the patient to reflect on their goals, values, and beliefs with their families and their physician and use this information to accurately document their future wishes for medical care and surrogate decision maker. There are several types of advance care directives, but those that are typically recognized by state law are the living will, Durable Power of Attorney for Health Care, and Physician Orders for Life-Sustaining Treatment (POLST). The living will documents the patient's preferences for life-sustaining treatments and resuscitation and the Durable Power of Attorney for Health Care the designated surrogate. A POLST converts patient's treatment preferences into medical orders that are transferrable throughout the health-care system. The presence of an advance directive is now at approximately 70 % in the United States [20]. This may climb higher as Medicare begins reimbursement of physicians for advance care planning discussions with patients in January 2016.

Typically the living will addresses resuscitation and life support but may include more specific treatments such as tube feeding for dementia, dialysis for renal failure, etc. Unfortunately, the LW cannot cover all possibilities and therefore is only applicable to seriously ill patients that have lost their decision-making capability. Physicians and surrogates are obligated to respect the wishes of the patient as reflected in the advance directive. The patient can revoke an advance directive at any time either orally or in writing if they retain decisional capacity.

Surrogate Decision Making

When a patient is judged to lack consent capacity, a surrogate decision maker is needed. A surrogate decision maker is charged with basing decisions on the patient's previous autonomous wishes as well as the patient's best interests given the information available. They should first honor the patient's wishes by following advance directives or relying on substituted judgment—what the patient would have wanted had the patient been able to express their own desires

(autonomy). If the patient's wishes are unknown, then the surrogate should advocate for the patient's best interests (beneficence).

Many surrogates are unaware of the patient's preferences. Covinsky et al. found that a surrogate's understanding of the patient's preference for cardiopulmonary resuscitation was only moderately better than chance [21]. There is often a disconnect between surrogate expectations and what medical care can realistically provide [22], leading to the potential of nonbeneficial surgery or treatment. In reality, surrogates also consider other factors such as their own preferences, interests, emotions, experiences, and religious beliefs in making decisions regarding the patient's health care [23].

Ideally the patient has chosen a potential surrogate in advance. In the absence of a designated surrogate, laws vary from state to state in terms of who can serve in this role; but, in general, the order is the spouse, adult children, parents, siblings, and other relatives. All states recognize a preidentified surrogate or legal guardian to make decisions about life-sustaining treatment; however some states limit their authority by medical precondition requirements or need for a witness when a surrogate consents to forego treatment [24].

Do Not Resuscitate

Based on the ethical principle of autonomy, patients and their surrogates have the right to refuse any medical procedure or treatment as long as they are deemed competent, have been adequately informed, and are not coerced into making the decision. Physicians should not allow their personal value judgments to obstruct implementation of the refusal. A patient's refusal of medical procedures may involve either withholding or withdrawing treatment. This can also include refusing cardiopulmonary resuscitation (CPR). A Do Not Resuscitate ("DNR") order refers to the withholding of CPR which generally includes the withholding of chest compressions, defibrillation, intubation, and pharmacologic interventions to stimulate the heart. Based on television's depictions of CPR, the general public has an unrealistic view of patient survival believing that three-quarters of patients survive CPR [25]. Unfortunately in reality, less than 20 % of patients survive CPR, and 10–44 % of those patients who do survive have permanent neurologic impairment. CPR was never intended for use in patients dying an expected death from a chronic, fatal medical illness, and a physician is under no obligation to perform CPR when it is futile or contraindicated.

Some patients with a Do Not Resuscitate order become candidates for surgery. Many of these procedures, such as treating intestinal obstruction in patients with advanced malignancy or traumatic injuries, fall into the purview of the acute care surgeon. When they undergo surgery, they are subject to potentially correctable risks of cardiopulmonary arrest. In addition, many of the medications and procedures used as an integral part of routine anesthesia management are employed in resuscitation (intubation, vasoactive medications). The American College of Surgeons "Statement on Advance Directives by Patients: "Do Not Resuscitate" in the Operating Room" recommends a policy of required reconsideration of the existing DNR orders [26]. Required reconsideration means that the patient or their surrogate and the physicians who will be responsible for the patient's care should discuss the intraoperative and perioperative risks associated with the surgical procedure, the patient's treatment goals, and an approach that is consistent with the patient's goals of care. The patient or surrogate may agree to suspend the DNR order during surgery and the perioperative period, retain the DNR order, or modify the DNR order. Once a decision is reached on the patient's DNR status following the required reconsideration conversation, the surgeon must document and convey the patient's advance directive and DNR status to the other members of the operative team, help the operative team members understand and interpret the patient's advance care directive, and if necessary find an alternate operative team member to replace any individual who has an ethical or professional conflict with the patient's advance directive instructions. Policies that lead to the automatic enforcement of all DNR orders or to disregard or automatically cancel such orders do not respect the patient's autonomy.

Futility

In medicine, interventions that are unlikely to produce any significant benefit for the patient are defined as futile. Futility does not apply to treatments globally ("it is futile to continue to treat this patient") but only to a single intervention in a specific patient at a particular time ("CPR would be medically futile for this patient"). Although the definition of futility appears simple, it is actually quite complex. There is no consensus or guideline to determine futility. Maerz et al. describe a futility concept using the effect-benefit principle [27]. An effect of an intervention is limited to a specific portion of a patient's body, whereas benefit improves the person as a whole. Futile care defines treatment that does not provide benefit to the patient whether it produces its desired effect or not.

Quantitative medical futility is goal directed. If surgery or the treatment cannot meet the accepted therapeutic goal, then it is deemed to be futile. Qualitative medical futility is whether the surgery or intervention can meet the patient's goals of care; if not, it is deemed futile. It is because of uncertainty of prognosis or outcome and lack of knowledge

of the patient's goals of care that make determining futility difficult. This becomes even more challenging when the patient is unable to communicate and surrogates are either not available or unsure of the patient's wishes.

An algorithmic approach to futility has been described by McCullough [28]. Step 1 is physiological futility. Will the clinical intervention produce its usually intended physiologic effect? If no, then it is physiologically futile. Step 2 asks whether the clinical intervention produces clinical benefit enabling the patient to interact with the environment and develop as a human being. If no, it is considered clinically futile. Step 3 asks whether the patient will die without regaining consciousness before discharge. If the answer is yes, it is further clinical futility. Step 4 asks whether the intervention will be physiologically and clinically effective, but with significant risk of disease-related or iatrogenic morbidity, loss of function, and unacceptable quality of life. If the answer is no, then the criteria for qualitative futility are met.

Medical care has reached a point where in our attempt to preserve life, we are often only prolonging dying. The American Medical Association states in the Code of Medical Ethics that "physicians are not ethically obligated to deliver care that, in their best professional judgment, will not have a reasonable chance of benefiting their patients" [2]. This must be discussed with the patient or surrogate, providing a frank explanation of why a particular intervention is not beneficial. It must also be emphasized that medical care is never futile but that specific therapies that do not advance goals of care are futile.

Conclusion

Caring for the injured or acutely ill elderly patient is challenging. The increasing presence of dementia, frailty, and aging of physiologic systems increases the vulnerability of this population. The treatment of these patients must take into account all four of the basic ethical principles: beneficence, non-maleficence, autonomy, and justice. The principle of double effect dictates that if a planned procedure is done with the intention of providing benefit to the patient, then the potential of undesirable effects is acceptable.

Communication in times of acute illness or injury is fraught with many pitfalls. Shared decision making allows active patient involvement, respecting the patient's autonomy. Older adults should be considered capable of making health-care decisions despite age or frailty. The information provided during consent must be at the appropriate level of understanding for each patient.

In the acute illness or injury, advance directives and involvement of the patient's surrogate can help the physician navigate patient and family through an emotional and potentially devastating time. Physicians must assure their patient and surrogate that even if a specific treatment or procedure is deemed futile, medical care is never futile.

Summary

- Ethics in Western medicine is governed by four basic principles: non-maleficence, beneficence, autonomy, and justice. Acutely ill and injured elderly patients often present ethical challenges to the physician as they attempt to balance conflicting ethical priorities.
- The principle of double effect often occurs in the geriatric trauma population. In attempting to restore the patient to their previous functional status (beneficence), the patient may incur pain, suffering, and even complications that cause death (maleficence).
- The utilization of scarce resources and access to care are major challenges that may face elderly trauma patients.
- The rules of confidentiality are the same for the elderly trauma patient as they are for other patients. We cannot break confidentiality simply because of their age.
- Elderly patients should be encouraged to participate in the informed consent process unless they lack decision-making capacity. In cases where they lack capacity, the informed consent process can be driven either by the patient's advanced directives or by surrogate decision makers.
- Specific treatments may be deemed futile by the medical team a patient or their surrogate, but medical care and dignity of the patient are never futile.

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Erratum to: Extremity Injury

Scott Ryan, Lisa Ceglia and Charles Cassidy

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The original version of Chapter 30 was inadvertently published with one author name "Charles Cassidy" instead of three author names "Scott Ryan*, Lisa Ceglia, Charles Cassidy". The chapter has been updated.

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Index

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