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Osvaldo Chiara *Editor*

Trauma Centers and Acute Care Surgery

A Novel Organizational and Cultural Model

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Foreword

It is at the same time a pleasure and an honor for me to introduce to the surgical community the excellent work of Professor Chiara in the traditional format used by the Italian Society of Surgery. It is also the appropriate occasion to congratulate my colleague on the extensive documentary work that offers the most qualified surgical readers an organic analysis of the modern problems surrounding the general management, logistics, and organization of a trauma center, while emphasizing the universally acquired model of coordinated multidisciplinary management of polytrauma, without overlooking the peculiarities of the different anatomical districts and systems.

The result is a complete, specific, and highly specialized review of the most important aspects of trauma care.

This book carefully guides the reader through the complex world of trauma centers and related aspects. It is destined to become a reference text in the variegated bibliographic landscape of monographs devoted to trauma and trauma centers, bringing the readers up to date on the most advanced techniques of polytrauma management, the results acquired, and the scientific debate surrounding the principal, yet still controversial, topics.

Looking at the results of this major endeavor, I would like to express, on behalf of the SIC, our gratitude to the editor and authors for presenting us with a tangible sign of their extensive field experience in a monograph that maintains the traditional high standard of the monothematic publications of the Italian Society of Surgery.

Catania, Italy
September 2021

Francesco Basile
President
Italian Society of Surgery

Preface

The history of trauma systems started in the US and, since the beginning, surgeons were launched into a full stewardship. In Europe, anesthesiologists and emergency physicians were more involved in trauma leadership but few surgical groups in the UK, Germany, and Italy, with a visionary interest toward emergency situations, joined in this path. Some studies on preventable trauma deaths attracted the attention of politicians sensitizing them to the need to institute an organized system founded on the concept that pre-hospital health care personnel should recognize and transport severely injured patients in the shortest time to the appropriate hospital capable of treating all injuries 24/7. Emergency Medical Systems and Trauma Centers were developed in almost all countries, both in North America and in Europe, with different models, different criteria for hospital standards, but with the same aim: to improve the care of the injured and to decrease the mortality due to trauma. In this period, a strong foundation and a springboard for the development of a trauma surgery discipline was established. In the first Trauma Center in the US, the Cook County Hospital in Chicago, Illinois, the Trauma and Burn unit greatly influenced the development of other activities, such as trauma radiology, trauma anesthesia, laboratory support, and computerized trauma registry. The first statewide trauma system was developed in the 1970s in Maryland with the Maryland Institute of Emergency Medical Service System (MIEMSS), which set up a sophisticated communication system, interfacing the emergency call center, paramedics on the scene, and doctors in the emergency room. The Baltimore Shock and Trauma Center, later dedicated to its founder, Dr. R. Adams Cowley, rapidly became one of the most crowded around the world, a model for the organization, protocols of care, and research in the field of trauma. Hundreds of well-equipped emergency ambulances, with thousands of pre-hospital providers, State Police helicopters, a level-one adult and a pediatric Trauma Center in Baltimore, and several lower-level facilities, realized an impressive network for the care of the injured.

The decrease in penetrating trauma and the improvement of techniques for non-operative management of solid organ injuries significantly reduced the number of operations by the general surgeon and a trauma surgery career became less attractive. This crisis had its nadir at the beginning of the new century and the solution was found with the creation of a new discipline that encompassed general and emergency surgery, trauma, rescue surgery, and surgical critical care. The discipline of "Acute Care Surgery" was born. This model had already been applied in Italy since the 1970s. Professor Vittorio Staudacher founded the first Italian surgical school for Emergency Surgery: the care of trauma and non-trauma emergencies all over the body was the proposal, with the knowledge of the pathophysiology of critically ill patients as a guide to make the most appropriate choices in time-dependent illnesses. In the Milan Institute of Emergency Surgery, led by Professor Staudacher, general surgeons developed different skills: some were interested in thoracic surgery, others in vascular surgery, others still in musculoskeletal surgery. Dedicated anesthesiologists, an emergency physician, and a cardiologist all worked exclusively inside the institute. A surgical intensive care unit with three beds (the so-called anti-shock room) managed by general surgeons was available—an *ante-litteram* model of an acute care surgery service and of a multidisciplinary facility for emergency care.

Nowadays, acute care surgery is spreading around the world and a career in this field is again attractive for young general surgeons. Probably in the near future general surgeons expert in acute care will be in great demand by hospitals with emergency departments, because the figure of a surgeon capable of managing life-threatening conditions in all body districts is currently missing.

In this book, the organizing criteria for an acute care surgery service and the major clinical challenges in both trauma and general emergencies have been considered. I would like to conclude this preface with a sentence by Dr. Cowley, the pioneer of trauma systems:

> Every critically ill or injured person had the right to the best medical care and not according to location, severity of injury or ability to pay.

Milan, Italy Osvaldo Chiara
September 2021

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Part I

Acute Care Surgery: Concept and Organization

A Tale of Two Cities: The Development of Trauma and Acute Care Surgery Between Baltimore and Milan

1

Shailvi Gupta and Thomas Scalea

1.1 Origins and Development of a Partnership

In April of 1969, under the leadership of R. Adams Cowley at the Maryland Institute for Emergency Medicine, the University of Maryland hospitals and State Police started a unique exchange. Police began the transport of patients by helicopter from the scene of injury to a dedicated trauma center, which achieved the dual goals of rapid evacuation and timely treatment of shock. Helicopters also enabled transfer of seriously injured patients from regional hospitals to the Shock Trauma Center in Baltimore. From this exchange, the first trauma system implementation in the United States was born, resulting in the reduction of mortality of injured patients [1, 2]. Dr. Osvaldo Chiara, a young surgeon from Milan was rotating at the Shock Trauma Center in Baltimore towards the end of Dr. Cowley's era, and the idea of a unified trauma system with the ability to wholly care for a critically injured patient, an uncommon model in Europe, became Dr. Chiara's life's passion. Getting the system set up in any real way was difficult, to say the least. Dr. Chiara continued to visit Baltimore, always soaking up any knowledge available that might assist him in his life's journey. He was in Baltimore again in the late 1990s and he met the Center's new chief, Dr. Thomas Scalea who has been recruited from New York. Dr. Chiara resolved to meet with Dr. Scalea, also of Italian heritage, and pitch his project to him.

Dr. Scalea had the privilege of being the American Association of the Surgery of Trauma's (AAST) President in 2015. In his Presidential address, he recalled his first meeting with Dr. Chiara [3]:

> Fifteen years ago, I was leaving for home after I had been at the hospital too long. I was dog-tired and thus dismayed when someone knocked on my door. There was a visiting Italian surgeon who said, "My name is Osvaldo Chiara, and I have an appointment to speak

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> with you." I really wanted to tell him to go away. I was just too tired. As I started, I heard my mother and ducked as she went to hit me in the back of the head. Instead, I asked him to please come in and asked if he would like some coffee. It turned out that Osvaldo was Dr. Chiara, and he had autopsy data on all trauma deaths in Milan in the last 2 years. We talked for hours. As we finished, I remarked that he had not touched his coffee and asked him if it was okay. He said for the first but not the last time, "This is not coffee, this is dirty water." Coffee means espresso. We convened a panel of experts and reviewed his data. Forty-three percent of the deaths were either definitely or potentially preventable.

In 2002, Drs. Chiara and Scalea published the preventable death data in *Injury* [4]. This reverberated and Dr. Chiara was blamed for exposing the poor results but he was not deterred. A Milanese professor who at that time was the Italian Minister of Health heard Dr. Chiara speak and was moved to facilitate change. The ultimate result was a free-standing trauma center at Ospedale Niguarda, the first trauma facility in Milan. Not surprisingly, Dr. Chiara used Baltimore Shock Trauma as his model and the trauma center at Ospedale Niguarda in Milan looks a lot like Shock Trauma in Baltimore. Patients are flown to a helipad and brought to the "Shock Room", a trauma bay where every trauma activation mandates an anesthesiologist, radiologist and trauma team consisting of trauma and acute care surgeons, trauma nurses, surgical residents and medical students. The CT scanner is one door down from the Shock Room and the operating theaters equipped with a hybrid room one floor away, where a surgical team specializing in trauma and emergency surgery awaits, 24 h a day. After the advent of Ospedale Niguarda's trauma center, the preventable death rate in Milan is now 3%. Thousands of people who would have died are now living – trauma prevention at its finest. With Dr. Scalea as his most trusted global partner and colleague, Dr. Chiara put this form of trauma and emergency surgical care on the map in Italy. Dr. Scalea continued the story in his AAST presidential address [3]:

> In response, the city of Milan established a trauma center at Ospedale Niguarda that looked a lot like Shock Trauma. With some help from me and others, Osvaldo has established a trauma system that links the hospitals in and around Milan with both ground and helicopter transport. The preventable death rate dropped to approximately 3%. This is trauma systems development and prevention at its finest. Thousands of people who would have died lived. Every December, I travel to Milan, participate in their annual congress, see their progress, complete my Christmas shopping, and on occasion, we even operate together. None of this would have happened if I had gone home that evening. He was leaving to return to Milan the next day. We have become close friends, colleagues, and collaborators. Another victory for poor life-work balance.

The trauma center became a trauma system. Dr. Chiara and Dr. Scalea started with clinical case reviews. The number of participants grew exponentially. Italian surgeons were interested in trauma and wanted more information. Under Dr. Chiara's direction, with a little help from his US friend, a trauma system that covered the Milanese region was established and started to mature. The clinical case reviews morphed into a yearly clinical congress that also matured. Each congress has a theme and is highly evidence-based. The proceedings have been published in the *Journal of Trauma and Acute Care Surgery*. Enlisting the help of Dr. Sharon Henry, another Shock Trauma surgeon and an important part of the American College of Surgeons Committee on Trauma's educational efforts, they brought the American College of Surgeons course Advanced Trauma Operative Management (ATOM) to Italy. These courses are designed to train providers to treat trauma patients efficiently and effectively. Students from all over Europe attend this course to better themselves at trauma care.

Dr. Chiara established a Trauma Team at Niguarda, became a university professor and began training residents and students. However, trauma and emergency surgery as a specialty is not fully recognized in most areas of Europe and formal training fellowships are not readily available. The Trauma Center of Grande Ospedale Metropolitano Niguarda in Milan has started one of the first trauma and acute care surgery fellowships in Europe, with R Adams Cowley Shock Trauma Center as a key partner. The curriculum ranges over 18 months and includes study in the development of trauma systems, clinical topics to care for the injured patient including critical care as well as clinical rotations. Fellows from Milan have the opportunity to rotate through the busy trauma center of Baltimore to see and experience trauma in a US urban setting. Trainees will be well versed in trauma care globally and this experience gives both institutions an opportunity to grow. While treatment protocols may differ in the two institutions, sharing of data and collaborative research projects helps elucidate best standard of practices globally and allows an exchange of ideas and clinical approaches.

The trauma partnership that has been created over the years between Baltimore and Milan can serve as a model for international trauma relationships globally. This partnership is focused on two-way education and opportunities for both environments to learn and help each other grow. An exchange of ideas is important to help push trauma needs forward.

1.2 The US Trauma System Development

Trauma is a pressing public health epidemic. It is estimated that one person in the world dies every 5 s as a result of traumatic injury, accounting for more than 5.8 million victims a year or 10% of the world's deaths – i.e., 32% more than malaria, tuberculosis and HIV/AIDS combined [5]. Serious injury is the leading cause of death in the world and it is associated with a significant human and social burden in terms of disability, cost and loss of productivity [6].

The recognition of traumatic injuries as an addressable public health epidemic rather than unavoidable accidents has led to the birth and expansion of trauma systems [7]. Improved understanding of shock and resuscitation as well as the more general advances in diagnostic imaging and surgical techniques have greatly improved the survival of critically injured patients. As important as these factors might be, their effectiveness is limited if they cannot be accessed rapidly. Thus, the organization of the process of trauma-care delivery is crucial to optimize outcomes [8]. Trauma systems have evolved as an organized approach to provide severely injured patients rapid initial treatment, and to promote optimal care along a continuum from prehospital care through rehabilitation aimed to provide the best outcome possible [9].

Civilian trauma, in general, has followed the evolution of military systems with regard to trauma care. Advances in rapid transport, volume resuscitation, wound management, blood banking, enteric injury management, vascular surgery and surgical critical care have all grown out of military experience.

From the American Civil War came the medical evacuation system, which was comprised of an ambulance corps and placing of surgeons near battlefields to determine who could return to battle or be transferred to field hospitals [10]. The mass casualties of World War I propagated triage through tiered echelons of increasingly capable treatment [2]. Adoption of motorized transportation for evacuation (i.e., helicopters in the Korean War) allowed more expeditious evacuation throughout subsequent conflicts. By one estimate, the average injury-to-surgery time progressively improved and mortality progressively decreased from 12 to 18 h and 8.5% (World War I), to 6 to 12 h and 5.8% (World War II), 2 to 4 h and 2.4% (Korean War), and 65 min and 1.7% (Vietnam War), respectively [7, 11].

While systematic care for the injured took its early roots in the military, the need for a structured trauma system did not receive civilian spotlight until the publication of *Accidental Death and Disability: The Neglected Disease of Modern Society* in 1966 [12]. This landmark report highlighted accidental injury as a neglected epidemic and the "leading cause of death in the first half of life's span". The report underscored the deficient emergency medical care capacity and urged the establishment of trauma registries, hospital trauma committees and increased funding for trauma research. The same year, the United States federal government launched the first national effort to care for injured patients through "The National Traffic and Motor Vehicle Safety Act" [13]. The mandate of vehicle standards such as seatbelts, improved road standards and public education of driver safety laws led to a rapid decrease in motor vehicle fatalities by 1970, showcasing traumatic injuries to be a preventable epidemic. This increased public awareness and led to a federal agenda for the general improvement of trauma care.

With the United States national spotlight on injury, local leaders advancing trauma systems emerged. The Cook County Hospital in Chicago consolidated care of all trauma patients and developed a dedicated trauma team unit, gaining recognition as one of the nation's first trauma centers in 1966 [14]. At the same time, Kings County Hospital in Brooklyn established a dedicated trauma service, with Gerry Shaftan as its director. The University of Maryland Hospital established its shock trauma unit and popularized the "golden hour" for trauma resuscitation. Governor Marvin Mandel established the Maryland Institute for Emergency Medical Services System (MIEMSS) with a gubernatorial proclamation in 1973, the first organized trauma system in the United States. MIEMSS partnered with the Maryland State Police to provide helicopter transport, greatly increasing the sophistication of trauma care in Maryland. This collaboration reduced trauma-related mortality by transporting critically injured patients from the field or regional hospitals via police helicopters to a dedicated trauma unit [1]. Prehospital provider programs were formalized, emergency medical technicians (EMTs) and other paramedical personnel were identified, and training programs were established.

The "Emergency Medical Service Systems Act" of 1973 became law and provided the first federal funds to establish emergency medical service (EMS) systems [15]. In addition to federal efforts, state and local legislatures began to organize strategies to care for injured patients by using prehospital care systems to stabilize and deliver patients to major hospitals where appropriate care could be given. In 1976, the American College of Surgeons "Optimal Hospital Resources for Care of the Injured Patient" report detailed what constitutes a trauma center and presented a method to designate trauma center levels based on capabilities, thus establishing a standard evaluation of care [16]. This classification – now ranging from level I (tertiary center with 24-h capability for definitive trauma care) to level IV/V (centers limited to initial evaluation/stabilization prior to transfer) – mirrored the tiered echelons of increasing treatment capacity conceptualized earlier in the military. Subsequent revisions expanded in scope to emphasize the need to care for the injured in the prehospital setting. There was growing recognition that optimal care of the critically injured mandates not only advancement of trauma centers, but also their integration within a comprehensive trauma system.

1.3 Trauma System Models

Trauma care delivery has much regional and international variation. To focus on a single system would be inappropriate because there is not clear evidence that one system is superior to another [8]. According to the region of the world, the development and organization of trauma systems may have been carried out in different ways depending on socioeconomic and geographical characteristics, medical organization and the epidemiology of trauma in that region.

Two forms of trauma systems have been developed: "exclusive" and "inclusive" [17]. In the exclusive system, patients are referred to specialized and designated trauma centers. With the introduction of such a system, the relative risk of death has been reduced by 20% as compared with patients admitted to non-specialized centers [18]. A number of studies have reported that patient survival is better in centers receiving the most patients, especially for the most severely injured (hemorrhagic shock, severe traumatic brain injury) [18–20]. Although the exclusive model works well in urban and suburban settings where there are enough trauma centers to provide access and to care for the expected number of injuries, in rural areas and areas with limited resources, transport times to the trauma center may be very long, especially in periods of inclement weather when air transport cannot be used. These limitations led to the development of the "inclusive" system in the early 90s.

In an inclusive system, all health-care facilities within a region are involved in the care of injured patients according to their capabilities and resources [17]. The objectives of such a system are to optimize the resources of the hospitals, to adapt the level of care required by the patient at the receiving center, to avoid saturation of the referral centers by patients with minor injuries, in the event of multiple casualties, to be able to have a sufficient number of hospitals to take care of the injured patients and to avoid too long transport times [6]. Ideally through a regional medical dispatch that interacts with EMS, the system functions to efficiently match an individual patient's needs with the most appropriate facility, based on abilities, resources and proximity. In a study published in 2006, the prognosis of trauma patients admitted in the United States was evaluated where three systems coexisted: "exclusive", "more inclusive" and "most inclusive". The most inclusive system had the most favorable prognosis [21].

Prehospital care is organized in a few different ways across the world. In one system, prehospital care relies on EMTs capable of providing basic life support (BLS) and sometimes advanced life support (ALS) with the goal to limit the time at the scene to as little as possible, the so-called "scoop and run" strategy. In another system, largely developed in Europe, the prehospital system is based on highly trained paramedics or doctors (anesthesiologist-intensivist or emergency physicians) [8, 22, 23]. In this system, it is possible to deliver care *en route*, including advanced airways, chest decompression and the administration of fluids and drugs. The goal is to initiate adequate treatment for injured patients, but also, after careful evaluation of the injury, to triage the patients to the most suitable hospital. Milan trauma system is an inclusive organization with the presence of doctors on the scene in the most cases of severe trauma. At present, however, there is still insufficient evidence to conclude that prehospital management by doctors improves outcomes in patients with major trauma [24].

Regardless of what particular system is used, numerous studies from around the world have reported that the implementation of a system for the management of severe trauma patients is accompanied by an improvement in their overall prognosis and mortality [25–29].

The trauma system of a given region or country represents a local solution to a complex organizational problem, involving coordination of resources and services provided by many players, and is largely dependent on tradition rather than outcome-driven data. In the absence of data, each system continues to evolve to suit the biases of those directing the systems and the perceived needs and wants of the population.

The burden of injury is global and often greater in low- and middle-income countries given the lack of human and material resources, the absence of organized trauma systems and inadequate injury surveillance [30, 31]. According to the World Health Organization (WHO), more than five million deaths annually are attributed to traumatic injuries and more than 90% of these deaths occur in mid-to-low income countries [32]. While many improvements have been made in trauma care globally this past century, the work has yet to be completed. With technology and globalization, our world is getting smaller. Helping each other move forward together is key to success for improving trauma care globally. By creating sustainable and productive global partnerships, like with Milan and Baltimore, improving trauma care globally will undoubtedly save lives. We, as a global trauma community, have an obligation for these relationships to continue to be spread worldwide.

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2 Organization and Training in Trauma and Acute Care Surgery in Italy

Osvaldo Chiara and Stefania Cimbanassi

2.1 History

The last three decades experienced a remarkable improvement in the quality of trauma care in Italy, with the contribution of many professionals from different fields: anesthesiology, surgery, emergency medicine, orthopedics, neurosurgery, plastic-reconstructive surgery, radiology, nursing, rehabilitation, administration, and politics. The idea of an integrated system between the community and the hospitals for emergencies originated in Bologna, with the terrorist attack at the train station on August 2, 1980, with more than 80 deceased and 200 injured. The city's health system was immediately overwhelmed by the number of wounded: many injured victims were transported by private cars, taxi and bus, and hospitals were not organized for the reception and treatment of patients. It was evident that an emergency dispatch center for coordination, the availability of a consistent number of ground and air ambulances and a network of hospitals for trauma were mandatory. Ten years later, still in Bologna, a first emergency dispatch center was set up during the Soccer World Championships. At the same time, in Friuli Venezia Giulia, a region of Italy's North-East, the area of the city of Gorizia was equipped with an operational center for emergencies. In 1992, the Italian Government promulgated a law (DPR 27-3-1992) which instituted a telephone number for health emergencies ("118"). At the end of the twentieth century two studies [1, 2] demonstrated a high number of potentially or frankly preventable trauma deaths in two urban areas of Italy, Parma and Milan. These data prompted the Ministry of Health to draft a

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document regarding the need for an integrated trauma system with a dispatch center and a network of hospitals with different levels of resources available for trauma care (Superior Health Council, 2006). Some Regions in the country started to organize themselves to this end and hospitals in Milan, Bologna, and Rome set up specific services for trauma care. The Milan trauma service was directed by surgeons, while the leadership in Bologna and Rome was held by anesthesiologists. Many scientific Societies were involved in spreading the culture of trauma, and a small group of passionate doctors organized three to five Trauma Update meetings every year around the country. International experts in traumatology were invited to join and these meetings were instrumental in establishing partnerships between Italian doctors and world-renowned trauma centers. Famous trauma and acute care surgeons from other countries, such as Tom Scalea, Sharon Henry (Baltimore, USA), Ernest Moore, Walter Biffl (Denver, USA), Demetrios Demetriades (Los Angeles, USA), Ari Leppäniemi (Finland), Andrew Kirkpatrick (Canada), Yoram Kluger (Israel), Mircea Chirica (France), Marc Maegele (Germany), and many others, became teachers and valuable guides in the project. These links created opportunities for fellowships for Italian doctors, educational programs introducing internationally certified courses, common research programs with the production of collaborative papers. Some of these studies were published in the *Journal of Trauma* [3–5], the prime showcase for trauma research worldwide. Finally, in August 2015 a decree of the Ministry of Health (DM 2-4-2015 n. 70) formally established the new trauma system on the Italian territory and many hospitals and doctors were immediately available to start with this program.

2.2 Organization

2.2.1 Trauma System

An integrated Trauma System in Italy (SIAT, Sistema integrato per l'assistenza al trauma) is a geographically defined area with a dispatch center and a network of trauma hospitals categorized into three levels: the high-specialization trauma center (CTS or level 1) with all specialties available 24/24; the area trauma center (CTZ or level 2) with only some specialists; the emergency hospital for trauma (PST or level 3), located in remote areas with resources for patient stabilization and transport to a higher level hospital. According to the Italian law, the trauma system provides for a level-1 trauma center every 2–4 million inhabitants, with four to five level-2 centers in the same area. Leadership is assigned to anesthesiologists, emergency physicians, or general surgeons, based on local tradition and experience. The Italian model is an inclusive one, so that the system takes care of local trauma patients suffering from any among the full spectrum of injuries and all the hospital of the area participate to the system. The role of the pre-hospital emergency medical system (EMS) is of paramount importance, as it must be able to identify major trauma patients on the scene and ensure their admission in the shortest time possible to a hospital capable of providing definitive care of injuries. The initial model of the Italian trauma system was based on the original document of the American College of Surgeon Committee of Trauma (ACS-COT) [6], which at the end of 70s outlined pre-hospital and institutional requirements for optimal care of injured patients, but substantial differences have been introduced: in Italy pre-hospital care of major trauma is mainly led by doctors, especially anesthesiologists, and critical care nurses; trauma hospitals are general hospitals where doctors in the emergency department organize a trauma service and also take care of other emergencies.

2.2.2 Pre-hospital Triage

Since the beginning of the trauma system era in Italy, a significant number of over-triaged patients (ISS < 16) has been recorded (Table 2.1). This situation has resulted from the admission to trauma centers of patients with indicators of high energy mechanism but normal vital signs. This is a typical choice of immature systems, where the organization is designed to ensure the maximum protection of the population. The reliability of these indicators, particularly in road-related accidents, has changed over years because of the development of devices for active and passive protection which can decrease the severity of trauma (Table 2.2). For this reason, in the past 2 years a modification of the ACS-COT pre-hospital triage rules has been introduced in Italy, in order to exploit the medical and nursing expertise on the scene. The new triage was inspired by the method used in the Region of the Northern French Alps, where optimal levels of undertriage and overtriage, respectively <10% and 40% [7], have been recorded. Trauma patients are defined *triage code 1,* if unstable vital signs unresponsive to initial resuscitation are recorded on the scene, *triage code 2,* when unstable vital signs responsive to initial resuscitation or anatomy of major injury are observed. *Triage code 3* patients have high energy mechanism, no altered vital signs and no anatomy of severe injury. The indication of the Ministry of Health is to send code 1 and 2 patients, whenever possible, to a level 1

Table 2.1 Trauma admissions to an Italian level-1 trauma center over a 5-year period

	2013	2014	2015	2016	2017
Number	425	508	576	618	682
Age (median)	39	41	41	41.3	40.5
Altered vital signs or anatomy of severe injury	159 37.4%	188 37%	138 24%	194 31.4%	150 22%
Mechanism with high energy only (normal vital signs, no anatomy)	266 62.6%	320 63%	436 75.7%	424 68.6%	532 78%
Normal vital signs, no anatomy, no mechanism	0	0	2 0.3%	0	0
ISS (median)	16.38	16	13.2	14.8	13.7
Overtriage	56.5%	60.5%	67.8%	62%	66.6%
Discharged directly from emergency department	22.6%	23.5%	31.7%	30.6%	36.5%

The increase in cases was due to the admission of patients only with high energy mechanism and normal vital signs, while patients with altered vital signs even decreased. This situation produced an increasing overtriage (patients with ISS < 16)

Table 2.2 Road-related indicators of high energy mechanism and correlation with the severity of trauma (ISS > 15, ICU admission, need for damage control surgery)

	N.	(*A*) ISS>15	(*B*) ICU admission	(*C*) Damage control surgery	*A* + *B* + *C*	%
Driver	379	64	78	77	219	57.8
Front passenger	98	15	8	4	27	27.5
Back passenger	69	7	2	3	12	17.4
Seat belts not worn	109	30	10	9	49	44.9
Airbag explosion	186	30	12	8	50	26.8
Ejection	23	6	3	3	12	52.2
Prolonged extrication	104	28	13	8	49	47.1
Dead in the same compartment	9	4	2	1	7	77.7
Deformation of the car	208	50	21	11	82	39.4
High speed	346	66	27	22	115	33.2
Rolling	118	11	5	1	17	14.4

Eight of 11 mechanisms are associated with less than 50% of severe trauma and four with less than 30%

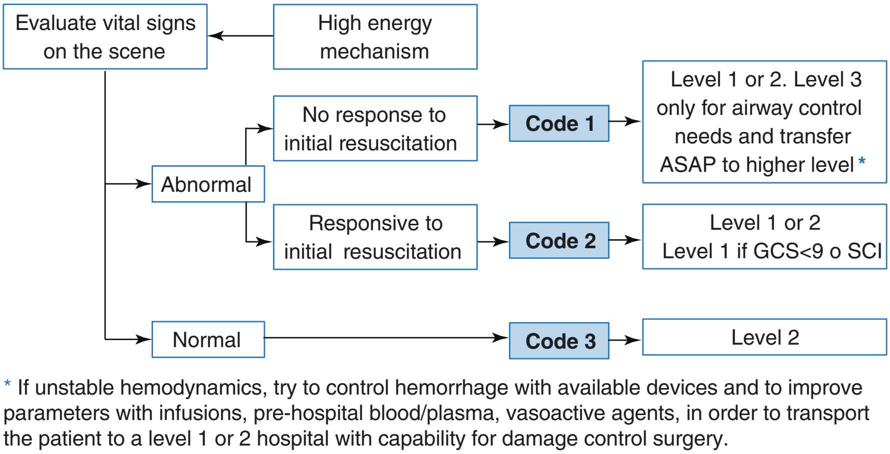


Fig. 2.1 New pre-hospital triage rules in Italy

or 2 (level 1 is preferred in cases of GCS < 9 or spinal cord injury) and code 3 patients to the closest level-2 trauma center. Patients with normal vital signs and no high energy mechanism are considered minor trauma and admitted to the closest emergency department of a non-trauma center hospital (Fig. 2.1) [8]. With this new system a decrease of overtriage in level-1 trauma centers, while maintaining an acceptable level of undertriage [9], is expected.

2.2.3 Epidemiology

A population-based study of hospitalized seriously injured patients [10] demonstrated in 1 year in a region of Northern Italy (Lombardy) 380–400 major trauma cases per million inhabitants, with an incidence rate of 40 hospital admissions every 100,000 inhabitants and a mortality of 24% (9.68 cases/100,000 per year). Road-related trauma (37%), injuries on domestic premises (15%) and at the workplace (5%) were the three principal mechanisms of trauma. Accidents on the road and at the workplace prevailed among males aged from 18 to 64 years. On the contrary, accidents on domestic premises increased with age, being the principal cause of trauma after 64 years, and older women were affected the most. Violence inflicted by others (assault) or self-inflicted violence were rare in Lombardy (4%) and affected principally persons aged 18–64 years. In children, severe trauma was unusual (16 patients per year in 100,000 inhabitants) and most cases were domestic (falls) or road-related (cyclists, pedestrians). The time distribution of deaths changed with the cause of trauma. Late deaths occurred more often in domestic trauma and in the category "other mechanisms" [11]. By contrast, deaths at work, on the road and after violence were acute in the majority of cases. Females and older age people showed a tendency to increase in late deaths, although not significantly. The same results were recorded in the regional epidemiologic survey in 2015 [10], with a tendency toward decrease of road-related trauma and increase of domestic trauma.

2.2.4 Trauma Services

Italian trauma centers are hospitals with a trauma service directed by anesthesiologists, emergency doctors or surgeons. The emergency call by the EMS activates the hospital trauma team that flows into the emergency room. A core trauma team consists of an airway doctor (emergency physician or anesthesiologist), a trauma surgeon, nurses and a radiology technician. Residents of different post-graduate schools assist the team members. A team leader, who coordinates the resuscitation phases and ensures adherence to the guidelines, acts as a supervisor and decides on the diagnostic and therapeutic pathway. The team can be led by an emergency physician, a surgeon or an anesthesiologist, depending on local tradition and organization [12]. Other surgical specialists, such as orthopedic, vascular, neuro and plastic surgeons may be involved in patient care. Hospital services such as blood bank, radiologic suite and operating theatre should be notified and be immediately available. Trauma patients are admitted to the appropriate hospital level of care (ICU, high dependency unit, standard ward) and continuity of care is guaranteed by components of the trauma team, including doctors and trauma nurse coordinator, until discharge to home or rehabilitation services.

2.2.5 Model of Acute Care Surgery

Since the introduction of Italian trauma centers, surgeons have been involved in the care not only of trauma but also of all surgical emergencies, such as peritonitis, bowel occlusion or perforation, gastrointestinal bleeding, pancreatitis, caustic ingestion, necrotizing soft tissue infections, surgical emergencies of ICU patients, rescue surgery for complex problems (e.g., entero-atmospheric fistula, complex repair of abdominal wall). The habit of working within a multidisciplinary team, the appropriate application of diagnostic tools, the use of alternative or complementary techniques such as interventional radiology or operative endoscopy are all useful for problem-solving in general emergencies as well. The experienced surgeon of a trauma center, compared with the general surgeon, who is principally exposed to elective activity, is more confident with these complex situations in a crowded and chaotic emergency department. In addition, many general emergencies can be managed with a stepwise approach, as occurs in trauma settings with the damage control philosophy. This is the model of Acute Care Surgery which has been adopted in the USA in the past 10 years and which is currently spreading in Europe [13].

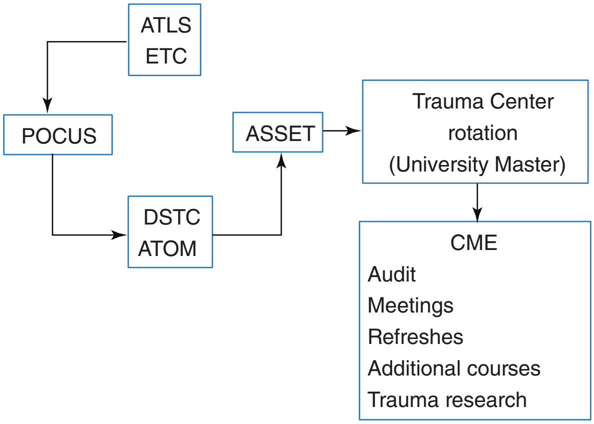
2.3 Training

In Italy, although anesthesiologists and emergency physicians have been most involved in the leadership of trauma care and organization, a new generation of young surgeons with expertise in acute care surgery is growing thanks to the numerous educational courses that have recently been implemented by scientific societies (American College of Surgeons, American Association of Surgery for Trauma, Società Italiana di Chirurgia, Associazione Chirurghi Ospedalieri Italiani, Società Italiana di Chirurgia d'Urgenza e del Trauma, World Society of Emergency Surgery, European Society of Trauma and Emergency Surgery), universities and single institutions. The training of an acute care surgeon is a complex process that takes many years. Different steps can be identified (Fig. 2.2):

Step 1: *General courses on the basic elements of trauma care*—such as Advanced Trauma Life Support (ATLS) [14] and European Trauma Course (ETC) [15]. The core of these courses is the concept of priorities with the ABCDE sequence, teamwork, leadership and non-technical skills. These competencies are complementary and the skills acquired allow the student to have the basis for the initial treatment of major trauma, with the learning of diagnostics and life-saving maneuvers in the emergency department.

Step 2: *Courses teaching the use of point-of-care ultrasound (POCUS) as an extension of the physical examination*. The role of extended focused assessment with sonography in trauma (E-FAST) in the initial management of trauma patients is well recognized, both for chest and abdominal injuries [16]. E-FAST should be performed by one of the trauma team doctors and it is important that everyone acquires this competency.

Fig. 2.2 Trauma surgeon step-up training program in Italy. *ATLS* advanced trauma life support, *ETC* European trauma course, *POCUS* point-of-care ultrasound, *DSTC* definitive surgical trauma care, *ATOM* advanced trauma operative management, *ASSET* advanced surgical skills for exposure in trauma, *CME* continuing medical education



Step 3: *Courses for surgical training on live animals in damage control techniques on different organs, in the chest, abdomen, and pelvis*. Two of these courses have gained wide diffusion around the world. The Definitive Surgical Trauma Care (DSTC), developed by the International Association for Trauma Surgery and Intensive Care (IATSIC), is a 3-day course encompassing causation of injuries, pre-hospital and emergency room care and operating room practical sessions for skills training [17]. The Advanced Trauma Operative Management (ATOM) course, by the American College of Surgeons, is a 1-day course focused on damage control operative techniques [18]. It has been specifically developed to increase surgical competence and confidence in penetrating injuries.

Step 4: *Courses on cadavers to improve surgical skills on the human body*. The most famous cadaver-lab course is the Advanced Surgical Skills for Exposure in Trauma (ASSET), by the American College of Surgeons. It is a 1-day course where, after a video demonstration, the student performs various surgical maneuvers on the neck, chest, abdomen, pelvis, and extremities, under the supervision of an instructor [19].

Step 5: *Rotation in a high-volume trauma center*. This rotation gives the doctor the chance to participate in the management of a large number of patients, acquiring competency in teamwork and decision making in complex trauma problems. In Italy, no residency program in trauma surgery exists, but in the past 2 years the Universities of Bologna and of Milan in association with Novara and Varese started a Master's in Trauma Management and Acute Care Surgery, which provides an official qualification in this field.

After this program, the trauma surgeon must pursue continuous medical education (CME) training, by participating in clinical audits, refreshment courses, trauma meetings, and research projects. Some additional courses can be useful to deepen knowledge about specific aspects of trauma care. The Basic Endovascular Skills for Trauma (BEST) course, by the American College of Surgeons, aims to demonstrate the indications and techniques for the use of resuscitative endovascular balloon occlusion of the aorta (REBOA). The Care of the Critically Ill Surgical Patient (CCrISP), a course by the Royal College of Surgeons, teaches the principles of critical care of different organ systems in the surgical patient. Of course, to maintain their skill, trauma surgeons must be exposed to a substantial number of complex trauma cases. Local expertise is preserved by a trauma system organization that centralizes severe trauma cases to a limited number of trauma centers in the area.

2.4 Conclusions

Up to the beginning of the 90s, trauma patients in Italy were often neglected and, depending on the prevailing lesion, they were placed under the care of different specialists who would focus on the specific injury relevant to their specialty without an overview of the general problems. The development of trauma care in Italy stemmed from the commitment and passion of doctors who 30 years ago understood the problem and believed in the possibility to build a new model for treatment. These visionary pioneers developed the knowledge and competence, analyzed the models in place in other countries, and evaluated how to adapt them to the Italian Health System. Finally, they indicated the way to politicians, with the result that today the Italian trauma system is a reality defined by a national law. The future challenge will be to create a formal educational program for young surgeons wishing to be involved in this field, with a specific professional profile and an attractive career. Universities have started to organize courses and master's programs in Acute Care Surgery but the expectation of many is the realization of a dedicated residency in Europe, as has been set up in the United States.

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The Development of a Regional Trauma Registry

3

Fabrizio Sammartano and Laura Briani

3.1 The Beginning of Standards in Trauma Care

The American College of Surgeons Committee on Trauma (ACS-COT) was set up in 1922 as a national body that focuses on improving the care of trauma patients; it has developed as an organization promoting a multidisciplinary approach to the management and care of this type of patient, both at a local level and at a national level. To this end, in 1976 the ACS-COT first published the care criteria that represented the necessary standards to optimize care for trauma patients in facilities designated as *trauma centers* [1]. In early 1987, the ACS-COT carried out a program of verification of all hospitals in the United States (US) that met the criteria established to be considered trauma centers. The purpose of this verification was to create national guidelines to help the various centers in improving the quality of care provided for trauma patients [2]. Currently, however, the US have neither a unified nationwide trauma system nor national standards defining how to designate a trauma center facility, although evidence has shown improved outcomes in terms of survival and coordination of care in dedicated centers [3–5]. The ACS-COT has made numerous efforts to establish a nationwide trauma system [6] but the responsibilities for coordinating the trauma system, and the mechanism by which a hospital is classified as a trauma center, vary from state to state and are subject to regulation by the legislative authorities.

The first Trauma Registry was set up in 1969 at Cook County Hospital in Chicago and in 1971 it was already permanently activated in the State of Illinois. In the majority of states of the US (about 80%), the registration process is voluntary,

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although in many emergency systems it is considered one of the mandatory criteria for accreditation of a hospital within the trauma network. The ACS has defined guidelines for this process by producing software, called National TRACS, which can be accessed through authorized registration. Subsequently, in agreement with other scientific societies, two other registries were established: the National Pediatric Trauma Registry and the National Burn Registry. This activity has gradually spread organically in other countries; in Europe, the most advanced country is Germany, while less organic activities are present in England, Scandinavia and Italy. The impact of the trauma registries has led to the development of prevention systems and adaptation of the legislation regulating emergency systems.

3.2 Birth and Development of Trauma Networks in England

In England there are around 40,000 cases of major trauma each year, with around 5400 deaths [7]. A national report, published in 2007 [8], identified some serious shortcomings in the organization of the management of trauma patients in England. Trauma care organization had evolved since the inception of the National Health Service in 1948 and was based on the principle that ambulances transported patients to the nearest emergency department (ED), regardless of the ability of these facilities to provide intensive and definitive care. Each region therefore developed independently a hospital network based on geography, available facilities, and transport times, in order to designate three types of hospitals that provide care for trauma patients:

- Major trauma centers (MTCs);
- Trauma units (TUs);
- Local emergency hospitals.

Pre-hospital staff use the triage criteria for major trauma to identify those patients who may have suffered major injuries. Patients who meet these criteria, and who are within an estimated time of arrival (ETA) of about 60 min from an MTC, are transported directly there, only stopping at a closer hospital if there is a need to quickly stabilize the patient's clinical condition that threatens his life. MTCs have all the resources necessary to provide definitive care to all trauma patients, thanks to the presence of a multidisciplinary team dedicated to the management of these patients [9]. Patients who have an ETA greater than 60 min from the nearest MTC are taken to the closest TU. These hospitals (127 in total) have the resources to stabilize the patient and manage those situations that would put their survival at immediate risk. However, the lack of specialized services, such as neurosurgery, cardiothoracic surgery, and pelvic surgery, do not allow definitive management of all possible injuries, so the purpose of these facilities is to stabilize the patient, identify the lesions and transfer him, when necessary, as quickly as possible to the relevant MTC. The establishment of the major trauma networks in England has led to a significant

(20%) increase in the likelihood of trauma survival for the population of 54 million people [10].

3.3 Birth and Development of the Trauma Network in Germany

Germany has more than seven million accidents every year, with around 35,000 cases of seriously injured patients. Due to the growing economic pressure on health care, after introduction of the diagnosis-related groups (DRG) system in Germany in 2003, an increasing number of hospitals have refrained from managing trauma patients. The German Trauma Society (DGU, Deutsche Gesellschaft für Unfallchirurgie) therefore embarked on a project of "regionalization" of the care of trauma patients in the framework of a national network (TN-DGU, TraumaNetzwerk DGU). The project started in 2006 with the publication of a "White book of medical care of the severely injured" (whose third edition was published in 2019 [11]), which defined both the standards of care, cooperation and communication between the various regional trauma networks, and the human and equipment resources to be used in the various trauma centers, thus outlining the concept of TN-DGU. The goal was not only to certify individual hospitals, but also to outline a regional network of hospitals with the characteristics of trauma centers (levels I–III). The typical regional trauma network is made up of 14 trauma centers: two level I, four level II, and eight level III [12]. The hospitals that met these criteria consequently participated in the drafting of the DGU TraumaRegister (DGU-TR), with periodic random verification of the quality of the data entered and of the medical records. Furthermore, the various hospitals had to demonstrate an improvement in the management of trauma patients, and increasing productivity in trauma care, so as to be able to guarantee their certification as level I–III trauma centers, which is renewed every 3 years after review of the individual centers. In order to improve communications and cooperation between the centers, the DGU also embarked on a telecommunications project for the transfer of radiographic, computed tomography (CT) and magnetic resonance images from one center to another. The drafting of a German trauma log began in 1993, long before the DGU project started. Data are collected prospectively in four different phases: in the pre-hospital phase (comprehensive of the arrival and stay in the ED), during the stay in intensive care, and at discharge. The data are entered into an online system and consist of personal information, injury reports, comorbidities, treatments provided in the pre- and in-hospital setting, admission to intensive care and outcomes. All patients with serious injuries, such as those admitted to the intensive care unit or who died in the ED, are included. The DGU-TR currently contains about 250,000 patient records, and today about 33,000 cases of severe trauma are recorded per year. The administration of the DGU-TR is provided by the DGU and the AUC (Akademie der Unfallchirurgie). In 2009, the TN-DGU proposed to introduce an annual meeting in order to present and discuss new emerging issues, analyze the processed data of the registry and provide each participating hospital with a report on its work [13].

3.4 RITG: Italian Severe Trauma Registry

The idea of creating an Italian trauma registry arose from the need to improve the quality of care in the context of traumatic events, and consequently reduce associated mortality. An integrated rescue system (SIAT, Sistema integrato di assistenza al trauma), both intra- and extra-hospital, was therefore set up whose correct functioning was based on the creation and development of trauma registries. The trauma registries make it possible to determine the epidemiological aspects of the traumatic pathology, to evaluate the care processes provided to this type of patient, to compare the performance of the different hospitals, and to promote research [14, 15].

The Multiregional Intrahospital Registry of Serious Trauma (RIGT, Registro intraospedaliero dei traumi gravi multiregionale) was set up in 2004 and involved the level II emergency and admissions departments of three hospitals: Santa Maria della Misericordia Hospital in Udine, Maggiore Hospital in Bologna, and San Camillo Forlanini Hospital in Rome. A common database was set up from which to easily record and access uniform data; to this end, they availed themselves of the collaboration of a team of European experts in charge of creating a similar registry on a European scale (EuroTARN), so that the two registries would be compatible. The group was coordinated by the Trauma Audit and Research Network of Manchester (England). The main data entered can be summarized in the following points [16]:

- *Demographic data*;
- *Essential pre-hospital data*: level of care, vital signs at the scene, time and type of diagnostic and therapeutic maneuvers, intervals;
- *In-hospital data in the first 24 h*: vital signs on arrival, time and type of diagnostic and therapeutic maneuvers, intervals, definitive hospitalization ward;
- *Severity*: injury severity score (ISS), abbreviated injury scale (AIS), revised trauma score (RTS), and new trauma and injury severity score (TRISS) [17, 18];
- *Outcome*: length of hospitalization and intensive care, complications, subsequent surgery, place and time of death, disability at 6 months (Glasgow outcome score), EQ5D questionnaire.

All the data collected were entered into a computerized database, with the exception of sensitive personal data. For calculation of the AIS score, a special validation system was used, according to which the score was calculated blindly by two expert researchers and, in cases of discrepancy, the opinion of a third expert researcher from another participating hospital was requested.

One of the aspects considered in creating the RIGT was the cost/benefit ratio, so the admission criteria were the first to be evaluated. In this context, it was decided to include only patients with an ISS ≥16 or need of resuscitation on admission to ED, since they represent that portion of traumatized patients likely to have higher morbidity and mortality rates and whose outcome would be more influenced by the care skills of individual centers. To this category, all those admitted to intensive care, regardless of their ISS score, were added. The combination of these two criteria sought to increase accuracy and evaluate the appropriateness of hospitalization in the intensive care unit. Another aspect that was taken into consideration was the competency of the staff responsible for collecting the data, which often proved to be insufficient. Based on these considerations, the strategy adopted in the RITG was twofold:

1. Enlist independent staff with specific skills able to collect data from all possible hospital sources in the shortest possible time, thus carrying out a double work of control and validation of the data.
2. Establish a validation process for the attribution of the ISS score to eliminate subjectivity in compiling the data.

Despite these precautions, the RITG project was stopped as it was not possible to obtain a standardized data compilation protocol, resulting in countless discrepancies in the assignment of the AIS. Another issue was the lack of overview of the entire trauma network, since in many cases the pre-hospital data were not reported.

3.5 First Lombardy Trauma Registry

The trauma network of the Lombardy Region was established by a regional decree (Decreto Direzione Generale Sanità n. 8531, 1 ottobre 2012) of October 2012, on the basis of data emerging from a 3-year epidemiological study. Following a Ministry of Health decree (Decreto Ministeriale n. 70, 2 aprile 2015) of August 2015, a review of the regional trauma network was carried out based on the analysis of hospital discharge forms. The trauma registry is considered a fundamental component of the network and an indispensable tool for improving the quality of trauma care.

The first Lombardy Trauma Registry developed out of the idea of devising a data collection system aiming to standardize trauma care in the future, by establishing common inclusion criteria that would enable the trauma team to be activated uniformly. This project stems from the increasing numbers of the population involved in traumatic events and the need to conform to European standards, trying to create a model that is as accurate as possible and avoids data collection bias as found in the RITG project.

The general objective of the Registry is to evaluate the incidence and mortality of major trauma, initially in the Milan Metropolitan Area and subsequently throughout the whole Lombardy region, with the aim of analyzing any critical issues of the integrated pre- and in-hospital system in order to promote corrective actions. For this reason, the database was conceived as a system registry, which observes and analyzes how the pre-hospital and in-hospital components work, thus providing more complete monitoring of the entire trauma network system.

The model was to build a DGU-TR-compatible registry. Its realization involved:

– Use of the Utstein criteria [19–21];

- Analysis and inclusion of patients in relation to severity criteria, both pre-hospital and in-hospital;
- Calculation of the real severity of the trauma in relation to the AIS and ISS value.

The project, designed as an observational, prospective and multicenter study, was presented and approved by the internal Ethics Committee of each participating hospital, while the Regional Emergency and Urgency Agency (AREU, Azienda Regionale Emergenza Urgenza) obtained approval from the Milan Ethics Committee. Privacy of the patients enrolled in the study was guaranteed by changing the procedure for managing nominal data; the cases entered in the AREU database have nominal references only in the compilation phase of the datasheet; once completed and closed, the record is stored in the database with immediate anonymization of personal data. The statistical analyses were therefore carried out on a database without nominal data.

Data collection began on an experimental basis in December 2017 and continued until September 2018. The official start of the Regional Database dates back to 1 October 2018.

The Regional Database is based on two types of inclusion criteria:

1. Pre-hospital severity criterion: all patients sent to the ED with a Priority 1 and Priority 2 code are enrolled, and with Alert that represents the mechanism by which the pre-hospital team requests precise assistance from the Level 1 and Level 2 centers. This concept concerns the pre-hospital severity principle and allows us to analyze the overtriage rate represented by patients directly discharged from the ED after initial evaluation or hospitalized with minor injuries.
2. In-hospital severity criterion: this allows inclusion of all those self-referred patients, those sent to the ED via basic life support (BLS) without alert and those patients classified with Priority 3 who, on clinical examination or diagnostic investigations, presented serious injuries (ISS > 15), emergency surgery or admission to intensive care directly from ED. These data allow us to analyze undertriage and "under-alert" rates.

Creation of the registry relied on the AREU information and communications technology (ICT) experts who, with the help of the local registry coordinator for the Metropolitan Area, produced an online database that can be used by project participants. The various compilers of the registry were issued with credentials to access the database according to the type of user (administrator, compiling doctor, data analyzing doctor, etc.).

Compilation of the registry can be done at any time. Within the database, each center finds a list of patients entered directly by the AREU computer system, selected on the basis of pre-hospital severity criteria and can enter the missing patients enrolled with the criteria of in-hospital severity. For hospitalized patients all fields in the form must be completed, including the ISS. For patients discharged from the ED, or those deceased on arrival, the mandatory fields to be completed are restricted to basic information. In any case, the single form provides for the compilation of a minimum core of information in order to be considered suitable and to be included in the data analysis. From the database it is possible to extract an Excel file from which to obtain data for statistical analysis.

In order to minimize subjectivity in compiling the ISS, it was decided to elect a small number of compilers for each hospital who were trained by a team of experts. To verify the uniformity of compilation of injury reports, checks are periodically carried out by sending sample clinical cases to individual compilers, with CT images and radiological reports. This verification is carried out both to minimize compilation biases and to be able to analyze the performance of individual centers in the future based on the real severity of the patients.

In order to obtain a regulated control in registry compilation and data management, the project envisaged the following bodies:

1. *Working Group* consisting of
   - The data contact person of the dispatch center
   - The compiler who has the role of data collector
   - The registry data coordinator
   - The data contact person for each individual hospital.
2. *Scientific Committee* (*Steering Committee*)
   - Regulates the use of data by evaluating and approving requests for scientific studies, as well as verifying their appropriateness in relation to the code of ethics
   - Evaluates and approves changes to the Registry
   - Manages the economic resources allocated to the Registry
   - Is made up of at least one SIAT district hospitals representative.
3. *Technical Committee*
   - Develops the ICT part of the Registry (ICT AREU)
   - Produces periodic reports
   - Processes the data
   - Verifies correct AIS assignment
   - Is formed by ICT AREU + contact person of the local coordinators.
4. *Data Collection Group*
   - Coordinates the data collection within the districts (formed by the four local Registry coordinators).

In order to regulate and control the progressive inclusion of data, the project provides that both plenary meetings and smaller meetings with the Scientific Committee alone are held periodically.

Appendix: Birth of the Utstein Style

The Utstein style was born in the early 1990s in conjunction with the growing interest in the management and prevention of cardiac arrest. In June 1991, at a meeting at the historic Utstein Abbey on the island of Mosterøy in Norway, representatives of the American Heart Association (AHA), European Resuscitation Council (ERC), Heart and Stroke Foundation of Canada (HSFC), and Australian Resuscitation Council defined the general rules for the collection of data relating to cardiopulmonary resuscitation (CPR) carried out in an out-of-hospital setting. This set of rules took the name of *Utstein style*. It was the first step that established the now universally accepted standards for data collection in and out of the hospital environment. A flow chart was designed to define a data recording method for the creation of a database, with the aim of evaluating the epidemiology of cardiac arrest episodes and the resulting responses to CPR maneuvers. This new organization of the cardiac arrest database was considered the cornerstone on which to base the development and improvement of the care chain also in other areas, such as that concerning serious trauma [19, 20].

To this end and in order to reach a European agreement, the various trauma management organizations (Scandinavian Networking Group for Trauma and Emergency Management, UK Trauma Audit and Research Network, DGU-TR, and RITG) convened at a symposium in 2007 in order to draft an Utstein style template to standardize the reporting of data on severe trauma [21]. An attempt was therefore made to create a registry that was as compatible as possible with the main Trauma Registries in Europe and that adhered to the EuroTARN program for the development of a European Trauma Registry, with the aim of promoting the development of a continental model for the prediction of outcome allowing international monitoring of severe trauma. In 2008 some authors further reviewed the criteria and parameters for the registration of trauma [21]; this revision led to the definition of the guidelines that are currently followed by the Lombardy Trauma Registry.

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Quality Assessment in Acute Care Surgery

4

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4.1 The Impact of Emergency and Trauma Surgery

Surgical emergencies represent a considerable health burden with over three million emergency admissions in the United States alone [1, 2]. Patients who need surgery for acute care diseases are often critically ill on presentation, often with multiple pre-existing comorbidities; 35% of emergency general surgery (EGS) patients are over the age of 70. Emergency surgery carries high rates of morbidity and mortality [3]. Patients undergoing EGS procedures are up to eight times more likely to die than those undergoing the same procedure electively [4]. EGS admissions and costs are projected to increase by 45% to $41.20 billion annually by 2060 using the United States Census projections [5]. This mandates that emergency general surgery undergo rigorous process and outcomes evaluation.

On the other hand, injuries are responsible for 10% of global mortality, causing more than five million deaths per year [6]. While trauma and injury were once ignored as one of the leading causes of death all over the world, being historically referred to as "the neglected disease" [7], there is still a need for innovative structuring in many countries, coupled with significant investment in improving EGS care. Trauma-related mortality is only the tip of the iceberg. The costs of hospitalization

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and ongoing medical expenditure arising from the substantial morbidity associated with these injuries are usually high. The individual psychological impact and the societal burden are even greater considering all the sequelae that physical trauma can leave on the survivors, who often find themselves unable to return to a "normal" productive life [8]. Trauma systems including quality outcome indicators are significantly more advanced than those in emergency general surgery.

4.2 Quality Improvement Concepts and Key Performance Indicators

Trauma and emergency surgery accounts for almost 15% of all hospital admissions. The economic and societal burden related to these two healthcare areas impact every country differently, falling disproportionally on low- and middle-income countries. Also, the standard of care presents significant disparities between countries. With increasing variability in care there is a need for clinical pathways to reduce variability, improve outcomes, and include measurable indicators [9].

However, defined pathways are required in order to improve patient outcomes. The "quality improvement" concept is not new and refers to the need to "make the changes that will lead to better patient outcomes (health), better system performance (care) and better professional development (learning)" [10]. In order to obtain these changes, monitoring emergency and trauma surgery performance and outcomes is essential; it is the key to improving the care system. These data collection systems must be tailored to the care providers and the environments in which they work.

Quality in healthcare and more specifically in trauma surgery has been described in terms of three components: structure, process, and outcome [11, 12].

The *structure* domain describes the structural characteristics of the settings in which care occurs, defining a healthcare center's ability to deliver high quality care to its patients. This includes the level of the infrastructure, of the facilities, of the tools and technologies available, of the resources in terms of number and level of hospital beds, staffing skills and availability, and financial aspects (levels of funding, payment, and incentives).

The *process* component refers to the process of care—the practical interconnection between the patient and the given care. It describes each step the patients go through once entered into the healthcare chain.

The *outcome* measures are essential to assess the final product of healthcare provision and are able to give a global assessment of hospital performance. Nevertheless, adverse outcomes (in terms of mortality and morbidity) cannot be used as a measure of quality in isolation, but rather need to be related back to structure and process.

There are many means through which performance and quality may be measured. The most important are quality indicators and key performance indicators (KPIs) [13]. KPIs are quality care measures that allow a comparison of care given to the patients between hospitals. A KPI has an optimum value that represents the ideal target for a given outcome. The quality indicators are essential tools in describing the actual performance and identifying improvement opportunities. It is important to involve not just the clinicians in defining outcome indicators but patients and their family [14].

4.3 Emergency Surgery Key Performance Indicators

Emergency surgery practice and its outcomes vary widely across the world. The use of quality indicators may help reducing outcome variation worldwide and administering medical care aligned with defined standards. One of the first international summits on emergency surgery performance and outcome indicators took place in Donegal, Ireland, in 2016 [15]. As is well known, acute care requires a multidisciplinary approach. In fact, 44 opinion leaders in emergency surgery, across seven disciplines (predominantly surgical, but also including critical care, internal and emergency medicine, radiology, and nursing) from 17 countries, composed evidence-based position papers on 14 key areas of emergency surgery. They also defined 112 KPIs in 20 acute conditions or emergency systems [15].

The 15 areas considered key aspects of emergency surgery are shown in Table 4.1. Table 4.2 shows the 19 acute conditions on which the consensus focused for the development of KPIs. Finally, in Table 4.3 there is an example of one of the 112 KPIs that were generated. The entire structure of the summit is available online (https://dcra.ie/images/Resources_2016_Emergency_Surgery.pdf). World leading surgical societies are increasingly recognizing the importance of promoting indicators in EGS and the World Society of Emergency Surgery have led the way in revising and expanding outcome indicators in EGS [16]. Individual hospitals are coming to grips with trying to implement these indicators [17]. The original Donegal Summit's KPIs have been modified to meet with the needs of hospital registries. While there is no question that the time has come for metrics and big data analytics, this comes at a financial cost and a mindset change in clinicians' desire to understand and improve outcome. Variability in care, however, remains a major challenge

Table 4.1 Key position topics for summit

• Resources and designation of emergency surgery
• Acute care unit structure
• Reception and triage
• Data systems, registry and evaluation
• Rural emergency care and transfer
• Pediatric emergency care
• Geriatric emergency care
• Interaction and laboratory, radiology, ICU gastroenterology
• Quality assurance and performance improvement
• Sepsis control in emergency room
• Research in acute care surgery
• Education in emergency surgery
• Accreditation review and consultative program
• Patient-related outcomes measures

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Table 4.2 Key performance indicator topics

- Appendicitis
- Cholecystitis
- Pancreatitis
- Perforated ulcer
- Gastrointestinal bleeding
- Bowel obstruction
- Diverticulitis
- Mesenteric ischemia
- Abdominal vascular emergencies
- Coagulation
- Complex pneumothorax and empyema
- Septic shock in emergency; ICU
- Fluid resuscitation in septic shock
- Abdominal compartment syndrome
- Geriatric care
- Triage; ICU admission
- Laboratory
- Wound care
- Emergency theatre
- Health care systems

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ICU intensive care unit

Table 4.3 Example of one of the 112 key performance indicators generated

Title	Negative appendectomy rate
Description	Percentage of negative appendectomies performed
Rationale	It is an indicator of diagnostic efficiency, aiming to avoid unnecessary surgery and decrease costs and complications
Target	<10% appendixes removed are normal
KPI collection frequency	Annually
KPI reporting frequency	Annually
KPI calculation	Numerator divided by denominator expressed as a percentage Numerator: number of patients underwent appendectomy with negative appendectomy Denominator: number of all patients who underwent appendectomy
Reporting aggregation	Hospital, hospital group
Data source(s)	OR registry, medical records, patient chart, hospital discharge data, emergency surgery database

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KPI key performance indicator, *OR* operating room

Table 4.4 Current key performance indicators for emergency general surgery outcomes in Letterkenny University Hospital [17]

Service provision	Functioning Emergency Surgical Service Registry >90% enrolled Surgical consultation in patients with diffuse peritonitis <30 min of ED Surgical consultation in patients with localized peritonitis <1 h Post-emergency laparotomy management in HDU/ICU EGS providers attend 1 EGS Educational Course annual Patient final diagnosis clear in discharge letter >90%
Disease specific	Negative appendectomy rate < 10% >90% of appendicectomy undertaken initially by laparoscopic approach Conversion rate from laparoscopic to open appendicitis <10% Re-admission rate post appendicectomy <5%
	Laparoscopic conversion rate in emergency cholecystectomy is <20% Subtotal cholecystectomy rate should be <20% >60% of acute cholecystitis have index cholecystectomy Re-admission following cholecystectomy; cholecystostomy or ERCP <10%
	The underlying cause of pancreatitis is identified in 75% Pancreatitis patients in HDU/ICU have IAP measured <24 h post admission 85% of open abdomen have primary fascial closure rate < 10 days Hospital survival in severe acute pancreatitis >80% 90% of patients with SBO enrolled in a hospital SBO pathway Patients >35 years presenting with SBO undergo abdominal CT <12 h of admission Small bowel resection rate in those undergoing surgery <30%
	Patients with large bowel obstruction have underlying diagnosis made <24 h Leak rate in patients under primary anastomosis is less than 10% Readmission rate within 30 days of bowel resection <15%
	Mesenteric ischemia is diagnosed <4 h of acute presentation >80% of patients with mesenteric ischemia have temporary abdominal closure In hospital mortality rate in patients with acute mesenteric ischemia <30% Abdominal CT reported in patients suspected with mesenteric ischemia <90 min Plain abdominal x-ray <20% of patients that proceed to laparotomy

CT computed tomography, *ED* emergency department, *EGS* emergency general surgery, *ERCP* endoscopic retrograde, *HDU* high-dependency unit, *IAP* intra-abdominal pressure, *ICU* intensive care unit cholangiopancreatography, *SBO* small bowel obstruction

and despite the large volume and significant patient- and system-level costs, public health-focused quality improvement efforts dedicated to EGS care are lacking [18, 19]. Defining the outcome is essential; it must be measurable and reproducible. The current KPIs to be measured with the European Union-funded Emergency Surgery Outcomes Advancement Project (eSOAP) program are shown in Table 4.4.

4.4 Trauma Quality Indicators

At the present time, several lists of trauma quality indicators (TQIs) exist and are used to improve the outcomes and performances of trauma centers around the world [20–22].

The United States were the first to set these lists of TQIs. Although essential in order to improve the system, TQIs may not be widely and homogeneously adopted. In fact, trauma systems are organized very differently around the globe and these differences make using the same set of TQIs difficult. With the aim to propose a core list of TQIs to be shared universally by trauma centers, Coccolini et al. accurately revised all the indicators available in the literature and after an international consensus conference produced a definitive core set (Tables 4.5, 4.6, and 4.7) [23]. This core set should be implemented and adapted to each system with the definition subgroups of TQIs, tailored to each trauma center according to necessity, its level and resources.

When creating a list of trauma quality indicators, the three domains of structure, process, and outcomes must be taken into account, in conjunction with two primary elements relating to the trauma itself [20]. The first of these are the factors preceding trauma, including primary prevention and the pre-hospital phase. The second is the post-hospital phase which includes all the aspects related to the societal, economic, and human impact of traumatic injuries and their sequelae. As important as the in-hospital phase is, these two primary elements are strongly related to the efficacy and the performance of the hospital management and may impact each other.

Table 4.5 Trauma quality indicators—prevention and structure indicators

Category	Subcategory	Indicators	Patients
Prevention		Activity to prevent and diffuse trauma risks and effects perception	All patients
		Measurement of injury risk perception and behavioral changes following sensitization programs	All patients
		Psychological consequences in observers	All patients
		Prevention of copycat events	All patients
		Quantification of direct medical costs	All patients
		Quantification of indirect costs	All patients
Structure	Center preparedness	Presence of data registry	All patients
		Staff training requirements	All patients

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Table 4.6 Trauma quality indicators—process indicators

Category	Subcategory	Indicators	Patients
Process	Triage/ pre-hospital	Time to first medical contact (on scene)	All patients
		Pre-hospital time	ISS > 15
		Time to definitive trauma center	All patients
		Acute pain management	Patients with documented pain assessment
		Intubation of unconscious patients	Pre-hospital GCS < 9
		Pelvic binder in pelvic fracture	Mechanically and/or hemodynamically unstable pelvic fractures (AIS 3–5)
		Field triage rate (undertriage)	All patients
		Patients in shock with documented blood pressure who die with no ED thoracotomy or REBOA placement	Patients who arrived with a documented blood pressure and died in emergency room
	ED management	TTA	Patients requiring TTA for whom TTA was activated
		Airway secured in ED for patients with GCS < 9	Patients with GCS < 9
		Tracheal intubation (GCS < 9)	Patients with GCS < 9
		Adequate rewarming measures for hypothermia (temperature ≤ 35 °C)	Patients admitted to a trauma center
		Operative management of patients with an abdominal gunshot wound	Patients with a penetrating abdominal firearm injury
		Tetanus prophylaxis	All patients with exposed soft tissues
		Antibiotics for open fractures	Number of patients with an open fracture receiving an antimicrobial agent within 1 h of hospital arrival
		Time to cranial CT for patients with GCS < 14	GCS < 14
		Patients with GCS < 13 have a head CT within 4 h of arrival in ED	Adult TBI: GCS < 13; pediatric TBI: GCS < 12
		Time to CT scan from ED admission	ED patients with blunt force injuries *and* TTA *or* ED documented GCS < 9, receiving CT scan within 1 h of ED arrival
		E-FAST in patient without CT	Patients without CT
		Blood tests performed/BE documented	All patients

(continued)

Table 4.6 (continued)

Category	Subcategory	Indicators	Patients
		Coagulation test (TEG/ROTEM)	All patients with active bleeding
		ED stay >1 h for patients with GCS < 9 or intubated (level I/II)	TBI patients with GCS ≥ 4 or ≤ 10 in a level I/II trauma center
		ED stay >1 h for patients admitted to ICU or OR	TBI patients with GCS ≥ 4 or ≤ 8 or intubated in a level I/II trauma center
		Massive transfusion protocol activation	Patients with active bleeding and signs of shock
		Time to start of blood transfusion	Patients with at least one unit transfused
		Orthopedic response time > 30 min in emergent case	Patients with orthopedic trauma
		Unplanned ICU admission	Patients initially admitted to ward then moved to ICU
	Surgical management	Definitive bleeding control (in patients with MTP)	All patients aged 18 years and older with an injury diagnosis *and* a massive transfusion prescribed who receive attempted definitive bleeding control (laparotomy, thoracotomy, percutaneous therapy) within 30 min of the massive transfusion prescription
	Trauma	Time to first emergency surgery	Operated patients
		Delay to OR exploratory laparotomy (>2 h): trauma	Operated patients
		Time to laparotomy <1 h for patients with proven intra-abdominal bleeding causing hypotension	SBP < 90 or requires >4 units of packed red blood cells in the first hour for hemorrhage due to injury
		Time to surgery in patients with shock	SBP < 90
		Patients with bleeding pelvic fracture who die within 60 min from ED arrival without preperitoneal pelvic packing or REBOA placement	Patients with bleeding pelvic fracture
	Neurosurgical	Time to surgical brain decompression	TBI with indication for decompression
		Patients with epidural or subdural hematoma receiving craniotomy >4 h after arrival	Patients with epidural or subdural hematoma
		Enteral or parenteral feeding for severe head injury patients <7 days post-injury	TBI patients with GCS ≤ 10
		Failure to monitor intracranial pressure in severe TBI with pathological CT finding	Severe TBI

Table 4.6 (continued)

Category	Subcategory	Indicators	Patients
	Orthopedic	Open fracture grade 3 to OR > 8 h	Open fractures grade 3
		Open long bone fracture surgery <6 h	Open fracture of the tibia, fibula, humerus, radius, or ulna
		Patient with pelvic fracture and hemodynamic instability on ED arrival with provisional stabilization of pelvic ring fracture within 12 h from arrival at the trauma center	Patients with SBP < 90 or requiring >4 units of packed red blood cells in the first hour
		Open fractures grade 1 or 2 to OR > 16 h	Open fractures grade 1 or 2
		Open fractures - stabilized >24 h	Long bone open fractures
	Vascular	Ischemic limb revascularized <6 h	Ischemic limb following vascular trauma
		Time to restore perfusion	Ischemic limb following vascular trauma
		Deep vein thrombosis prophylaxis (within 24 h) in immobile patients	Patients immobilized ≥24 h (without CNS bleeds or spine/CNS surgery within 24 h)
		Patients who experienced limb amputation without previous vascular shunt placement	Patients with limb amputation

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AIS Abbreviated Injury Scale, *BE* base excess, *CNS* central nervous system, *CT* computed tomography, *ED* emergency department, *E-FAST* extended focused assessment with sonography for trauma, *GCS* Glasgow Coma Scale, *ICU* intensive care unit, *ISS* Injury Severity Score, *OR* operating room, *MTP* massive transfusion protocol, *REBOA* resuscitative endovascular balloon of the aorta, *ROTEM* rotational thromboelastometry, *SBP* systolic blood pressure, *TTA* trauma team activation, *TBI* traumatic brain injury, *TEG* thromboelastography

Table 4.7 Trauma quality indicators—outcome, post-traumatic management, and society integrational effects indicators

Category	Subcategory	Indicators	Patients
Outcome	Admission data	ICU length of stay	Patients admitted to ICU
		Length of stay	All patients
		Ventilator-associated events	All patients
	Adverse events (according to Clavien-Dindo classification)	Complications during hospital stay	All patients
		Pulmonary embolus	All patients
	Mortality	Mortality rate	Admitted patients
		Death <48 h after arrival	All patients
		Deaths >1 h after arrival occur on ward (not in ED)	Vital signs on arrival
		Death >48 h after arrival	All patients
		Mortality in severe TBI	Severe TBI
		Penetrating injury mortality	Patients with penetrating injury
		Blunt multisystem injury mortality	Patients with multisystem injury
		Blunt single-system mortality	Patients with single-system injury
		TBI deaths >3 h following arrival in level III/IV center	TBI with GCS > 12 and max head AIS > max AIS in other anatomic regions
	Failure to rescue (severe)	Patients who die with unsolved severe complication	Patients who die among those with Clavien-Dindo grade 3–5 complications
	Functional outcome	Evaluation of patient functional status (at hospital)	All patients
	Outcomes review	Peer review of trauma deaths to evaluate quality of care and determine whether the death was potentially preventable	Dead patients
	Early postoperative events	Tertiary survey	All patients
		Unexpected return to OR	All operated patients without ongoing damage control surgery
Post-traumatic management		Long-term physical disability: facilities/support	All patients
		Psychological disability: facilities/support	All patients
		Behavioral change and secondary health loss: quantification	All patients
		Tangible costs: quantification	All patients
		Intangible costs: quantification	All patients

Table 4.7 (continued)

Category	Subcategory	Indicators	Patients
Society integrational effects		Observer consequences: evaluation/support	All patients
		Carer consequences: evaluation/support	All patients
		Dependant consequences: evaluation/support	All patients

From [23] (published under the terms of the Creative Commons CC-BY license)
AIS Abbreviated Injury Scale, *ED* emergency department, *GCS* Glasgow Coma Scale, *ICU* intensive care unit, *OR* operating room, *TBI* traumatic brain injury

4.5 Conclusion

Emergency and trauma surgery encompass a wide variety of pathology and patients presenting to hospitals across the world. Little regard is given to the resources or condition of the associated healthcare system. Patients and the acute teams need proper commitment to both trauma and emergency general surgery. Quality analysis and improvement are cornerstones of clinical governance. Recent years observe an international drive towards developing standards and indicators to facilitate comparable quality analysis in trauma and emergency surgery. There remains, however, considerable work to be done in emergency surgery when compared with trauma. There exists a need for universally defined indicators in emergency surgery. Ultimately these developments will facilitate patient outcome improvements and help optimize resource utilization.

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Part II

Principles of Trauma Care

Diagnostic Protocols in Trauma Care

5

Stefania Cimbanassi and Osvaldo Chiara

5.1 Introduction

Every patient who arrives in the emergency department (ED)/trauma bay must be considered acutely ill with potentially life-threatening injuries until proven otherwise. The trauma team must approach each patient in this fashion in order to minimize the risk of mistakes, the most important being those of omission. To avoid such mistakes, the team must adhere to a strict set of clinical-instrumental protocols. Most of these are guidelines established by the American College of Surgeons Committee on Trauma (ACS-COT) [1, 2] in their Advanced Trauma Life Support (ATLS) course [3]. For a patient with multiple injuries, the team leader must conceive a well-organized, integrated approach with the radiology members of the team (radiologist and technicians) to provide the best economy of time. Treatment priorities must be established and fully understood not only by the surgeons and anesthesiologist, but also by the radiologist.

The instrumental work-up is run along with all the strategies needed to achieve the patient's complete evaluation and stabilization. In the case of patient instability, it could be necessary to interrupt, modify, or delay the radiologic series to perform life-saving maneuvers according to the damage control strategy [4]. The team leader must have a well-thought-out justification to deviate from the standard protocols (omission of films). He or she should question any reason to break the radiologic protocols rather than question which imaging to obtain. This method permits the

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narrowest margin of error and offers the greatest economy of time in recognizing and treating injuries.

There are two levels of diagnostic work-up in trauma:

- ***First level diagnostic work-up***
  This is represented by Emergency Room (ER) exams—clinical evaluation, laboratory tests, extended focused assessment with sonography for trauma (E-FAST), supine anteroposterior (AP) chest-x ray, supine AP pelvis x-ray—which allow identification of life-threatening injuries requiring immediate treatment in unstable patients and of injuries which mandate further imaging in stable/stabilized patients.
- ***Second level diagnostic work-up***
  This includes a series of instrumental evaluations—extremity x-ray, non-contrast head/spine computed tomography (CT), torso contrast-enhanced computed tomography (CECT), CT angiography (CTA) of the neck vessels, interventional radiology (IR), and magnetic resonance imaging (MRI)—which allow the staging of injuries in stable/stabilized patients, and the resolution of special problems.

5.2 Trauma Series

- ***Clinical evaluation*** [3]
  The evaluation includes a primary survey encompassing the ABCDE sequence from ATLS to identify life-threatening injuries which need to be immediately managed, and a secondary survey (a head-to-toe evaluation and patient history). During the clinical evaluation, treatment priorities are established, based on the patient's vital signs, detected injuries and mechanism of trauma. Resuscitation is started. Adjuncts include continuous electrocardiography, pulse oximetry, carbon dioxide monitoring, and assessment of ventilatory rate, laboratory tests. Urinary catheters are placed to monitor urine output and assess for hematuria. Gastric tubes are used to decompress distention and assess for evidence of blood.
- ***Laboratory tests*** [5–7]
  Hemoglobin, red and white blood cells, platelets, transaminases, bilirubin, amylase, lactates, aPT, aPTT, blood in the urine, blood gas analysis, and troponins are evaluated. If available, viscoelastometric assays (TEG/ROTEM) should be considered to detect coagulopathy and to begin a goal-directed resuscitation strategy. Altered values of AST ($\geq$109 U/L) and/or ALT ($\geq$97 U/L), amylase ($\geq$250 IU) and/or lipase ($\geq$100 IU 3 h from trauma), and microhematuria must be considered markers of solid organ or hollow viscus injuries, mandating further investigations.
- ***FAST and E-FAST*** [2]
  Focused assessment with sonography for trauma (FAST) includes evaluation of the right upper quadrant view (perihepatic and Morrison's pouch), the left upper quadrant view (perisplenic), the pelvic view (Douglas' pouch) and the pericardial view (subxiphoid view). The examination evaluates the three gravitationally

dependent abdominal views for the presence of free fluid that could indicate major abdominal injuries. It is accepted that the sonographic threshold for detection of fluid is 250 mL. The pericardial view examines potential injury of the pericardial sac. FAST has reported variations in sensitivity ranging from 42 to 86% when looking for fluid (blood) in the peritoneum. However, in the unstable patient, the sensitivity is higher than 85% with a specificity of 96%. Concerning the indications for trauma laparotomy, the sensitivity and specificity are near 100%. Extended FAST (E-FAST) is an evolution of the FAST examination and includes assessment of the thorax to rapidly rule out a pneumothorax or hemothorax. The four additional views include the right and left pleural space (anterior axillary line between the sixth and ninth intercostal space) and the two anterior pleural spaces (midclavicular line between the second and third intercostal space). E-FAST has been reported to have a greater sensitivity for the detection of pneumothorax than the supine AP chest x-ray (48.8% vs. 20.9%, respectively), while maintaining a high specificity (99.6% vs. 98.7%, respectively).

- ***C-spine x-ray*** [2]
  Traditionally indicated by ATLS as part of conventional radiology for trauma, nowadays this technique is no longer performed in major trauma since its limitations have been recognized. The main disadvantage of C-spine radiography is that it has poor sensitivity for fractures (52%). It has been superseded by C-spine CT including the junction (C0-T2).
- ***Supine AP chest x-ray*** [2]
  The chest radiograph is performed early in the ATLS secondary survey, and it must be read in a systematic fashion. It gives useful information about pneumothorax or hemothorax, pulmonary infiltrates (contusions or aspiration), abnormal mediastinal contour suggesting potential damage to mediastinal great vessels, diaphragms for evidence of direct injury or elevation due to abdominal pathology, ribs, clavicles, scapulae, and proximal humeral fractures, which provide important clues about the degree of energy transfer to the thorax and the potential for other extrathoracic injuries. Chest x-ray also provides information about lines and tubes (endotracheal, thoracostomy tubes) placed during resuscitation.
- ***Supine AP pelvis x-ray*** [2]
  The pelvis radiograph is obtained during the ATLS secondary survey, and it remains an integral part of the initial evaluation of traumatized patients. It allows identification of the patterns of pelvic fractures, some of which can be mechanically unstable, requiring temporary stabilization in the ED with binders. Pelvic injuries may cause massive retroperitoneal hemorrhage, representing life-threatening conditions requiring damage control maneuvers, such as extraperitoneal pelvic packing (EPP) or REBOA.
- ***Extremity x-ray*** [2]
  In stable patients, not requiring immediate surgery or interventional radiology (IR), radiographs of the limb should be obtained using the "rule of twos": *two views* (AP and lateral-LL, 90° orthogonal to each other), *two joints* (above and below the injury site, to rule out any potential dislocation in a corresponding

joint), *two limbs* (injured and non-injured limbs, to evaluate rotation and limb length, mostly if severe comminuted fractures are present), *two times* (pre- and postreduction of the fracture/dislocation).

- ***Thoracic and lumbar spine x-ray*** [2]
  No widely used and validated criteria exist to guide the appropriate use of thoracolumbar spine imaging. A low threshold for imaging the thoracolumbar spine with traditional radiology should be maintained in hemodynamically stable patients who do not require a torso contrast-enhanced CT scan at the end of the first level diagnostic work-up. Radiographs must be obtained in two views (AP, LL, 90° orthogonal to each other), and evaluated for abnormalities of alignment and fractures of vertebral bodies and pedicles.
- ***CT*** [2, 8–16]
  Computed tomography is now a mainstay of trauma imaging. It is fast, relatively inexpensive, and has high diagnostic accuracy. Whole-body CT (WBCT) generally includes non-contrast imaging of head and C-spine CT followed by contrast-enhanced imaging of the chest, abdomen and pelvis (torso CECT). Indications for WBCT (immediate as a screening test vs. further tool after clinical and standard radiological work-up), such as the possibility to perform WBCT in hemodynamically unstable patients, are still a matter of concern. The exact technique of the entire run is also a matter of debate, being different among trauma centers, because uniform consensus does not exist. The technique will in part depend on the trauma center's volume, patient's conditions, and mechanism of injury (high energy vs. low energy, blunt vs. penetrating). The run may be conducted as a *single pass* (head CT, then CTA neck through pelvis, then venous phase abdomen and pelvis) or *dual pass* (head CT, face, C-spine, then enhanced chest, abdomen and pelvis after arms elevated). Conventional protocols use a single i.v. injection of 90–150 mL of contrast medium and two spiral acquisitions, the first at 30 s to obtain an arterial phase study and the second at 70 s to obtain a portal venous phase. In recent years, in order to reduce the risk of cancer resulting from exposure to ionizing radiation, the protocols have been modified (biphasic protocols) combining a two-bolus injection (first bolus of 65 mL commenced at a rate of 1.5 mL/s completed at 43 s, followed by a second bolus of 65 mL at rate of 3.5 mL/s) and a single spiral acquisition at 60–70 s. Further, advances in dual energy CT technology using both dual and single x-ray sources can help reduce both the time and dose penalties incurred where a separate non-contrast head CT is performed.
- ***Interventional Radiology*** [2]
  The availability of an IR service 24/7 is essential to treat traumatic hemorrhage in a variety of vascular beds. A rapid response time and time to intervention are essential to improve the outcome of patients with severe trauma, particularly when hemorrhage derives from a pelvic arterial source. Angioembolization is also an important component of the non-operative management of solid organ injuries. IR becomes more relevant if performed in a hybrid operating room (OR) having both angiographic and surgical capabilities. This allows a rapid transition between operative and endovascular procedures without the risk associated with

transferring the patient to an area that may be less equipped to manage the many simultaneous requirements of severe trauma.

- ***MRI*** [2]
  Prolonged exploration times and a particular hostile environment limit the use of MRI for trauma in the acute setting. To undergo MRI examination, the patient must be hemodynamically stable/stabilized, any ferromagnetic materials must be removed and compatible life-support material must be used. The sole indication to perform MRI in acute settings is to investigate the patient with an incomplete spinal cord injury, or with progressive peripheral neurological impairment, after the spine has been investigated by non-contrast CT or with multiple planar reformations (MPR) from torso CECT. After 48–72 h from severe traumatic brain injury MRI is used if a diffuse axonal injury is suspected. For torso injuries, after 72–96 h from trauma MRI may identify pancreatic injury, if suspected based on laboratory tests.

5.3 Diagnostic Protocols

Selection of the appropriate diagnostic protocol depends on the patient's hemodynamic stability, the presence/absence of neurological impairment (anisocoria, loss of more than 2 points in the Glasgow Coma Score motor component), and the mechanism of trauma (blunt vs. penetrating).

Pediatric and pregnant patients deserve special attention. In both groups adherence to the ALARA (as low as reasonably achievable) criteria [17] is mandatory, which means that every investigation should be tailored to deliver the lowest possible dose necessary to give a diagnostic quality result.

5.3.1 Hemodynamically Stable Patient Without Neurological Impairment

The controversy in this scenario is the use of CECT as a second level diagnostic work-up after injuries have been identified at the first level diagnostic work-up [8, 9], or its use as a screening test (WBCT) to detect major injury [10]. This second policy is at risk of overscanning [11] and excessive exposure to ionizing radiation [12]. The concern of overscanning is substantial, higher than 30%, mostly for those patients referred to a trauma center based on high energy mechanism of trauma as the sole triage criterion [11]. Moreover, it has been demonstrated [13] that the use of WBCT on the basis of the sole mechanism of trauma is not justified and it does not modify decision-making and the patient's outcome. A recent retrospective analysis [18] demonstrated for the first level diagnostic work-up an overall accuracy of 96% to correctly identify, after initial ED management or after a 6–8-h period of observation [19], torso injuries requiring a CECT scan.

According to this evidence, a CECT scan is indicated if there is any of the followings [18]:

– persistently impaired clinical evaluation;
– any abnormal blood tests or urinalysis: AST ≥109 U/L and/or ALT ≥97 U/L; amylase ≥250 IU and/or lipase ≥100 IU (3 h from trauma), hematuria;
– positive E-FAST: abdominal free fluid, pleural or pericardial effusion, absence of sliding, parenchymal injury;
– positive supine AP chest x-ray: hemo/pneumothorax, bilateral clavicle fractures, scapula fracture, fracture of vertebral bodies, more than two rib fractures on one side, bilateral rib fractures or fracture of the first and second rib, pulmonary contusion, widening of the mediastinum, alterations of the diaphragmatic profile, mediastinal or subcutaneous emphysema;
– positive supine AP pelvis x-ray: pelvis fracture may induce a huge retroperitoneal hematoma; IR is potentially required.

The protocol is applied according to the following sequence of steps:

1. ATLS primary and secondary clinical evaluation and AMPLE (allergies, medicine, past, last meal, event) [3].
2. Laboratory tests (hemoglobin, red and white blood cells, platelets, transaminases, bilirubin, amylase, lactates, aPT, aPTT, blood in the urine, blood gas analysis, troponins if chest trauma).
3. E-FAST.
4. Supine AP pelvis x-ray; supine AP chest-ray is performed if E-FAST examination is unreliable or doubtful.
5. Twelve-lead ECG.
6. Head CT if head trauma is suspected. Clearance of the spine is obtained with a CT scan from C0 to T4 and plain x-ray studies of the thoracic (lower than T4) and lumbar spine and of the extremities if there is pain or deformities.
7. Additional segmental standard x-ray and CT studies for orthopedic injuries (spine, pelvis, shoulder, elbow, knee) are requested when deemed necessary.

Torso CECT scan is performed only if one of the criteria indicated above is positive. In these cases, thoracolumbar spine x-rays are not performed and CT of the spine and pelvis is reformatted from the CECT.

5.3.2 Hemodynamically Stable Patient with Neurological Impairment

In this scenario, the main goals are: to prevent/limit the onset/progression of the secondary brain injury and to quickly obtain information to properly manage those injuries causing neurologic impairment.

Clinical evaluation is performed according to the ABCDE sequence, with particular attention to step A, protecting the airway patency by orotracheal intubation if GCS < 9, and to step B, identifying and managing all the causes of breathing compromise, while it is expected that bleeding injuries are minimal.

Instrumental evaluation is limited to the thoracic windows of E-FAST, followed by non-contrast head CT and C-spine CT. C-spine CT allows detection of vertebral injuries often associated with head injuries. Contrast medium must be administered (CTA) if carotid artery or vertebral artery injuries are suspected, in accordance with the Denver criteria [20]. Potential extracranial injuries are investigated by torso CECT, improving decision-making. MRI is usually not warranted in the emergency setting, but it could represent a useful tool in penetrating head trauma, to evaluate the presence of retained wooden foreign bodies.

The protocol is applied according to the following sequence of steps:

1. ATLS primary and secondary clinical evaluation and AMPLE [3].
2. Laboratory tests (hemoglobin, red and white blood cells, platelets, transaminases, bilirubin, amylase, lactates, aPT, aPTT, blood in the urine, blood gas analysis, troponins if chest trauma) are performed. If available, viscoelastometric assays are used to investigate the coagulation profile.
3. Any concern of steps A and B is addressed and managed by orotracheal intubation and/or tube thoracostomy or decompressive thoracotomy.
4. Thoracic windows of the E-FAST are evaluated.
5. Non-contrast head CT and C-spine CT are performed, associated with CTA of the carotid and vertebral arteries if injuries are suspected. Torso CECT is performed to detect extracranial injuries.
6. Once completed the CT evaluation, any identified cerebral and extracranial injuries are properly managed.

5.3.3 Patient with Altered Vital Signs

The evaluation of the traumatized patient with altered vital signs is oriented to the rapid identification of life-threatening injuries, which must be managed according to the damage control strategy, in order to minimize exhaustion of the physiologic reserve and, in case of hemorrhage as the cause of instability, to limit/correct the coagulopathy.

Hemodynamic instability is defined as:

- Systolic blood pressure (SBP) <90 mmHg, or SBP >90 mmHg with continuous infusions and/or vasopressor drugs
- Base excess (BE) > −6 mmol/L and/or
- Shock index (SI) >1 and/or
- Transfusion requirement ≥4 blood units within 24 h from admission,
- Heart rate > 120 bpm
- Altered level of consciousness

- Altered respiratory rate
- Capillary refill >3 s.

The clinical evaluation is performed according to the ABCDE sequence.

The instrumental evaluation is limited to the first level diagnostic work-up. If penetrating injuries of the extremities are present, plain films of the skeletal segments must be obtained to detect bullets or their retained fragments, and to evaluate their position with respect to major vascular structures. Radiopaque markers (i.e., ECG leads) must be positioned close to the entry/exit wounds to better identify the potential projectile trajectory.

If the patient is still unstable, with negative E-FAST, pelvis and chest x-ray, a torso CECT in association with non-contrast head/C-spine CT is useful for investigating other causes of instability. During this step, resuscitation efforts are ongoing.

If anisocoria is present and the patient remains unstable, but SBP is kept ≥70 mmHg, a sole non-contrast head CT should be obtained, before rushing to the OR, to detect cerebral injuries potentially amenable to damage control neurosurgery. Otherwise, the head CT is performed once the patient is stabilized.

The protocol is applied according to the following sequence of steps:

1. Clinical evaluation is performed according to the ABCDE sequence, and any concerns of steps A and/or B are addressed with the dedicated damage control maneuvers
2. External hemorrhages are controlled by direct pressure or tourniquets
3. Laboratory tests (hemoglobin, red and white blood cells, platelets, transaminases, bilirubin, amylase, lactates, aPT, aPTT, blood in the urine, blood gas analysis, troponins if chest trauma) are performed. If available, viscoelastometric assays are used to investigate the coagulation profile
4. Damage control resuscitation is provided.

The subsequent steps depend on the degree of the patient's hemodynamic compromise, mechanism of trauma (blunt versus penetrating), and presence/absence of anisocoria.

- ***Blunt trauma without anisocoria***
  A first level diagnostic work-up is performed, and life-saving maneuvers are applied in the ED or OR according to the location of injuries. If the patient is stabilized after the ED procedures, torso CECT associated with non-contrast head CT and C-spine CT (CTA in the event of suspected injuries to the carotid and vertebral arteries) are performed. IR should be used to control residual torso bleeding. If the patient remains unstable, CT has to be postponed after damage control surgery.
- ***Blunt trauma with anisocoria***
  After the first level diagnostic work-up and ED life-saving maneuvers, if the SBP ≥70 mmHg, non-contrast head CT has to be performed before the OR. Otherwise, the second level work-up has to be postponed after the patient has been

stabilized. In the absence of torso injuries, extremity trauma should be considered as a potential cause of instability.

- ***Blunt extremity trauma***
  Hemorrhage control is obtained with a tourniquet. Plain film of involved skeletal segments allows detection of the level and type of fractures. Then damage control orthopedics is applied.
- ***Blunt trauma with neurogenic shock***
  If hemorrhagic causes of shock are excluded, torso CECT with non-contrast head CT and C-spine CT (CTA if carotid and vertebral artery injuries are suspected) must be performed to investigate the possible causes of neurogenic shock.
- ***Blunt trauma with cardiogenic shock***
  A 12-lead ECG must be performed and troponin levels investigated. If myocardial or valvular injuries are suspected, a transesophageal echocardiogram must be performed.
- ***Penetrating injuries***
  In the case of stab wound, the E-FAST is the only instrumental test needed to identify in which body cavity fluid and/or air are present, before providing damage control surgery. In gunshot wounds, chest, abdomen and extremity plain films with radiopaque markers have to be performed.
  - *Torso injuries* If the patient is agonic, an ED thoracotomy represents the life-saving maneuver. In the absence of intrathoracic bleeding injuries, the patient must undergo a damage control laparotomy. If the patient is unstable but not agonic, the surgical maneuvers are tailored according to the result of the ED instrumental evaluation.
  - *Neck injuries* After airway patency is secured, if not yet performed, a chest x-ray is obtained. Life-saving maneuvers are tailored to the involved neck zone (I, II, III).
  - *Extremity injuries* Extremity plain films are obtained, with radiopaque markers. Hard signs of vascular injury (active hemorrhage/ischemia, pulsatile/expanding hematoma, pulse absence, thrill) must be detected. If present, damage control surgery is necessary. If the patient can be stabilized or hard signs are not detected, CTA is mandatory to investigate the involvement of vascular structures. IR techniques could be applied in stabilized patients to manage injuries amenable to stenting or embolization procedures.

5.4 Pediatric Patient

The anatomical and physiological peculiarities of the pediatric patient must be kept in mind during the clinical evaluation, in accordance with the ATLS principles [3]. Because of the higher risk of radiation exposure and subsequent risk of neoplasm, instrumental evaluation should be always carefully applied, according to the ALARA criteria [17]. In particular, the indications for CECT must be strictly selected.

Imaging tools and their limitations in pediatrics are listed below.

- ***E-FAST***
  In unstable patients, this allows one to rapidly identify the life-threatening conditions. In stable patients with normal clinical evaluation and laboratory tests, a negative E-FAST rules out the need for further imaging.
- ***Supine AP chest x-ray***
  This is mandatory if thoracic clinical evaluation is positive. Rib, clavicle, scapula fractures mandate CECT.
- ***Supine AP pelvis x-ray***
  This is mandatory if the patient is hemodynamically unstable. In stable patients, it is not necessary if the patient is alert, with negative abdominopelvic clinical evaluation, or if there are other indications for CECT.
- ***Contrast-enhanced ultrasound (CEUS)***
  If available, this is the preferred method for the follow-up of the non-operative management of solid organ injuries, previously evaluated by CECT.
- ***CECT***
  This must be performed according to the ALARA criteria [17]. The volume of intravenous contrast medium is proportional to the body weight, on average 2 mL/kg. The indications for CECT are: positive E-FAST, positive chest x-ray, positive abdominopelvic clinical evaluation, GCS <9, altered laboratory tests (AST/ALT >200/125; amylase >100, hematocrit <30%, hematuria), hypotension with negative E-FAST and stable pelvis.
- ***Head/C-spine CT***
  To avoid overscanning, the indications for head CT depend on the patient's age. In patients younger than 2 years of age, head CT is indicated if there is: loss of consciousness >5 s, forehead hematoma, vault fracture, high energy mechanism of trauma. In patients older than 2 years of age, if there are: skull base fractures, loss of consciousness, increasing headache, vomiting, high energy mechanism of trauma. Because of the frequent association of vertebral injuries with head trauma, C-spine CT is mandatory if at least one of the following triggers are present: unreliable clinical evaluation, altered consciousness, peripheral neurological impairment, midline pain, wryneck, high energy mechanism of trauma. On the other hand, an MRI scan could be performed.
- ***MRI***
  Indications and timing depend on the injuries to be evaluated. In emergency settings, MRI is indicated for incomplete spinal cord injuries. It should be performed within 72 h from trauma in patients with GCS < 9 if diffuse axonal injury is suspected. In the case of suspected pancreatic injuries, MRI should be performed within 72–96 h from trauma.
- ***Interventional radiology***
  It is rarely used in pediatrics because of the high risk of vessel laceration and a more frequent spontaneous hemostasis. IR could be useful to embolize bleeding from pelvic fracture, if contrast medium extravasation is detected at CECT, and to improve non-operative management of solid organ injuries if parenchymal hemorrhage is present.

The protocol is applied according to the following sequence of steps:

1. Clinical evaluation according to ABCDE(F) from ATLS, and laboratory tests performed
2. If the patient is *stable,* E-FAST and chest/pelvis x-ray (if indicated according to the criteria listed above) are performed. If at least one of these tools and/or laboratory tests are positive, a CECT is preferred (associated with head/C-spine CT if indicated as listed above). Otherwise, the patient undergoes a 6–8-h clinical observation. At the end of this period, E-FAST, upright chest x-ray and laboratory tests are repeated. If repeated tests are normal the patient is discharged, if at least one of these becomes positive CECT is obtained.
3. If the patient is *unstable,* E-FAST and pelvis x-ray must be performed, and volume resuscitation started according to the ATLS indications [3]. If E-FAST and pelvis x-ray are negative, a different cause of shock must be investigated with a torso CECT, in association with head/C-spine CT.

5.5 Pregnant Patient

Clinical evaluation of the pregnant trauma patient must take into account the alterations of physiology and anatomy induced by the pregnancy itself [3]. The instrumental evaluation has the same indications applied in the non-pregnant patient, though, when using ionizing radiation, the ALARA criteria [17] should be respected. In general, a radiation dose of 50 mGy is considered safe, and lower doses are harmless for the fetus.

The commonest diagnostic tools are E-FAST, CECT and MRI.

- ***E-FAST***
  This exam allows evaluation of the presence/absence of free fluid/air, fetal heartbeat and gestational period. During pregnancy the sensitivity and specificity of E-FAST in detecting intraperitoneal injuries are 61–83% and 94–100%, respectively
- ***CECT***
  The radiation dose should be kept lower than 50 Gy, and the technical parameters of the machine tailored to deliver the lowest dose possible necessary to guarantee a good quality result. Contrast medium is necessary to detect maternal injuries and also to evaluate the degree of placental perfusion.
- ***MRI***
  This is not usually performed in the acute setting, but it represents a useful tool during the follow-up of non-operative management of solid organ injuries, previously graded with CECT and to evaluate spinal cord or soft tissue injuries. It is also useful to further investigate symptoms arising after an initial negative evaluation.

The protocol is applied according to the following sequence of steps:

1. Clinical evaluation according to the ABDCE sequence and laboratory tests are performed. Attention must be paid to obtain information about the gestational period, if necessary indirectly by using ultrasound or evaluating the size of the uterus by manual palpation
2. First level and second level diagnostic work-up are performed according to the patient's hemodynamic status and neurological condition.
3. In the absence of traumatic injuries, a clinical observation period in the gynecology department is warranted, especially if risk factors for obstetric complications are present (contractions >5/h, vaginal bleeding, amniotic fluid leakage, increased uterus tone, abdominal tenderness).
4. If the maternal traumatic injuries require surgery, a concomitant cesarean section should be considered in the event of: injured uterus, placental abruption >50%, fetal impairment, maternal pelvis fracture, gestational period >23 weeks.
5. If the maternal traumatic injuries can be managed non-operatively, the patient must be admitted to the trauma ward and an obstetric re-evaluation performed.

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Damage Control Surgery: An Update

6

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6.1 Introduction

Damage control surgery (DCS) represents a staged management approach for those injured patients who present with severe physiological compromise and who require surgical intervention. This strategy focuses on physiological and biochemical stabilization of the patient prior to the comprehensive anatomical and functional repair of all injuries. DCS can be applied across all body cavities as a continuum, according to the degree of physiological derangement [1, 2]. The DCS paradigm is strictly related to the concept of damage control resuscitation, which focuses on initial hypotensive resuscitation and early use of blood products to prevent/correct the lethal triad of acidosis, coagulopathy, and hypothermia [3]. Appropriate selection of patients requiring DCS is critical. It is estimated that 10% of traumatized patients require DCS [3]. However, although this strategy is widely used and has been reported to result in improved survival, up to 50–70% [4] in the severely injured, it is associated with a high incidence of potentially severe complications, hospital readmissions, subsequent surgical procedures, and a reduced quality of life because of the aftermath of the treatment [5]. For these reasons, it is crucial to ensure that DCS is provided to the right patients within the correct scenarios.

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6.2 Indication for DCS

As general rule, the patient who truly requires DCS is a patient who is more likely to die from an uncorrected shock state than from failure to complete organ repair [6]. It must be noted that not all patients with initial physiological derangement require DCS, if their physiological parameters improve after rapid control of hemorrhage and effective resuscitation, allowing definitive repair of the injuries.

In two content analysis and appropriateness rating studies, Roberts et al. [7, 8] identified the trigger points to dictate DCS with the greatest expected benefit-to harm ratio (Table 6.1). The results of these analyses showed that the presence of physiologic reserve compromise, defined as hypothermia, acidosis, coagulopathy in the pre- or intraoperative setting, represents the indication for DCS in more than 47% of cases.

Table 6.1 Indications for use of damage control surgery in civilian trauma patients [7, 8]

Degree of physiologic insult – Hypothermia (core T < 34 °C), acidosis (pH <7.2), and/or clinical or laboratory coagulopathy in the pre- or intraoperative settings (PT and PTT >1.5 times normal) – Persistent intraoperative cellular shock (VO_2I < 100 mL/min/m^2, lactate >5 mmol/L, pH <7.2, BD >15 mmol/L, core T < 34 °C) – Development of intraoperative ventricular arrhythmias
Amount of resuscitation provided – A large volume of PRBCs (median > 10 U), other blood products, and crystalloids combined (median > 12 L) administered preoperatively or across the pre- and intraoperative settings
Injury patterns – A difficult access major venous injury (intrahepatic, retroperitoneal, or pelvic) – A major liver or combined pancreaticoduodenal injury with hemodynamic instability in the OR – A combined pancreaticoduodenal injury with massive hemorrhage from the head of the pancreas – Devascularization or massive disruption of the duodenum, pancreas, or pancreaticoduodenal complex with involvement of the ampulla/proximal pancreatic duct and/or distal CBD – Pulmonary hilum, lung parenchymal injuries – Cardiac injury – Major vascular injuries of the extremities – Complex pelvic injuries – Complex extremities injuries
Inability to control bleeding by conventional methods
Need for staged abdominal or thoracic wall reconstruction – Inability to close the abdominal or thoracic wall without tension because of visceral edema – Signs of an abdominal or thoracic compartment syndrome developed during attempted abdominal or thoracic wall closure
Need to reassess the extent of bowel viability after a period of further resuscitation in the ICU

BD base deficit, *CBD* common bile duct, *ICU* intensive care unit, *OR* operating room, *PRBCs* packed red blood cells, *PT* prothrombin time, *PTT* partial thromboplastin time, VO_2I oxygen consumption index

Additional highly appropriate indications are represented by the need for large-volume fluid resuscitation, both pre- and intraoperatively, because it carries the risks of dilutional coagulopathy, visceral edema, intra-abdominal hypertension, and abdominal compartment syndrome.

The injury patterns which better indicate the appropriateness of DCS are represented by those injuries presenting significant management challenges. These include zone I and III neck injuries with concurrent internal and external hemorrhage; major lung and pulmonary hilum, cardiac, liver and juxtahepatic venous injuries, and combined pancreaticoduodenal injuries; actively bleeding major abdominal, pelvic, and peripheral vascular injuries [9]. These patterns are characteristic of those with competing management priorities, which have the potential for intraoperative exsanguination during attempted definitive repair.

6.3 Steps of Damage Control Surgery

The historical three-step DCS has recently been outlined in five clinical phases, which follow one another as a continuum, from recognition of the unwell patient to definitive repair of the injuries [10].

6.3.1 DCS Part 0: Recognition of Injuries and Goal-Directed Hemostatic Resuscitation Without Delaying Surgery

This step begins on the field, with truncated scene times, after the rapid recognition of the patient needing expeditious transfer to the referral center, and continues in the emergency department (ED), through a rapid assessment of the injuries, and applying the principles of damage control resuscitation (DCR) to minimize blood loss, maximize tissue oxygenation, and optimize the outcome.

In the ED a minimal work-up is required. The cornerstones are extended focused assessment with sonography for trauma (E-FAST), an antero-posterior pelvic plain film, and an antero-posterior chest plain film, in order to identify the most probable site of the hemorrhagic injuries. Whole-body computed tomography (WBCT) in unstable patients not responding to resuscitation efforts is not warranted, so as not to delay access to hemostatic maneuvers. A WBCT scan in the unstable patient could be considered only in a logistically favorable environment and by a well-organized trauma team. Hemorrhagic patients with associated neurological impairment and lateral signs (anisocoria) and those who remain unstable without any evidence of bleeding may represent the exception for CT. In the former case, head CT alone, after the ED work-up, allows rapid recognition of any cerebral injuries potentially amenable to surgery; in the latter case, torso contrast-enhanced CT (CECT) allows detection of other causes of instability (i.e., spinal cord trauma).

The main elements of DCR are:

- **CAB resuscitation** [3]
  Borrowed from the military experience, the aim is to rapidly deal with life-threatening external bleeding using the field-dressing, tourniquet and topical hemostatic agents. When control of catastrophic hemorrhage(s) has been achieved, AB is dealt with along the conventional trauma paradigm.
- **Permissive hypotension**
  A mean arterial pressure (MAP) of 50 mmHg is a well-tolerated strategy that results in less overall blood product and fluid administration, decreased dilutional coagulopathy, and reduced early death [11]. In patients having associated traumatic brain injury, permissive hypotension should last as little as possible. After hemorrhage control a MAP of 85 mmHg is advised.
- **Massive transfusion protocol (MTP) and limitation of crystalloids**
  Early and balanced transfusion of plasma and platelets along with units of red blood cells (i.e., maintaining the plasma:platelet:red blood cell ratio closer to the 1:1:1 ratio of whole blood), while simultaneously minimizing crystalloid use in order to avert or reverse the triad of coagulopathy, acidosis, and hypothermia and decrease endothelial permeability is warranted [12–14].
- **Early use of tranexamic acid (TXA)**
  Tranexamic acid reduces bleeding by inhibiting the enzymatic breakdown of fibrin blood clots (fibrinolysis). The CRASH2 trial [15] showed that in patients with trauma with major extracranial bleeding, early administration (within 3 h of injury) of tranexamic acid reduces bleeding deaths by a third.
- **Pre-hospital and emergency department hemostatic procedures**
  Surgical life-saving maneuvers (i.e., pleural decompression, wound packing, tourniquet, extraperitoneal pelvic packing [16]), angioembolization [17], use of resuscitative endovascular balloon occlusion of the aorta (REBOA) [18] represent the strategies to obtain expeditious bleeding control.

6.3.2 DCS Part 1: Abbreviated Surgery, Prioritizing Physiology over Anatomy

During this phase, truncated surgery is used to rapidly control exsanguinating hemorrhage, massive air leak, and/or gross contamination [7]. Additional surgery has to be performed only once the physiological reserve has been restored. Historically introduced for abdominal trauma [19], nowadays damage control techniques are generally accepted throughout all body regions (Table 6.2) [20–29], although liver and major abdominopelvic vascular injuries still remain the main indications for DCS.

6.3.2.1 Operating Room Set-Up

The operating room must be set up properly. Room temperature should be kept between 70 °F and 80 °F (21–26 °C) and equipped with all devices and technology which can be useful in DCS, such as rapid infuser with warming of infusions, blood saver equipment, instruments for abdominal and chest surgery, vascular clamps, laparotomy pads, stapler for intestinal resection, temporary vascular shunts.

Table 6.2 Damage control surgery across body cavities [19–31]

Body region	DCS Intervention	Description
Head/spine	ICP monitoring	A probe is positioned, usually intraparenchymal, to monitor intracranial pressure
	Decompressive craniectomy	A large bone flap is removed to release brain swelling. Focal injuries are evacuated and hemostasis achieved. Dura is always closed primarily
	Spine decompression and stabilization	Epidural hematoma is evacuated, posterior fixation/instrumentation performed
Maxillofacial	Airway management	Orotracheal intubation, cricothyroidotomy, or surgical tracheotomy are performed
	Bleeding control	Nasal or oral packing is used to control bleeding, angioembolization or selective ligation of the external carotid artery may be used to control life-threatening hemorrhages
Neck	Airway management	Orotracheal intubation, cricothyroidotomy, or surgical tracheotomy are performed. Direct intubation through the airway injury may be performed in cases of open wound
	Bleeding control	Packing, Foley catheter through the wound, bone wax may be used to control hemorrhage, angioembolization controls bleeding in zone III

(continued)

Table 6.2 (continued)

Body region	DCS Intervention	Description
Thorax	Cardiorraphy	Interrupted stiches are placed after temporary hemorrhage control with stapler or Foley catheter inserted into the bleeding wound tract
	Pneumonorrhaphy	After small injured vessels and bronchi within the parenchyma of a superficial pulmonary laceration are selectively ligated, the edges are approximated
	Pulmonary tractotomy	The lung bridging a pulmonary parenchymal wound is divided using a GIA 55/75 vascular stapler or between two long vascular clamps and then small injured parenchymal vessels and bronchi lying underneath are selectively ligated
	Pulmonary wedge resection	A GIA 55/75 or TA 30/60/90 vascular stapler is used to resect a peripheral portion of a pulmonary lobe or segment of lung
	Rapid, simultaneously stapled pneumonectomy	A TA 90/55 vascular stapler is placed across the pulmonary hilar structures and fired, resulting in an *en masse* simultaneous division of the mainstem bronchus and pulmonary vessels
	Intraluminal drainage of the proximal esophagus and wide drainage of the pleural space	The esophagus above or at the site of an esophageal injury is drained with a nasogastric tube connected to low suction while the pleural space is widely drained with thoracostomy tubes
	Therapeutic mediastinal and/or pleural space packing	Compressive gauze packing is applied to the mediastinal and/or pleural surface to tamponade venous and/or coagulopathic hemorrhage at least until the first reoperation (which frequently occurs within 24–48 h)
	Temporary thoracic closure	The thoracotomy incision is temporarily closed *en masse* using a heavy, nonabsorbable, running suture or with towel clips, a patch or silo/Bogota bag, or a modified Barker's vacuum pack or commercial negative-pressure wound therapy device

(continued)

Table 6.2 (continued)

Body region	DCS Intervention	Description
Abdomen	Packing	Compressive gauze packing is placed above and below the liver and spleen, and in the paracolic gutters. The interposition of a plastic sheet is not warranted
	Balloon catheter tamponade	For penetrating liver injuries, A Foley, Fogarty, Sengstaken-Blakemore, or improvised balloon catheter (created using a red rubber catheter and Penrose drain) is inserted into a bleeding wound tract. The balloon of the catheter is then inflated with sterile water and repositioned until adequate hemostasis is achieved
	REBOA	A REBOA device is inflated in zone I (supradiaphragmatic) to control bleeding from parenchymal injuries. The aortic occlusion may be complete, partial, intermittent, depending on the patient's physiologic derangement
	Staged pancreaticoduodenectomy	Major vascular hemorrhage is controlled and, where necessary (sometimes this has already been done by the inciting trauma), the duodenum distal to the pylorus, common bile duct, pancreas distal to the injury, and distal duodenum or jejunum are transected; and the right upper quadrant and peripancreatic space are widely drained
	Bilateral externalized ureteral stenting and diversion	When neither transurethral or suprapubic drainage effectively evacuates urine from the injured bladder, J-stents are passed up each ureteral orifice and then externalized to divert the urinary output of both kidneys until definitive repair of the bladder is possible
	Bilateral internal iliac artery ligation	Both internal iliac arteries are ligated using heavy, permanent sutures during laparotomy
	Interventional radiology	Angioembolization may be used to control residual bleeding or in cases of challenging bleeding control
	TAC/open abdominal management	The abdomen is temporarily closed using a Barker's vacuum pack, commercial negative-pressure peritoneal therapy device

(continued)

Table 6.2 (continued)

Body region	DCS Intervention	Description
Pelvis	EPP	After a 6- to 8-cm midline incision is made extending from the pubic symphysis cephalad (dividing the midline abdominal fascia) and the preperitoneal space is opened using digital dissection (where necessary), laparotomy pads are placed on either side of the bladder, the fascia is closed with a heavy suture, and the skin is closed with staples
	Interventional radiology	Angioembolization is useful to control bleeding if the patient remains unstable despite external mechanical compression or after EPP
	ExFx	Anterior ExFx can be placed into the iliac crest or supra-acetabular area. In unstable patients, the iliac crest route is faster, the pins can by placed without fluoroscopic guidance. The C-clamp is indicated in the presence of ligamentous VS injuries through the sacroiliac joint, VS injuries with "zone 1" sacral body fractures and APC3 equivalent injuries with vertical instability
Extremities	ExFx	External fixation, especially in the setting of bilateral femoral fractures in patients with multiple injuries, should be considered
	Temporary intravascular shunt	After an embolectomy and administration of local intravascular heparinized saline, the defect in the injured artery and/or vein is bridged with vascular shunt or with a piece of an intravenous line or nasogastric/chest tube (cut to length such that it overlaps within the vessel by approximately 2 cm and secured into place with a heavy silk tie on either end). The shunt is left in place until at least the first reoperation (which frequently occurs within 24–48 h)
	Interventional radiology	Angiography may facilitate endovascular repair of particularly anatomically challenging injuries

APC3 anterior posterior compression type III, *EPP* extraperitoneal pelvic packing, *ExFx* external fixators, *ICP* intracranial pressure, *REBOA* resuscitative endovascular balloon occlusion of the aorta, *TAC* temporary abdominal closure, *VS* vertical shear

6.3.2.2 Patient Position

For torso procedures the patient lays supine in a cruciform position with both arms abducted, prepped from chin to middle thighs and laterally down to the table. This preparation of the field allows surgical incisions of the neck, the chest (antero-lateral thoracotomy, sternotomy, tube thoracostomy), laparotomy, and femoral vessels at the groin. The patient is instrumented with electrocardiogram, arterial and venous lines, urinary catheter and gastric tube, while resuscitation and control of hemorrhage are ongoing: the instrumentation of the patient should not interfere and delay surgical control of the source of bleeding.

6.3.2.3 Surgical Incisions for Torso Injuries

The abdomen is explored through a midline incision extended from xiphoid to pubis. The incision is limited to the area around the umbilicus in the presence of pelvic fracture because separation of the muscles at the midline causes further opening of the pelvic bones, with worsening of retroperitoneal hematoma. The midline incision of the abdomen allows optimal exposure and can be extended subcostally to improve the view of difficult areas, such as the suprahepatic-caval junction. In the case of thoracic DCS, the thorax is entered through an anterolateral thoracotomy in the left fifth intercostal space, with the possibility to extend the incision contralaterally (clam-shell thoracotomy). Neck DCS is approached through a standard incision along the sternocleidomastoid muscle, with the head slightly rotated contralaterally.

6.3.2.4 Hemorrhage Control

For abdominal DCS, the steps of laparotomy are as follows:

1. Incision at the midline
2. Removal of large clots and release of tamponade
3. Packing of all four quadrants
4. Rapid control of major vascular bleeding, achieving proximal and distal control of vessels.

Adequate packing should provide a good degree of hemorrhage control for venous and solid organ bleeding (Fig. 6.1).

The technique to perform adequate packing is:

1. Retract the anterior abdominal wall
2. Hand over organ to protect it
3. Take down the falciform ligament
4. Pack above and below the liver and spleen
5. Sweep small bowel and colon medially to pack the paracolic gutters and base of mesentery
6. Sweep bowel cephalad to pack the pelvis.

Radiopaque pads only are to be used and an accurate count by scrub nurse must be done. The use of plastic sheets between solid organ parenchyma and pads is not warranted. Attention must be paid not to either overpack, which may worsen diaphragmatic excursions and compression of the inferior vena cava, or underpack, which may be not effective. If the patient remains profoundly unstable after packing, aortic inflow at the diaphragmatic hiatus should be obtained. This can be achieved with manual occlusion, vascular clamp or with REBOA placed in zone I. Once clamped, time should be noted as severe ischemia will develop unless aortic outflow is restored. For major vascular injuries, DCS options are either ligation or placement of temporary vascular shunts in critical arteries. Ligation of almost any major vein is usually a survivable procedure, if required.

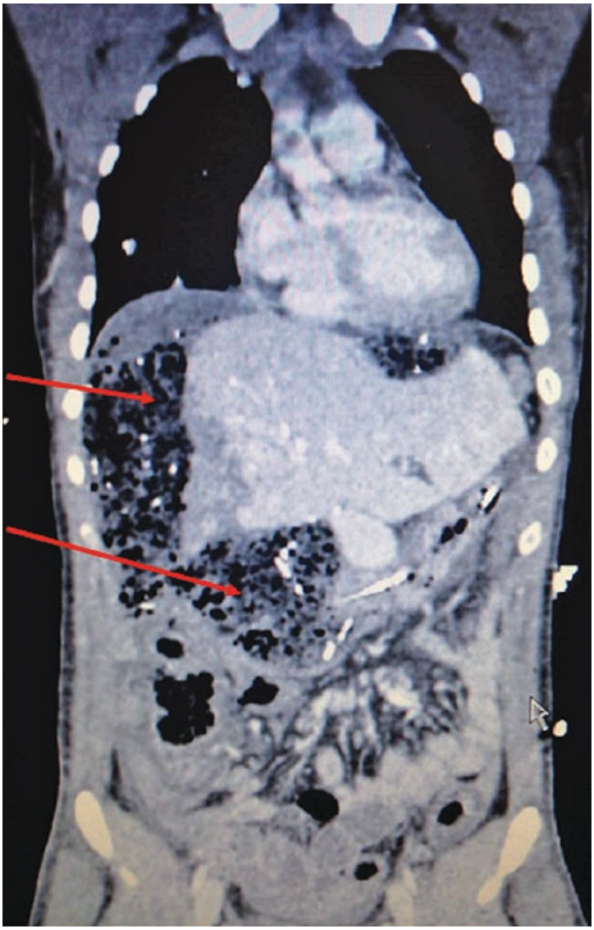

Fig. 6.1 Computed tomography scan after abdominal packing for a liver trauma (*red arrows*, laparotomy pads for packing)

Once the patient has been stabilized the surgeon may address the injuries:

1. Removing the packs one quadrant at a time, starting from the remote area of suspected injury
2. Inspecting for active bleeding (expendable organs such as the spleen and, to some extent, the kidney should be removed), bowel, diaphragm, and bladder injuries.

6.3.2.5 Contamination Control

Spillage of biliary and pancreatic juice, intestinal content and urine can be addressed after hemorrhage control:

1. Biliopancreatic injuries, in a vast majority, can be managed initially with closed-suction drainage, until ultimate repair or resection can be undertaken later.

Drains are brought out through the flank, if possible laterally to the external edge of the rectus muscle, and intra-abdominal packs are carefully placed so as not to cause kinking of these tubes.
2. All bowels must be inspected completely. Spillage control may be achieved with simple suture, clamps, skin staples, or resection leaving the stump abandoned.
3. Bladder injuries can be rapidly oversewn, and ureteral injuries are amenable to either ligation or exteriorization. Temporary nephrostomy may be required to relieve the renal obstruction as a result of ureteral ligation.

DCS Part 1 cannot be considered completed until all surgical bleedings are arrested. Interventional radiology techniques are useful to halt uncontrolled bleeding in complex hepatic, retroperitoneal, and pelvic injuries that are not amenable to surgical control or would require lengthy surgical exploration in the setting of coagulopathy. Endovascular procedures may be performed using either mobile imaging or a hybrid operating room.

6.3.3 DCS Part 2: Dynamic Intraoperative Reassessment of Physiology

A continuous reassessment of the patient's metabolic derangement is mandatory during DCS Part 1. Although it has commonly been suggested that prolonged operation should be avoided in severely injured patients, recent indications for use of DCS in civilian trauma [7] suggest that if patients are not already in physiological extremis, it may be appropriate to complete a definitive operation as long as they demonstrate an adequate response to resuscitation. If not, the surgical intervention is truncated and a temporary closure of the body cavity performed. Options for effective temporary closure are well described for the abdomen (temporary abdominal closure), ranging from simple skin-only closure to industry-made devices (i.e., negative pressure wound therapy) [30].

6.3.4 DCS Part 3: Continued Physiological Restoration in the Intensive Care Unit

The goal of this phase is to restore the physiological reserve to allow within 24–36 h the take-back to the operating room for definitive repair of the injuries and abdominal closure. Acidosis and coagulopathy must be corrected with an aggressive strategy, and the patient rewarmed and re-evaluated with a tertiary survey. Unplanned reoperation before physiological restoration may be necessary in the event of:

– a patient with ongoing transfusion requirements or persistent acidosis despite normalized clotting and core temperature; missed surgical bleeding or visceral injury must be suspected;

– onset of abdominal compartment syndrome, defined as sustained intra-abdominal pressure (IAP) >20 mmHg in the presence of new single or multiple organ system failure.

6.3.5 DCS Part 4: Definitive Reconstruction

At this stage, all packs are irrigated copiously and removed carefully to avoid further visceral damage or rebleeding. If a persisting bleeding is encountered the definitive repairs must be delayed and repacking performed to avoid recurrent physiological deterioration. After successful depacking, a complete re-examination of the cavity should occur, paying particular attention to previous repairs made during DCS Part 1. A plain film of the body cavity must be obtained not to miss retained pads. In the abdomen, gastrointestinal continuity is re-established, a stoma is formed if necessary, and solid organ debridement is performed as needed. Formal abdominal closure without tension is attempted. Nevertheless, if the peak airway pressure increases by >10 cmH_2O or IAP is higher than 15 mmHg the fascia should be left open and the temporary abdominal closure device replaced. In this case the aim is to achieve a fascial closure within 7 days to avoid complications such as enteroatmospheric fistula [31].

6.4 Damage Control for Extra-Abdominal Injuries

6.4.1 DCS for Neurosurgical Injuries [20, 21]

Principles are the early monitoring of intracranial pressure, the arrest of intracranial bleeding, the evacuation of intracranial hematomas, and the limiting of contamination of compound wounds of the head by early surgical debridement. The dura is always closed primarily and the scalp is preferably closed over the dura so that the risk of intracranial infection is minimized. The bone flap must be removed after hematoma evacuation if there is a risk of brain swelling. Application of damage control principles to the spine varies depending on the pattern of injury to the bony structures and extent of spinal cord involvement, according to the postulate that primary mechanical spinal cord injury initiates a series of secondary injury events that exacerbate spinal cord damage. The steps are to evacuate epidural hematoma, to stabilize major fracture(s)/reduce dislocated joint(s) with posterior fixation and instrumentation within 24 h, and to decontaminate open wound(s). Scheduled surgery for a 360° fusion should be done within 3 days if an anterior decompression is indicated for neurological or biomechanical reasons.

6.4.2 DCS for Maxillo-Facial Injuries [22]

Critical hemorrhage from bone fractures and soft tissue injuries and airway compromise can be challenging in maxillo-facial injuries. The airway can be controlled with orotracheal intubation, but a surgical airway may be the only chance (cricothyroidotomy, tracheostomy). Bleeding is addressed in emergency with oral and nasal packing and, in critical conditions, ligation of the external carotid artery/ies is an option. Bone fractures are temporarily stabilized with external fixation or handmade interdental splints. After damage control, a contrast-enhanced CT scan is obtained to detect residual bleeding, and angioembolization will definitely control ongoing hemorrhage. Definitive reconstruction of maxillo-facial injuries will be performed after few days, when the tissue edema has regressed and physiology is restored.

6.4.3 DCS for Neck Injuries [23]

Because of the peculiar anatomy of the neck, DCS must guarantee airway control, hemorrhage control and control of potential contamination from the airway and digestive tract. For the purposes of initial assessment and management planning, the neck is divided into three zones:

- ***Zone I***
  Zone I extends between the clavicle/suprasternal notch and the cricoid cartilage (including the thoracic inlet). Surgical access to this zone may require thoracotomy or sternotomy. Major arteries and veins, trachea and nerves, esophagus, lower thyroid and parathyroid glands and thymus are located in this zone.
- ***Zone II***
  Zone II lies between horizontal lines drawn at the level of the cricoid cartilage and the angle of the mandible. It contains the internal and external carotid arteries, jugular veins, pharynx, larynx, esophagus, recurrent laryngeal nerves, spinal cord, trachea, upper thyroid and parathyroid glands.
- ***Zone III***
  Zone III extends between the angle of the mandible and base of skull. It contains the extracranial internal carotid and vertebral arteries, jugular veins, cranial nerves IX–XII and sympathetic nerve trunk.

The surgical approach is usually made through a standard incision along the sternocleidomastoid muscle, with the head slightly rotated contralaterally. Hemorrhage may be controlled with packing, a Foley catheter, or bone wax. Angiography may represent the only effective strategy to control ominous bleeding in zone III.

6.4.4 DCS for Thoracic Injuries [24–26]

Since some intrathoracic injuries require definitive repair while others can be temporized, the approach to thoracic DCS should be to perform procedures that are technically faster and simpler for definitive repair and to perform maneuvers to temporize those injuries that do not require immediate repair in the patient in extremis. The standard approach is through a left anterolateral thoracotomy extending from the sternum to the stretcher laterally, below the nipple at the fifth intercostal space, with the aims to release pericardial tamponade, to control intrathoracic bleeding, massive air embolism or bronchopleural fistula, to permit open cardiac massage and to allow for cross-clamping of the descending thoracic aorta. The patient is supine, with both arms out. If deflation of the left lung is needed, a bronchial blocker or advancement of the endotracheal tube into the right main stem is easier than trying to place a double-lumen endotracheal tube. Clam-shell thoracotomy should be performed to gain access to mediastinal structures or to control contralateral injuries. Median sternotomy or supraclavicular extension or both may be required to provide proximal vascular control in subclavian artery injuries; the "trap door" incision has been abandoned, due to the significant associated morbidity. Successful hemostasis may be achieved by packing around the apex, diaphragm and vertebrae. Moreover, packing should be carefully considered, because the presence of bulky gauzes may induce increased intrathoracic pressures, with potential cardiopulmonary collapse, desaturation and ventilation disorders. In this case, a temporary thoracic closure may be achieved with a Bogota bag, without exerting undue intrathoracic pressure.

6.4.5 DCS for Orthopedic Injuries [27]

Damage control orthopedics is the current treatment of choice for the severely injured patient, especially those with unstable pelvic ring injuries associated with hemodynamic instability and proximal long bone fractures. Timely control of bleeding in pelvis fractures should use damage control principles, such as packing and adjunctive measures such as REBOA. Provisional fracture stabilization is obtained by closed reduction with binder or sheet and external fixator of any fractured pelvis with increased pelvic volume. After damage control of the pelvis, a contrast-enhanced CT scan is obtained to detect occult bleeding and angioembolization, if needed, is the treatment of choice. Blood loss from long bone fractures can be reduced by temporary splinting followed by external fixation in emergency, as a bridge to definitive stabilization.

6.4.6 DCS for Extremity Vascular Injuries [28, 29]

Complex vascular injuries of the extremity accompanied by skeletal fractures or soft tissue destruction still result in a rate of limb loss of up to 20%. Tourniquets may prevent exsanguination, as can ligation, balloon occlusion or clamping of an injured blood vessel, but irreversible tissue loss may occur if such measures are maintained while other injuries are treated. Complex repairs, including end-to-end anastomosis, saphenous vein grafts and vascular prosthesis transplantation, are time-consuming. Temporary intravascular shunts in such cases have the potential advantage of facilitating rapid control of hemorrhage and restoration of distal flow while permitting deferment of definitive repairs to higher echelons of care where greater resources and expertise will be available. Commercially available shunts (the Javid, Sundt, Argyle and Pruitt-Inahara carotid shunts) or self-made tubes (i.v. lines, feeding tubes, chest tubes) may be used, depending in the vessel diameter. The shunt size should be the largest diameter that fits comfortably into the injured vessel. Once obtained proximal and distal vascular control a Fogarty is passed to remove intraluminal thrombi, the shunt distal edge is inserted first and back-flow appreciated; the proximal edge is inserted after heparinized saline; the shunt is secured as close to the vessel edge as possible. The flow through the shunt should be regularly monitored by palpating distal pulses or by Doppler ultrasound. A temporary arterial shunt could maintain patency with adequate distal perfusion for up to 24 h without systemic anticoagulation. Primary amputation should be considered for mangled extremities which threaten life and when patient survival may be jeopardized by limb salvage efforts.

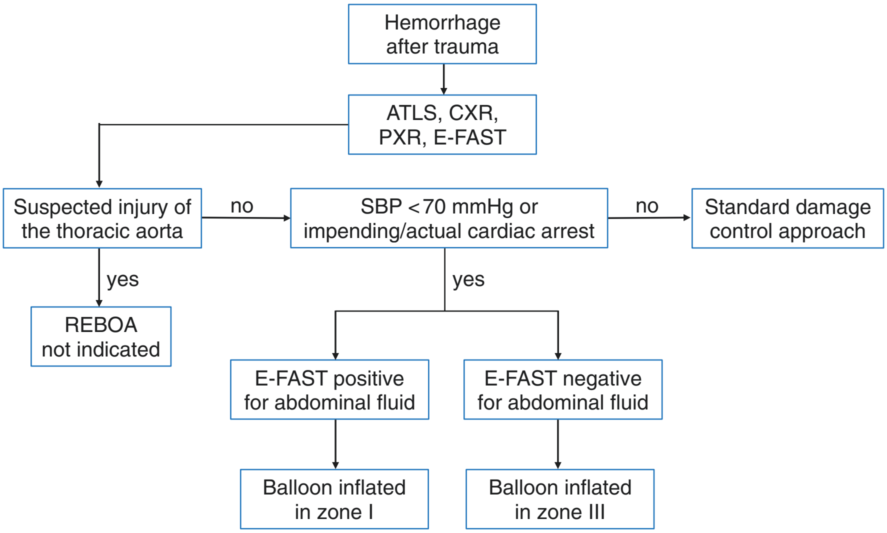

Fig. 6.2 Algorithm for the use of resuscitative endovascular balloon occlusion of the aorta (REBOA) in hemorrhagic trauma patient. *ATLS* advanced trauma life support, *CXR* chest x-ray, *PXR* pelvis x-ray, *E-FAST* extended focused assessment with sonography for trauma, *SBP* systolic blood pressure

6.5 Resuscitative Endovascular Balloon for the Occlusion of the Aorta

The resuscitative endovascular balloon for the occlusion of the aorta (REBOA) has been introduced in recent years as a technique for limitation or cessation of blood flow through the thoracic or abdominal aorta in patients with non-compressible torso hemorrhages [32]. This technique for temporary control of bleeding should be applied as a bridge to more definitive damage control procedures in very sick patients (Fig. 6.2).

6.5.1 Technique of Insertion

REBOA can be inserted via the common femoral artery either percutaneously, with or without ultrasound guidance, or through a surgical cutdown. The balloon is inflated in aortic zone I (from the left subclavian artery origin to the celiac axis), in patients with positive E-FAST for abdominal fluid, with the aim of stopping bleeding from the abdomen, pelvis and lower extremities. Ischemia of this large part of the body is poorly tolerated and the occlusion should not be kept for more than 15 min. In hemorrhagic patients with negative E-FAST and x-ray of the pelvis showing unstable pelvic fractures, the REBOA is inflated in aortic zone III (below the renal arteries) to stop retroperitoneal bleeding. The aortic occlusion in zone III can be maintained for 20 min. In both zones I and III occlusion time can be prolonged if the balloon is partially inflated, but the evidence is still limited. Modern catheters allow proximal pressure recording from the tip and the inflation can be adjusted to maintain the desired pressure in the aorta above the balloon without the need for a complete vascular occlusion.

6.5.2 Complications

The use of REBOA is associated with a high incidence of complications, up to 20%. The most important problems with this technique are injuries to the femoral artery requiring surgical reconstruction, and limb ischemia provoked by distal dissection or embolization, with sometimes a need for amputation. Injury of the thoracic and abdominal aorta have been described due to dissection or perforation of the wall during progression of the catheter, and aortic rupture caused by hyperinflation of the balloon. The complication rate is reduced if a low diameter catheter (7–8 Fr) with atraumatic tip is used.

6.5.3 Evidence

The application of REBOA for temporary control of torso hemorrhage is a controversial issue. After initial enthusiasm, many concerns have been expressed for the high rate of complications, on the one hand, and the uncertain results, on the other. A review of the literature suggests that REBOA can be associated with a survival benefit in patients with impending or actual cardiac arrest from hemorrhagic shock, when compared to resuscitative thoracotomy [33]. Conversely, when REBOA was compared with standard damage control procedures (abdominal or pelvic packing) in less severe conditions of hemorrhagic shock, no clear survival improvement was observed [34].

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Damage Control Resuscitation and Massive Transfusion

7

Marc Maegele

7.1 Introduction

Uncontrolled hemorrhage and exsanguination remain a significant problem during acute care for the severely injured and the most common cause of preventable death after trauma [1, 2]. On hospital admission, one out of four patients is coagulopathic according to standard coagulation tests—prothrombin time (PT), activated partial thromboplastin time (aPTT), and/or viscoelastic signs of disturbed hemostasis—which has been associated with poor outcomes [3, 4]. Early detection and aggressive treatment are key, as death from exsanguination, if uncontrolled, occurs rapidly at median 1.65 h from hospital admission [5].

Data from the German Trauma Registry database (TR-DGU, TraumaRegister der Deutschen Gesellschaft für Unfallchirurgie) have shown that the percentage of trauma patients in need of immediate transfusion of blood products on arrival to the trauma bay has declined consistently over the last two decades, from 42% before 2000 to 19% in 2009 and to 7% in 2017 [6]; the percentage of patients in need of massive transfusion (MT) decreased from 12.4% in 2002 to 1.4% in 2017 (Fig. 7.1) In a single-center cohort of major trauma patients reported from Australia, the proportion of patients receiving MT decreased from 8.2% to 4.4% ($p < 0.001$) between 2006 and 2011 [7]. This development mainly corresponded to improvements in both pre-hospital and early in-hospital trauma care through the implementation of standardized protocols and algorithms for acute care surgery and resuscitation—such as Pre-Hospital Trauma Life Support (PHTLS), Advanced Trauma Life Support (ATLS), Damage Control Surgery (DCS) and Damage Control Resuscitation (DCR) principles—as well as more selective fluid resuscitation strategies, which make it possible to prevent the detrimental "lethal triad of death".

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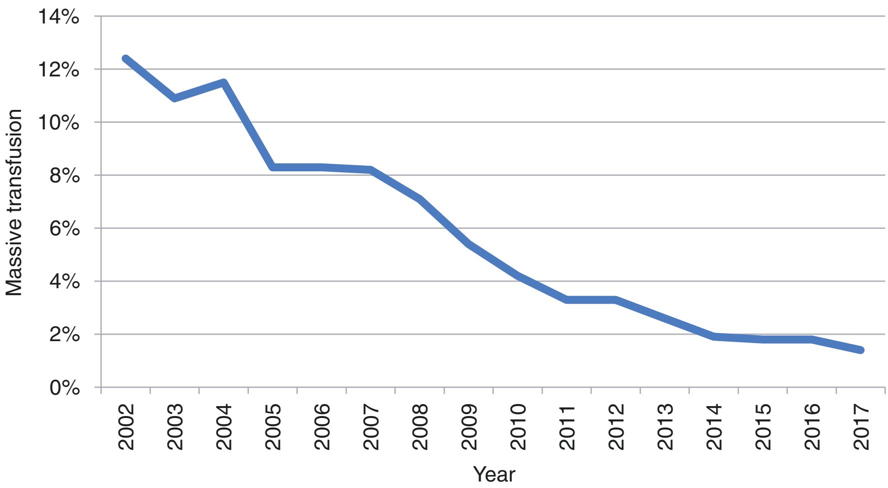


Fig. 7.1 Percentage of patients in need of massive transfusion upon emergency room arrival 2002–2017. Data from the German Trauma Registry database (TraumaRegister der Deutschen Gesellschaft für Unfallchirurgie): n = 98,873 patients; primary admissions with an ISS > 16

7.2 Damage Control Resuscitation

In principle, DCR is considered the natural extension of the initial concept of DCS [8]. It comprises:

1. immediate arrest and /or temporization of the bleeding;
2. early blood product administration;
3. restoration of blood volume;
4. restoration of physiologic/hematologic stability (correcting coagulopathy, acidosis and hypothermia).

Along with DCS, it extends the overall concept through the early initiation of blood product transfusions, limited crystalloid fluid administration, permissive hypotension in selected populations and immediate hemorrhage control (operative or angiographic). A recent analysis of all United States military casualties from October 2001 through December 2017 found that survival among the most critically injured casualties increased three-fold during the course of the conflicts in Afghanistan and Iraq and that three key interventions were associated with 44% of mortality reduction:

1. use of tourniquets to control acute hemorrhage;
2. early blood transfusions;
3. limitation of prehospital transport time to 60 min [9].

7.3 Massive Transfusion Protocols

Coagulopathy in the context of trauma was historically considered a consequence of resuscitation, hemodilution and hypothermia, but the pathophysiology behind this novel entity appears now much more complex than initially thought. The key players as yet identified include tissue trauma, shock, hemodilution, hypothermia, acidemia and inflammation [1] but also damage to the endothelium triggering further downstream sequels [10, 11]. The recognition as well as the improved understanding of the mechanisms including their interplay supports the modern use of massive transfusion protocols.

To date, MT practice in most trauma centers follows locally implemented massive transfusion protocols (MTPs) and algorithms with different activation triggers and different strategies in the use of blood products and hemostatic agents [12]. The protocolized resuscitation with blood products aims to achieve an early high plasma:packed red blood cells (pRBC) ratio approximating fresh whole blood, and has been associated with improved survival in trauma patients through better proximal resuscitation [13]. The 2019 European guideline on the management of major bleeding and coagulopathy following trauma in its fifth edition currently recommends (Grade 1C) a fresh frozen plasma (FFP):pRBC ratio of at least 1:2 for the initial management of patients with expected massive hemorrhage [14]. The benefits of a formal MTP comprise earlier administration of blood products during acute care and resuscitation, enhanced blood banking efficiency, reduced overall blood product use during a hospital stay and economic savings [15]. If the initiation of an MTP is accurately based on rapid recognition of physiologic exhaustion secondary to persistent hemorrhage, then it also typically acts as a trigger for the entire damage control process [8]. Vice versa, it is re-emphasized that some severely injured patients may dramatically improve with an MTP and reverse their physiologic derangements to an extent to allow the surgeon to complete the operative intervention with definitive care (i.e., rather than leaving the abdomen open) [8]. However, the optimum dose, timing and ratio to pRBC of other blood components, such as FFP, platelets, cryoprecipitate or fibrinogen concentrate, to reduce morbidity and mortality in critically bleeding trauma patients requiring MT remains a topic of discussion [16]. Likewise, there remains scientific concern with respect to the apparent improvement in survival with MTPs due to potential survival bias, i.e., surviving long enough to receive the most RBC units [17]. With the 2015 findings of the PROPPR trial (one of the very few prospective and randomized trials on blood product ratios in the context of DCR) study group, most hospitals follow on a 1:1:1 ratio of pRBC:FFP:platelet products [18] but with variable success [19].

7.4 Prediction of Massive Transfusion and Activation of Massive Transfusion Protocols

The early identification of bleeding trauma patients in need of MT is key for the timely activation of MTPs including corresponding logistics. However, current practice can be best described as institutional- or provider-centered, which should be supplemented by score-based protocols with auditing and monitoring tools for further refinement [20]. It has been demonstrated that both short- and long-term survival is significantly increased when MTPs are activated immediately upon hospital admission rather than later in the operating theatre [21].

7.4.1 Scoring Systems

A range of scoring systems and prediction models for early risk stratification of patients requiring MT have been derived through means of retrospective analyses from civilian and military datasets [20, 22]. Of course, these models need to have appropriate sensitivity and specificity to safely exclude those patients not in need of large volumes of blood products so as to limit unnecessary infectious exposure through over-transfusion and to save valuable resources. Six scoring systems to stratify patients for the risk of MT at a very early stage after trauma have been validated on one single dataset of severely injured patients (n = 5147 patients) derived from the TR-DGU database [22]. The overall MT rate in this cohort was 5.6% (n = 289) and 95% (n = 4889) of patients had sustained a blunt trauma. The Trauma Associated Severe Hemorrhage (TASH) score had the highest overall accuracy as reflected by an area under the curve (AUC) of 0.889 (Table 7.1). Overall, weighted and more sophisticated systems including higher numbers of variables may perform better than simple non-weighted models. However, all scores are still lacking prospective validation. The TASH score considers the following variables: hemoglobin (Hb), base excess (BE), systolic blood pressure (SBP), heart rate (HR), presence of free intra-abdominal fluid (e.g., via E-FAST), presence of a clinically unstable pelvic fracture, and male gender [23].

Table 7.1 Performance of the scores

Score	TASH	PWH/ Rainer	Vandromme	Larson	Schreiber	ABC
AUC	0.889	0.860	0.840	0.823	0.800	0.763
95% CI	0.871–0.907	0.839–0.881	0.817–0.863	0.800–0.847	0.773–0.828	0.732–0.794
Cut-off point	≥8.5	≥2.5	≥1.5	≥1.5	≥0.5	≥0.5
Sensitivity, %	84.4	80.6	78.9	70.9	85.8	76.1
Specificity, %	78.4	77.7	76.2	80.4	61.7	70.3
PPV, %	18.9	17.7	16.5	17.4	11.8	13.2
NPV, %	98.8	98.5	98.4	97.9	98.7	98.0

Modified from [22]

Weighted and more sophisticated systems, such as TASH and PWH scores including higher numbers of variables, may perform better than simple non-weighted models

AUC area under the curve, *CI* confidence interval, *PPV* positive predictive value, *NPV* negative predictive value, *PWH* Prince of Wales Hospital score, *TASH* trauma-associated severe hemorrhage score, *ABC* assessment of blood consumption

7.4.2 The ATLS Classification of Hypovolemic Shock

The clinical value of the Advanced Life Support (ATLS) classification of hypovolemic shock to early identify trauma patients at risk for major hemorrhage and MT has recently been critically reassessed in a series of studies [24, 25]. Follow-up studies confirmed BE and shock index to be superior to the ATLS classification of hypovolemic shock to predict the need for early blood product transfusion [26, 27], which led to the adoption of the BE as an additional parameter to the updated ATLS classification of hypovolemic shock (tenth edition) in 2018 [28]. Simultaneously, these observations also translated into a strong recommendation (Grade 1A) provided by the 2019 updated European guideline on the management of major bleeding and coagulopathy following trauma to use BE as a sensitive test to estimate and monitor the extent of bleeding and shock [14].

7.4.3 Laboratory Parameters

A low initial Hb is still considered an indicator of severe hemorrhage associated with coagulopathy (Grade 1B), and repeated Hb measurements as a laboratory marker for bleeding are recommended, as an initial Hb value within normal ranges may mask bleeding (Grade 1B) [14]. Current routine practice should consider the early and repeated monitoring of hemostasis, using either a combined traditional laboratory determination (PT, platelet counts and Clauss fibrinogen level) and/or point-of-care PT/INR (Grade 1C) and/or a viscoelastic method (Grade 1C) [14]. The predictive power of a set of selected coagulation parameters for MT which were obtained from bleeding trauma patients upon emergency room admission is shown in Table 7.2. A multivariate analysis based upon data from the UK Trauma Audit and Research Network (TARN) identified age, admission pulse rate, systolic blood pressure and injury type to be significant clinical predictors for massive blood transfusion [19].

7.5 Cessation of Massive Transfusion

Cessation of MT and corresponding protocols is as critical as activation but remains much more nebulous and reliant on clinician gestalt given the dynamics of the patient's condition during further resuscitation. For patients alive at hour 6 after admission, the revised Massive Transfusion Score (MTS) was shown to be predictive of ongoing need for red blood cell transfusion (AUC, 0.87) in hours 7 to 12, 24-h mortality (AUC, 0.95), and 28-day mortality (AUC, 0.77) [30]. The revised MTS includes the following parameters:

(i) systolic blood pressure < 90 mmHg
(ii) base deficit ≥6
(iii) temperature < 35.5 °C
(iv) international normalized ratio (INR) >1.5
(v) hemoglobin <11 g/dL.

Table 7.2 Coagulation parameters and their value in predicting massive transfusion

Parameter	ROC-AUC (95% CI)	Optimum threshold (for best sensitivity and specificity)	Sensitivity (95% CI)	Specificity (95% CI)
FIBTEM MCF	0.84 (0.79–0.88)	≤7 mm	77.5 (66.8–86.1)	74.9 (68.9–80.3)
FIBTEM A10	0.83 (0.78–0.87)	≤4 mm	63.3 (51.7–73.9)	83.2 (77.8–87.7)
EXTEM CT	0.71 (0.66–0.76)	≤72 s	76.3 (65.2–85.3)	59.4 (52.7–65.8)
EXTEM CFT	0.74 (0.68–0.79)	≤147 s	64.5 (52.7–75.1)	75.1 (69.0–80.6)
EXTEM MCF	0.76 (0.71–0.81)	≤52 mm	67.1 (55.4–77.5)	71.2 (64.8–77.0)
Platelet count	0.70 (0.65–0.75)	≤161 × 10^3/μL	62.0 (50.4–72.7)	73.8 (67.8–79.3)
Quick value	0.87 (0.83–0.90)	≤60%	84.8 (75.0–91.9)	82.1 (76.6–86.8)
aPTT	0.85 (0.81–0.89)	≤35.2 s	71.6 (59.9–81.5)	87.8 (82.8–91.7)
Fibrinogen concentration	0.83 (0.78–0.87)	≤148 mg/dL	84.2 (74.0–91.6)	68.3 (61.8–74.3)
Hemoglobin	0.87 (0.83–0.91)	≤10.1 g/dL	77.5 (66.8–86.1)	84.5 (79.3–88.9)
Base deficit	0.76 (0.76–0.86)	≤6.3	69.6 (57.3–80.1)	79.8 (73.3–85.3)
pH	0.76 (0.70–0.81)	≤7.276	62.3 (49.8–73.7)	80.0 (73.6–85.4)
Lactate	0.74 (0.69–0.79)	≤4.18 mmol/L	54.9 (42.7–66.8)	88.0 (82.9–92.0)

Single-center experience based upon retrospective analysis of 78 severely bleeding trauma patients requiring massive transfusion [29]

A 10 clot amplitude 10 min after CT, *aPTT* activated partial thromboplastin time, *CFT* clot formation time, *CI* confidence interval, *CT* clotting time, *EXTEM* extrinsically activated thromboelastometric test, *FIBTEM* extrinsically activated thromboelastometric test with cytochalasin D, *MCF* maximum clot firmness, *ROC-AUC* area under the receiving operating characteristic curve

For each additional positive trigger of the MTS at hour 6, the odds ratio (OR) of death at 24 h and 28 days increased substantially (24-h OR, 4.6; 95% CI, 2.3–9.3; 28-day OR, 2.2; 95% CI, 1.5–3.2; $p < 0.0001$).

7.6 Outcome of Massive Transfusion

The overall in-hospital mortality of massively transfused patients remains high [19, 29, 31–33]. Data from the TR-DGU (years 2002–2017; n = 102,395 patients; primary admissions with an ISS > 16) still reveals a mortality rate of around 58% in patients with MT [6]. In a retrospective analysis of the American College of Surgeons Trauma Quality Improvement Program (TQIP) for outcome among 2776 adult trauma patients who required MT, the overall in-hospital mortality was

43.5% with a mean pRBC transfusion within the first 24 h of 20 ± 13 units and a mean plasma transfusion of 13 ± 11 units [34]. While receiving MT in a level I trauma center was independently associated with a lower rate of mortality (OR: 0.75 [0.46–0.96], $p < 0.001$), a higher magnitude of injury (OR: 1.020 [1.010–1.030], $p < 0.001$) along with increased units of pRBC transfused (OR: 1.067 [1.041–1.093], $p < 0.001$) were independently associated with increased mortality [34]. There was no association between teaching status, age, gender, emergency department vitals, and units of plasma transfused. Another analysis of data from 1062 patients with MT from the TR-DGU reported a similar mortality rate (43.1%) [33]. There was an increase in mortality observed in relation to the number of pRBC units transfused; in the subgroup that had received >30 pRBC units (mean 40.6) the mortality rate was 60.4% [33]. From another cohort of bleeding trauma patients, a mortality rate of 41% for patients with MT versus 13% with no MT was reported [29]. An overview of studies which have examined massive blood transfusion in European and North American civilian trauma populations is shown in Table 7.3 [19]. However, comparisons including rates for mortality between the studies remain difficult due to heterogeneity of definitions for MT as well as variations in case-mix.

Table 7.3 Overview of massive blood transfusion studies including incidence and outcome

Study	Setting/sample size	Definition of massive transfusion	Number of cases/ incidence	Mortality	ISS (median)
Hamidi et al. (2019) [31]	Trauma receiving centers (ACS TQIP program), US n = 416,957	>10 U pRBC/24 h	n = 2776 0.6%	43.5%	29
Fuller et al. (2012) [19]	Trauma receiving centers, UK n = 38,283	>10 U pRBC/24 h	n = 157 0.4%	40%	27
Schöchl et al. (2011) [29]	Trauma center, Austria n = 323	>10 U pRBC/24 h	n = 78 24%	41%	42
Johansson et al. (2009) [36]	Trauma center, Denmark n = NA	>10 U pRBC/24 h	n = 832 NA	41%	Not reported
Snyder et al. (2009) [17]	Level 1 Trauma center, US n = NA	>10 U pRBC/24 h	n = 134 NA	50%	29/39[a]
Duchesne et al. (2008) [37]	Level 1 Trauma center, US n = 2746	>10 U pRBC/24 h	n = 135 4.9%	57%	27
Gunter et al. (2008) [38]	Level 1 Trauma center, US n = NA	>10 U pRBC/24 h	n = 213 NA	41%	25
Holcomb et al. (2008) [39]	16 Level 1 Trauma centers, US n = NA	>10 U pRBC/24 h	n = 466 NA	26–59%	32

(continued)

Table 7.3 (continued)

Study	Setting/sample size	Definition of massive transfusion	Number of cases/ incidence	Mortality	ISS (median)
Kashuk et al. (2008) [40]	Level 1 Trauma center, US n = NA	>10 U pRBC/24 h	n = 133 NA	56%	36
Maegele et al. (2008) [41]	German Trauma Registry, Germany n = NA	>10 U pRBC prior to ICU	n = 713 NA	42%	41
Sperry et al. (2008) [42]	7 Level 1 Trauma centers, US n = 1036	>8 U pRBC/24 h	n = 415 40%	33%	41
Mitra et al. (2007) [43]	Level 1 Trauma center, Australia n = NA	>5 U pRBC/4 h	n = 119 NA	28%	34
Huber-Wagner et al. (2007) [33]	German Trauma Registry, Germany n = 8812	>10 U pRBC prior to ICU	n = 1062 13%	43%	25[b]
Como et al. (2004) [44]	Level 1 Trauma center, US n = 5645	>10 U pRBC	n = 147 3%	39%	29–32[c]
Vaslef et al. (2002) [45]	Level 1 Trauma center, US n = 7734	50 U of blood components/24 h	n = 44 0.6%	57%	30
Cinat et al. (1999) [46]	Level 1 Trauma center, US n = NA	50 U pRBC/48 h	n = 45 NA	71%	30
Velmahos et al. (1998) [47]	Level 1 Trauma center, US n = NA	20 U pRBC during admission	n = 141 NA	70%	29
Cosgriff et al. (1997) [48]	Level 1 Trauma center, US n = NA	10 U pRBC/24 h	n = 58 NA	43%	31

Modified from [19]
ACS TQIP American College of Surgeons Trauma Quality Improvement Program, *ICU* intensive care unit, *ISS* Injury Severity Score, *NA* not available, *pRBC* packed red blood cells, *U* units, *UK* United Kingdom, *US* United States
[a]ISS for survivors/non-survivors
[b]ISS for whole sample
[c]Range of mean ISS for patients that had received 10–19 and ≥20 pRBC units

7.7 Risks and Harmful Effects of Blood Product Transfusions

The use of large amounts of potentially inflammatory, immunomodulatory, and infectious blood products in the context of hemorrhagic shock may be related to the morbidities typically observed during MT. Transfusion-related lung injury (TRALI) with subsequent acute respiratory distress syndrome (ARDS) may be encountered in up to one-fifth of patients undergoing MT [34]. The amount of transfused blood in a prospective cohort of 102 patients with severe trauma was independently associated with both the development of ARDS and hospital mortality [35]. Compared to the 21% of patients who received 0–5 units of pRBC, 31% of those who received 6–10 units and 57% of those who received >10 units developed ARDS ($p = 0.007$). In a multicenter prospective cohort study involving 1175 blunt injured adults with hemorrhagic shock, each unit of FFP administered was independently associated with a 2.1% and 2.5% increased risk of multiorgan failure and ARDS, respectively [49]. Transfusion-associated circulatory overload, which represents the second leading cause of transfusion-related fatalities reported in the United States, is likely to be underestimated by passive reporting [50].

MT may also increase the risk for both viral and bacterial infections. The estimated risk for HIV in the United States is 1 in 2,135,000 while the greatest risk is for hepatitis B at 1 in 277,000 [51]. In general, the transfusion of platelets carries a greater risk of infection, sepsis, and death compared to any other blood product, primarily through bacterial contamination [52]. It is assumed that between 1:1000 and 1:2500 platelet units are bacterially contaminated. The skin bacterial microflora is considered a primary source of contamination; enteric contaminants are rare but may be clinically devastating, while platelet storage conditions can support bacterial growth [52]. The two most common electrolyte abnormalities to occur in the context of MT are ionized hypocalcemia, caused by the preservative citrate, and hyperkalemia.

7.8 Refining Strategies for Massive Hemorrhage

MT can be a life-saving maneuver in acute trauma hemorrhage, but potential complications need to be considered. Ideally, patients in acute need of blood transfusion may receive blood and blood products quicker, whereas blood may be withheld in those where alternate treatment may be more adequate [7]. The principle remains to prevent the patient from being both over- and undertreated with blood products. As previously mentioned, scoring systems and prediction models may inform clinical decision making on when to activate and stop an MTP. It has been shown that early and timely activation of MT protocols in the emergency department together with direct blood bank notification as well as compliance with the MT protocol may be associated with outcome, including improved survival [21].

A single-center retrospective study has critically assessed the compliance with a set of 13 selected compliance criteria among 72 consecutive MTP activations [53]. The average compliance with the local MT protocol was 72%, while the most common causes for non-compliance were (a) failure to send a complete hemorrhage panel from the trauma bay (96%), (b) failure to regularly order laboratory investigations every 30 min (89%), and (c) delay in both activation and deactivation of the protocol, which was equally distributed in 50% of cases [53]. Of note, non-compliance with protocol-based administration of blood products was documented in 47% of the cases. When the cohort was grouped according to compliance, group A with <60% compliance had a mortality rate of 62%, group B with 60–80% compliance had a mortality rate of 50%, and group C with >80%

compliance had a mortality rate of only 10% [53]. There were no statistical differences between the three groups with respect to demographics and injury characteristics [53].

To prevent over-transfusion and to aim for a more targeted and individualized approach for the administration of blood products and hemostatic agents in massive bleeding, advanced trauma centers on both sides of the Atlantic have started to shift away from rather unguided and ratio-based approaches to "hybrid" concepts in which further resuscitation is guided by advanced coagulation testing [54]. Once the bleeding patient is hemodynamically stabilized, the updated 2019 European guideline on the management of major bleeding and coagulopathy following trauma currently recommends (Grade 1B) that resuscitation measures including blood products and hemostatic agents be continued using a goal-directed strategy, guided either by standard coagulation and/or viscoelastic assays [14]. An example of such a "hybrid" approach to hemostatic resuscitation in massive bleeding and accompanying trauma-induced coagulopathy is shown in Fig. 7.2 [54].

Functional viscoelastic assays have entered the trauma arena to diagnose, monitor and guide novel treatment strategies in acute trauma hemorrhage but no uniformly accepted guidelines have yet been established on how these technologies are to be integrated into clinical practice [14]. Viscoelastic blood clot stability measures (e.g., thromboelastometric FIBTEM A10 and MCF amplitudes) may provide comparable prediction for MT in trauma patients as conventional laboratory parameters [29] but turnaround times are much shorter [55]. Various algorithms suggesting viscoelastic thresholds for the initiation of specific goal-directed treatments through a

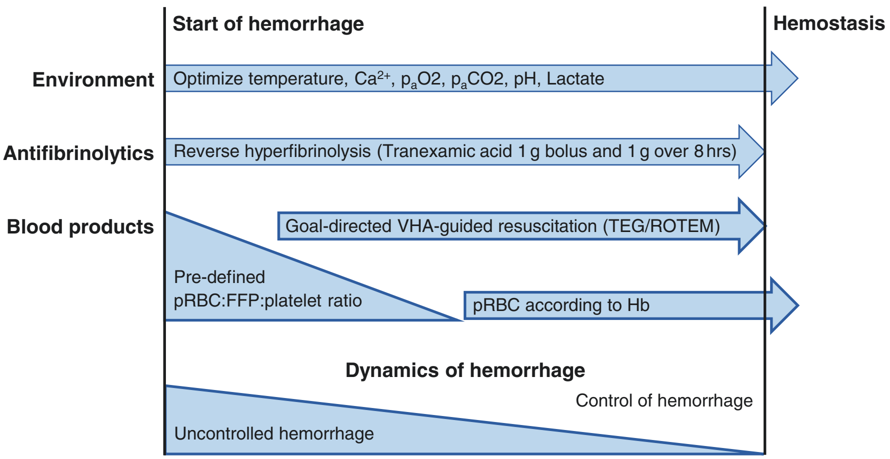


Fig. 7.2 "Hybrid" concept of hemostatic resuscitation. Acute resuscitation in patients presenting in hemorrhagic shock is initiated according to Damage Control Resuscitation principles using balanced pRBC, FFP and platelet concentrates, followed by an early shift towards a more targeted and goal-directed approach based upon results from VHAs. TXA is administered according to the CRASH-2 protocol. *FFP* fresh frozen plasma, *Hb* hemoglobin, *pRBC* packed red blood cells, *ROTEM* rotational thromboelastometry, *TEG* rotational thromboelastography, *TXA* tranexamic acid, *VHAs* viscoelastic hemostatic assays. Modified from [54]

more selective use of fibrinogen, platelets, plasma, and prothrombin complex concentrates in the bleeding trauma patient have been clinically introduced but are mostly based upon retrospective evidence and expert opinion [54–57]. The results from a recent Cochrane review supported the use of viscoelastic assays as resulting in better survival, reduction in the need for allogeneic blood products, and fewer patients with dialysis-dependent renal failure compared with transfusion guided by any method in adults or children with bleeding [58]. In Fig. 7.3 an example

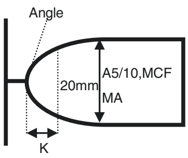
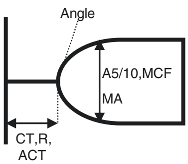
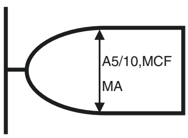
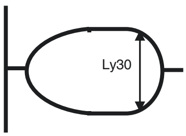
Hemostatic therapy	ROTEM®/ TEG® trace	ROTEM®/ TEG® Triggers
Fibrinogen (concentrate or cryoprecipitate)		**ROTEM®**: EXTEM A10 < 45 mm (A5 < 35 mm) or MCF < 55 mm and FIBTEM A10 < 10 mm (A5 < 9 mm) or MCF < 12 mm **TEG®**: FF MA < 14 mm cryoprecipitate pool (3-5 ml/kg) or fibrinogen concentrate (1-2 g) or FFP 20-30 ml/kg **RapidTEG® (rTEG®):** K > 2.5 min cryoprecipitate/ fibrinogen/plasma; Angle < 56°(<65°)* cryoprecipitate/ fibrinogen/plasma
Plasma transfusion (FFP) (or Prothrombin complex concentrate (PCC))		**ROTEM®**: EXTEM CT ≥ 80 s and A10 ≥ 45 mm (A5 ≥ 35 mm) or MCF ≥ 55 mm and normal FIBTEM A10 (A5 ≥ 9 mm) or normal MCF **TEG®**: R 10-14 min FFP 10-20 ml/kg; R > 14 min FFP 30 ml/kg; Angle < 52° FFP 20-30 ml/kg; TEG FF MA < 14 mm FFP 20-30 ml/kg **RapidTEG® (rTEG®):** R > 1.1 min plasma and pRBCs; ACT > 128 s plasma and pRBCs
Platelet concentrate transfusion		**ROTEM®**: EXTEM A10 < 45 mm (A5 < 35 mm) or MCF < 55 mm and normal FIBTEM A10 (A5 ≥ 9 mm) or normal MCF **TEG®**: KaolinTEG MA 45-49 mm 1 PC or 5 ml/kg; KaolinTEG MA < 45 mm 2 PC or 10 ml/kg (in patients with normal TEG FF MA!) **RapidTEG® (rTEG®):** MA < 55 mm PC/ cryoprecipitate/ fibrinogen
Antifibrinolytics		**ROTEM®**: Any evidence of hyperfibrinolysis in EXTEM or FIBTEM **TEG®**: KaolinTEG Ly30 > 4% TXA (1-2 g) (if > 4% and angle and/or MA↑ TXA contraindicated as considered reactive hyperfibrinolysis!) **RapidTEG® (rTEG®):** Ly30 > 3% (5%)* TXA (if time from injury < 3 hours and patient is bleeding!)

Fig. 7.3 Viscoelastic assay-driven algorithm for the use of hemostatic agents and blood products in bleeding trauma patients**.** Overview of viscoelastic triggers for the differential and goal-directed use or not use of blood products and hemostatic agents based on expert opinion, for ROTEM, TEG and rapid TEG (rTEG). If available, specific treatments are given (TEG and rTEG only). ROTEM parameters: *EXTEM*, test for the (extrinsic) hemostasis system; *FIBTEM* test for the fibrin part of the clot, *CT* clotting time (s), *A5/A10* clot amplitude after 5 or 10 min (mm), *MCF* maximum clot firmness (mm). TEG parameters: *R* reaction time (min), *Angle* speed of clot formation (degrees), *MA* maximum amplitude (mm), *FF MA* functional fibrinogen test maximum amplitude (mm), *Ly30* amplitude reduction after 30 min as an indicator of hyperfibrinolysis (%). Additional definitions for rTEG: *K* time from end of R until the clot reaches 20 mm amplitude, *ACT* activated clotting time. Treatments: *FFP* fresh frozen plasma, *PCC* prothrombin complex concentrate, *pRBC* packed red blood cells, *TXA* tranexamic acid. *Consider alternative treatments if first-line strategies are not available. †Recommended values differ between publications. Modified from [56, 57]

algorithm for the viscoelastic test-driven use of hemostatic agents and blood products in bleeding trauma patients is given.

Fibrinolysis activation occurs almost universally after severe trauma, and systemic hyperfibrinolysis has been identified as a key component of acute traumatic coagulopathy associated with poor clinical outcomes [59]. Recent large randomized controlled trials have consistently documented that the use of the synthetic lysine analogue tranexamic acid (TXA) confers a survival advantage in a number of globally critical clinical conditions associated with acute bleeding, including traumatic injury (CRASH-2), traumatic brain injury (CRASH-3) and post-partum hemorrhage (WOMAN), without increasing the thromboembolic risk [60]. Tranexamic acid should be given as early as possible and within 3 h of injury in the trauma patient who is bleeding or at risk of significant hemorrhage, as further analysis of the CRASH-2 trial showed that treatment later than this is unlikely to be effective and may even be harmful [14, 61, 62]. To date, TXA has evolved into a chief component of many MTP protocols [14, 63] but the two most recent randomized trials using TXA in the prehospital setting of trauma [64] and traumatic brain injury [65] failed to reproduce the beneficial effects of TXA seen in earlier studies with respect to 30-day mortality and neurologic outcome at 6 months. However, when comparing the TXA effect stratified by time to treatment and qualifying shock severity in a post hoc comparison, 30-day mortality was lower when TXA was administered within 1 h of injury (4.6% vs. 7.6%; difference, −3.0%; 95% CI, −5.7% to −0.3%; $p < 0.002$) and in patients with severe shock (18.5% vs. 35.5%; difference, −17%; 95% CI, −25.8% to −8.1%; $p < 0.003$) [64]. While in the conventional dosing groups with 1 g TXA bolus followed by 1 g over 8 h there was no increased risk of thromboembolic events, these were more seen in groups that were treated with 2 g TXA bolus (9% vs. 4%) [65]. In another study, 4 g TXA bolus to patients with severe injuries was associated with a 32% rate of thromboembolic events and only minimal immunomodulatory effects with respect to leukocyte phenotypes and circulating cytokines [66].

Fibrinogen, also referred to as coagulation factor I, represents the substrate for blood to clot and is the first coagulation factor reaching critical levels in the setting of severe hemorrhage. Substantial drops in fibrinogen levels have been detected in blood samples collected at the site of the injury and this as a function of injury severity [67]. Fibrinogen may independently but also synergistically work with TXA in the seriously injured requiring blood transfusion [68]. In any case, hyperfibrinolysis needs to be inhibited prior to any coagulation factor supplementation, e.g., fibrinogen, and a median 3.8 g fibrinogen concentrate can increase clot stability by 5.2 mm at 5 min of viscoelastic test initiation, while TXA can decrease lysis by 5.4% [69]. Meanwhile, the protective effects to the glycocalyx as well as to the endothelial barrier integrity have been linked to the fibrinogen component rather than to plasma *per se* [70]. The 2019 updated European guideline on the management of major bleeding and coagulopathy following trauma strongly recommends against the use of FFP in patients without major bleeding (Grade 1B) and for the treatment of hypofibrinogenemia (Grade 1C) [14]. The treatment with fibrinogen concentrate or cryoprecipitate is currently recommended by the guideline if major bleeding is accompanied by hypofibrinogenemia, as evidenced by viscoelastic signs of a functional fibrinogen deficit or a Clauss plasma fibrinogen level ≤ 1.5 g/L (Grade 1C) [14]. The suggested initial dose is 3–4 g and repeated doses should be guided by viscoelastic testing assays and laboratory assessment of fibrinogen levels (Grade 2C) [14].

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8 Definitive Care of Abdominal Solid Organ Injuries

Chiara Cipressi, Guido Fallani, Jacopo Neri, and Gregorio Tugnoli

8.1 Introduction

Non-operative management (NOM) for solid organ injuries has long become the standard of care and it continues to have high success rates in the appropriate patient population [1], both in blunt and penetrating trauma. In selected and well-developed trauma centers, NOM can even be pursued in borderline patients or transient responders without other indications for laparotomy.

At the Trauma Center of the Ospedale Maggiore in Bologna (Italy), in the last 5 years the success rate of NOM was 75% for splenic injuries, 90.9% for hepatic injuries, 88.6% for pancreatic and 89.9% for kidney injuries, out of all traumas observed.

The development of NOM has meant that we now perform surgical interventions only in unstable patients with serious bleeding lesions, which almost always require either removal of the organ or a damage control procedure [2, 3].

Other surgical options for the definitive treatment of such injuries are to be reserved for either complications of NOM, after damage control surgery (DCS) [4] or—as in the case of kidney and pancreatic trauma—when there is a rupture of the main duct or urine leakage.

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8.2 Definitive Care of Liver Injuries

Most liver injuries are currently treated non-operatively, with the aid of angioembolization (AE) for cases where an active source of bleeding is present. The patient with hepatic injury who requires surgical intervention is generally hemodynamically unstable, with a grade 4 or 5 hepatic injury according to the classification of the American Association for the Surgery of Trauma Organ Injury Scale (AAST-OIS) [5]. Surgical control of bleeding is the main goal in a damage control strategy, as is the prevention of biliary complications which are specific to liver injuries. Packing is the simplest procedure and has been advocated as an effective method to control hemorrhage from liver parenchyma injury [6]. Richardson et al. [7] stated that the main reasons for the decrease in mortality from liver injury over the past 25 years were improved results from packing and planned relaparotomy, the use of AE, advances in operative techniques for major liver injuries and the decrease in the number of hepatic venous injuries treated with surgery.

Simple surgical procedures such as hepatotomy, hepatorraphy, direct vessel ligation, and non-anatomic resection to remove devitalized parenchyma have replaced prolonged and extensive procedures such as anatomic liver resection, [8] with a significant reduction in the duration of laparotomy. At our Center, between 2009 and 2019, 86% (44/51) of patients with severe hepatic injury underwent surgery with DCS techniques; five of the remaining patients required surgery for lesions of the biliary tract, and only in two cases a liver resection was performed.

8.2.1 Angioembolization

AE has emerged as an important adjunct that is of paramount importance to the success of NOM for blunt hepatic injuries. The most common indication for AE is contrast blush on computed tomography (CT) scan, followed by persistent arterial bleeding after damage control laparotomy. Many authors support AE in the presence of contrast extravasation on initial CT scan, regardless of injury grade. Similarly, AE should be considered if pseudoaneurysms (PSAs) are detected on the initial CT, as they carry a high risk of delayed hemorrhage [9]. In our experience, in NOM cases we perform angiography only in the presence of active bleeding detected at CT scan. On the other hand, we routinely subject patients treated with DCS to postoperative angiography: over the past 5 years, AE has been used in 3.7% of NOM cases and in 56% of cases initially treated with DCS (Fig. 8.1).

Selective arterial embolization also represents the initial treatment of choice for hemobilia, with a substantial rate of success and a low incidence of serious complications [10].

8.2.2 Endoscopic Retrograde Cholangiopancreatography

Endoscopic retrograde cholangiopancreatography (ERCP) with sphincterotomy and/or biliary stenting, percutaneous drainage and surgical intervention (open or laparoscopic) are all effective for managing biliary complications [11].

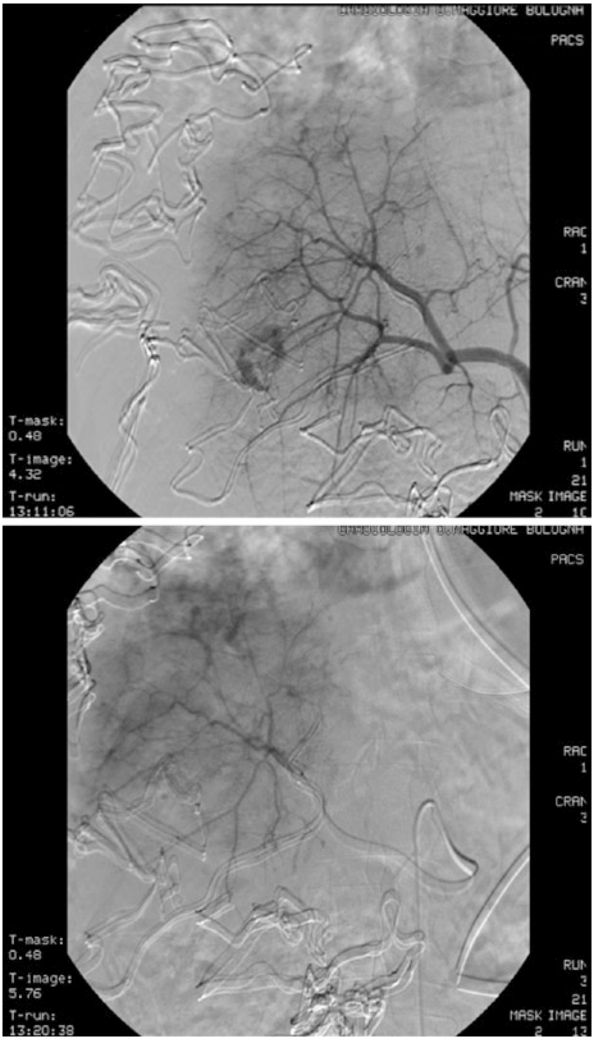


Fig. 8.1 Angioembolization after packing for severe liver injury

8.2.3 Mesh Wrapping

Mesh wrapping is rarely used, but it may be useful to be familiar with the technique. Mesh wrapping appears to be an effective approach for achieving hemostasis through a tamponade effect (Fig. 8.2). It was first introduced by Buntain and Lynn for the control of splenic hemorrhage. The use of a mesh has also been described after liver transplantation following graft injury in pediatric liver trauma as well as in adult liver trauma with or without absorbable gauze packing. The mesh is sutured to the diaphragmatic crus and to the falciform ligament so that it is secured on two anchor points. Compared to packing, liver wrapping does not need re-laparotomy to remove the mesh, it carries a lower risk of re-bleeding because the mesh is left in place, and it has a low incidence of septic complications [12].

8.2.4 Liver Resection

Non-anatomic resection to remove devitalized liver (Fig. 8.3) has replaced more prolonged and extensive procedures such as anatomic liver resection; moreover, debridement of necrotic tissue is a safe maneuver that can be performed during or after a DCS procedure.

Major anatomic resections for severe hepatic trauma were often performed in the late 1960s and early 1970s. In most series, mortality was high, and liver resection for trauma was discouraged by most authors; thus, resection fell out of favor until recently, when several groups reported improved outcomes. Polanco et al. [13] reported their experience of patients who underwent hepatic resection during the initial operation, with a morbidity of 30% and a mortality of 17.8%. Based on these data, the authors recommended hepatic resection in patients with massive bleeding related to hepatic venous injury with a compelling need for direct repair, in patients with massive destruction of hepatic tissue, and in patients with major bile leak from

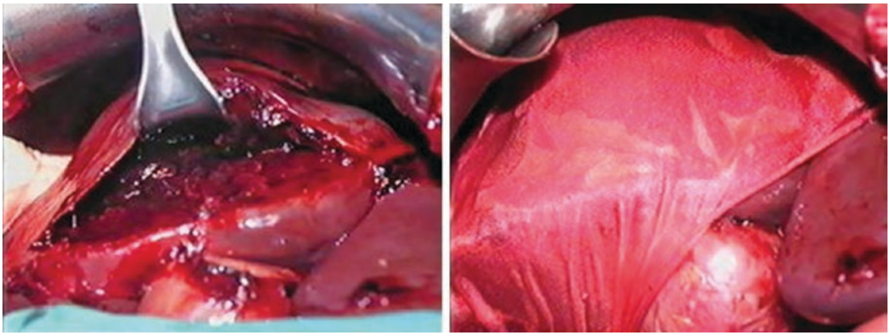
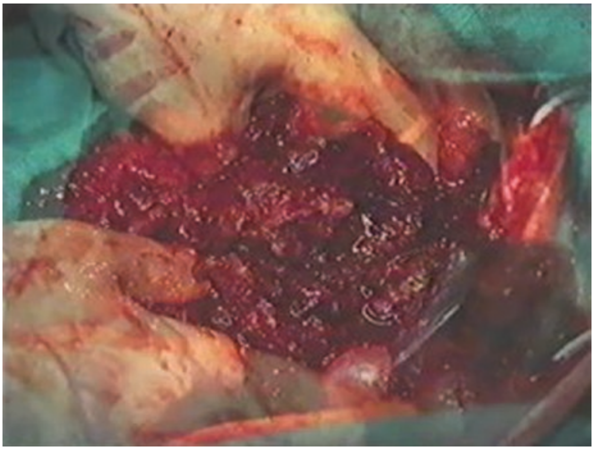


Fig. 8.2 Massive subcapsular traumatic hematoma of the liver treated with mesh wrapping

Fig. 8.3 Resectional debridement



a proximal main intrahepatic bile duct. However, major anatomic resections for trauma remain complex maneuvers that should only be performed by experienced surgeons.

8.2.5 Liver Transplantation

Finally, liver transplantation (LT) should be mentioned amongst the definitive treatments, as it indeed represents the most extreme form of surgical management of patients with hepatic trauma. Although rare, LT for liver trauma has been successfully reported and the indication is well-established. LT seems to be justified in selected patients with otherwise fatal liver injuries, particularly those in whom caval cross-clamping with extracorporeal bypass can be omitted. The patient must have an overall excellent chance of survival with minimal other injuries, especially in the abdomen or brain. In this sense, the injury severity score (ISS) has been proven as a useful tool to discriminate patients eligible for urgent LT as patients with values <33 have been shown to have lower mortality rates [14].

8.3 Definitive Care of Traumatic Kidney Injuries

Renal injuries occur in up to 10% of patients with abdominal trauma and are frequently associated with concomitant injuries to other organs. Blunt trauma, often resulting from rapid deceleration, accounts for more than 90% of renal injuries, while penetrating lesions are less common [15]. As for other traumatic abdominal organ injuries, management has sharply evolved toward NOM, although surgery remains the gold standard for unstable patients with major vascular injuries. The pediatric population is more susceptible to renal trauma due to anatomic peculiarities, and it is characterized by a higher incidence of injuries to the collecting system (forniceal avulsion, pelvic laceration and ureteropelvic junction avulsion).

8.3.1 Endovascular Repair

Selective angiography with AE has dramatically modified the management of bleeding patients with kidney injury, with a success rate of 88% in arresting hemorrhage and a renal salvage rate up to 92% [16]; in cases of failure, repeat AE has similar success rates to the initial procedure [17]. Angiography and possible embolization are indicated in hemodynamically stable patients with arterial contrast extravasation upon CT scan, non-self-limiting macrohematuria, expanding perirenal hematoma, PSA and arteriovenous fistula [18]. Patients with initial hemodynamic instability should undergo angiography only in high-volume centers with immediately available interventional radiologists; otherwise, they should be taken to the operating room [19].

Finally, endovascular treatment with bare metal stent (or stent-graft in the case of concomitant contrast extravasation) represents the preferred option in renal artery dissection, as it shows better outcomes than surgical repair [20].

8.3.2 Surgical Repair

Operative management of renal traumas is mandatory in hemodynamically unstable patients despite resuscitation or non-self-limiting bleeding from the main renal vein; whenever other indications for surgical exploration subsist (e.g., penetrating injury with violation of the peritoneal cavity), a retroperitoneal hematoma should be explored only if pulsatile or if it represents the only plausible cause of hemodynamic instability [18].

Surgical exploration of the kidneys in trauma is most often performed through a transperitoneal approach with medial visceral rotation; whenever preoperative imaging is absent, it is advisable to assess the absence of lesions contralateral to the damaged kidney. The need for initial vascular control is debated: some authors suggest isolation of the renal vein and artery prior to opening Gerota's fascia to prevent bleeding [21, 22], although other studies demonstrated that this procedure does not affect nephrectomy rate, blood loss or transfusion requirement [23]. Gerota's fascia should be opened through a single vertical incision, and the kidney should be inspected on both surfaces to assess the injuries and the viability for repair, if the patient's conditions are favorable.

Parenchymal lacerations can be reconstructed through renorraphy, ensuring that the margins are vital, while polar lesions can be managed through partial nephrectomy; in the latter case, capsule suturing is advisable to promote parenchymal hemostasis. Whenever concomitant injuries of the collecting system exist, they should be closed tightly with absorbable sutures; ureteral stenting or percutaneous nephrostomy are necessary only if the final repair is incomplete or tenuous. Furthermore, the application of topical hemostatic agents over parenchymal defects and repairs has been described as useful for enhancing hemostasis and minimizing postoperative urine leak [24, 25].

Renovascular injuries, whether from blunt or penetrating trauma, are certainly challenging and most often result in nephrectomy. In cases of vascular avulsion, repair can be attempted through resection of the injured segment and end-to-end anastomosis, direct or graft-interposed. Isolated vascular repair is also feasible, most often for injuries of the renal vein. Although rarely indicated, ex-vivo repair and autotransplantation can be used in the trauma setting for highly selected patients (e.g., solitary kidney). Nevertheless, vascular repair procedures are reported to have a low success rate, particularly in cases of arterial repair (25–35%) [26, 27]; therefore, accurate patient selection based on hemodynamic and metabolic conditions and on the briefest warm ischemia time is crucial.

As concerns injuries of the renal pelvis, they are often associated with preexisting ureteral obstruction, and do not *per se* contraindicate NOM; however, they may require delayed surgical repair [18].

8.4 Definitive Care of Pancreatic Injuries

Traumatic pancreatic injury is extremely difficult to evaluate, and its prognosis depends on the diagnostic delay and on the grade of the injury.

As previously stated, pancreatic lesions can be categorized according to the American Association for the Surgery of Trauma Pancreas Organ Injury Scale [28].

Once the lesion has been correctly diagnosed and, if needed, DCS has been performed, for example by closed suction drainage and/or biliary or intestinal diversion, it is necessary to provide definitive treatment of the damaged pancreas.

Before attempting definitive surgery, the damage needs to be precisely assessed with CT: direct signs of injury include laceration, transaction, focal enlargement and enhancement; secondary signs include peripancreatic fat stranding, peripancreatic fluid, hemorrhage, hematoma, and associated injury to adjacent structures. CT can identify clear signs of pancreatic injury such as the fracture or clear separation of fragments. It can also identify intrapancreatic hematoma which is very specific for traumatic pancreatitis. To improve the accuracy, it is mandatory to perform magnetic resonance cholangiopancreatography (MRCP) so as not to miss lesions of the main duct (this method has 97% sensitivity) and to evaluate the entire pancreatic ductal system as well as fluid collections or disruptions. ERCP can be performed when there is a high index of suspicion for pancreatic injury to identify both acute and delayed pancreatic injury and also provide image-guided intervention such as ductal stenting in selected injuries as a NOM procedure, and treatment of delayed complications such as drainage of pseudocysts [29–31].

The initial treatment of the polytrauma patient consists of resuscitation and hemodynamic stabilization; once achieved patient stability, the final surgical goal is dictated by the damage to the major pancreatic duct, its location, the extent of parenchyma involved, and other associated injuries.

Grade I and II lesions (low-grade injury according to the 2016 Eastern Association of the Surgery of Trauma, EAST) should be treated by NOM [29], and surgery can be considered only after NOM failure or delayed complications: necrosectomy, surgical drainage of refractory collections, surgical treatment of pseudocysts.

A high-grade injury is defined as grade III through V and should be treated with conditional surgical intervention; the procedural approach will be also dependent on duodenal involvement (Fig. 8.4).

When the disruption of the pancreatic duct lies on the left of the superior mesenteric vein, the recommendations suggest performing a distal pancreatectomy with no clear indication on routine splenectomy.

Main duct lesions should initially be alternatively treated with ERCP-guided stent placement or drainage in selected cases, while penetrating injury usually requires exploratory laparotomy.

Pancreatic head injuries pose particular challenges for the surgeon, given the technical difficulty and the associated potential complications: stable patients with a major lesion of the pancreatic duct on the right of the superior mesenteric vein require, after external drainage, definitive management with pyloric exclusion,

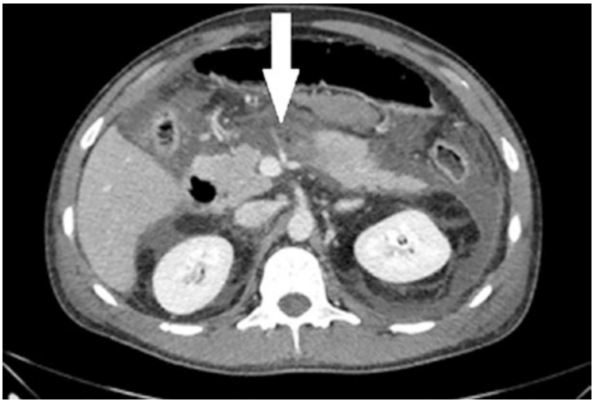


Fig. 8.4 Pancreatic grade IV injury

duodenal diversion, a Letton Wilson procedure in selected patients, pancreaticojejunostomy or pancreaticoduodenostomy when the papilla is not involved [32].

There is still uncertain data for the indication and timing of pancreaticoduodenectomy (Whipple procedure), although this is still performed in grade V lesions in some centers [33].

Because of the position of the pancreas, surrounded by the liver, biliary tract, spleen, stomach, duodenum, colon, and large blood vessels, the frequency of concomitant other organ injury is also high; surgical treatment and outcomes depend on the associated injuries, the age of the patient, the severity of the injury and response to treatment; the mortality rate of traumatic pancreatic injury reaches 10%. The most frequent complication of pancreatic surgery in trauma patients is pancreatic fistula (around 0–27%), as in elective surgery [34–36].

8.5 Definitive Care of Splenic Injuries

Splenic injury can be treated either with non-operative or operative management. The decision to perform NOM versus operative management should be based upon the grade of injury (AAST classification), presence of associated injuries, patient's overall condition and experience of the institution. Both NOM and operative management can be considered definitive treatments, provided that complete recovery from the injury is achieved [37, 38].

8.5.1 Non-operative Management

NOM is a treatment which does not include surgical procedures and usually consists of observation and/or AE. It is typically used to manage 50–70% of cases with lower grade injuries and it is not suitable in hemodynamically unstable patients, patients with generalized peritonitis or with other intra-abdominal injuries requiring surgical exploration [39, 40]. The main reasons to prefer NOM is to avoid the surgical and anesthesiologic risks associated with laparotomy and the risk of early infectious complications and postsplenectomy sepsis [41].

Hemodynamically stable patients with CT scan findings of vascular blush and AAST injury grade III or higher regardless the presence of vascular injuries, might be treated with AE in order to provide better outcomes. The failure rate of angiographic treatment increases with the grade of injury, age and comorbidities. AAST grade V injuries are generally unsuitable for AE because of vascular disruption [42, 43].

If indicated, embolization of the splenic artery proximally or distally can be performed. There is no evidence of the superiority of one technique over the other [40]. Observation is a crucial period for NOM and requires proper patient selection and adequate resources within the institution. Close monitoring and follow-up imaging should be performed, and sufficient flexibility to switch the management type is also required [44]. Since delayed splenic ruptures have been reported to occur up to 12 days after injury and are often secondary to spleen PSA, the observation period should consider this possibility and should be longer in higher injury grades [45].

8.5.2 Operative Management

If NOM fails or if the patient is hemodynamically unstable, physicians should consider surgery to achieve definitive treatment of splenic injuries. Splenectomy is the most commonly used procedure when bleeding from the spleen is the cause of hemodynamic instability and it remains a more appropriate choice for patients with high-grade splenic injury who might not tolerate significant/recurrent hypotension or a second surgical procedure due to comorbidities or associated injuries [46, 47]. According to the experience of our institution (Ospedale Maggiore, Bologna, Italy) splenectomy represents only 0.6% of splenic injury treatments.

The decision to perform splenectomy rather than surgical splenic salvage is based on the experience of the surgeon. Splenectomy is also the best option for those surgeons whose institutional resources cannot support NOM of splenic injury. Splenectomy is commonly performed with an open approach with a median xipho-pubic laparotomy and it consists of removing the entire spleen. Entering the abdomen, the surgeon should provide an efficient packing of all abdominal quadrants and evacuate the hemoperitoneum measuring the amount of blood. The spleen is then detached from its ligaments to achieve complete mobilization. The vessels can be individually ligated and divided or separated en bloc with a vascular stapler. Short gastric vessels should be divided avoiding any encroachment on the gastric wall (Fig. 8.5).

Laparoscopy may be an option in selected hemodynamically stable patients not suitable for NOM, but it is not commonly used.

Splenic salvage procedures consist of splenorraphy, partial splenectomy and the local use of hemostatic devices. These procedures are not commonly used because of the diffusion of NOM, which provides comparable results with fewer risks. Splenorraphy could be performed with or without splenic wrapping. U-stiches with

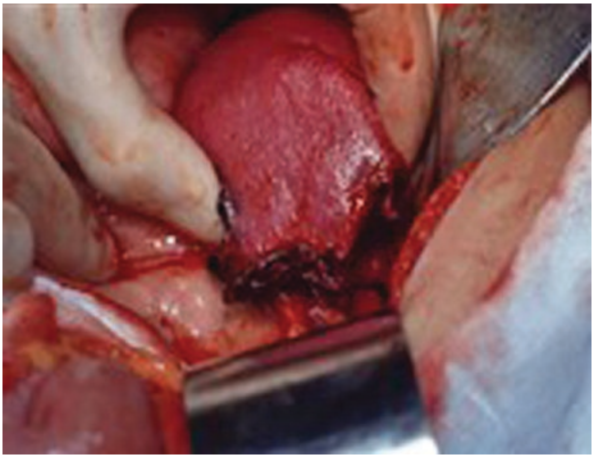


Fig. 8.5 Laparotomic splenectomy for blunt splenic injury of the lower pole in a hemodynamically unstable patient

interposed pledgets are also used. Partial splenectomy consists of removing a portion of the spleen with its segmental blood supply. Whatever operative management with splenic salvage is selected, the duration of surgery should not be significantly longer than the duration of a splenectomy in order to prevent coagulopathy.

Complications of splenic surgery include thrombocytosis, splenosis, postoperative bleeding, gastric perforation, vascular thrombosis, perioperative infections, and pancreatic fistula. Another important issue is the frequent need for thromboprophylaxis.

8.6 Conclusions

- The spread of NOM for injuries to solid abdominal organs has led to a significant decrease in traditional surgical interventions.
- Currently "definitive care" is reserved for complications of non-operative treatment or for particular situations after emergency treatment.
- The timing of any definitive treatment must be evaluated considering the patient's general conditions.
- Any major hepatic resections should be performed only after the patient has reached hemodynamic stability.
- In these cases, it would be advisable to refer patients to centers with great experience.

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Trauma to the Chest: The Role of the Trauma Surgeon

9

Osvaldo Chiara and Stefania Cimbanassi

9.1 Introduction

Damage control surgery is a staged approach to manage a traumatized patient with signs of physiologic exhaustion. This philosophy, in general, favors treatment of the patient's physiology derangement induced by trauma with a delay of the definitive correction of anatomic injuries [1–6]. It can be applied across all body cavities, following the same steps: abbreviated interventions, intensive care recovery with the correction of the lethal triad (acidosis, coagulopathy, hypothermia) and delayed definitive repair of injuries once physiologic reserve is restored. Triggers to damage control are the same reported in Chap. 6 for abdominal damage control [5, 6] (see Table 6.1).

Chest injuries requiring a surgical approach are quite rare (Table 9.1) and expertise of the trauma surgeon in these settings is often not optimal. Thoracic damage control surgery (TDCS) is an approach to complex chest problems, rather than a specific set of procedures. It focuses on the chest-injured patient rather than on the injuries themselves [7, 8]. There is no special technique in TDSC, all procedures are established and integral parts of general cardiothoracic surgery. Unfortunately, many general and trauma surgeons are not confident with these disciplines, while thoracic surgeons, used to patients undergoing elective surgery, are not familiar with the completely different physiology of trauma patients requiring a damage control approach.

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Table 9.1 Chest injuries in 3095 consecutive trauma admissions to Niguarda Trauma Center, Milan, Italy

Chest trauma in 41% (multiple injuries in 31.9%)	
Ribs	63.80%
Hemothorax/pneumothorax	42.55%
Pulmonary contusion/laceration	38.29%
Blunt cardiac injury	4.25%
Diaphragm	3.99%
Pericardial tamponade	2.98%
Thoracic vessel injuries	2.12%
Treatment	
Surgery outside the chest	70.21%
Observation only	63.82%
Chest drain only	31.90%
Thoracotomy	2.12%
Endovascular procedure	2.12%

Table 9.2 Chest damage control procedures over 1 year at Niguarda Trauma Center, Milan, Italy

Mechanism	Surgery	ISS	Outcome
Stab wound	Anterolateral thoracotomy, stapler lung resection	18	Survived
Blunt	Anterolateral thoracotomy, stapler lung resection	45	Deceased (tracheobronchial injury and hemorrhage)
Gunshot wound	Anterolateral thoracotomy. Multiple lung resections, pulmonary artery repair	25	Survived
Stab wound	Emergency department thoracotomy, left ventricle repair	25	Survived
Stab wound	Sternotomy, left atrium and diaphragm repair	35	Survived
Blunt	Sternotomy and bilateral auricle repair	43	Survived
Blunt	Anterolateral thoracotomy, diaphragm and celiac axis repair	41	Survived
Blunt	Anterolateral thoracotomy and twist left pneumonectomy for hilar injury	41	Survived
Blunt	Resuscitative thoracotomy for cardiac arrest after abdominal packing	45	Deceased (hemorrhage)

ISS injury severity score

Trauma surgeons performing TDCS have two enemies: exsanguinating and pleural space-occupying injuries with lung-compression conditions. The two primary aims of TDCS are to stop the bleeding and preserve gas exchange. Contamination should be another concern, but the danger is not immediate, and it is not usually a reason to choose a TDCS approach.

Conditions which mandate a damage control approach of the chest may be the followings (Table 9.2):

- cardiac injuries inducing cardiac tamponade;
- massive hemothorax with a significant and persistent blood loss from the pleural cavity after the initial tube thoracostomy, associated with hemodynamic instability requiring blood transfusions;

– massive air leak from lung laceration or tracheobronchial injuries;
– massive air embolism.

The TDCS approach has two strategies. The first is to use procedures that are simpler and quicker and that restore a survivable physiology with a single operation. The second approach, less usual for the chest than for the abdomen, is an abbreviated thoracotomy to restore physiology, temporary closure, while the definitive procedure is postponed at a second operation.

9.2 Preparation for Thoracic Damage Control Surgery

9.2.1 Patient Position/Preparation

The patient is supine, with both arms out (crucifixion position). If deflation of one lung is needed, a bronchial blocker can be used; for collapse of the left lung, advancement of the endotracheal tube into the right main stem is easier than placing a double-lumen endotracheal tube. Appropriate vascular accesses are obtained with large-bore peripheral lines. Positioning of central venous lines or arterial lines is not a priority. If a subclavian venous catheter is required in a patient with a suspected subclavian vascular injury, the contralateral side should be used for cannulation. The patient is prepped from chin to knees, so that the neck and abdomen are available for additional explorations and the groin for additional vascular access or for the harvest of a saphenous vein.

9.2.2 Operating Room Setup

If the patient is not agonic with the need of life-saving maneuvers in the emergency department, TDCS is accomplished in a properly set up operating room. Room temperature should be kept between 70 °F and 80 °F (21°–26 °C). Rapid infuser, cell salvage suction equipment, instrument trays consisting of standard chest (including a sternal saw) and vascular instruments should be all immediately available. It is useful to have a trolley stocked with all damage control equipment available in or immediately adjacent to theatre, reducing the time runners need to spend fetching equipment.

9.3 Surgical Incisions

9.3.1 Anterolateral Thoracotomy

Left anterolateral thoracotomy is the standard approach in a patient in extremis and it is the one which specifically offers the greatest number of options [9]. It is made from the sternal edge, under the mammary fold (in the female it is accomplished by moving the breast tissue cranially), in a curvilinear fashion toward the axilla, in close proximity to the fourth or fifth intercostal space. This incision should not be a straight-line incision nor be carried through the female breast. The intercostal muscles should be divided, in proximity to the upper border of the rib to avoid damage to the neurovascular bundle and attention should be paid to avoid injury to the lung throughout the incision. By placing a bump to elevate the thorax approximately 20°, the incision can be carried slightly longer, improving posterior exposure. The chest retractor is placed with the rack toward the table because, if the incision needs to be extended to the opposite side (clamshell thoracotomy), the retractor should not be an obstacle. The difficulties with this incision involve access to the posterior mediastinal structures such as the descending aorta and the esophagus.

9.3.2 Clamshell Thoracotomy

This is the extension of an anterolateral thoracotomy across the sternum. The sternum is cut with a Gigli saw or other device and the internal mammary arteries are ligated on both sides on the upper and lower edge of the incision (four ligatures). Both chest incisions should be curvilinear, with the trans-sternal cut high enough on the sternum to expose the midportion of the heart, and also with sufficient sternum to accomplish a solid bony closure. On occasion, when the right-sided injury is suspected high in the pleural cavity, the incision might even be above the right nipple. This incision affords excellent exposure to both pleural spaces and the anterior mediastinum.

9.3.3 Median Sternotomy

This can be used in responder patients to gain control of the heart and anterior mediastinal structures. A skin incision is made from the manubrial notch to below the xiphoid. Using blunt dissection, the fingers are inserted just beneath the sternum from below and above, carefully dissecting the pericardium and loose fatty tissue away from the back of the sternum. Using a sternal saw, keeping in the midline of the sternum and exerting upward pressure on the saw, the total length of the sternum is cut. A sternal retractor is placed into the incision, first with the two blades touching each other, and gently opening the sternum, avoiding sternal or any rib fracture. This incision affords the exposure of the pericardium, thoracic vena cava, ascending aorta, pulmonary artery, and lower neck structures. It could also be associated with an anterior neck or supraclavicular extension for exposure of injuries to the thoracic outlet great vessels and of zone 1 of the neck.

9.3.4 Trapdoor ("Book") Incision

This combined anterolateral thoracotomy in the third space, partial sternotomy, and supraclavicular incision was historically used for injuries of the thoracic outlet, but it offers few exposure advantages and carries high morbidity. Nowadays, proximal vascular control can be obtained with an intravascular balloon, followed by either endovascular repair or open surgery via a supraclavicular incision.

9.3.5 Posterolateral Thoracotomy

This incision traverses the latissimus dorsi muscle and the portions of other chest muscles. The scapula must be retracted superiorly to achieve the fourth or fifth intercostal space. This is the standard incision for most elective thorax operations because it provides good exposure of the posterior mediastinal structures, such as the aorta, lung hilum, esophagus, trachea and azygos vein. In hemodynamically unstable patients, the lateral decubitus is poorly tolerated and it may exacerbate hypotension. In addition, the contralateral lung, which is in dependent position, may be injured itself, with impaired expansion, and other body cavities (abdomen, neck) which may require operative care are inaccessible. Because of its lack of versatility the use of this incision in acute settings is limited.

9.4 Procedures: Tips and Tricks

9.4.1 Tube Thoracostomy

This is the sole invasive procedure for most patients (>85%) suffering from chest trauma [10]. It allows drainage of blood and air and, according to the extent of the outlet and the patient's condition, it may trigger further procedures. The drain is inserted after the clinical diagnosis of a tension pneumothorax or evidence at chest x-ray or E-FAST of blood or air in the pleural cavity. It should be inserted in the area of the auscultatory triangle in the midaxillary line near the fourth or fifth intercostal space, where the chest wall is thinner. After adequate anesthesia a generous skin incision parallel to the intercostal space is accomplished. Using a scissor, dissection of the subcutaneous tissue and spreading of the intercostal muscles is obtained, laying in the proximity of the superior border of the inferior rib, to avoid damage to the intercostal neurovascular bundle. Once the pleura is entered, a gentle exploration of the pleural cavity with a probing finger is done, to discern pericardium or diaphragmatic hernia, or to release pleural adhesions. A 28–32 French tube is inserted: if a trocar-tipped chest tube is chosen, the trocar is used only to cross the wall and must be retracted from the tip of the tube in order to avoid iatrogenic injuries. It is directed toward the back and the apex of the pleural space, and attached to an appropriate collection, water seal and negative pressure device. The chest tube must be kept open, even during patient movement or positioning, especially if the patient is intubated, to prevent undue increase of intrathoracic pressure which may worsen hemodynamic condition.

9.4.2 Decompressive Thoracotomy

This is a life-saving procedure to rapidly release a tension pneumothorax which has replaced needle decompression also in prehospital settings. A 5–7 cm incision is performed in the fourth or fifth intercostal space at the midaxillary line and the pleural cavity is entered in the same manner as described for tube thoracostomy. In patients in cardiac arrest after trauma unresponsive to external massage, bilateral decompressive thoracotomy is performed for blind relief of pleural cavity hypertension. If recovery of spontaneous cardiac activity is not accomplished, the left incision is extended into an anterolateral thoracotomy for direct cardiac massage (see below).

9.4.3 Emergency Department Thoracotomy

Patients in extremis can require emergency department thoracotomy (EDT) for resuscitation. The clear indications for EDT are:

1. Patients in extremis or witnessed cardiac arrest with signs of life and high likelihood of correctable intrathoracic injury, particularly for penetrating cardiac wounds with tamponade or lung hilar injuries with air embolism.
2. Severe hypotension or witnessed cardiac arrest for extrathoracic injuries unresponsive to external massage and bilateral chest decompression.

The objectives of an emergency thoracotomy include: relief of diastolic restriction in cardiac tamponade, control of a heart wound or exsanguinating thoracic vascular injury, descending aorta clamping to increase coronary and brain blood flow, occlusion of pulmonary hilum to reduce possibility of air embolism and decreased bleeding in severe lung injury, and internal cardiac compressions to maintain cardiac output in a more efficient way [11].

EDT is accomplished through a left anterolateral thoracotomy. Once the pleural cavity has been entered, the injuries are addressed. Cardiac tamponade is relieved by opening the pericardium anterior to the phrenic nerve, and cardiac injury, if present, is directly controlled; the aorta can be cross-clamped using a spring (non-crushing) vascular clamp, higher in the chest, at the proximal descending aorta, distal to the origin of the left subclavian artery, or lower, after the lung has been pushed upward with inferior pulmonary ligament transection and the aorta localized between the esophagus and the spine. A nasogastric tube in place allows easier recognition of the esophagus and avoids its damage during aortic control. Open chest cardiac massage, performed by gentle bimanual compression of the heart, provides increased cardiac output if compared to closed chest cardiopulmonary resuscitation [12]. Especially after penetrating gunshot wounds, the risk of pulmonary hilum involvement with dramatic bleeding and air embolism is high. In this situation, if a suitable clamp is unavailable or if it is particularly difficult to cross-clamp the hilum, the inferior ligament can be rapidly taken down and the entire lung twisted 180° on itself by moving the upper lobe to the area of the diaphragm and the lung diaphragmatic surface to the apex of the pleural space. This maneuver (hilar twist) achieves vascular and bronchial control and usually is followed by stapler pneumonectomy for definitive treatment of hilar injuries.

In patients in extremis or cardiac arrest from extrathoracic injuries, the suggested approach is bilateral decompressive thoracotomy to relieve compressive intrathoracic conditions. If recovery of spontaneous cardiac activity is not achieved, the left thoracic incision is extended to obtain a formal EDT. Internal cardiac massage and aortic clamping are performed to optimize coronary and brain blood flow. Recently, introduction of REBOA (resuscitative endovascular balloon occlusion of the aorta) ballon inflated in aorta zone I has been proposed as a substitute for EDT with favorable results on patient outcome [13].

EDT is a dangerous procedure performed in an uncontrolled environment that requires multiple sharp instruments. It is not without potential complications, which can be divided into two broad categories:

1. Technical complications: an improperly placed incision can lead to poor exposure and potential damage to soft tissue (female breast), vascular injuries (intercostal, internal mammary, pulmonary vessels), lung parenchymal injury.
2. Direct injury to the treating surgeon: He or she is at remarkable risk for infections by communicable diseases, such as hepatitis B (20%), hepatitis C (14%) and HIV (4%) [14].

In order to protect the emergency department and the trauma surgeon performing this procedure, universal precautions must be enforced and formal indications must be strictly followed.

9.4.4 Packing

Successful hemostasis may be achieved by packing around the apex, diaphragm and vertebrae. Moreover, packing should be carefully considered because the presence of bulky gauzes may induce increased intrathoracic pressures, with potential cardiopulmonary collapse, desaturation and ventilation disorders. Packing should be removed as soon as the patient's normal physiology is restored.

9.4.5 Temporary Damage Control Thoracic Closure

Temporary closure of the chest is indicated in two conditions. The first is the temporary control of injuries with delayed definitive repair. An example is massive bleeding from the chest wall or the lung in a coagulopathic patient treated with packing, with the need for reoperation for depacking and definitive hemorrhage control. The second indication is intrathoracic hypertension after an anterolateral thoracotomy or sternotomy due to edema of internal organs. In this context, closing of the wall will restrict the heart beats and significantly decrease cardiac output. Favorable options for temporary closure are single *en mass* closure of muscles and skin without approximation of bones (ribs, sternum), or the use of a sterile drape or a Bogota bag sutured to the skin. Of course, the patient needs to be sedated and ventilated until definitive wall reconstruction. These are rare situations associated with multiple complications (bleeding, infections), to be applied in highly selected cases.

9.5 Specific Injuries

9.5.1 Lung

Hemorrhage control in lung injuries may be difficult because the pulmonary vasculature houses a low-pressure system and bleeding foci are difficult to be addressed. Anatomic lung resections in critically injured patients can be daunting procedures for surgeons unfamiliar with these interventions. Non-anatomic wedge resections of peripheral injuries using a stapler can often achieve hemostasis and rapidly decrease air leak [15, 16] (Fig. 9.1). However, some injuries may be particularly challenging:

- ***Through-and-through injury***
  These injuries are usually a consequence of penetrating trauma. Simple closure of these injuries would imply a large lung dissecting hematoma or infection in the postoperative period, with abscess formation. The suggested technical

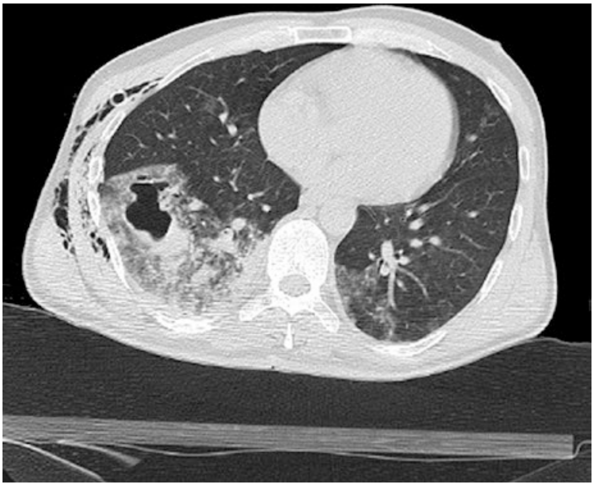

Fig. 9.1 Complex injuries of the right lung. Large contusion with parenchymal lacerations

solution for this type of injury is *pulmonary tractotomy*. This consists in applying two long vascular clamps or parts of a linear cutting stapler through the "path" of the laceration and sectioning the parenchymal bridge between the clamps, exposing the interior of the injury to the outside, and holding selective hemostasis and aerostasis inside. When using clamps, aerostasis and hemostasis are terminated with a running absorbable suture over the clamps, unnecessary when using the stapler.

- ***Hilar injury***
  This type of injury is often lethal. Primary control of hilar bleeding should be manual, by fastening between the thumb and index finger, followed by pulmonary mobilization, section of the inferior pulmonary ligament and placement of a large vascular clamp around the hilum. These patients generally tolerate badly this maneuver, often developing severe right ventricular dysfunction, which requires rapid diagnosis and repair of the hilar structures. Partial arterial or venous injuries should be treated with lateral sutures. Venous transection requires corresponding lobectomy, while the main arterial injury will be usually treated with pneumonectomy, with a high degree of mortality. When this is unavoidable, it can be quickly obtained using a stapler with a vascular charge. The technique consists in applying the stapler as distal as possible so that one can perform reinforcement sutures.
- ***Diffuse lung injuries***
  Sometimes the lungs may be diffusely bruised or lacerated and the patient already has coagulopathy. In such dramatic situations, the options are pneumonectomy, which can cause devasting impairment of physiology, particularly on the right side. Alternatively, it is possible to set up selective ventilation of the non-traumatized lung, with packing of the traumatized one. Packing is removed once the physiology reserve is restored and more focused procedures on the damaged lung are possible. In bilateral injuries with diffuse air leak extracorporeal membrane oxygenation (ECMO) could be an option only in highly experienced centers.

9.5.2 Heart

Cardiac injuries which survive until emergency department admission are usually a consequence of wounds from penetrating objects, or blunt injuries with rupture of low-pressure chambers. Cardiac tamponade is a life-threatening condition which requires immediate release. It is accomplished through an EDT, opening the pericardium, inspection and identification of the heart injury. The posterior aspect of the heart is inspected by gently lifting it, placing a rolled gauzed beneath. Once the injury is identified, temporary bleeding control is gained with different damage control techniques:

- ***Digital pressure***
  A fingertip of the surgeon's non-dominant hand or of the assistant's hand is applied over the wound and the suture is accomplished with a 3/0 Prolene suture, passing the needle beneath the occluding finger, in a figure-of-eight fashion.
- ***Foley catheter***
  The tip of a 14 French Foley catheter is gently inserted into the cardiac wound and advanced for 3 cm. The balloon is inflated with saline and a Kelly clamp is placed at the end of the Foley. The catheter is retracted against the myocardium and pulled to one side of the wound allowing the apposition of stiches (with or without pledgets) or staples. The maneuver is repeated until complete suture is obtained and the Foley is removed.
- ***Staples***
  After digital control of the bleeding wound, skin staples are applied and left in situ permanently. The stapled line may be buttressed with 3/0 Prolene sutures with pledgets.

Fig. 9.2 Pneumopericardium with cardiac tamponade. The patient was decompressed through an emergency department thoracotomy

In injuries near the coronary artery, care should be taken to avoid their iatrogenic occlusion by passing the suture beneath the coronary artery and around the injury with a pledgeted horizontal mattress technique. If the patient is in cardiac arrest or fibrillation, cardiac injury repair must be performed before restoring cardiac activity.

Once the intervention is completed, a 20 French drainage is left in place on the posterior surface of the heart, and the pericardial sac is sutured, maintaining a little hole to avoid postoperative tamponade. At the end of the procedure, in the operating room or intensive care unit, transesophageal echocardiography must be performed to rule out valvular or septal injuries which may require delayed cardiac surgery. An unusual injury is pericardial tamponade due to air entrapped in the pericardial sac (Fig. 9.2). The treatment is chest and pericardial decompression with control of air leak.

9.5.3 Vessels

Primary repair, after exposure and control are obtained, can frequently be performed. When primary repair cannot be achieved, a graft should be placed. For vessels greater than 5 mm, polytetrafluoroethylene or knitted Dacron are the conduits of choice. If the patient is in extremis and there is not enough time to suture a graft in place, an option is to place a temporary shunt. An Argyle carotid shunt can be placed into the vessel as a temporary measure with plans for later repair when the patient has been physiologically captured. Aortic injuries can often be managed with primary repair; however, these injuries may require placement of a Dacron graft. It is important to gain proximal and distal vascular control before entering the hematoma. Clamps may be used to gain control and a roller pump or passive shunt (Gott shunt) are applied to maintain perfusion of the aorta distal to the injury to prevent spinal cord ischemia.

9.5.4 Trachea

Injury to the tracheobronchial tree is rare. Blunt trauma is the most frequent cause of trauma of the distal half of the trachea (Fig. 9.3). Only 18% of distal tracheal or bronchial injuries are due to penetrating trauma. Airway control is mandatory and in the case of open wounds it may be achieved by direct intubation of the wound tract. Interrupted monofilament absorbable suture is used around the tracheal rings making sure that there is mucosa-to-mucosa approximation to obtain an airtight tension-free suture. The knots should be placed outside of the airway to reduce the likelihood of suture granuloma or stricture. If a significant length of the trachea needs to be resected, additional length can be achieved by mobilizing the trachea by blunt dissection in the avascular pretracheal plane. A vascular pedicle, such as intercostal muscle, should be used to buttress the repair and to decrease the likelihood of leak

Fig. 9.3 Massive air leak and pneumothorax notwithstanding chest drain from tracheal injury (*arrow*)

or fistula formation. A gap of tracheal or bronchial wall can be closed with apposition of lung parenchyma. A postoperative goal is the early removal of the tracheal tube except in the case of associated conditions requiring prolonged ventilation. In this setting, the balloon cuff ideally should be positioned distal to the repair.

9.5.5 Esophagus

The majority of esophageal injuries are caused by gunshot wounds. The treatment should be primary repair if less than 50% of the circumference is injured. The repair should be reinforced with pleura, intercostal muscle, pericardium, or omentum. If the injury is greater than 50% circumference, one option is exclusion with a cervical esophagostomy and a gastrostomy tube. A second option is placement of a full covered stent and external wide drainage of the esophageal wound with a thoracostomy tube.

9.6 Postoperative Care and Complications

The most severe complications that need to be anticipated in the postoperative care of a patient after TDCS are tamponade and air leak. Tamponade can be heralded by distended neck veins, muffled cardiac sounds, and hypotension (Beck's triad). However, these signs can be difficult to elicit postoperatively. Echocardiography may be helpful in determining the diagnosis. A re-exploration is needed to correct the cause of tamponade.

The second most common complication is air leak following pulmonary procedures. Care should be taken to place appropriate chest tubes prior to definitive closure of the chest to achieve lung expansion. Usually two chest tubes are required. An anterior drain placed high in the apex can allow full lung expansion. The second drain should be placed low and posteriorly for fluid drainage. Both tubes should be maintained on suction. Multiple therapeutic bronchoscopies avoid obstruction of the bronchial tree by mucous plugging. If the air leak does not preclude ventilation, this complication may be managed conservatively. If the air leak results in a significant loss of minute volume from the ventilator, or if the lung does not expand sufficiently, an operative approach is required to close the site of leakage or reinforce the raw area of the lung.

9.7 Conclusion

Chest trauma is frequently the cause of physiologic derangement of the patient, requiring a series of actions with the aim to restore airway patency and integrity, gas exchange and circulation of the blood. In the case of severe chest trauma requiring immediate treatment for life-threatening injuries, the trauma surgeon should be capable of life-saving maneuvers on all thoracic organs. Damage control of chest injuries should be in the armamentarium of trauma surgeons because specialists in thoracic surgery are often not available inside the hospital and can only intervene at a later time.

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10 Abdominopelvic Trauma

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10.1 Introduction

Trauma injuries and patients have been historically stratified and managed following the American Association of Surgery of Trauma Organ Injury Scale (AAST-OIS) classification [1]. This anatomy-based classification describes the site and extent of damage. Trauma lesions are graded on an ordinal scale that defines each level of organ injury, ranging from grade I (relatively minor) to grade V (likely fatal).

Born with the goal to create a standardized language that trauma surgeons can use to communicate among themselves and with other physicians, this model proved to be a useful and effective tool in the decision-making process [2, 3]. The increasing spread of computed tomography (CT), at the time when this classification was published, allowed physicians to diagnose and, more importantly, to stratify trauma patients preoperatively according to their injuries [3]. For decades, anatomy has been successfully used as the most reliable factor for classifying trauma injuries and driving management algorithms for hemodynamically stable trauma patients.

In recent decades, trauma management has profited extensively from an incredible evolution. Innovative techniques, such as interventional endovascular procedures, opened a wide range of options in trauma management that increased the rate of patients treated non-operatively. For example, the new concept of endovascular and hybrid trauma and bleeding management (EVTM), where surgery and endovascular tools are used as combined strategies to control the bleeding, have led to good outcomes [4, 5]. In fact, obtaining bleeding control by using endovascular means may facilitate open surgery (limiting the need for aortic cross-clamping and minimizing blood loss, operative time and complications) but, even more important, it may prevent it [6].

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Non-operative management, associated with the above techniques, has been successfully applied and has gained increasing consent, showing good outcomes even in severe trauma patients [7]. Since non-operative management protocols have allowed non-operative treatment of even severe anatomical injuries in hemodynamically stable patients, the keystones in driving trauma management decisions are anatomy as well as physiology. When a trauma occurs, anatomical lesions trigger a metabolic chain and unleash a set of biochemical consequences that require some sort of regulation as a part of the trauma treatment. That is where the concept of integrating physiology into severity scores and classifications stems from and shows its importance. Also, in all those countries where CT availability is low and the anatomical aspect of traumatic injuries cannot be assessed preoperatively, physiology is the only and most important driving tool in decision-making processes.

The World Society of Emergency Surgery (WSES) proposed a classification system not anchored only on the anatomical aspect of injuries but also on their effect on the physiological status of the patient [8].

Regarding the patients' physiological status several authors, as well as the Advanced Trauma Life Support (ATLS) guidelines, have proposed the following definitions:

- ***Normal hemodynamic status*** is when "the patient does not require fluids or blood to maintain blood pressure, without signs of hypoperfusion" [9].
- ***Hemodynamic stability*** "is the condition in which the patient achieves a constant or an amelioration of blood pressure after fluids, with a blood pressure >90 mmHg and heart rate <100 bpm" [9].
- ***Hemodynamic instability*** "is considered the condition in which the patient has:
  - admission systolic blood pressure < 90 mmHg
  - admission heart rate > 120 bpm
  - evidence of skin vasoconstriction (cool, clammy, decreased capillary refill),
  - altered level of consciousness and/or shortness of breath
    or
  - >90 mmHg but requiring bolus infusions/transfusions and/or vasopressor drugs
  - and/or admission base excess >−5 mmol/L
  - and/or shock index >1
  - and/or a transfusion requirement of at least 4–6 units of packed red blood cells within the first 24 h" [9].
- ***Transient responder patients*** are those showing an initial response to adequate fluid resuscitation but then subsequent signs of ongoing loss and perfusion deficits. More in general these patients respond to therapy but do not reach sufficient stabilization to undergo interventional radiology treatments [10, 11].

In abdominopelvic trauma, the most commonly damaged and bleeding organs are the liver, spleen, kidneys and the pelvic ring. These were the first four classifications that WSES focused on [9, 10, 12, 13].

10.2 General Management Strategies

Operative management (OM) is the treatment of choice in cases of:

- evisceration
- impalement
- peritonitis on abdominal examination
- hemodynamic instability with positive focused assessment with sonography for trauma (FAST)
- CT scan evidence of intra-abdominal injury requiring surgery (i.e., hollow viscus injury)
- failed embolization or persistent bleeding.

Non-operative management (NOM) should be considered in cases of:

- hemodynamic stability
- and absence of other lesions requiring operative management.

10.2.1 Diagnosis

Hemodynamic status drives the decision on what diagnostic study should be done. Serum lactate and base deficit are sensitive diagnostic markers of the grade of hemorrhagic shock and can be used to monitor the response to resuscitation. Extended FAST (E-FAST) has high sensitivity in effectively and rapidly detecting intra-abdominal fluid. For hemodynamically stable patients, CT scan with intravenous contrast is the gold standard; it helps differentiate patients with active bleeding (active contrast extravasation) from those with contained vascular injuries.

10.2.2 Non-operative Management

In the case of hemodynamic stability and absence of other lesions requiring operative management, NOM should be considered the treatment of choice regardless of the injury grade (WSES I–III/AAST I–V) of the damaged abdominal solid organ (i.e., liver, spleen, or kidney).

In transient responder patients with moderate and severe injuries, NOM should be considered only in selected settings having immediate availability of trained surgeons, operating room, continuous monitoring, access to angiography (AG), angioembolization (AE), blood and blood products.

As an "extension" of NOM, angiography with angioembolization (AG/AE) is the first-line intervention in the hemodynamically stable patient showing an arterial blush at the CT scan.

It is important to note that in hemodynamically stable children the presence of active blush on CT is not an absolute indication for AG/AE.

AG/AE may be performed in:

1. Hemodynamically stable or rapid responder patients with moderate and severe lesions (depending on the injured organ: i.e., spleen)
2. Patients with vascular injuries detected at CT scan (contrast blush, pseudoaneurysm, arteriovenous fistula).

NOM can be considered also in selected patients with penetrating trauma. Low-energy penetrating trauma, such as stab wound or low-energy gunshot wounds, particularly of the right upper quadrant, may benefit from NOM, avoiding negative laparotomies and their high rates of morbidity. High-energy gunshot wounds are less likely to be successfully treated with NOM (OM is required in 90% of cases). In penetrating trauma patients treated with NOM, serial clinical evaluations (physical examinations and laboratory testing), associated with repeated radiological assessment, are the cornerstones and must be performed to detect any change in clinical status.

The greatest risk of NOM is missing intra-abdominal injuries, especially in penetrating trauma and mainly perforation of a hollow viscus, which can be suspected even in stable and asymptomatic patients considering the trajectory of the bullet or of the stab tract.

In all those patients where intra-abdominal injuries are suspected but not detected, interval laparoscopy should be always considered as an “extension” of NOM in order to confirm/exclude injuries requiring surgery. Interval laparoscopy is an important tool that works as a bridge strategy to plan a step-up treatment (subsequent laparoscopy/laparotomy).

Patients with concomitant neurotrauma (i.e., spinal cord or head trauma) need high perfusion pressure to the brain in order to avoid secondary damage (following hypotension and hypoperfusion). Specific hemodynamic goals for these patients are:

1. Systolic blood pressure > 110 mmHg
2. Central perfusion pressure of 60–70 mmHg in the case of moderate head or spinal cord trauma
3. Central perfusion pressure > 80 mmHg in the case of severe head or spinal cord trauma.

For these reasons, in cases of concomitant head trauma and/or spinal cord injuries with reliable clinical examination, NOM is a strategy that may be attempted if the above hemodynamic goals are achieved and maintained without intra-abdominal bleeding that may cause subsequent hemodynamic instability.

10.2.3 Thromboprophylaxis, Feeding and Mobilization

Unless some contraindication exists, all trauma patients should receive mechanical prophylaxis, which has been shown to be safe, and early mobilization should be considered in all stable patients.

Trauma patients should receive anticoagulant prophylaxis with low-molecular-weight heparin as soon as possible, this strategy may be safe in selected patients with solid organ injuries treated with NOM. It is recommended to start enteral feeding as soon as possible, in the absence of contraindications.

10.3 Liver Trauma

Hepatic injuries can be divided into three grades, according to the WSES classification that considers the AAST-OIS classification (Table 10.1) and hemodynamic status (Table 10.2) [12]:

- minor (WSES grade I);
- moderate (WSES grade II);
- severe (WSES grade III and IV).

Table 10.1 AAST-OIS liver injury scale (1994 revision)

Grade	Injury type	Injury description
I	Hematoma	Subcapsular, <10% surface area
	Laceration	Capsular tear, <1 cm parenchymal depth
II	Hematoma	Subcapsular, 10–50% surface area: Intraparenchymal <10 cm in diameter
	Laceration	Capsular tear 1–3 parenchymal depth, <10 cm in length
III	Hematoma	Subcapsular, >50% surface area of ruptured subcapsular or parenchymal hematoma; intraparenchymal hematoma >10 cm or expanding
	Laceration	>3 cm parenchymal depth
IV	Laceration	Parenchymal disruption involving 25–75% hepatic lobe or 1–3 Couinaud's segments
V	Laceration	Parenchymal disruption involving >75% of hepatic lobe or >3 Couinaud's segments within a single lobe
	Vascular	Juxtahepatic venous injuries, i.e., retrohepatic vena cava/central major hepatic veins
VI	Vascular	Hepatic avulsion

Advance one grade for multiple injuries up to grade III
AAST-OIS American Association for the Surgery of Trauma Organ Injury Scale

Table 10.2 Liver trauma classification

	WSES grade	AAST grade	Hemodynamic status
Minor	WSES grade I	I–II	Stable
Moderate	WSES grade II	III	Stable
Severe	WSES grade III	IV–V	Stable
	WSES grade IV	Any	Unstable

From [12] (published under the terms of the Creative Commons CC-BY license)
WSES World Society of Emergency Surgery, *AAST* American Association for the Surgery of Trauma

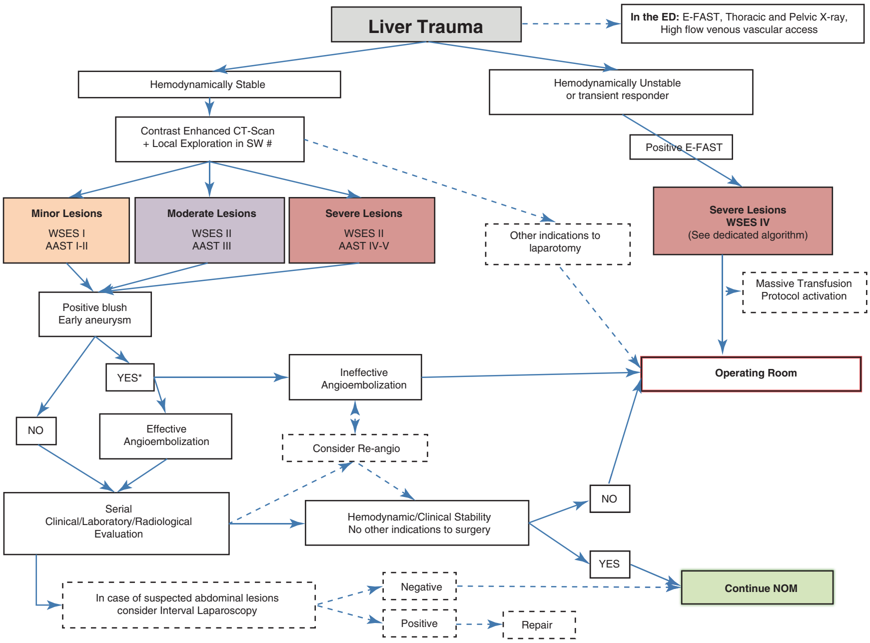

Fig. 10.1 Liver trauma management algorithm. *CT* computed tomography, *ED* emergency department, *E-FAST* extended focused assessment with sonography for trauma, *NOM* non-operative management, *SW* stab wound. #Wound exploration near the inferior costal margin should be avoided if not strictly necessary. *Angioembolization should be always considered for adults, only in selected patients and in selected centers for pediatrics. Reproduced from [12] published under the terms of the Creative Commons CC-BY license

Two algorithms for the management of hepatic injuries are presented in Figs. 10.1 and 10.2.

10.3.1 Specific Non-operative Management Aspects

The liver is the most commonly injured intra-abdominal solid organ and the majority of injuries do not require surgical treatment. All the aforementioned general rules remain key points in liver trauma NOM. Only moderate (WSES II, AAST III) and severe (WSES III, AAST IV–V) lesions may require admission to the intensive care unit, in the case of isolated liver injury.

10.3.2 Operative Management

OM should be the treatment of choice for hemodynamically unstable and non-responder patients (WSES IV), other than the general indications above mentioned.

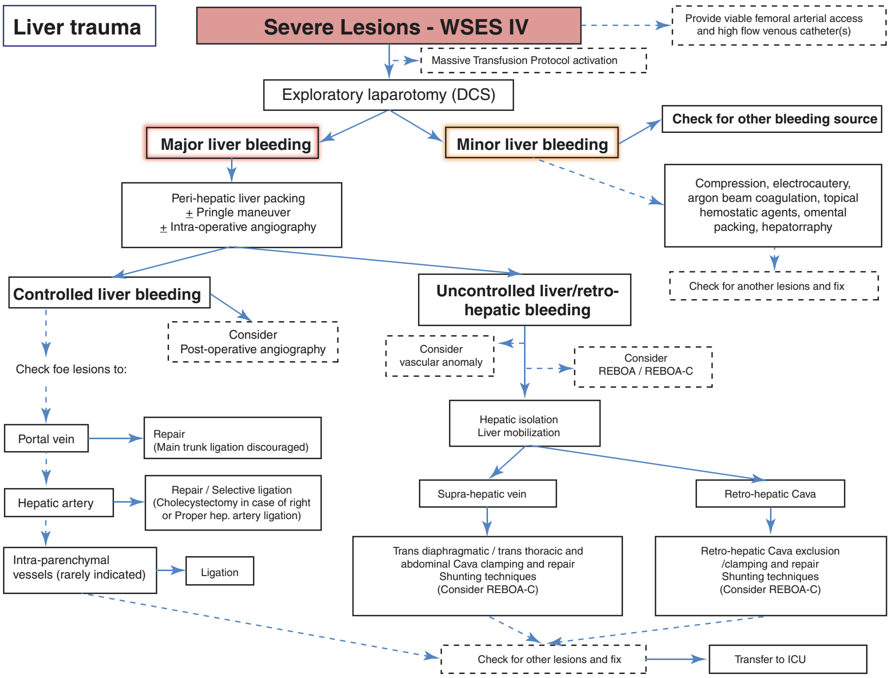

Fig. 10.2 Hemodynamically unstable liver trauma management algorithm. *DCS* damage control surgery, *ICU* intensive care unit, *REBOA-C* resuscitative endovascular balloon occlusion of the aorta-cava. Reproduced from [12] published under the terms of the Creative Commons CC-BY license

The primary goal during laparotomy in OM are control of the hemorrhage and of the bile leak and initiation of damage control resuscitation as soon as possible.

If no major bleeding is present, compression alone or any other tool for hemostasis control (i.e., electrocautery, bipolar devices, argon, topical hemostatic agents, etc.) may be sufficient to stop the bleed.

In the case of major hemorrhage, several strategies can be considered:

1. Manual compression and hepatic packing.
2. Ligation of the vessels in the wound.
3. Hepatic debridement or finger fracture.
4. Balloon tamponade.
5. Temporary ligation of hepatic vessels (Pringle maneuver) in order to control the bleeding and allow for repair.
6. Repair of hepatic vessels (i.e., hepatic artery or portal vein injuries).
7. Hepatic artery ligation or selective ligation (concomitant cholecystectomy if the right hepatic artery has been ligated, to avoid gallbladder necrosis).
8. In the event of suspected injuries to the retrohepatic cava or hepatic vein: tamponade with hepatic packing, direct repair, lobar resection.

Complete vascular exclusion or other techniques, such as atriocaval shunt, are generally poorly tolerated.

Major hepatic resections should be avoided at first and only considered in subsequent operations. In selected patients with large areas of devitalized liver tissue, resectional debridement done by experienced surgeons may be considered a strategy.

Resuscitative endovascular balloon occlusion of the aorta (REBOA) may be used as a temporary bleeding control maneuver and as a bridge to other more definitive procedures of hemorrhage control in hemodynamically unstable patients.

Indications for postoperative AG/AE are:

1. Persistent arterial bleeding despite emergency laparotomy and hemostasis attempt.
2. After initial operative hemostasis, in stable or stabilized patients with contrast blush at completion CT scan.

10.3.3 Complications

The most frequent complications after liver trauma are:

- vascular complications: rebleeding or secondary hemorrhage (i.e., subcaspular hematoma), pseudoaneurysm (PSA), arteriovenous fistula;
- biliary complications: bile leak, biloma, biliary peritonitis, biliary fistula and hemobilia);
- hepatic necrosis and abscess;
- abdominal compartment syndrome.

Delayed hemorrhage without severe hemodynamic compromise may be managed at first with AG/AE, and this should also be considered in hepatic artery PSA, in order to prevent rupture.

Percutaneous drainage is a viable treatment strategy in cases of symptomatic or infected bilomas as well as intrahepatic abscesses.

Post-traumatic biliary complications not suitable for percutaneous management alone can be managed with a combination of percutaneous drainage and endoscopic techniques. A post-traumatic biliary fistula may be treated with laparoscopic lavage/drainage or endoscopic stenting as a first approach; if there is any other concomitant indication for surgery, laparotomy should be considered.

10.4 Splenic Trauma

Splenic injuries can be divided into three grades according to the WSES classification that considers the AAST-OIS classification (Table 10.3) and hemodynamic status (Table 10.4) [10]:

Table 10.3 AAST-OIS spleen injury scale (1994 revision)

Grade	Injury type	Injury description
I	Hematoma	Subcapsular, <10% surface area
	Laceration	Capsular tear, <1 cm parenchymal depth
II	Hematoma	Subcapsular, 10–50% surface area; intraparenchymal, <5 cm in diameter
	Laceration	Capsular tear, 1–3 cm parenchymal depth that does not involve a trabecular vessel
III	Hematoma	Subcapsular, >50% surface area or expanding; ruptured subcapsular or parenchymal hematoma; intraparenchymal hematoma, >5 cm or expanding
	Laceration	>3 cm parenchymal depth or involving trabecular vessels
IV	Laceration	Laceration involving segmental or hilar vessels producing major devascularization (>25% of spleen)
V	Laceration	Completely shattered spleen
	Vascular	Hilar vascular injury which devascularizes spleen

Advance one grade for multiple injuries up to grade III
AAST-OIS American Association for the Surgery of Trauma Organ Injury Scale

Table 10.4 Spleen trauma classification

	WSES grade	AAST grade	Hemodynamic status
Minor	WSES grade I	I–II	Stable
Moderate	WSES grade II	III	Stable
	WSES grade III	IV–V	Stable
Severe	WSES grade IV	Any	Unstable

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WSES World Society of Emergency Surgery, *AAST* American Association for the Surgery of Trauma

- minor (WSES grade I);
- moderate (WSES grade II and III);
- severe (WSES grade IV).

An algorithm for the management of splenic injuries is presented in Fig. 10.3.

10.4.1 Specific Diagnostic Procedures and Non-operative Management Aspects

The spleen is the second most commonly injured abdominal solid organ and NOM is successful in around 80% of patients.

Doppler ultrasound (US) and contrast-enhanced US are useful to evaluate splenic vascularization, to better define some vascular anomalies (i.e., PSA) and during the follow-up.

Injury grade on CT scan, extent of free fluid and presence of a PSA are not predictive factors of NOM failure. Conversely, age > 55 years old, high Injury Severity Score (ISS) and moderate to severe splenic injuries seem to be prognostic factors for failure.

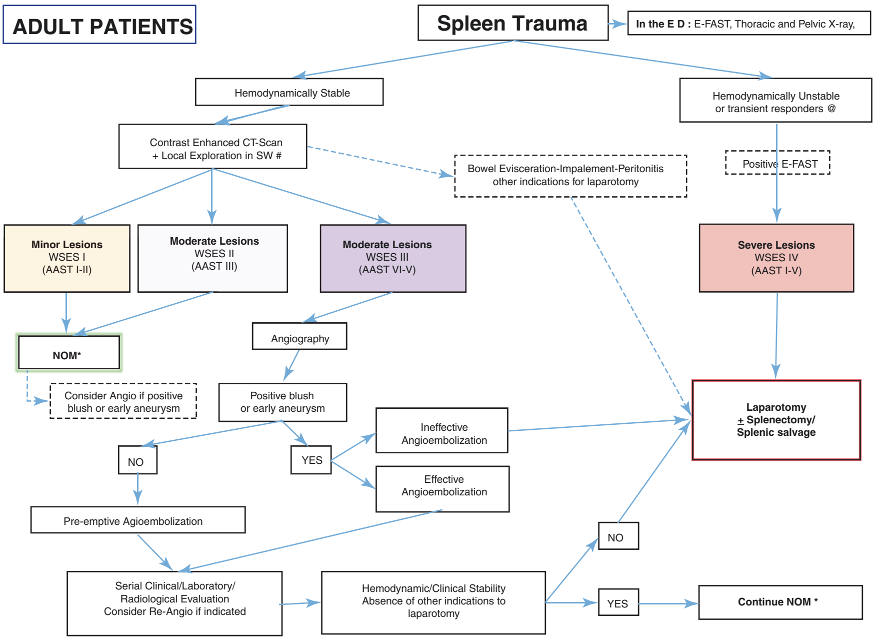

Fig. 10.3 Spleen trauma management algorithm for adult patients. *CT* computed tomography, *ED* emergency department, *E-FAST* extended focused assessment with sonography for trauma, *NOM* non-operative management, *GSW* gunshot wound, *SW* stab wound. * NOM should only be attempted in centers capable of a precise diagnosis of the severity of spleen injuries and capable of intensive management (close clinical observation and hemodynamic monitoring in a high dependency/intensive care environment, including serial clinical examination and laboratory assay, with immediate access to diagnostics, interventional radiology, and surgery and immediately available access to blood and blood products) or alternatively in the presence of a rapid centralization system in those patients amenable to be transferred. @ Hemodynamic instability is considered the condition in which the patient has an admission systolic blood pressure <90 mmHg with evidence of skin vasoconstriction (cool, clammy, decreased capillary refill), altered level of consciousness and/or shortness of breath, or >90 mmHg but requiring bolus infusions/transfusions and/or vasopressor drugs and/or admission base excess >−5 mmol/L and/or shock index >1 and/or transfusion requirement of at least 4–6 units of packed red blood cells within the first 24 h; moreover, transient responder patients (those showing an initial response to adequate fluid resuscitation, and then signs of ongoing loss and perfusion deficits) and more in general those responding to therapy but not amenable to sufficient stabilization to undergo interventional radiology treatments. # Wound exploration near the inferior costal margin should be avoided if not strictly necessary because of the high risk of damaging the intercostal vessels. Reproduced from [10] published under the terms of the Creative Commons CC-BY license

The following conditions are not absolute contraindications for NOM but require intensive monitoring and a higher index of suspicion (for NOM failure):

1. Age > 55 years old.
2. Large hemoperitoneum.
3. Hypotension before resuscitation.

4. Glasgow Coma Scale <12.
5. Low hematocrit level at admission.
6. Blush at CT scan.
7. Anticoagulant drugs.
8. HIV disease, drug addition, cirrhosis.
9. Associated abdominal injuries and need for blood transfusion.

Other than the general indications (mentioned above), proximal or combined AG/AE can also be considered in hemodynamically stable patients with:

1. WSES grade II lesions without blush but with risk factors for NOM failure (not routinely recommended but to be considered).
2. An absent blush at AG but previously seen at CT scan (not routinely recommended but to be considered).
3. WSES grade III lesions, regardless of the presence of CT blush (recommended).
4. Multiple splenic vascular abnormalities or in the presence of a severe lesion (recommended).

In performing proximal AE for splenic vascular injuries, it is important to always evaluate and confirm a permissive pancreatic vascular anatomy. Usually, coils should be preferred to temporary agents.

There is no current agreement in the literature regarding whether proximal or distal embolization should be used in the event of a single vascular injury (contrast blush, pseudoaneurysm, and arteriovenous fistula) in minor and moderate injuries.

In WSES II–III splenic injuries and concomitant neurological trauma, a NOM strategy should be considered with caution and only in centers with rapidly available operating room and/or AG/AE; otherwise, splenectomy has been shown to be a safe strategy that helps prevent secondary damage due to hypoperfusion.

10.4.2 Operative Management

OM should be the treatment of choice for hemodynamically unstable and non-responder patients (WSES IV), other than the general indications mentioned above.

Stable patients with moderate and severe lesions should undergo OM in centers where intensive monitoring cannot be performed and/or when AG/AE is not rapidly available.

Splenectomy should be performed when NOM with AG/AE has failed and:

- the patient remains hemodynamically unstable *or*
- shows a significant drop in hematocrit levels *or*
- continuous transfusions are required.

During OM, salvage of at least a part of the spleen is debated and cannot be suggested.

Laparoscopic splenectomy in the early trauma scenario in bleeding patients is described but cannot be recommended.

10.4.3 Follow-Up in Non-operative Management

In the first 48–72 h of follow-up in moderate and severe lesions, clinical and laboratory observation associated with bed rest is essential.

During hospitalization, the CT scan should be repeated in the case of:

- patients with moderate and severe lesions;
- decreasing hematocrit;
- presence of vascular anomalies;
- underlying splenic pathology or coagulopathy;
- neurologically impaired patients.

CT follow-up is recommended also after discharge in the presence of underlying splenic pathology or coagulopathy and in neurologically impaired patients.

Activity restriction may be suggested for 4–6 weeks in minor injuries and up to 2–4 months in moderate and severe injuries.

10.4.4 Infection Prophylaxis in Asplenic and Hyposplenic Patients

After splenectomy or AG/AE, patients should receive immunization against encapsulated bacteria (*Streptococcus pneumoniae*, *Haemophilus influenzae*, and *Neisseria meningitidis*). Vaccination programs should be started 14 days after splenectomy or spleen total vascular exclusion. In patients discharged before 15 days after splenectomy or AE, where the risk of missing vaccination is deemed high, the best choice is to vaccinate before discharge.

Malaria prophylaxis is strongly recommended for travelers, immunization against seasonal flu is recommended for patients over 6 months of age, and antibiotic therapy should be strongly considered in the event of any sudden onset of unexplained fever, malaise, chills or other constitutional symptoms, especially when medical review is not readily accessible.

10.5 Kidney Trauma

Kidney injuries can be divided into three grades according to the WSES classification that considers the AAST-OIS classification (Table 10.5) and hemodynamic status (Table 10.6) [13]:

Table 10.5 AAST-OIS kidney injury scale

Grade	Injury type	Injury description
I	Contusion	Microscopic or gross hematuria; urologic studies normal
	Hematoma	Subcapsular, nonexpanding without parenchymal laceration
II	Hematoma	Nonexpanding perirenal hematoma confirmed to renal retroperitoneum
	Laceration	<1.0 cm parenchymal depth of renal cortex without urinary extravasation
III	Laceration	<1.0 cm parenchymal depth of renal cortex without collecting system rupture or urinary extravasation
IV	Laceration	Parenchymal laceration extending through renal cortex, medulla, and collecting system
	Vascular	Main renal artery or vein injury with contained hemorrhage
V	Laceration	Completely shattered kidney
	Vascular	Avulsion of renal hilum which devascularizes kidney

Advance one grade for multiple injuries up to grade III
AAST-OIS American Association for the Surgery of Trauma Organ Injury Scale

Table 10.6 Kidney trauma classification

	WSES grade	AAST grade	Hemodynamic status
Minor	WSES grade I	I–II	Stable
Moderate	WSES grade II	III or segmental vascular injuries	Stable
Severe	WSES grade III	IV–V or any grade parenchymal lesion with main vessels dissection/occlusion	Stable
	WSES grade IV	Any	Unstable

From [13] (published under the terms of the Creative Commons CC-BY license)
WSES World Society of Emergency Surgery, *AAST* American Association for the Surgery of Trauma

- minor (WSES grade I);
- moderate (WSES grade II);
- severe (WSES grade III and IV).

An algorithm for the management of kidney injuries is presented in Fig. 10.4.

10.5.1 Specific Diagnostic Procedures

Blunt trauma, and especially high-velocity deceleration mechanism, is the most frequent cause of kidney injuries. This same mechanism is also responsible for a very rare type of lesion, namely isolated renal artery transection or divulsion.

Micro- and macrohematuria are often highly suggestive of kidney damage (being present in around 85–90% of cases) but do not predict the grade and the severity of the injury itself.

E-FAST has low sensitivity and specificity in diagnosing kidney lesions, the kidney being a retroperitoneal organ.

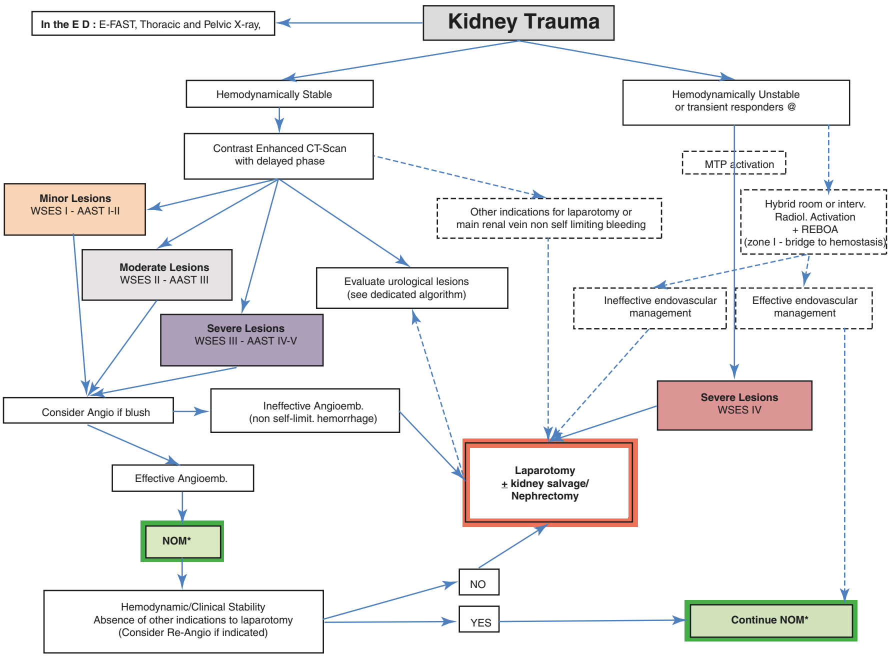

Fig. 10.4 Kidney trauma management algorithm. *CT* computed tomography, *ED* emergency department, *E-FAST* extended focused assessment with sonography for trauma, *MTP* massive transfusion protocol, *NOM* non-operative management, *REBOA* resuscitative endovascular balloon occlusion of the aorta. Reproduced from [13] published under the terms of the Creative Commons CC-BY license

CT scan with intravenous contrast is able to diagnose almost all kidney injuries, but the urographic phase (5-min delayed or excretory phase) makes it the gold standard in stable patients when a kidney or urinary tract lesion is suspected. This examination becomes mandatory in hemodynamically stable blunt trauma where micro- or macrohematuria is associated with hypotension or when the mechanism is rapid deceleration (even in the absence of hematuria).

Other imaging techniques, such as intravenous urography or retrograde urethrography, may be useful during surgery in the presence of an intraoperatively discovered kidney injury or in low resource settings when CT may not be available, but urinary tract damage is suspected.

10.5.2 Specific Non-operative Management and Angiography/Angioembolization Aspects

In moderate/severe injuries, the presence of at least two of the following criteria suggests a high risk of NOM failure:

1. Contrast blush.
2. Perirenal hematoma >3.5 cm.
3. Medial laceration with medial urinary extravasation.
4. Lack of contrast in the ureter (suggesting a complete ureteropelvic junction avulsion).

In the absence of other indications for laparotomy and in hemodynamically stable patients, NOM is feasible in cases of:

1. Isolated urinary extravasation.
2. Prerenal hematoma.
3. Renal fragmentation or a shattered kidney.
4. Damage to the renal pelvis (including disruption of the ureteropelvic junction).

All of these injuries may require acute or delayed, endoscopic or surgical repair, but in a later planned step-up treatment outside the acute setting. NOM may result in non-resolving urinomas that will require urinary stenting or percutaneous drainage, for example.

An isolated penetrating injury to the kidney is rare, being often associated with other organ lesions. However, NOM may be considered as first-line treatment in penetrating lateral kidney injuries in the absence of other indications for laparotomy.

In renal trauma, AG with possible superselective AE plays a role in the treatment of all the above-mentioned vascular anomalies (i.e., active contrast, PSA, arteriovenous fistula, etc.) other than in cases of non-self-limiting macrohematuria or extended perirenal hematoma.

AE should be performed as subselectively as possible, in order to limit the extension of devascularized parenchymal tissue.

If AG is negative for active bleeding, prophylactic AE is not recommended in kidney trauma (as performed for splenic injuries, for example), regardless of the presence of active contrast at the previous CT scan.

In hemodynamically stable patients with no other indications for surgical treatment and if the first AE fails resulting in active bleeding at repeated AG, it is possible to consider an additional AE as a treatment.

10.5.3 Operative Management

OM should be the treatment of choice for hemodynamically unstable and nonresponder patients (WSES IV), other than the general indications mentioned above.

Specific absolute indications for OM are:

1. Avulsion of the renal pedicle.
2. Pulsating/expanding retroperitoneal hematoma.
3. Renal vein lesion with non-self-limiting hemorrhage.

These three conditions often cause a life-threatening hemorrhage that needs an urgent surgical approach.

During laparotomy, renal artery laceration or severe parenchymal disruption often results in nephrectomy. Some arterial injuries are amenable to surgical repair.

In the event of an intraoperatively discovered retroperitoneal hematoma, surgical exploration of the kidney is mandatory in the presence of:

- an expanding hematoma in patients with blunt trauma;
- a hematoma that seems to be the only cause of hemodynamic instability in patients with blunt trauma;
- all hematomas caused by a penetrating trauma.

REBOA may be considered as a bridge to more definitive treatment (surgical repair) in hemodynamically unstable patients.

Some cases of renal trauma may result in a high percentage of nonviable tissue (devascularized kidney). These patients may develop persistent hypertension, not responsive to antihypertensive drugs, caused by dysregulation of the renin-angiotensin-aldosterone cascade response and amenable to surgical treatment (nephrectomy) in selected cases (i.e., functional contralateral kidney and failure of every other treatment option).

10.5.4 Renal Artery Injuries

In hemodynamically stable patients with renal artery damage, dissection or occlusion, one treatment option that needs to be considered is AE and/or percutaneous revascularization with stents or stent-grafts. This strategy finds application in experienced centers and in patients with limited warm ischemia time (<240 min).

Percutaneous revascularization of the renal artery with the use of stents leads to better outcomes compared with surgical revascularization, while the conservative approach often causes severe hypertension.

10.5.5 Follow-Up in Non-operative Management

Minor lesions do not require follow-up, while moderate and severe injuries may need follow-up according to the patient's condition.

CT scan with excretory phase is suggested in following up a kidney trauma with suspected or diagnosed urinary extravasation, within the first 48 h after the trauma itself.

10.6 Pelvic Trauma

10.6.1 Specific Anatomical and Physiological Aspects

The pelvic ring is a closed compartment of bones containing several structures: organs such as the small bowel, rectum, urogenital organs, and many vessels and nerves. As a result, pelvic trauma is one of the most complex traumas to manage due to the severe bleeding, difficult hemostasis and the intra-abdominal injuries that may be associated.

Patients with pelvic injuries usually have a high overall ISS and the mortality rates are high, especially in those who are hemodynamically unstable. For all these reasons, the management needs to be multidisciplinary in order to combine different areas of expertise and decide among several strategies. Integrated management must have the goal of resuscitating the patient and achieving hemostasis as soon as possible, as well as treating bone fracture and any associated intra-abdominal injuries.

The most common mechanism of injury that can cause pelvic damage is high-energy impact (i.e., falls from height and any type of traffic accident).

The pelvic retroperitoneal space can hold up to 3–4 liters of blood before venous tamponade can occur. Some pelvic fractures, such as “open book fractures” with a significant pubic diastasis (>2.5 cm), can cause instability of the pelvic ring itself and increase the internal volume reducing the effectiveness of tamponade.

Bleeding associated with pelvic fractures occurs from:

1. Venous plexuses (presacral or prevesical) in 80% of cases.
2. Branches of the internal iliac artery (pudendal, obturator, superior gluteal and lateral sacral arteries) in around 20% of cases; injuries to major iliac veins and arteries can occur in 4–10% of severe fractures.
3. Cancellous bone surfaces: some fractures are associated with greater transfusion rates but no association between fracture pattern and bleeding rate has been proven.
4. Soft tissue injuries.

Complex pelvic fractures are associated with intra-abdominal injuries in 30% of cases and up to 80% of patients have multisystem injuries. Associated intra-abdominal injuries may occur at a distance (i.e., liver and spleen) or, more commonly, inside the pelvis. The most frequent associated injuries involve the bladder, urethra, rectum and genital organs. Perineal hematoma or large soft tissue damage warrant a high index of suspicion for these injuries.

Independent predictors of major pelvic bleeding are:

- persistent hypotension;
- contrast extravasation on CT scan;
- large pelvic hematoma;

- sacroiliac joint disruption;
- symphysis diastasis >2.5 cm;
- bilateral and concomitant superior and inferior pubic rami fractures ("butterfly fracture");
- age < 55 years old;
- female sex.

In general, closed book fractures are frequently associated with urogenital and gastrointestinal injuries, whereas open book fractures often result in pelvic vascular injuries and hemodynamic compromise.

10.6.2 Classification

For the management of pelvic trauma it is essential to consider two main and strictly correlated aspects:

- the anatomical aspect of the pelvic ring fracture;
- hemodynamic status, which is its physiological consequence.

The Young-Burgees classification divides pelvic ring fractures according to their mechanism of injury and grade of anatomical damage:

- anteroposterior compression (APC I, II, III);
- lateral compression (LC I, II, III);
- vertical shear (VS);
- combined mechanisms (CM).

Pelvic ring injuries can be divided into three grades according to the WSES classification that considers the Young-Burgees classification, hemodynamic status, and mechanical status (Table 10.7) [9]:

Table 10.7 Pelvic ring injury classification

	WSES grade	Young-Burgees classification	Hemodynamic status	Mechanical status
Minor	WSES grade I	APC I–LC I	Stable	Stable
Moderate	WSES grade II	LC II/III–APC II/III	Stable	Unstable
	WSES grade III	VS	Stable	Unstable
Severe	WSES grade IV	Any	Unstable	Any

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WSES World Society of Emergency Surgery

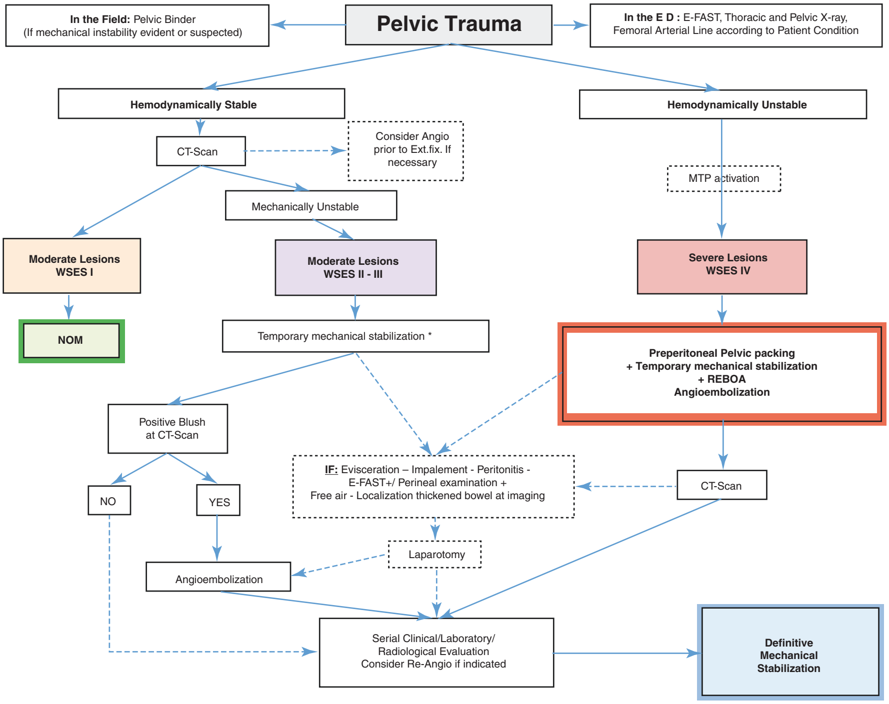

Fig. 10.5 Pelvic trauma management algorithm. *CT* computed tomography, *ED* emergency department, *E-FAST* extended focused assessment with sonography for trauma, *MTP* massive transfusion protocol, *NOM* non-operative management. * Patients hemodynamically stable and mechanically unstable with no other lesions requiring treatment and with a negative CT scan can proceed directly to definitive mechanical stabilization. Hemodynamic stability is the condition in which the patient achieves a constant or an amelioration of blood pressure after fluids, with a blood pressure >90 mmHg and heart rate <100 bpm. Hemodynamic instability is the condition in which the patient has an admission systolic blood pressure <90 mmHg, or >90 mmHg but requiring bolus infusions/transfusions and/or vasopressor drugs, or admission base deficit >6 mmol/L, or shock index >1, or transfusion requirement of at least 4–6 units of packed red blood cells within the first 24 h). Reproduced from [9] published under the terms of the Creative Commons CC-BY license

- minor (WSES grade I);
- moderate (WSES grade II and III);
- severe (WSES grade IV).

An algorithm for the management of pelvic trauma is presented in Fig. 10.5.

10.6.3 Specific Diagnostic Procedures

Patients with hemodynamically and mechanically unstable pelvic trauma need to undergo a pelvic x-ray (PXR) and E-FAST in the shock room in order to plan as soon as possible the best management strategy, which may be an early reductive maneuver and/or pelvic stabilization and /or AG and/or laparotomy.

PXR is useful and effective in detecting life-threatening pelvic ring fractures that require life-saving measures (i.e., open book fractures) or other lesions necessitating prompt management (i.e., hip dislocation that needs to be reduced).

E-FAST is not sensitive enough to detect retroperitoneal pelvic bleeding but it plays an important role in diagnosing associated intra-abdominal injuries and the need to perform a laparotomy in unstable patients.

Hemodynamically stable patients with pelvic trauma should undergo further diagnostic imaging with the following examinations in order to better define the extent of damage:

1. CT with intravenous contrast: to diagnose possible bleeding (active contrast extravasation) and pelvic hematoma size, both important factors in planning subsequent AG.
2. CT scan with also bone reconstruction.
3. Retrograde urethrocystogram prior to the urethral catheterization: in the case of local clinical signs (perineal/scrotal hematoma, blood from the urethral meatus, prostate alterations on rectal examination) or pelvis disruption.
4. Rectal examination and/or proctoscopy: in cases of highly suspected rectal injuries.

10.6.4 Management Strategies

The majority of patients with bleeding from pelvic fractures can safely be managed with supportive measures, such as pelvic immobilization (with a pelvic binder), blood transfusions and AE (if CT shows active extravasation). A massive transfusion protocol is an often-necessary resuscitative maneuver that needs to be activated.

A pelvic binder may be an effective tool for temporary control of both venous and arterial bleeding, whereas AE is able to treat arterial bleeding.

Hemodynamically and mechanically unstable patients can benefit from different treatments (other than the usual resuscitative supportive measures), which need to be accurately tailored to the single patient:

1. Pelvic stabilization with pelvic binder (i.e., T-POD)
2. REBOA
3. Preperitoneal pelvic packing and/or laparotomy
4. External pelvic fixation
5. AG/AE.

10.6.4.1 Pelvic Binders

Pelvic binders, which can be “home-made” (i.e., bed sheets) or commercial like the T-POD, act as non-invasive external pelvic compression devices that reduce pelvic ring volume, thus helping to achieve hemostasis and stabilize the trauma patient in the early resuscitative phase. Usually, commercial binders are more effective than home-made ones.

Pelvic binders should be applied over the greater trochanters to appropriately reduce the pelvic fracture, adduct the limbs, and reduce pelvic internal volume.

Pubic symphysis diastasis is the main indication for pelvic binder application, while a fracture of the iliac wing or other VS types are absolute contraindications, since they can be worsened by pelvic binders. The importance of PXR, especially in unstable patients, is precisely the ability to distinguish the types of fracture that can benefit from a pelvic binder from those who cannot.

Pelvic binders should be removed once the patient has stabilized and should be replaced by external pelvic fixation or definitive pelvic fixation if indicated. They should not be kept more than 24–48 h because of the increasing rate of complications (i.e., skin necrosis, ulcers, etc.) after that time.

10.6.4.2 Resuscitative Endovascular Balloon Occlusion of the Aorta

Introduced in recent years as an alternative to aortic cross-clamping during resuscitative thoracotomy for trauma patients, REBOA may constitute a bridge to definitive treatment for pelvic bleeding in unstable patients.

When pelvic bleeding is suspected in a hemodynamically unstable patient, REBOA can be placed in Zone III (infrarenal) as a temporary maneuver to gain some time before subsequent more definitive strategies, such as surgery or embolization. Depending on the suspected injuries, REBOA may be placed also in Zone I (supraceliac or descending aorta), helping to preserve carotid and coronary flow.

REBOA is, however, a controversial tool, with major limitations and contradictory results according to different studies in the literature. In addition, new concepts, such as partial-REBOA and/or intermittent-REBOA, are emerging as strategies that can reduce occlusion time and consequent ischemia.

10.6.4.3 Preperitoneal Pelvic Packing and/or Laparotomy

Some patients with severe bleeding not responding to conventional resuscitative maneuvers may need damage control procedures such as pelvic packing or even a laparotomy if there are associated injuries that require surgical correction [14].

The indications for operative management are:

1. Severe instability not responding to resuscitation.
2. Need for laparotomy for associated intra-abdominal injuries.
3. Failed (persistent bleeding after AG/AE) angiography or service not available.

Preperitoneal pelvic packing (PPP) serves as an effective surgical maneuver for early bleeding control in hemodynamically unstable pelvic trauma patients. The main rationale for PPP use is the fact that the main cause of bleeding from complex pelvic fractures are venous plexus injuries.

PPP consists of a quick and easy-to-perform surgical measure that can be accomplished either in the shock room or in operating room. Through a 10 cm-long midline suprapubic incision, the surgeon can enter the extraperitoneal pelvic space (preperitoneal Retzius space), remove the clots and place three packs along the pelvic sidewall on both sides of the bladder, towards the sacroiliac joint and internal iliac vessels. With this technique the peritoneum is left untouched.

In cases of hemodynamic instability, complex pelvic fractures and associated intra-abdominal injuries, the surgeon has the possibility to perform a subsequent laparotomy after the PPP, with a separate midline incision proximal to the suprapubic approach. In this case, the two compartments are kept separate in order to prevent contamination from intra-abdominal injuries and decrease the rate of postoperative infections.

After performing a PPP, especially if this was the first life-saving maneuver and once the patient has been stabilized, the next step should be a CT scan with possible AG/AE in the event of active extravasation or contrast blush. A specific cohort of patients with ongoing bleeding and/or persistent need for transfusions after PPP will benefit from subsequent AE (around 20% of patients).

10.6.4.4 External Pelvic Fixation

PPP should be followed by or even performed along with external pelvic fixation in order to maximize hemorrhage control by treating either the vascular bleeding or bleeding from cancellous bone surfaces.

External pelvic fixation (EPF) allows one to obtain a rigid temporary pelvic ring stability that helps preventing further hemorrhage, as an early adjunctive maneuver in controlling the bleeding from pelvic ring disruption.

EPF not only acts by reducing the retroperitoneal pelvic space repositioning and temporarily fixing the bones, but it also provides a stable counterpressure to the packs place during PPP.

10.6.4.5 Angioembolization

AG/AE is effective in controlling arterial bleeding in pelvic fractures.

The two most important signs predictive of the need for AE are:

- active contrast extravasation at the CT scan;
- large pelvic hematoma.

AG/AE should be considered as a bleeding control strategy in patients with hemodynamic instability or evidence of ongoing hemorrhage after pelvic stabilization, PPP and aggressive hemostatic resuscitation and after exclusion of an extrapelvic source of blood loss. AG/AE also plays an important role in patients with an arterial contrast extravasation in the pelvis demonstrated at the CT scan, regardless of the hemodynamic status.

Elderly patients have been shown to need AG/AE more often than younger people, even in the case of hemodynamic instability and low-energy mechanism of injury: in this selected cohort of patients AG/AE should be always considered.

10.6.5 Definitive Surgical Fixation

Hemodynamically stable patients can undergo definitive pelvic fixation in the early post-trauma period (within 24 h), whereas in physiologically deranged trauma patients this procedure should be performed at least 4 days after the trauma itself.

Fractures that require definitive surgical fixation are those where the pelvic ring disruption is rotational unstable (APC II, LC II) and/or vertical unstable (APC III, LC III, VS and CM). The specific type of definitive fixation varies according to the biomechanical aspects of the fracture. In cases of "open book fracture" with a pubic symphysis diastasis >2.5 cm (APC II, III), symphysis plating is used for anterior fixation.

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Part III

Emergency General Surgery

11 The Open Abdomen: Indications and Techniques

Sergio Ribaldi, Antonella Puzzovio, and Federica Scarno

11.1 Introduction

Open abdomen (OA) is a condition where fascial edges and skin are purposefully left open to allow planned re-exploration and to avoid intra-abdominal hypertension. The management of the OA is a rational surgical choice for treating a complex patient in a challenging environment; it is necessary to clearly communicate the actual clinical situation and the course of action undertaken, while maintaining a continuous relationship with the patient's family and the patient himself. The patient is managed by a multi-specialty, multi-professional team that works in close collaboration, identifies with the project and constantly endeavor to acquire and consolidate a methodology, using all of the available resources in a flexible manner according to the changing clinical setting. The aim is "fast closure of the abdomen" while closely monitoring the patient and being constantly on alert to prevent or to respond to the inevitable critical moments [1].

11.2 Indications

The OA can be considered a preventive measure at the end of a surgical procedure or a therapeutic approach in a complex pathological and/or progressive condition, and should not be considered the *extrema ratio* in the management of a complicated condition with a high risk of failure.

The indications are determined by severe and complex clinical conditions where surgical management is in continuity with the pathophysiological evolution [2–4].

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In recent years, the improvement in management skills and the gradual selection of indications have allowed the following conditions to be identified:

- Progressive clinical deterioration with acidosis (pH < 7.2), hypothermia (T < 34 °C), severe coagulopathy.
- Damage control surgery for the management of complex traumatic injury, uncompleted control of peritoneal contamination, abdominal vascular emergencies.
- Risk of abdominal compartment syndrome for intestinal edema after high volume resuscitation
- Second look for the assessment of intestinal perfusion and sutures.
- Abdominal compartment syndrome with a pressure greater than 20 mmHg and initial visceral deficit due to pathophysiological conditions, such as systemic inflammatory response, or to organ-related conditions, such as acute pancreatitis.
- Complete abdominal wall dehiscence.

11.3 Classification

The OA is a fragile, difficult, and risky environment that needs systemic and local management based on the clinical situation. For these reasons Bjork developed a classification that identifies four classes considering the presence of contamination, adhesions, and fistulas [5]:

1A: Clean, no fixation
1B: Contaminated, no fixation
1C: Enteric leak, no fixation
2A: Clean, developing fixation
2B: Contaminated, developing fixation
2C: Enteric leak, developing fixation
3A: Clean, frozen abdomen
3B: Contaminated, frozen abdomen
4: Established enteroatmospheric fistula, frozen abdomen.

11.4 Systemic Management

Management of the OA requires intensive monitoring and adequate systemic support; it can also be handled in non-ventilated patients and it does not represent a limit to their mobilization.

A conservative strategy of fluid infusion aims to maintain a constant negative input-output balance, to favor the restoration of homeostasis and limit the progressive increase of systemic permeation.

Cordemans et al. demonstrated how this strategy is correlated to an increased incidence of abdominal wall closure and better survival rates. The use of inotrope and vasopressor agents must be personalized and limited to the clinical needs of the patient [6].

Preservation of intestinal function is decisive in the evolution of the inflammatory response: early oral feeding or the early use of enteral nutrition lead to better outcomes.

The Working Group on Abdominal Problems of the European Society of Intensive Care Medicine has developed recommendations for the management of gastrointestinal function in critical patients, defining the classification of Acute Gastrointestinal Injury and the specific nutritional indications, without considering the presence of gastric residue as a limit [7–9]. In this context, an enteral nutrition tube located beyond the ligament of Treitz (or in the lumen of the distal bowel tract in the case of enteric fistula) is useful.

Antibiotic therapy is guided by the basal clinical condition: it must be started at full dosage and wide spectrum, with a personalized duration. An early de-escalation must be considered based on changes in the inflammatory blood markers and microbiological tests.

11.5 Abdominal Management

The peritoneum-parietal compartment has its own clinical evolution directly related to the inflammatory response to the acute event: an initial resuscitation phase with the formation of edema is followed by a period of increased surgical opportunities between day 5 and day 10; eventually a condition of immune depression develops with an increased risk of complications.

Management of the OA requires an indication for a large laparotomy that can assure safe handling of the pathological condition and maximal practicability of the exploratory maneuver in the following phases, maintaining the peritoneal space free from adhesion with the visceral organs and abdominal wall; all the above, while keeping the skin and fascia free and avoiding their fusion and retraction [3, 4].

The damage control strategy does not take into consideration the creation of a stoma, which, if really necessary, must be positioned laterally to the rectus muscles in order to preserve complete parietal sliding.

The therapeutic pathway requires maximal attention to fluid loss, preservation of bowel consistency and fluidity and, in cases of sepsis, the containment of contamination with progressive peritoneal cleaning.

The timing of reoperations can be conditioned by different factors, such as the underlying pathology and its clinical evolution, the technique used, nursing skills, and hospital organization. It is necessary to constantly monitor the abdominal situation with short-term revisions of the abdominal cavity, usually within 2 days.

The OA technique started with passive management with the Bogota Bag, invented by Boarrez, and is now characterized by active management with the negative pressure systems, initially utilized by Barker with the vacuum pack and currently applied in the newest vacuum-assisted closure (VAC) therapy [3, 4].

Negative pressure has the capacity to remove inflammatory substances, to promote reduction of parietal and visceral edema, to develop a regenerative tissue reaction, to progressively contain the wound preventing fascial retraction and to improve nursing and surgical timing [10, 11].

This strategy can be implemented with different approaches depending on the available instruments and devices:

- A “homemade” technique according to Barker consisting in the use of a fenestrated “organ bag” in which the bowel is positioned, two laparotomic gauzes located above containing 1 or 2 Jackson-Pratt tubes in aspiration, an adhesive drape to seal. The drains are connected to wall suction to obtain negative pressure.
- Commercial instruments with different methodologies that use sponges for aspiration:
  – a plastic sheet which contains granufoam sponges disposed radially on six axes and united in a large central sponge with a progressive negative pressure from the periphery to the central area.
  – a sponge located on the surface and centrally in a high-density polyethylene drainage sheet with holes for the passage of the liquids, with a prevalence of negative pressure in the central area.

These systems are hermetically closed with adhesive sheets and obtain negative pressure by means of hospital vacuum lines or dedicated commercial aspiration devices. The latter have constant security control for functioning and pressure; in addition, they offer the opportunity to use different negative pressures based on the purpose and clinical phase.

Negative pressure has facilitated the OA technique; it is important that the pressure level is progressively adapted to the evolution of the clinical condition and to the utilization time.

The presence of infection needs a higher pressure, between 75 and 110 mmHg, to promote the peritoneal cleansing; according to the extension of the peritoneal contamination, the system with radial sponges works better because it can be positioned differently in order to optimize the pressure gradient from the periphery to the center.

The presence of hemorrhagic risk due to a trauma or bleeding disorders requires a lower pressure (25 mmHg) and a device with central aspiration.

The complete absence of peritoneal contamination without hemorrhagic risk allows the use of intermediate pressures, between 50 and 75 mmHg, and the choice of the type of pressure (central or with peripheral gradient) is based on the clinical conditions.

The relationship between the exposure time and the pressure used is an important factor: it can determine an effect of dehydration and fibrotic retraction of both the bowel and abdominal wall. For these reasons, whenever possible, the omentum must be utilized for bowel protection, and the anastomosis should be buried deep in the abdomen in an area with no direct contact with the temporary closure device and negative pressure.

Peritoneal exclusion is a technique that uses a plastic device without holes in order to separate the bowel and to avoid applying a direct pressure, maintaining a central aspiration between 50 and 70 mmHg (enough to remove fluids). This technique is used in conditions of a completely clean abdominal cavity, to promote the progressive parietal closure, or in prolonged OA.

More recently, continuous or intermitted irrigation, using devices with controlled infusion has been introduced as an addition to the negative pressure systems. Peritoneal irrigation allows draining of secretions, maintaining humidity of the abdominal cavity and intestinal serosa and reduction of the direct pressure on the bowel.

Peritoneal irrigation can be applied using:

- A commercial system with a flow applied to the sponge, which, as it becomes wet, determines a "shower diffusion" of the liquids in the peritoneum.
- A small diameter drainage that crosses the sponge avoiding the opening and that is positioned in a specific point of the abdominal cavity depending on the clinical situation in order to obtain better diffusion and aspiration conditions.

The irrigation can be connected to two different flow systems:

- Intermittent system, using a commercial device that controls the aspiration and washing times and the amount of the fluid used.
- Continuous system, using a pump-controlled infusion system or a dial-a-flow connected to one or more drainage tubes.

Integration of irrigation with negative pressure permits the use of a volume flow of 300 cc/h of warm saline. The evolution of this technique is direct peritoneal resuscitation (DPR) that uses a dialysis fluid infusion to rapidly reduce tissue and parietal edema and improve bowel consistency [12, 13].

Peritoneal irrigation has demonstrated its efficacy in a 6-month follow-up period, permitting an increased incidence of earlier primary closure of the abdominal fascia and a reduced incidence of intra-abdominal complications and hernias (Fig. 11.1).

11.6 The Closure Path

The physiological evolution of the peritoneum-parietal compartment and the possibility of definitive closure of OA are related to the systemic inflammatory response. The initial phases of resuscitation are characterized by the presence of edema, parietal tension, and fluid loss. Between the fifth and the tenth day, a progressive reduction of the edema and the formation of fine adhesions are observed: this is the right time for the surgical opportunity of an early closure of the abdomen. After the eighth day the incidence of complications increases (especially the formation of enteric

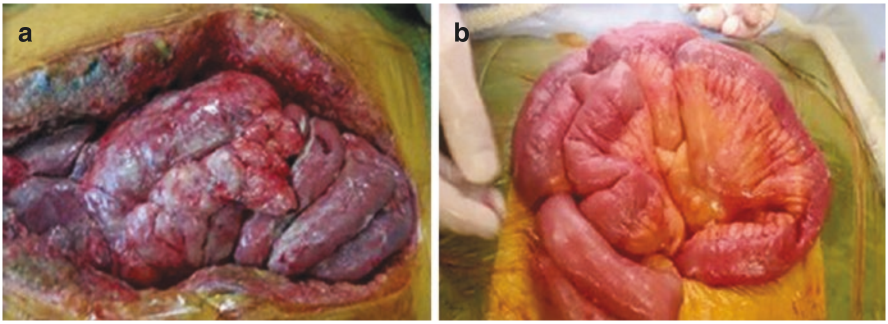

Fig. 11.1 Open abdomen with peritoneal irrigation according to direct peritoneal resuscitation: (**a**) peritonitis secondary to intestinal suture dehiscence in an immunocompromised patient; (**b**) the same patient on the fourth postoperative day

fistulas) and there is a reduced possibility to obtain a primary closure. After this stage a progressive growth of granulation tissue is observed: the parietal retraction with formation of thick adhesions leads to progressive fusion of the visceral organs with the risk of "frozen abdomen". The presence of these adhesions limits bowel mobility and peristaltic movements, causing the formation of bends and segmental obstructions responsible for changes in intraluminal pressure in some bowel tracts (*locus minoris resistentiae*) and the risk of fistula development. This local evolution is part of a systemic condition characterized by immunosuppression that is observed after the 15th day [3, 4, 10].

The ideal condition is early primary closure, preferably within the first 6 days, evaluating the local conditions and monitoring the intra-abdominal pressure. This situation is frequently obtained (in more than 80% of cases) in non-complicated post-traumatic OA for damage control procedures, while it is more difficult to achieve in OA after complex surgical cases and critical patients with systemic deterioration, where the rate of early primary closure is lower than 60%.

After primary fascial closure in critical patients, it is better not to complete the closure of the skin and subcutaneous tissue. Instead, negative pressure should be applied over the fascia to prevent excessive tension and local inflammation and infection, with risk of suture leak; the delayed skin closure reduces the incidence of surgical site infections and fascia dehiscence.

In the presence of conditions that do not allow an early primary closure, management must be careful and conservative in order to exclude the peritoneal content using the available techniques. This strategy is useful to avoid a persistent OA in cases of completely clean abdominal cavity.

The first option is the progressive primary closure using the peritoneal exclusion technique with a negative pressure of 50 mmHg applied on the sponges positioned with the aim of reducing the parietal gap. Progressive closure of the fascia can be obtained in 2/4 phases by suturing fascial edges in centripetal sequence, proceeding with superficial negative pressure followed by closure of the skin.

The closure may be facilitated by the use of some devices in the case of parietal retraction and/or parietal layer fusion, conditions that need more complex interventions.

Popular devices are the abdominal reapproximation anchor (ABRA) system or the Wittman's technique. The ABRA system is simple to use and needs at least 5–8 cm of abdominal wall free from adhesions to work properly. It is composed by a silicone traction system positioned through the abdominal wall and fixed to the skin with a dedicated blocking mechanism that allows progressive alignment of the fascia (greater than 10–15 cm in 6–10 days). Its application requires treatment of the peritoneal cavity with negative pressure or with peritoneal exclusion using different devices, drainage tubes, or sponges in order to avoid decubitus pressure on the bowel. Alternatively, the Wittman's technique is characterized by the utilization of a Velcro mesh, fixed to the parietal boundaries, that permits application of a tension force for the progressive reduction of the parietal gap. An evolution is the combined use of negative pressure with a mesh fixed to the fascial edges. At every dressing change the mesh is trimmed on the midline to make a progressive traction on fascial edges until complete closure.

The component separation technique is the procedure of choice for the definitive repair of the abdominal wall defects resulting from the OA. It must be performed late in a condition of clinical stability of the patient with completely clean wall, free from adhesions with the bowel: the rectus abdominis is separated from the lateral muscles, allowing a shift toward the midline. A mesh can be used for reinforcement of the wall, in sublay (retromuscular) position or bridging a fascial defect when the midline cannot be reconstructed.

A biological or biosynthetic mesh is the preferred option for manageability and compatibility with contaminated fields. A thicker mesh fixed to the tissue with closed single stitches is preferred, as it ensures a tension that can reduce the parietal gap and compensate the parietal relaxation occurring after edema reduction.

The choice of the biological mesh type is correlated to the clinical conditions of the patient: a non-crosslinked mesh in a sublay position with linea alba closure is preferred in cases of surgical site contamination; with a clean abdominal wall, a crosslinked mesh is recommended [3, 4].

The superficial layers are not immediately fixed, and the mesh is protected with a plastic foil without holes on which negative pressure (not greater than 50 mmHg) is applied with irrigation. The purpose of this is to facilitate the regenerative reaction and granulation, to prevent dryness and fluid deficiency, avoiding the formation of a serous collection. Skin closure is done within 4 days with stitches, with a closed incision negative pressure wound therapy to promote definitive healing.

11.7 Management of Enteric Fistula

The occurrence of fistulas affects the treatment in 3–15% of cases and is considered a severe complication for morbidity and mortality. The fistulas are created by the serosal deterioration caused by parietal vascular deficiency or by its failure due to circumferential or segmental obstructions resulting from modification of the intraluminal pressure.

Fistula management is difficult when it is not possible to achieve complete exteriorization of the fistulated bowel, with the risk of an enteric hole inside the frozen abdomen (entero-atmospheric fistula). This topic is extensively treated in Chap. 12. In these cases, it is necessary to perform a containment technique: every attempt at direct closure will lead to dehiscence. Fistula isolation is achieved with silicone cylinders which fit with the enteric opening and can be surrounded by foam for negative pressure therapy. This device works promoting granulation and allowing skin grafting of the tissue around the enteroatmospheric fistula while enteric spillage is controlled by an ostomy bag [14].

11.8 Conclusion

The scientific societies and the institutional scientific organizations declared the safety and the efficacy of negative pressure for the OA; it must be performed by health professionals with specific training in the procedures and in conformity with the producers' instructions when commercial products are used. The activity must be evaluated according to systemic indicators and local conditions, examining the morbidity and mortality and the length of hospital stay.

The prevention of intra-abdominal hypertension and the early management of the OA have allowed in Cheatham's experience a reduction in time to closure from 20 to 10 days in 5 years, an increase in the incidence of primary closure of the fascia from 59% to 81%, and a reduction on the incidence of fistulas from 8.6% to 3.6% [15].

The management of the OA requires specific experience in order to develop the skills to use the available techniques in a flexible manner in such a complex environment, with the aim of preserving intestinal function, performing a short-term abdominal cavity revision and obtaining abdominal closure as soon as possible.

Open fast and close faster! should be considered the most important rule of this surgical challenge.

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12 Enteroatmospheric Fistula: A Challenge of Acute Care Surgery

Roberto Bini, Stefano Piero Bernardo Cioffi, and Luca Del Prete

12.1 Introduction

12.1.1 Definition

Enteroatmospheric fistula (EAF) is defined as an abnormal communication between the enterocolic tract and the atmosphere in the context of an open abdomen (OA), as occurs in grade IV of Bjork classification [1]. Unlike enterocutaneous fistulas (ECF), which have a spontaneous closure rate of 50–80% [2], spontaneous healing of EAF is almost impossible because of the absence of a proper fistula tract of skin and vascularized soft tissue.

12.1.2 Epidemiology and Costs

The real incidence of EAF is not known but has been reported to range from 5% to 19% of patients who have undergone damage control laparotomy [3] and is currently growing due to the increasing use of open abdomen (OA) in damage control surgery.

The mortality rate associated with EAF is 36–64%, which is markedly higher than current outcomes with more traditional ECF [2].

Long hospitalization and daily dressing changes entail a high cost for the national healthcare system. In the USA, the daily cost of simple dressings every 3 h is estimated to be $95.36 per day, whereas the cost for foam changes can reach $230.06. Furthermore, hospitalization on a general care floor carries a weekly patient charge of $12,600 [4].

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Table 12.1 Classification of enteroatmospheric fistulas

Anatomic location	Proximal	Stomach, duodenum, jejunum, and proximal ileum
	Distal	Distal ileum, colon
Output volume	Low	<200 mL/24 h
	Moderate	200–500 mL/24 h
	High	>500 mL/24 h
Location inside the open abdomen	Superficial	Drains on top of a granulating abdominal wound
	Deep	Drains intestinal content into the peritoneal cavity
Number of fistula openings	Single fistula	Only one fistula opening
	Multiple nearby fistulas	Two or more fistula openings in close proximity
	Multiple distant fistulas	Two or more fistula openings at a distance from each other

12.1.3 Classification

EAF can be classified according to mainly anatomical and physiological parameters. The anatomical classification is based on the segment of the enteric tract involved. Fistulas may be deep or superficial: a deep fistula drains directly into the peritoneum causing ongoing peritonitis; a superficial fistula drains outside the abdomen increasing wound bacterial burden. Moreover, considering the daily output, EAF can be classified into three categories: low-output if the effluent is less than 200 mL/24 h, moderate-output from 200–500 mL/24 h, or high-output for >500 mL/24 h [5]. Another important aspect is the number of fistula openings and their distance from one other. The characteristics of EAF are summarized in Table 12.1.

12.2 Clinical Assessment

Every patient affected by EAF should be evaluated taking into account the following aspects:

- nutritional and metabolic evaluation;
- sepsis;
- anatomy of fistulas.

Because prevention is the best treatment, the risk factors for fistula development should be taken into consideration when deciding to perform an OA; however, we still know relatively little about the risk factors associated with EAF development.

12.2.1 Prevention

A broad knowledge of the risk factors is key to prevention. A careful analysis of the patient's clinical and surgical history can disclose most prognostic factors for EAF.

Table 12.2 Risk factors and preventive measures for enteroatmospheric fistulas

Risk factors	Preventive measures
Bowel desiccation	Protect the viscera with a fenestrated plastic sheet
	Choose temporary closure systems that completely seal the abdominal cavity
Ischemic insult	In cases of NPWT, a trend toward lower suction pressures could avoid ischemic insult
Mechanical trauma	Cover bowel with greater omentum
	Senior surgeon attending every dressing change
	Avoid any contact between temporary closure system and viscera
	Avoid unnecessary aggressive tissue preparation and extensive debridement
	Avoid prosthetic mesh application
Prolonged open abdomen	Choose a temporary closure system able to prevent fascial retraction
	Carefully plan dressing changes
	Close abdomen as soon as possible

NPWT negative pressure wound therapy

A history of cancer seems to be the only clinical element related to EAF development [6].

Perioperative factors such as resuscitation with large volumes of fluid at 48 h, high number of re-explorations, large bowel resection [7], occurrence of bowel perforation, anastomotic leakage and development of abdominal compartment syndrome are predictors of EAF within an OA after trauma. EAF occur in septic OA more than in non-septic OA (12.1% vs. 3.7%, respectively) [8]. Closing the abdomen as soon as possible remains the best strategy for preventing EAF formation, because any prolonged duration of bowel exposure to the outside environment invariably results in an increased rate of complications, including EAF formation [9, 10].

Considering preoperative factors, a serum lactate value >3.5 mmol/L prior to emergency laparotomy is described as an independent predictor for EAF [11]. Delayed time to provision of nutrition is an independent predictor of EAF [6]. The latter is further supported by Mintziras et al., who highlighted that long-term vacuum-assisted closure (VAC) treatment in OA due to secondary peritonitis results in a low fascia closure rate and a high risk of fistula formation. VAC treatment should not exceed 13 days [12]. The risk factors and preventive measures for EAF are summarized in Table 12.2.

12.2.2 Metabolic and Nutritional Evaluation

Malnutrition is one of the main issues in a patient with EAF. Three different mechanisms are usually involved: inadequate calorie intake, catabolism related to sepsis and ongoing losses from the gastrointestinal tract [13]. In patients who have undergone extensive intestinal resection, intestinal loss of fluids is inversely associated with the length of the remnant functioning small bowel. Partial or total resection of the colon may worsen fluid loss. Patients with an end-jejunostomy or proximal ileostomy often develop dehydration and electrolyte deficiencies (especially

Table 12.3 Classification of intestinal failure

Type	Clinical behavior and therapy	Cause
Type 1	Self-limiting Duration <14 days TPN	Usually postoperative (e.g., ileus, small bowel obstruction)
Type 2	Medium-term Duration 14 days–6 months Likely to require surgery TPN/fistuloclysis	Intestinal fistula, high output stoma Postoperative septic and metabolic complications
Type 3	Long-term TPN Usually permanent May require intestinal lengthening/ transplantation	Short bowel syndrome after multiple resections or severe intrinsic disease

TPN total parenteral nutrition

magnesium, potassium and sodium) [14]. The small bowel normally reabsorbs up to 75 g/day of protein, so all or part of this is likely to be lost through the fistula. Furthermore, the abdominal fluid lost from the OA itself contains up to 2 g of nitrogen per liter. Table 12.3 summarizes the relationship between EAF and intestinal failure.

Measurement of urine sodium concentration is a sensitive gauge of hydration status, with a urine sodium <20 mmol/L (or < 50 mmol/24 h), together with Na/K ratio < 1, indicating fluid and/or sodium depletion.

A number of malnutrition screening tools can be used to evaluate nutritional status or nutritional risk. All of them combine comparable variables, typically weight loss, body mass index, food intake, and nutritional risk (according to Nutritional Risk Screening 2002).

Acute intestinal failure is a severe clinical condition in which an accurate determination of nutritional status becomes pivotal. Historically, markers such as serum albumin were considered reliable expressions of the patient's nutritional status. A position paper from the European Society for Clinical Nutrition and Metabolism (ESPEN) stated that a drop in serum albumin does not have any clinical relationship with nutritional condition during the acute phase, being directly related to capillary leakage and albumin migration to the extravascular space induced by acute inflammatory cytokine response. Moreover, other blood tests such as transferrin, creatinine, blood urea nitrogen, lymphocyte count do not add definitive and valuable information for a complete nutritional assessment [15].

12.2.3 Sepsis

According to the task force convened by the 2014 Third International Consensus Definitions for Sepsis and Septic Shock (Sepsis-3), the clinical criteria for sepsis are a suspected or documented infection and an acute increase of ≥2 SOFA (Sequential Organ Failure Assessment) points. The task force considered that positive qSOFA (quick SOFA) criteria should also prompt consideration of possible infection in

Table 12.4 Hour-1 surviving sepsis campaign bundle of care

• Measure lactate level. Remeasure if initial lactate is >2 mmol/L
• Obtain cultures prior to administration of antibiotics
• Administer broad spectrum antibiotics
• Begin rapid administration of 30 mL/kg crystalloid for hypotension or lactate ≥4 mmol/L
• Apply vasopressor if patient is hypotensive during or after fluid resuscitation to maintain MAP ≥65 mmHg

Modified from [16] *MAP* mean arterial pressure

patients not previously recognized as infected. qSOFA score ranges 0–3 points, with 1 point for each of the following criteria: altered mental status (GCS score < 15); systolic blood pressure ≤ 100 mmHg; respiratory rate ≥ 22 breaths per minute. Sepsis is suspected when qSOFA ≥ 2.

Septic shock is defined as a subset of sepsis in which underlying circulatory and cellular metabolism abnormalities are profound enough to substantially increase mortality. Septic shock can also be defined with a clinical construct of sepsis with persisting hypotension, requiring vasopressor therapy to elevate mean arterial pressure ≥ 65 mmHg and lactate >2 mmol/L despite adequate fluid resuscitation (Table 12.4) [16].

Clinicians should focus on detection and treatment of sepsis with performance of cultures and swabs, abdominal imaging, and identification of other possible sources of infection (e.g., respiratory and urinary tract infection, endocarditis).

Additional non-abdominal sources of sepsis need to be considered, pneumonia being the most common of them. The central venous catheter should always be considered as a possible source of infection. Risk of fungal sepsis is increased in critically ill patients with prolonged sepsis and exposure to antibiotics. This is particularly likely in those with poor dental hygiene.

12.2.4 Anatomy of Fistulas: Clinical and Radiological Evaluation

In a patient presenting with EAF a careful exploration of the abdominal cavity is essential.

Evaluation must be performed: first, to exclude the presence of other hidden undiagnosed fistulas that can maintain the sepsis and, second, to rule out any condition which can possibly preclude closure of the fistula. It is important to assess for the presence of a foreign body, inflammatory bowel disease, or neoplasm, or any kind of distal obstruction. EAFs that are single, small, distal, superficial, and of low output are more likely to close spontaneously [17]. In large, deep, proximal, and high-output fistulas, or in those with multiple openings, spontaneous closure is unlikely to be successful.

The first approach to an EAF should be the study of its anatomy by using a triple-contrast CT scan with administration of intravenous, oral and rectal soluble contrast. This study permits planning of the best feeding strategy, also by estimating the length of the enteral tube excluded from absorption.

Patients should undergo computed tomography (CT) or magnetic resonance imaging (MRI) studies not only to provide comprehensive cross-sectional information on ECFs but also to better understand the presence of underlying disorders.

In our experience, CT fistulography with prior administration of contrast medium orally and then through the fistulas using a Foley catheter represents a useful one-stop-shop technique, which combines cross-sectional information with opacification of involved bowel tract.

12.3 Systemic Approach and Treatment

The acronym SNAP (Sepsis and Skin care, Nutritional support, definition of intestinal Anatomy, and development of a surgical Procedure to deal with the fistula), first introduced for ECF, is a useful reminder for a comprehensive approach. There is no defined order in which each of these points should be approached.

12.3.1 Sepsis Control

Management of sepsis in complex surgical patients is one of the toughest challenges for the emergency surgeon. Source control is based on every possible effort to find and eradicate any infectious focus and maintaining factor [18]. It should be based on four principles, to be applied independently at any moment of patient management: drainage, decompression, debridement and restoration of anatomy and function. Along with source control another essential factor for sepsis management is antimicrobial therapy.

Antibiotics should be started as soon as abdominal sepsis is identified or strongly suspected. Broad spectrum drugs should be the choice, with few specific insights for critically ill surgical patients. Beta-lactams are the first choice and the mainstay; in addition, coverage for fungal infection (especially in cases of anastomotic leakage) and enterococci should be taken into account [19]. Additional issues related to altered volume of distribution, reduced binding proteins, altered renal and/or liver function should be considered when dosing the antimicrobial therapy [20].

A comprehensive approach [21] to sepsis management, considering all the different clinical scenarios related to EAF and abdominal sepsis, can be based on three main patient categories:

- patients affected by life-threatening conditions with single or multiorgan failure, in whom resuscitation and source control should be immediate;
- patients in whom physiology derangement can be optimized before any definitive attempt to control the source;
- patients in whom source control can be delayed and any interventional procedure would be too risky.

The clinical and surgical scenario can be studied and better defined.

12.3.2 Nutritional Support

The persistent inflammatory condition that affects patients with EAF is associated with a chronic catabolic state. This warrants a focus on the importance of delivering nutritional support, respecting the patient's physiology, through the enteral route.

Enteral nutrition (EN) outperforms parenteral nutrition (PN) and is related to better outcomes in terms of morbidity in surgical patients. EN can be safely used in critically ill surgical patients even during OA management when at least 75 cm of viable small intestine are available. Attention should be paid, and EN limited, in the case of septic status requiring vasopressor support or in pathological conditions with alterations in gastrointestinal perfusion.

Bulking agents, antisecretory and antimotility drugs could be useful for decreasing the output, even if they could reduce the splanchnic blood flow. The correct enteral feeding access should be different according to the fistula anatomy: for patients with EAF involving the stomach or the duodenum, a nasojejunal or a jejunostomy feeding tube are safe; if a jejunal-atmospheric fistula occurs, fistuloclysis could be considered; nasogastric or postpyloric feeding could be tolerated with a distal ileus or colic-atmospheric fistula. Furthermore, in severe intestinal failure due to one proximal and one distal fistula, recycling the proximal effluent into the distal bowel to improve nutrient absorption should not be excluded. The ESPEN guidelines for clinical nutrition in surgery recommend that, if energy and nutrient requirements cannot be met by oral or enteral intake for more than 7 days, it is appropriate to start a combination of PN and EN. In cases of clear contraindication to EN, PN should be started as soon as possible [22].

12.4 Local Control

12.4.1 Fistula Management

Control of enteric output may be very challenging (Fig. 12.1). Many types of dressing are described in the literature.

- ***Floating stoma***
  This is based on covering the granulation tissue with a plastic silo sutured to the edges of the abdominal wall and fistula. The fistula is controlled with a stoma bag and negative pressure wound therapy (NPWT) is applied around.
- ***Nipple technique***
  A standard baby nipple is placed over the fistula; a Foley catheter can be inserted into the fistula through the nipple with the balloon inflated and NPWT applied around (Fig. 12.2).
- ***Fistula adapter***
  This device is a cylinder with a double brim which can be applied over the fistula opening to obtain effluent control with an ostomy bag. The adapter is surrounded by foam for NPWT.

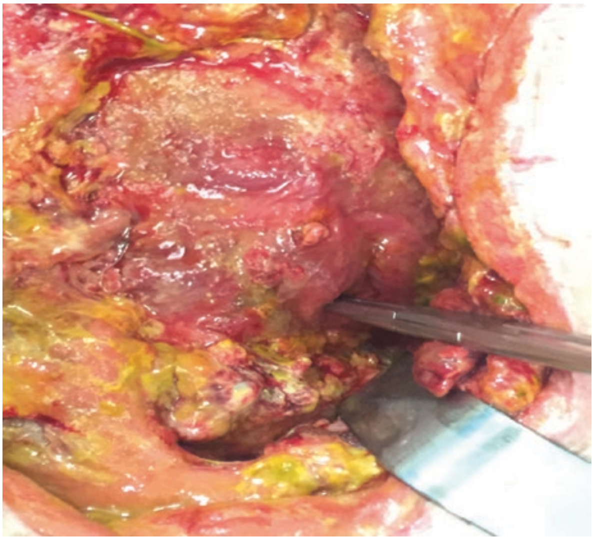

Fig. 12.1 Enteroatmospheric fistula management. Fistula isolation and identification

- ***Fistula VAC***
  A Malecot catheter is inserted into the fistula, the tube may be tunneled through the skin and subcutaneous flap or is passed through a foam for NPWT.

All the above techniques use NPWT for granulation tissue healing around the fistula. The aim is to allow skin grafting and to transform EAF in ECF.

- ***Fistula patch***
  The fistula is treated from the inside by placing a lamellar silicone patch which acts as a stopper and is sutured to the bowel wall. A skin graft can be used to cover the granulating tissue around the fistula. The aim of this technique is again to transform an EAF into an ECF.

Attempting definitive fistula correction is the final step of a long-standing care process [23] (Fig. 12.3). Fistula takedown must be planned and rationalized taking into account some required conditions.

- *Sepsis control*, following all of the abovementioned principles, must be obtained.
- *Fistula anatomy* must be clarified after accurate study, as described in the previous section. The amount of bowel involved and amenable to resection should be determined, as well as the number and localization of fistulas.
- *Surgical plan* has to be defined and discussed with the acute care surgery team. Abdominal wall reconstruction must be planned starting from a detailed assessment of the size and nature of the defect. Plastic surgeons should be involved in the case of large defects, to include the chance of flaps or skin grafts for a complete reconstruction.

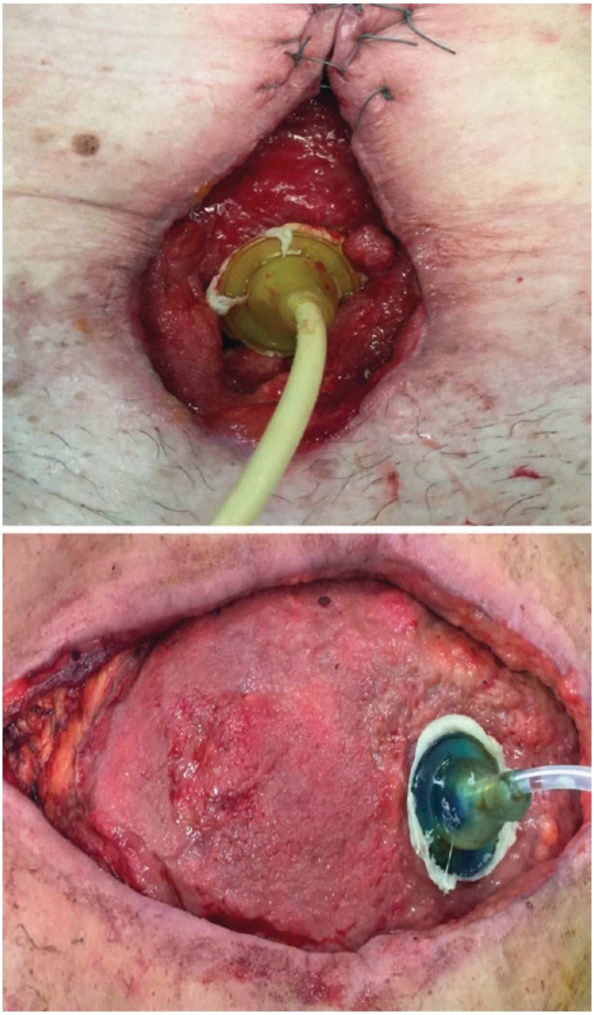

Fig. 12.2 Enteroatmospheric fistula management. An example of fistula isolation from surrounding granulation tissue with the baby nipple technique

12.4.2 Definitive Surgery

Timing of definitive surgery is as essential as the previously mentioned conditions. All authors agree on delaying fistula takedown at least 4–6 months after optimization of clinical conditions. Generally, optimal timing is from 6 to 12 months to wait for resolution of the inflammatory response and softening of intra-abdominal adhesions [23]. Consequences of an early approach can be devastating with non-tolerable rates of bowel injuries, fistula recurrences and mortality.

Delayed abdominal wall closure is safer after component separation, with the application of suprafascial NPWT for 48–72 h to prevent seromas, before definitive skin closure. Furthermore, extreme defects are suitable for repair with muscular-cutaneous rotation or free flap [24].

Fig. 12.3 Enteroatmospheric fistula management. Final phase of definitive surgical attempt with primary closure and bridging biological mesh

Martinez et al. described a 37% recurrence rate after definitive surgical attempt for fistula takedown [25]. Factors significantly related to recurrence were multiple fistulas, preoperative CRP >0.5 mg/dL and failure to achieve primary abdominal wall closure. At multivariate analysis, factors related to death were preoperative hypoalbuminemia and more than two anastomoses. Martinez et al. reported a 13% mortality rate. In those patients, recurrence was the only factor related to death [25].

12.5 Conclusion

Based on a review of the literature and our experience we propose the Niguarda's 4S as a step-up approach for the management of EAF:

– *Stabilization of the patient* (intensive care support and surgical interventions to solve the problem leading to OA)
– *Studies* (to identify the number and location of fistulas, agents of sepsis, nutritional evaluation, anatomy)
– *Strategies* (surgical techniques to isolate the fistula effluent and plan radiologic or endoscopic drainage)
– *Surgery* (definitive surgery to restore bowel continuity and close the abdomen).

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Operative Endoscopy in Gastrointestinal and Biliopancreatic Acute Care Surgery

13

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13.1 Gastrointestinal Endoscopy

13.1.1 Upper Gastrointestinal Dehiscence/Perforations

Gastrointestinal injury to the stomach and small bowel can be due to blunt or penetrating trauma. The nature and severity of the injury depends on the injury mechanism. Perforations of the bowel loops can be associated with minor or major vascular damage. The duodenum is frequently injured in association with the pancreas, and the management of these combined injuries is complex.

Although upper gastrointestinal (UGI) perforations are generally managed by surgery (especially if vascular injuries are associated), endoscopy can be used in selected cases [1].

Settings for endoscopy can be divided into: (1) primary dehiscence/perforations as in Boerhaave syndrome or traumatic rupture of the intestinal wall (0.1–0.5%) and (2) postoperative dehiscence as an adverse event of emergency/trauma surgery (20–45%) [2, 3]. The etiology of the perforation is an important prognostic factor as endoscopy has a higher success rate in the case of traumatic injuries [4].

The aims of endotherapy are both to cover and/or close the site of perforation and to drain the extraluminal collection [5] (Fig. 13.1). Indeed, without adequate drainage of the perivisceral collection, effective closure of the perforation site would be prevented by the digestive enzymes and infected fluid collections.

Endoscopic direct closure of the perforation can therefore succeed if the perforation is treated early, the associated extraluminal collection is correctly drained and the surrounding tissue is vital (Fig. 13.2). The use of self-expanding metal stents (SEMSs) for the treatment of benign UGI leaks and perforations is feasible,

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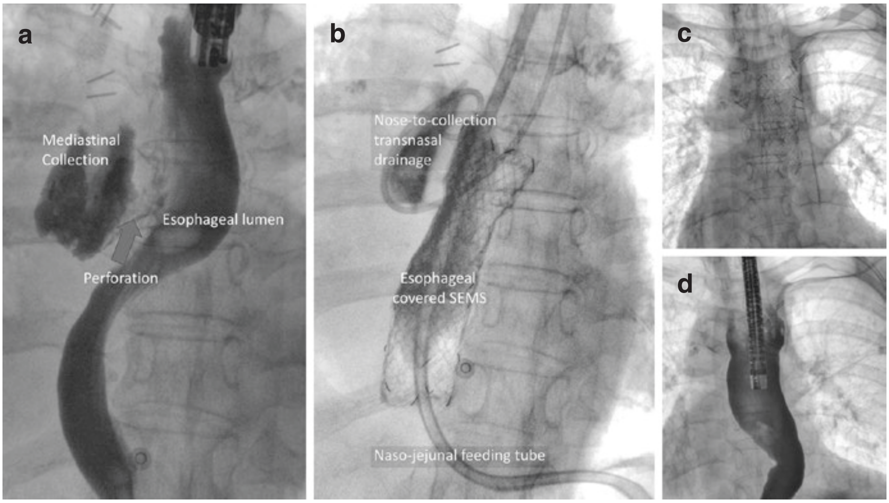

Fig. 13.1 Esophageal perforation after lung lobectomy. (**a**) The site of perforation was localized in the middle third of the esophagus and it was associated with a mediastinal infected collection. (**b**) Endoscopic treatment: fully covered self-expandable metal stent 22 mm 10 cm; 10 Fr nose-to-collection drainage through the site of perforation into the infected collection; 14 Fr nasojejunal feeding tube. (**c**) The metal stent after 6 weeks (nasojejunal tube and nose-to-collection tube were previously removed). (**d**) Fluoroscopic check after stent removal showed no residual fistula

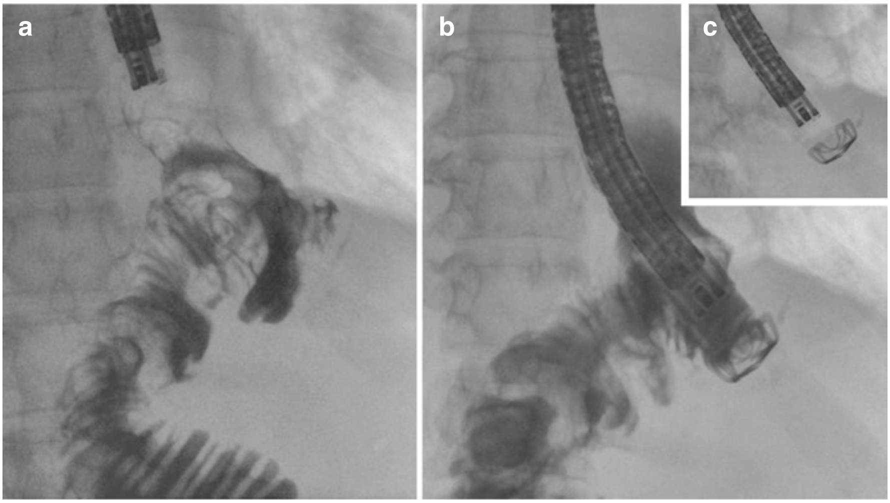

Fig. 13.2 Jejunal dehiscence of the cul-de-sac in esophagojejunal anastomosis after total gastrectomy. (**a**) Fluoroscopic view of the small fistula. (**b**) Over-the-scope clip placement at the level of the dehiscence. (**c**) Fluoroscopic view of no extraluminal residual collection after the placement

relatively safe, and effective, and SEMSs can be easily removed 4–8 weeks after insertion [6].

Direct closure can be performed in several manners: through-the-scope clips, over-the-scope clips (OTSC), or endoscopic sutures [2, 7]. The choice of method depends on the endoscopist's experience, the site of the leak and the availability of devices in the center. It should be considered that endoclips, especially OTSC, can cause transmural necrosis at the site of application; if the clip detaches before the tissue has healed, the resulting ulcer can cause recurrence of the leak. In the case of large and not promptly diagnosed leaks, stenting using fully covered SEMSs is recommended. Unlike those used for luminal strictures, the stents should be longer and wider because of the higher risk of migration. Through the stent, a nose-to-collection suction tube can be placed to drain the infected extraluminal collections. As the tube reduces adherence of the stent to the enteral wall, it should be removed as soon as the external collection has been fully drained. When the stent is not well adhered to the enteral wall, an aspiration tube can be placed into the stent and set to continuous mild aspiration (−40/−50 mmHg) to promote collapse of the enteral walls on the stent and to improve adherence [8]. Patients who undergo stenting must be kept fasted throughout the treatment, and a nasojejunal tube is generally positioned to guarantee enteral nutrition. Nil per os should include anything (also candies, gums, etc.) able to stimulate bowel movements and subsequent stent migration. Stents can be left in place for 6–8 weeks and should be removed after the results have been checked with a computed tomography (CT) scan. In the case of late diagnosis or chronic fistulas, the use of a nose-to-collection suction tube can be effective because it has the double effect of drying the fistula and promoting development of granulation tissue [9] (Fig. 13.3). In these cases, the aspiration tube has to be gradually retrieved to allow granulation tissue to fill the fistula lumen.

Endoscopic retrograde cholangiopancreatography (ERCP)-related perforations present a few specific features that should be borne in mind. They are classified according to the Stapfer classification into four types [10]. Depending on the type and the absence of retroperitoneal infected collections (generally due to late diagnosis), they can be managed endoscopically by placement of biliary stents associated, if necessary, with enteral stenting (Fig. 13.4). Duodenal leaks near the biliary orifice are generally treated surgically because duodenal stenting alone can close the papilla. However, they may be treated endoscopically by double or triple stenting: a first enteral stent is associated with biliary stenting and, if necessary, pancreatic stenting through the meshes of the enteral stent [11, 12] (Fig. 13.5). In the presence of signs of retroperitoneal infection, a minimally invasive surgical approach to drain the area, such as videoscopic retroperitoneal debridement, is recommended [13].

Imaging is used for diagnostic and follow-up purposes. As for diagnosis, if a perforation has been already established during the endoscopic procedure, oral contrast medium should not be used as it may increase the risk of contamination and subsequent infection of the retroperitoneal tissues. Follow-up should be performed 4–6 weeks later, when the infectious reaction surrounding the stents will have packed and healed the dehiscence.

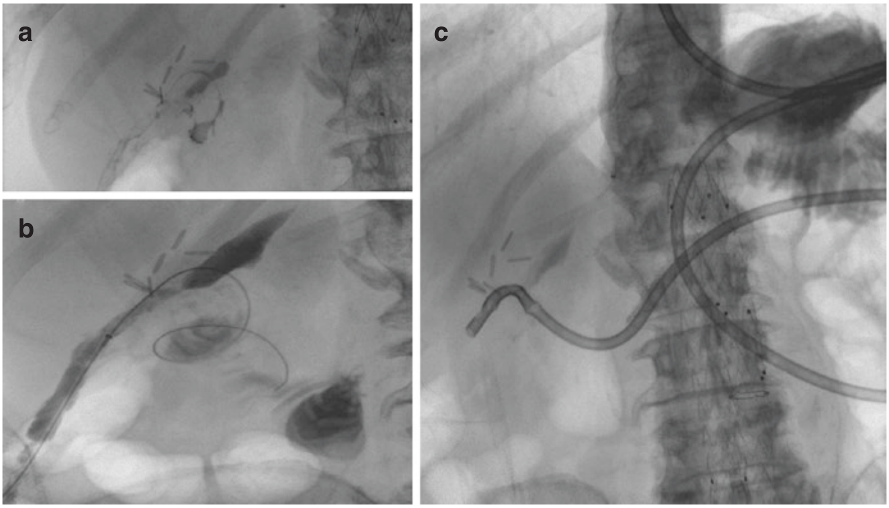

Fig. 13.3 Dehiscence of the duodenal stump after subtotal gastrectomy. (**a**) Fluoroscopic view of the fistula from the fistula path to the duodenal stump. (**b**) Placement of a guidewire into the duodenal lumen passing through the fistula path. (**c**) Placement of a nose-to-fistula tube put in mild aspiration (−40/−50 mmHg)

13.1.2 Lower Gastrointestinal Dehiscence/Perforations

Traumatic injuries of colon and rectum are less common than UGI perforations (2.9%) [14]. Anastomotic colonic leaks occur in almost 6% of patients after emergency surgery, especially in left-sided colonic resections with primary anastomosis [15]. The endoscopic treatment of lower gastrointestinal (LGI) leaks generally requires creation of a stoma (colostomy/ileostomy) to divert the fecal passage away from the site of perforation [16]. Small (<1 cm) perforations with well-positioned drains at the level of the extraluminal collection and normally vascularized surrounding tissue can be treated by direct closure using endoclips (through-the-scope or over-the-scope) [17]. In the case of anastomotic dehiscence, however, direct closure has a high rate (85–90%) of success only if there is a defect in mechanical suture. On the other hand, if the dehiscence is related to hypovascularization, direct closure can worsen the perforation by causing further ischemia of the tissue and subsequent ulceration, especially in the event that OTSC are used.

In such cases, continuous washing via a transanal tube with the distal edge in the perivisceral abscess cavity and endoscopic vacuum-assisted closure therapy (EVT) (Endosponge, B-Braun) provide better results [9, 18] (Fig. 13.6). EVT requires multiple retrieval sessions (changing the system every 48–72 h until a residual cavity <1 cm is achieved). The main advantages are the safety and feasibility of the procedure, which can also be safely administered in an ambulatory setting [19]; the main disadvantages are the need for continuous aspiration devices and the time required by the entire therapy [20]. Adverse events are uncommon (0.5–1%), and include

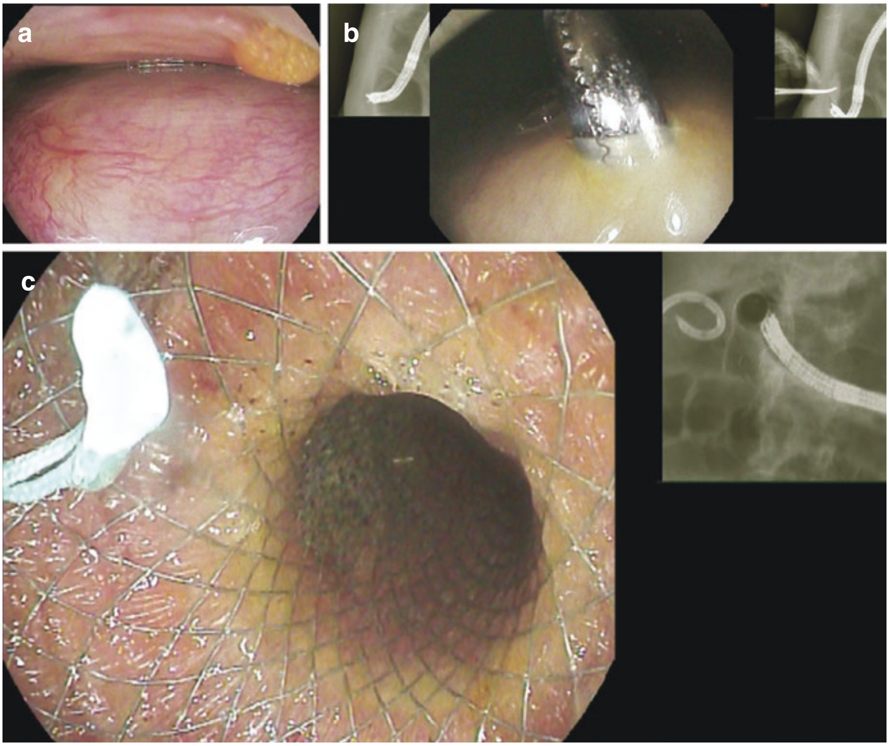

Fig. 13.4 Endoscopic treatment of a Stapfer type I duodenal perforation after ERCP. (**a**) Endoscopic peritoneoscopy passing through the site of duodenal perforation. (**b**) Combined endoscopic and fluoroscopic placement of a periduodenal abdominal drain. (**c**) Endoscopic view of a fully covered self-expandable metal duodenal stent placed to cover the site of perforation and fluoroscopic view of the stent and endoscopically placed 14 Fr abdominal drainage tube

bleeding and anastomotic stricture; the risk of residual sinus at the end of the treatment is higher in the event of late treatment and/or previous percutaneous drainage [20]. EVT is also useful in presacral abscesses [18].

SEMSs can also be used in very selected cases, namely, duodenal/jejunocolonic fistulas (Fig. 13.7). In these cases, the migration of the stent is the main cause of treatment failure.

13.2 Biliopancreatic Endoscopy

13.2.1 Acute Cholangitis

Acute cholangitis (AC) is an endoscopic urgency that occurs in 6–9% of patients admitted with cholelithiasis [21]. ERCP should be performed as soon as possible because the lack of basal membrane at the level of biliary epithelium and increased

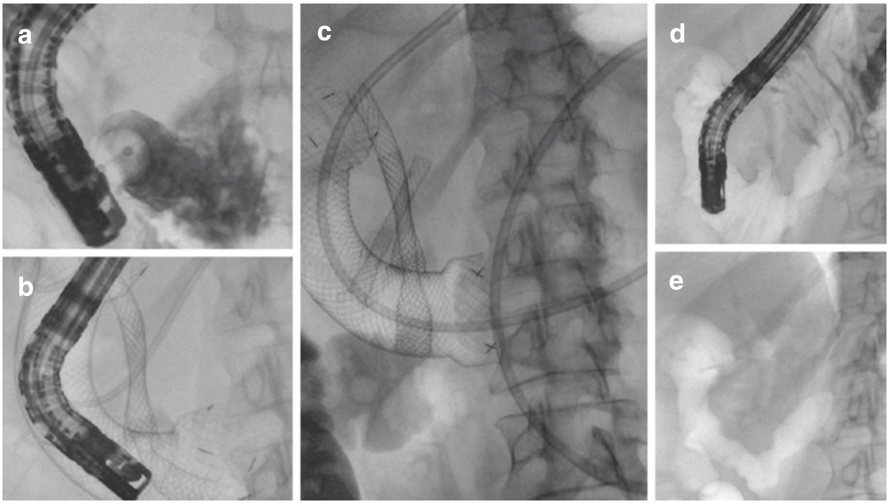

Fig. 13.5 Spontaneous perforation of duodenal diverticulum. (**a**) Fluoroscopic view of the extraluminal periduodenal fluid collection. (**b**) Placement of a fully covered self-expandable duodenal stent, two imbricated fully covered biliary metal stents through the meshes of the duodenal stent and a "hand-made" 6 Fr plastic pancreatic stent (in Santorini's duct because of pancreas divisum). (**c**) Placement of an additional fully covered metal pancreatic stent into the Santorini's duct because of accidental displacement of the plastic pancreatic stent. (**d**) Fluoroscopic check after removal of the stents at 6 weeks. (**e**) Fluoroscopic view of aerogram of duodenum and biliary tree

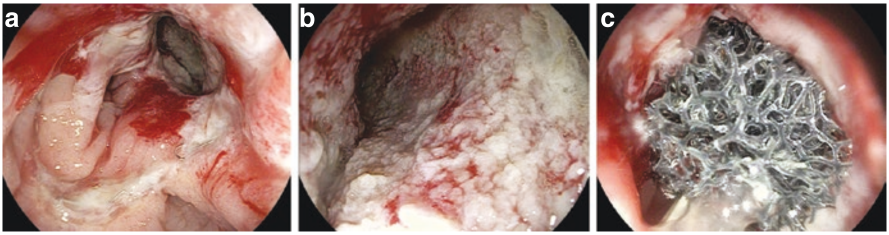

Fig. 13.6 Dehiscence of colorectal anastomosis. (**a**) Endoscopic view of the dehiscence. (**b**) Endoscopic view of the abscess cavity. (**c**) Endoscopic view of the vacuum-assisted medication sponge in place

tension in the bile ducts allow the bacteria to pass directly into the bloodstream [22], with a risk of AC rapidly evolving to severe sepsis (and septic shock) within hours [21]. The patients' risks and the urgency of treatment are stratified using the Tokyo classification [23]. Decompression of the biliary tree is crucial. Biliary cannulation and sphincterotomy are generally followed by extraction of the gallstones and/or biliary stenting, depending on the cause of AC. Biliary stenting is recommended as an effective alternative to gallstone extraction to reduce manipulation of the biliary tree. If acute cholecystitis coexists, a *rendez-vous* technique can be performed in which a guidewire is surgically (laparoscopic or open) introduced through the cystic

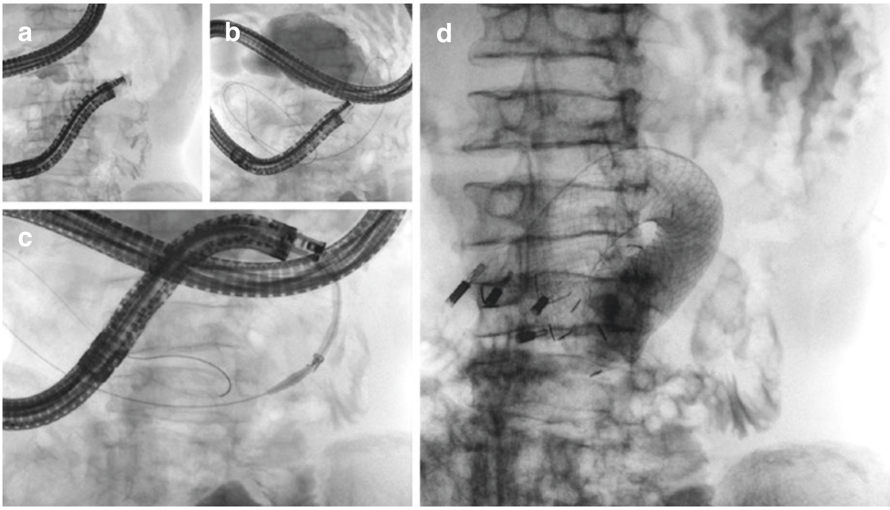

Fig. 13.7 Post-traumatic duodenal-colonic fistula. (**a**) Fluoroscopy showed the passage of contrast medium from the duodenum to the colonic lumen. (**b**) A guidewire was passed into the duodenal lumen overpassing the site of the fistula. (**c**) Placement of a fully covered self-expandable metal stent. (**d**) Fluoroscopic view of the duodenal stent deployed to cover the site of the fistula

stump and advanced to the papilla major into the duodenum to be caught by the endoscopist to introduce the sphincterotome on the guidewire. This technique reduces the risk of ERCP-related adverse events, especially post-ERCP acute pancreatitis (PEP) [24].

If coagulopathy is associated with AC, it must be kept in mind that it can be worsened by the septic status, so ERCP should not be delayed for this reason. Pneumatic balloon dilation of the papilla is considered in this situation safer than sphincterotomy [25, 26]; however, it is associated with a higher rate of late complications [26]. Otherwise, the risk of PEP is higher and the thermal coagulation that can be obtained in these cases is as safe as that obtained using a surgical bovie [25]. Antibiotics should be regarded as support therapy as they do not significantly modify patient prognosis if ERCP is not performed [21, 23]. Administration of rectal non-steroidal anti-inflammatory (NSAID) suppositories is a well-known strategy for preoperative prevention of PEP. Prophylactic pancreatic stenting has been shown to be also highly effective in preventing PEP [27]. Following ERCP, patients can start a light diet on the first postoperative day. Postprocedural blood tests are not always needed, especially amylase levels, because they are usually altered in the hours following ERCP. The decrease of cholestatic and cytolytic enzymes is better seen at 48–72 h. On the other hand, clinical observation is crucial: the presence of hyperchromic urine, persistence of acholic stools, onset of melena must all be carefully investigated in the days after the procedure. The association of persistent melena for more than 24 h and anemia is sufficient to prompt a second-look endoscopy because bleeding from the site of sphincterotomy must be suspected. If bleeding is present, timing is important, and the sooner endoscopic hemostasis is performed, the better the clinical outcome will be [28].

13.2.2 Acute Cholecystitis

Acute cholecystitis develops in 1–3% of patients with symptomatic gallstones [29].

The current standard of care in acute cholecystitis is an early laparoscopic cholecystectomy with the appropriate administration of fluid, electrolytes, and antibiotics [30]. About 20% of patients with acute cholecystitis need emergency surgery [23].

Endoscopy should be considered in patients who are unfit for surgery. Surgery can be precluded by the patient's general condition related to pre-existing comorbidities and/or by the presence of septic shock (Tokyo stage 3) [23].

Two different modalities of endoscopic drainage can be performed: transpapillary or endoscopic ultrasound (EUS)-guided.

Transpapillary drainage can be performed using a double pig-tailed plastic stent and it avoids the possible passage of bile stones from the gallbladder into the biliary tree. It is considered a suitable bridging option for patients who have acute calculous cholecystitis and are unfit for urgent cholecystectomy [31]. A few studies also consider nasobiliary tube placement as a bridge for elective surgery [32].

EUS-guided cholecystoduodenostomy, where a connection between the gallbladder and the duodenal lumen is created by a lumen-apposing metal stent, is regarded as the treatment of choice and can be considered definitive therapy in comparison with the transpapillary and percutaneous approaches [33]. It guarantees a larger drainage pathway than the other techniques and the creation of a stable internal bilioduodenal fistula that works also as a secondary draining access for the gallbladder, avoiding gallstone recurrence [33].

13.2.3 Acute Pancreatitis and Pancreatic Pseudocysts

Biliary acute pancreatitis (AP) is an indication for ERCP to manage the biliary etiology (75–85%) [34]. However, AP is a systemic disease and as such requires systemic supportive therapy [35]. Severe grades of AP have a 20% mortality rate [34].

Generally, biliary sphincterotomy associated with stone extraction is the endoscopic treatment of choice [34]. Urgent endoscopy is considered only if there is an impacted stone or persistence of the obstruction or associated AC.

Pancreatic pseudocysts and walled-off pancreatic necrosis (WOPN) are common adverse events of AP [36]. WOPN represent mixed fluid-solid collections with a similar appearance to pancreatic pseudocysts. Indications for treatment are the presence of infected necrosis and/or signs of compression of the nearby organs and/or persistent symptoms (i.e., abdominal pain) [37]. Large dimension is not considered among the criteria for drainage because many huge pseudocysts can resolve spontaneously [36]. Otherwise, the presence of necrosis is not *per se* an indication to drain: if the necrotic tissue is sterile, the drainage tube can cause an over-infection with all its consequences. Endoscopic therapy has become the gold standard for treatment, where EUS-guided placement of a special type of fully covered SEMS (called a lumen-apposing metal stent, also used for endoscopic cholecystoduodenostomy) between the gastric/duodenal wall and the pseudocyst/WOPN wall is performed [38]. Percutaneous drainage and surgical necrosectomy have a high rate of pancreatic fistula development as an adverse event. Surgery is also associated with many other adverse events such as bleeding, bowel perforation and the impossibility to close the abdominal walls because of concomitant compartment syndrome [13]. Nowadays, surgical treatment should be reserved to lateral WOPN, not amenable to endoscopic drainage, through an extraperitoneal mini-invasive approach (video-assisted retroperitoneal debridement).

The amount of necrotic tissue in WOPN estimated on CT scan can be considered an indication to necrosectomy after stent deployment: if the necrotic tissue is more than 50% of the overall WOPN, endoscopic necrosectomy should be performed [13]. Otherwise, stent placement alone is sufficient. The management of pancreatic pseudocysts and WOPN can require multiple sessions of drainage and necrosectomy. Surgery requires an open access, while a EUS-guided transgastric approach offers an access to perform internal drainage of the pseudocyst using lumen-apposing metal stents with multiple sessions of necrosectomy passing through the stent (Fig. 13.8). The treatment is safe also in the case of thin-walled pseudocysts (especially early infected ones). In large pseudocysts, it is possible to place more than one stent: generally, one is placed from the gastric fundus and the second from the duodenal bulb with the aim of creating a double gateway access to the cavity for

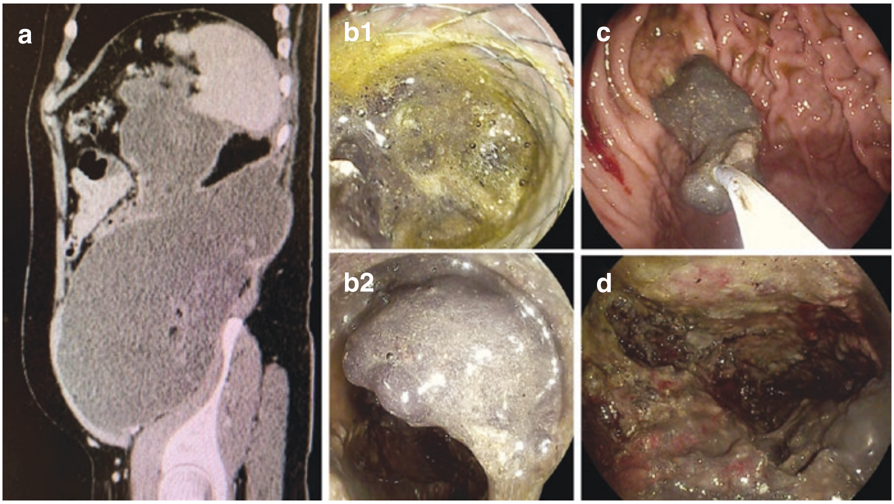

Fig. 13.8 Endoscopic necrosectomy of an infected walled-off pancreatic necrosis (WOPN). (**a**) CT view of a large WOPN. (**b1**) Infected necrosis obstructs the biflanged fully covered metal stent (placed through the gastric wall under EUS guidance). (**b2**) Infected necrotic tissue inside the neocavity. (**c**) Necrosectomy performed using a polypectomy snare with necrotic tissue inside the gastric cavity. (**d**) The neocavity after partial necrosectomy

faster and more effective treatment [39]. The flow through the stent in EUS-guided drainage is unilateral from the pseudocyst into the gastric cavity; food will not pass into the pseudocyst cavity because the pressure inside the pseudocyst is higher than that in the stomach. The stent guarantees long-term drainage of the pseudocyst and can be removed after several months, when the collection has completely dried. A follow-up CT scan should always be performed before stent removal to reduce the risk of recurrences.

PEP can be managed in the same manner. It should be remembered that if it is caused by obstruction with retro-dilation of the main pancreatic duct (i.e., after large-bore biliary metal stenting), a pancreatic stent must be placed as soon as possible [24].

13.2.4 Postoperative and Traumatic Biliary Fistulas

Bile leaks can result from penetrating injury, such as gunshot or knife wounds, or from blunt trauma such as motor vehicle accidents or falls. The incidence of bile leaks following liver trauma ranges from 0.5% to 21%, depending on the criteria and methods used to diagnose the bile leak [40]. Postoperative bile leaks occur in 10–15% of cases after liver trauma surgery [41].

Traumatic biliary fistulas are usually treated by surgery as a first approach. Endotherapy should be considered in cases of failure of postoperative closure or postoperative bile leaks [42].

Biliary fistulas can be classified using many classifications. However, specific classifications on traumatic bile duct injuries are not available.

With regard to endoscopic treatment, we prefer to consider the Bergman classification that includes four types of biliary fistulas [43]:

(a) leakage from peripheral bile ducts (including the cystic stump);
(b) major bile duct injury with leakage from the common bile duct or from an aberrant segmental extrahepatic duct or the right hepatic duct with or without concomitant stricture;
(c) stricture of the common bile duct without leakage;
(d) complete transection of the common bile duct, with or without partial resection of the bile ducts.

The majority (80–90%) of traumatic and postoperative leaks are type A and B [42, 44], so we will focus on the therapy of these two types.

Type A bile leaks originate from the peripheral bile ducts and are the commonest type of biliary fistula. Involved ducts include the cystic stump, peripheral ducts of the fifth and sixth hepatic segments or, more rarely, true accessory hepatocholecystic ducts. Endotherapy consists of two aspects: (1) biliary sphincterotomy (with the rationale of reducing the pressure gradient between the bile duct and the duodenum); (2) checking the position of the abdominal drain (to avoid an excessive biliary-atmospheric pressure gradient) (Fig. 13.9). If the abdominal drain is very near

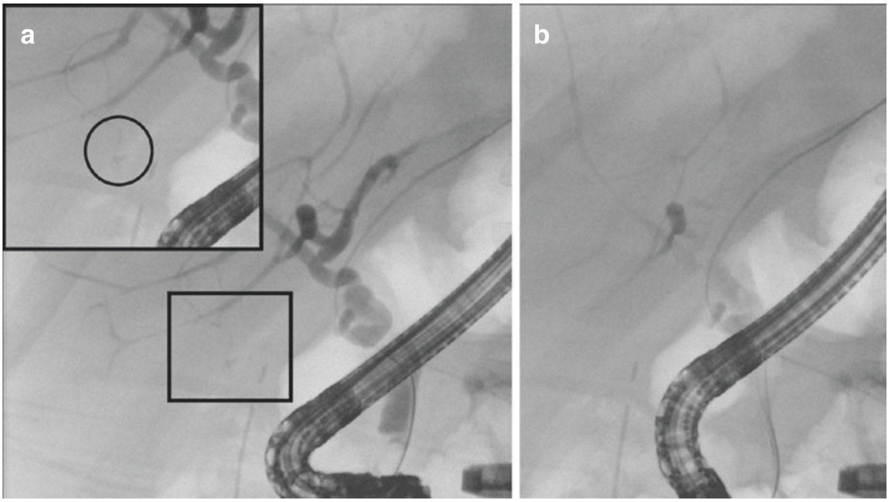

Fig. 13.9 Bile leak after perihepatic packing for traumatic liver injury. (**a**) Cholangiography showing the site of the leak. (**b**) Endoscopic treatment consisted in biliary sphincterotomy and retrieval of surgical abdominal drain

to the bile leak, even if biliary sphincterotomy is correctly performed, the bile may continue to flow from the biliary tree into the abdominal drain because the biliary-atmospheric pressure gradient is higher than the biliary-duodenal one. Thus, the abdominal drain has to be retrieved distally 4–6 cm from the site of the bilary leak, immediately after biliary sphincterotomy [45]. A nasobiliary tube can be placed in cases of high-output fistula to check the presence of a correct pressure gradient after 24–48 h; diagnostic cholangiography is then performed to check if the pressure gradient is well-balanced and, if so, the nasobiliary tube can be removed. Biliary stents should be reserved for specific cases, i.e., incomplete extrinsic compression/stenosis of the common bile duct, incomplete biliary sphincterotomy or remnant bile duct stones not removed during ERCP.

Type B bile leaks involve the common bile duct. The main risk associated with this type of leak is the synchronous or delayed development of a biliary stricture. Sometimes, these leaks can occur in the presence of or after removal of a Kehr T-tube. Endoscopic treatment includes two steps: (1) biliary sphincterotomy; (2) biliary stenting (bypassing the site of the defect) (Fig. 13.10).

No strong evidence helps in the choice between plastic or metal stents: a plastic stent is usually tried first [46, 47]. Subsequently, in the event of stricture development, plastic multi-stenting or fully covered metal stenting can be performed. A few experiences with biodegradable stents suggest more comfortable treatment for patients, with similar clinical outcomes [48]. Spontaneous migration of plastic biliary stents is reported in 10–17% of cases [49] and additional flaps seem to reduce this percentage. Timing for stent removal is not reported in the international literature: generally, plastic stents can be removed after 6–8 weeks and a

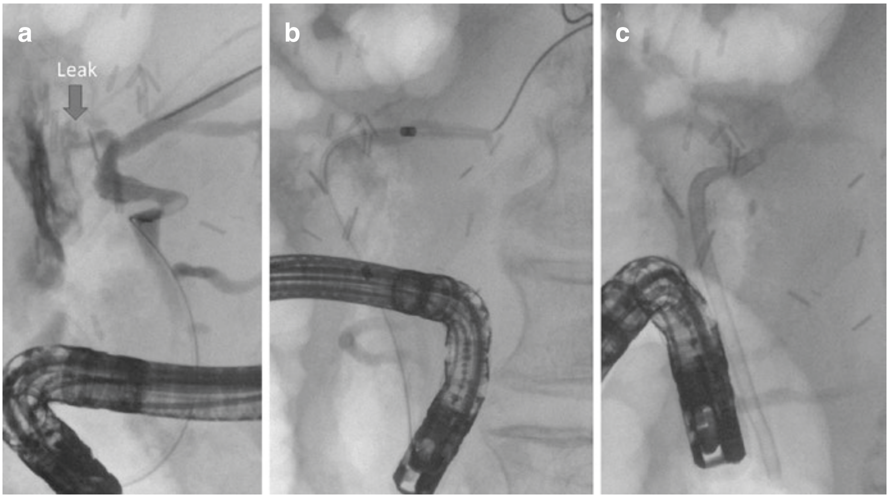

Fig. 13.10 Post-right hepatectomy bile leak. Endoscopic treatment was performed by preliminary cholangiography (**a**), reaching the left hepatic duct (**b**) and plastic biliary stenting of the left hepatic duct to exclude the site of the leak (**c**)

cholangiographic check must be performed to decide the next management step (plastic multi-stenting for 1 year or fully covered metal stents for 6–12 months).

The prognosis of traumatic bile leaks is excellent (98–100% of positive outcome), according to the available literature [42].

13.2.5 Postoperative and Traumatic Pancreatic Fistulas

Pancreatic injuries during abdominal trauma account for 4–5% of major traumas. Multiple pancreatic injury grading systems have been proposed, one of the best known being the American Association for the Surgery of Trauma classification, which envisages five grades on the basis of parenchymal, main vessel and duct damage [50].

Wong et al. proposed a classification for grading the severity pancreatic injuries on CT scan [51]:

- **Grade A**
  - Pancreatitis or superficial laceration only
- **Grade B**
  - BI: Deep laceration involving pancreatic tail
  - BII: Complete transection of pancreatic tail
- **Grade C**
  - CI: Deep laceration involving pancreatic head
  - CII: Complete transection of pancreatic head.

The latter classification may be more useful from an endoscopically oriented point of view.

Pancreatic duct leaks and fistulas can lead to significant morbidity and mortality. Traditionally, pancreatic fistulas are managed conservatively with fluid drainage, supportive therapy, total parenteral nutrition and pancreatic secretion inhibitors [50]. This strategy will heal most low-volume leaks. For persistent leaks, surgical treatment was traditionally considered the treatment of choice [50, 51]. However, there has recently been a trend toward aggressive yet minimally invasive management, to avoid surgery.

Endoscopic transpapillary or transmural drainage of pancreatic collections/leaks is now increasingly performed, thus introducing pancreatic endotherapy as a key player in the management of pancreatic leaks and fistulae. After reviewing the current literature, three distinct types of pancreatic injury leading to pancreatic leak/fistula were identified by our group [52]. We briefly summarize the endoscopic treatment of these conditions based on our classification:

- **Type I pancreatic fistula** (from peripheral ducts, i.e., postsplenectomy) (Fig. 13.11)
  - Head (IH): Bridging stent or nasopancreatic drain (NPD)
  - Body (IB): Bridging stent or NPD
  - Tail (IT): Bridging stent if duct caliber allows or cyanoacrylate/fibrin glue/other polymer injection at pancreatic tail/fistulous tract

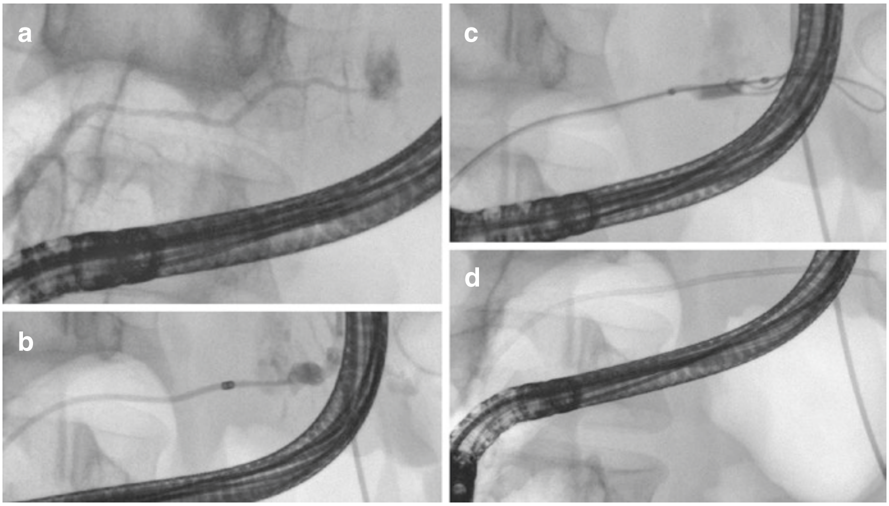

Fig. 13.11 Pancreatic fistula after splenectomy. The fistula was well identified at pancreatography at the level of the tail (**a**). The site of the fistula was enlarged with a Sohendra dilator (**b**) and 4 mm pneumatic dilation (**c**). A plastic pancreatic stent was placed with the distal edge in the peritoneal cavity (**d**)

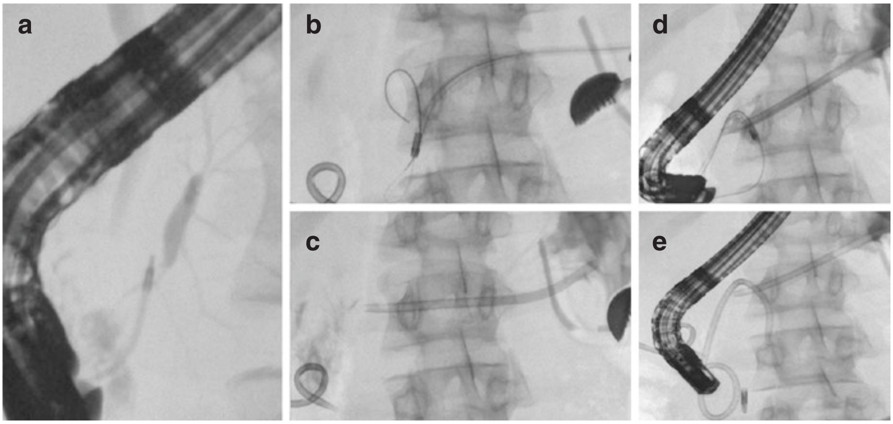

Fig. 13.12 Traumatic pancreatic fistula. (**a**) Pancreatography showed a disconnected main pancreatic duct. (**b**) Using a cystoenterostome, transgastric access to the distal portion of the pancreatic duct was obtained under both fluoroscopic and EUS guidance. (**c**) Pancreaticogastrostomy was performed using a pancreatic plastic stent. (**d**) A guidewire was placed in the proximal part of the disconnected pancreatic duct. (**e**) A transpapillary pancreatic nose-to-collection tube was placed

- **Type II pancreatic fistula** (disconnecting main pancreatic duct)
  - Open proximal stump (IIO): Bridging stent or NPD or extrapancreatic transpapillary protruding stent
  - Closed proximal stump (IIC) (Fig. 13.12): EUS for transmural drainage of the fluid collection from the distal gland into the stomach/intestine or EUS-guided pancreaticogastrostomy or conversion to open procedure (bridging stent)
- **Type III pancreatic fistula** (postoperative)
  - Proximal (after distal pancreatectomy): Transpapillary protruding stent to drain the collection (with the distal edge in the pancreatic collection)
  - Distal (after duodenopancreatectomy): Triple stenting (enteral stenting at the level of the jejunal stump, pancreatic stenting with proximal edge in the enteral stent and biliary stenting through the biliodigestive anastomosis to stabilize the prosthetic complex) [53] or EUS for transmural drainage of peripancreatic collections or pancreaticogastrostomy.

The endoscopic approach is useful for choosing a treatment modality for major pancreatic duct injury as it provides precise information about the major pancreatic duct injury and it also shows promise as a substitute for laparotomy or pancreatic resection in selected case series [54].

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Point-of-Care Ultrasound in Acute Care Surgery: A Strategic Tool

14

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14.1 Introduction

Point-of-care ultrasound (POCUS) is currently used in daily clinical practice in many different specialties, including surgery [1–3]. In the acute care setting, FAST (focused assessment with sonography for trauma) and E-FAST (extended FAST, including views for the detection of pneumothorax) have gained an evidence-based role in the management of trauma [4–6]. Nonetheless, the concept of POCUS as a routinely used extension of the surgeon's hand to quickly obtain clinical responses during physical examination still remains far from being widespread [7–14]. In non-trauma settings, there are many applications of ultrasound (US) in acute patients (pre-hospital emergencies, acute abdomen, soft tissue infections, deep venous thrombosis, pulmonary embolism, fracture detection and management, interventional maneuvers, shock management, intravascular volume assessment, etc.) [15–29].

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Rapid assessment and treatment of acute abdomen are essential. In this setting, POCUS, being a bedside examination, is the preferred tool for evaluating the acutely ill patient. As it is often time-dependent, in 2001 the American College of Emergency Physicians (ACEP) advocated the need for emergency US on a 24/7 basis, in order to provide immediate information within the scope of practice of emergency physicians [30]. This is not yet true for surgery, even though technological improvement in both equipment and imaging definition allows a detailed assessment of almost every organ. Portable US machines have resulted in high-quality resolution and clearer definition. Compared to other medical imaging methods, POCUS has become the ideal first diagnostic tool in emergency settings. By picking up a US probe, any doctor in either high- or low-resource settings can use US to obtain detailed anatomical, physiological, and pathological information as part of the clinical evaluation. Like any other diagnostic examination, there are risks of diagnostic errors, such as misdiagnoses, mainly due to inexperience.

There are many reasons explaining why general, acute and trauma surgeons are so reluctant to carry out a US probe in acute settings: adequate training, equipment availability, and probably the unacknowledged fear to rely on US findings for decisions.

In fact, the key point of POCUS is that it has to be performed by the clinician himself. The best performances of POCUS in surgical patients are obtained when the surgeon, who formulates the clinical question related to an acute patient, handles the probe, obtains the findings, and elaborates answers or new questions while performing US. This entails that surgeons should become familiar with US. Tailored educational formats have shown to really improve proficiency and enhance daily use [31]. This chapter offers a brief overview of the current applications of POCUS in the management of the critically ill surgical patient.

14.2 Trauma

US in trauma is nowadays well beyond FAST, the historical first standardized US approach to polytrauma, which may be really considered the "mother" of emergency US. FAST represents the paradigm of point-of-care critical US and probably the easiest way to start training.

E-FAST is systematically included in trauma management algorithms, in both hemodynamically normal and not normal patients. US doubles the sensitivity of chest x-ray for the detection of pneumothorax, and should be used as a first step in primary and secondary surveys [14]. In a recent large study, a controversial application of FAST, such as in the algorithm for pelvic trauma [32], has been recently shown to be reliable for decision making in a large study [33]. A more comprehensive approach, including the use of US, whenever required, in any step of management (the so-called ABCDE-US), was described many years ago and combines skills and applications to handle airways, thoracic injuries, venous cannulations, shock evaluation, soft tissue and skeletal injuries, neurotrauma assessment, and other interventional maneuvers [9, 10, 34]. Not all applications are competencies

Fig. 14.1 Ultrasound-assisted drainage of a small traumatic pneumothorax

for surgeons, but trauma surgeons should be aware of them and should be able to personally perform some of them.

POCUS has been shown to enhance the management of trauma patients even after the initial assessment.

Shock evaluation through the examination of lungs, heart, inferior vena cava and the detection of free fluid in serosal cavities (Rush protocol or Blue protocol), which represent the basic approaches, has been expanded by a systematic use of POCUS in intensive care patient management, for intravascular assessment and monitoring [20, 21, 35, 36]. This approach should actually be considered as a best practice and implemented [37]. US plays a role in selected cases for omitting more advanced imaging like computed tomography (CT). In hemodynamically normal patients with blunt abdominal trauma and negative E-FAST and no other suspicion for major injuries, a negative standard complete B-mode US, performed at 12–24 hours (usually by a radiologist), can reliably allow discharge without admission and further imaging [38]. Interventional US can sometimes help even in case of some relatively uncommon complications of trauma, such as retained hemothorax, Morel-Lavallée injuries, precise aspiration of small pneumothorax (when required) (Fig. 14.1), drainage of bilomas, diagnostic peritoneal aspiration, drainage of soft tissue abscesses [39]. The follow-up after non-operative management (NOM) of solid organ injuries could be carried out through US. Morphological follow-up after NOM of splenic injuries can be safely and effectively performed with contrast-enhanced US, according to standardized protocols, without harming the patient and avoiding the use of CT [40]. Similarly, the evolution of liver injuries admitted for NOM can be monitored on an outpatient basis with B-mode US [12].

14.3 Acute Cholecystitis and Biliary Emergencies

US is considered the gold standard and the first diagnostic tool for establishing a diagnosis of acute cholecystitis in the 2018 Tokyo Guidelines [41] and in a recently published consensus statement from the European Society for Trauma and

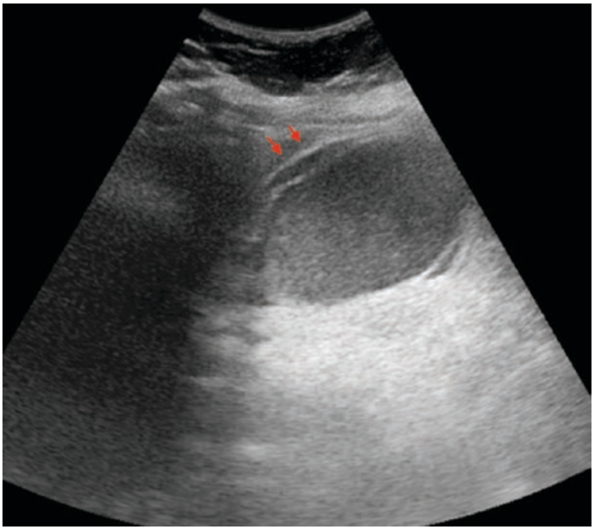

Fig. 14.2 Double-railway sign in acute cholecystitis (*arrow*), marking edema between the gallbladder wall and the liver

Emergency Surgery (ESTES) [42]. Similarly, US allows easy recognition of intrahepatic biliary dilation in patients with obstructive jaundice. Moreover, when indicated, US-guided cholecystostomy can be performed at the bedside. In the surgeon's perspective, a surgeon-performed POCUS may give additional information. Identification of the double-rail sign in the gallbladder wall (Fig. 14.2), which is a marker of acute cholecystitis, helps to overcome the problem of the optimal timing for operation; the presence of the sign reflects the presence of edema in the gallbladder bed, which usually predicts a good timing for operation, irrespectively from the onset of symptoms. Conversely, a multilayered wall or comet-tail artifacts in the wall predict a gangrenous gallbladder and a difficult operation.

It should be noted, however, that US accuracy in the detection of acute cholecystitis decreases in the presence of acute pancreatitis, due to the generalized edema produced by the inflammatory pancreatic disease [15].

14.4 Acute Appendicitis

Despite the use of dedicated scores, a specific diagnostic test does not yet exist, resulting in possible misdiagnosed acute appendicitis. The reported rates of negative appendectomy can be as high as 15–30%.

POCUS is the first-line imaging modality when facing with acute appendicitis, although still not routinely adopted in all institutions. CT and magnetic resonance imaging (MRI) are considered more sensitive and specific, but US is competitive in terms of accuracy, availability, and absence of ionizing radiation [43, 44].

The use of US in the diagnosis of acute appendicitis was first reported by Puylaert in 1986, who described the "graded compression" technique [45]. Over time, this US application was found to have satisfactory sensitivity and specificity both in

Table 14.1 Ultrasound differential diagnoses in the suspicion of acute appendicitis

• Small bowel diverticulitis
• Meckel's diverticulum (complications)
• Inflammatory bowel disease
• Volvulus
• Mesenteric lymphadenitis
• Gynecologic conditions
• Infectious ileocolitis
• Invagination
• Bowel ischemia
• Sigmoid diverticulitis
• Epiploic appendagitis
• Tumor
• Right-side colonic diverticulitis
• Omental infarction
• Right basal pneumonia
• Urolithiasis (e.g., ureteral stones, pyelonephritis)
• Acute cholecystitis
• Duodenal ulcer
• Ileocecal tuberculosis

pediatric and adult populations. The positive predictive value (PPV) and negative predictive value (NPV) of POCUS for acute appendicitis are 94% and 97%, respectively [46].

Criteria for a US diagnosis of acute appendicitis are the following: tubular non-compressible hollow viscus; pain on compression; outer diameter >6 mm (a size exceeding 6 mm is considered 95% sensitive and specific); bull's eye sign (or target sign).

Secondary findings that can help in the diagnosis of acute appendicitis are fat stranding, free fluid or fluid collections, detection of appendicolith, thickening of adjacent cecum and small bowel loops, dilation of adjacent small bowel loops (with or without loss of peristalsis).

In 2015, Larson et al. proposed a standardized structured appendix US report, incorporating a five-category interpretative scheme according to US findings, both primary and secondary. This approach entailed a 97% accuracy for the diagnosis of acute appendicitis [47].

POCUS in the suspicion of acute appendicitis must rule out or rule in a number of possible differential diagnoses, listed in Table 14.1.

14.5 Acute Colonic Diverticulitis

The use of US in the detection of acute colonic diverticulitis is well established [48–50], and should be assumed as the first-line diagnostic imaging method.

A large meta-analysis investigated the diagnostic accuracy of graded compression US and CT in acute colonic diverticulitis: 630 US-assessed patients were

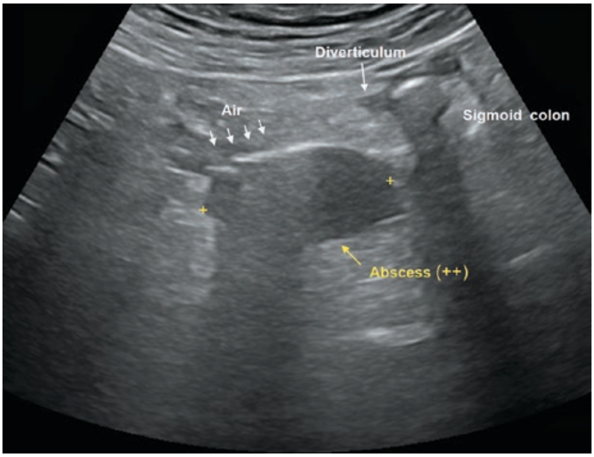

Fig. 14.3 Pericolic abscess in Hinchey-Wasvary Ib acute diverticulitis

compared with 684 patients who underwent CT. The results did not show any statistical difference between US and CT in terms of sensitivity and specificity [51]. POCUS can easily detect pericolic collections and/or be used as a guide for interventional maneuvers in complicated diverticulitis (Fig. 14.3).

A preliminary report demonstrated a very high correspondence between US and CT staging for H1 and H2 diverticulitis [52]. In experienced hands, POCUS can replace CT as a staging tool for non-complicated acute diverticulitis, expediting the decision on outpatient management in the emergency department.

14.6 Small Bowel Obstruction

Recent studies have shown that POCUS has an acceptable accuracy in diagnosing small bowel obstruction (SBO), and can replace plain abdominal x-ray as a first diagnostic method [27, 53, 54], significantly decreasing the time for diagnosis. US performed by emergency department physicians, surgeons, and radiologists, revealed 92.4% sensitivity and 96.6% specificity for SBO in a recent meta-analysis [53]. POCUS for SBO can be easily learned [27] and gives additional information compared with plain abdominal film.

POCUS aims to search for the following signs for the diagnosis of SBO: presence of fluid-filled, dilated bowel loops (defined as a diameter ≥25 mm); detection of normal or collapsed bowel loops; absent or ineffective peristalsis resulting in back-and-forth movements inside the fluid-filled loops (the so-called "to-and-fro" motion); free fluid between the dilated loops; empty colonic lumen. The possibility to obtain a sample of the free fluid through diagnostic peritoneal aspiration enhances the clinical decision, giving immediate confirmation of bowel critical ischemia when serosanguinous fluid is retrieved [55]. A CT scan usually follows the POCUS approach when the etiology and the precise site of obstruction are not detected by US. US could be also used for monitoring the evolution of a conservative treatment.

14.7 Bowel Perforation

US can detect peritoneal free air, even if it is not widely used with this aim and its reliability is still controversial. The intuitive shortcoming of US is its failure to detect pneumoperitoneum, mainly due to the difficulty to accurately differentiate between intra- and extra-luminal air. Nonetheless, many US signs can help in the diagnosis of free peritoneal air, shortening the diagnostic process in suspected cases. There are direct and indirect US signs of free extra-intestinal gas. The presence of both strongly increases POCUS sensitivity for pneumoperitoneum. Direct signs of free peritoneal air are increased echogenicity of the peritoneal stripe in a non-dependent area (usually anteriorly to the liver surface), non sliding comet-tail artifacts, detection of a step between air in the costophrenic sinus and the abdominal gas reflex. The "Zenith sign" (air in the right upper quadrant obscuring the liver in a patient in left lateral decubitus position) is 100% sensitive for pneumoperitoneum. Indirect signs of pneumoperitoneum are the presence of free fluid (which is the first sign of bowel perforation), thickened bowel wall, absence of peristalsis, fluid collections (with or without included air bubbles) [56–59].

14.8 Postoperative Complications

POCUS is an invaluable tool for detecting and managing postoperative complications in both elective and emergency surgical patients. The fact that it can be performed at the bedside is paramount. A large number of US applications can be useful in ruling out/in the vast majority of situations, sometimes by applying very simple and common US views. A superficial surgical site infection can be confirmed with linear probe scanning of the wound; a deep venous thrombosis with a bedside compression US; a pulmonary thromboembolism with the addition of heart and lung views; pleural effusions are easily detected with simple E-FAST views and can explain dyspnea or indicate immediate drainage; an unexplained fever could be clarified by the detection of an intra-abdominal collection; a postoperative hypotension could be easily interpreted using the Rush protocol. These are only a few of the daily situations that can arise on the ward and be helped by the bedside use of US.

14.9 Hemodynamics Assessment and Shock

Monitoring hemodynamic status with US is a widely accepted method in intensive care. Similarly, POCUS can be used at the bedside in any setting (inpatient, emergency, postoperative, and trauma care) for assessing intravascular volume, monitoring therapeutic intervention, discriminating the type of shock (hypovolemic, septic, cardiogenic) [20, 21, 35–37, 60]. This approach dramatically shortens the time to appropriate treatment and improves final outcomes. As stated by Ferrada et al., the use of US to resuscitate surgical patients will become the standard of care. Surgeons are responsible for gaining expertise in a technique that is already part of other disciplines' common practice in the clinical decision making process [61].

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15 Large Bowel Emergencies

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15.1 Large Bowel Perforation

Perforations of the large bowel constitute an abdominal emergency that result from a wide range of etiologies. Perforations are rare but severe complications, mainly of colorectal cancer and colonic diverticulitis. Common etiologies causing large bowel perforation are colon cancer, foreign body aspiration, stercoral colitis, diverticulitis, ischemia, inflammatory and infectious colitis, and various iatrogenic causes. Peritonitis secondary to large bowel perforation due to colonic cancer or benign colorectal disease still remains a major clinical life-threatening condition associated with high morbidity and mortality [1–3]. The reported incidence of malignant perforation from colorectal cancer ranges from 1.2 to 9% and bacterial contamination of the peritoneal cavity may lead to septic shock [4, 5].

15.1.1 Diagnosis

Computed tomography (CT) is the most reliable modality in detecting the site of large bowel perforation. The diagnosis is made by identifying direct CT findings such as extraluminal gas or contrast and discontinuity along the bowel wall. Extraluminal gas is specific for gastrointestinal perforation, and the location of extraluminal gas can elucidate the site of perforation. In detail, free intraperitoneal gas located only in the supramesocolic and inframesocolic compartments defines 100% of large bowel perforations. Extraluminal gas exclusively in the pelvis is most

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often related to colonic perforation. The amount of pneumoperitoneum varies depending on the cause and the site of perforation, as well as the acuity of the pathology. In a chronic process, the perforation is often walled off and localized, and the amount of extraluminal gas or fluid may be relatively small and difficult to detect. Colonic perforation may result in pneumoretroperitoneum if the site of perforation is in a retroperitoneal segment of colon.

Indirect CT findings can help support the diagnosis. The main indirect CT findings include wall thickening, pericolic fat stranding, abnormal bowel wall enhancement, abscess, and feculent collection adjacent to the bowel [6, 7]. CT identification of the perforation site increases from 34 to 97% for ascending-to-sigmoid colonic perforations and from 40 to 80% for rectal perforations, when direct CT findings are combined with indirect CT findings [8].

In such cases, pneumoperitoneum is often absent and the diagnosis is made by recognizing extraluminal bowel contents and fecal spillage [9]. It can be difficult to differentiate extraluminal stool from a normal loop of colon. If a large bowel perforation is not promptly diagnosed, there can be dire consequences for the patient, with rapid development of peritonitis and sepsis. In cases of non-opacified large bowel, repeat CT imaging with oral contrast may be helpful in excluding a perforation. Water-soluble contrast enema or CT with rectal contrast administration can be used as problem-solving tools in confirming colonic perforation in equivocal cases.

15.1.2 Perforated Colorectal Cancer

Perforation is the second most common reason for urgent or emergent surgery associated with colorectal carcinoma (CRC), with an incidence of 2.6–12% [10, 11].

Perforations most commonly occur at the site of the primary tumor, due to necrosis and friable tissue. Depending on the location, these may progress to either free or contained perforations. Perforation can also occur proximal to an obstructing carcinoma [12]. Indeed, there are two mechanisms by which a colon cancer can perforate. The first one is by direct necrosis at the site of the tumor; often, the amount of extraluminal air at the CT scan is small. The second mechanism is by “blowout” proximal to the tumor: a closed-loop obstruction in which the colon cancer causes increased colonic pressure between a competent ileocecal valve and the cancer, leading to a perforation [13]. The cecum is the most common site of this type of diastatic perforation [14]. An obstructing cancer increases the risk of perforation, with rates of 12–19% [15]. Perforation is reported to be the most lethal complication of CRC. In some studies, mortality associated with secondary peritonitis from perforation is as high as 30–50% [12].

CRC may be detected early through asymptomatic screening tests or as a result of diagnostic workup for symptomatic disease. Symptomatic disease tends to be a later stage and may not be curable. Up to 33% of patients who were ultimately diagnosed with CRC initially presented an acute condition [16]. Patients presenting to an emergency department and requiring surgery within 72 h of admission had more advanced disease than patients who underwent elective surgery longer after diagnosis.

Moreover, CRC may be the cause of acute lower gastrointestinal bleeding in 8–26% of cases [17, 18]. Bleeding caused by CRC is thought to result from erosion of the mucosal surface and rarely causes brisk hemorrhage.

Metastases to the colon can result in either extrinsic or internal colonic obstruction, also leading to perforation [16]. Tumor lysis syndrome causes a loss of gastrointestinal wall integrity.

The presentation of a free perforation may demonstrate classic findings of peritonitis, including generalized tenderness, involuntary guarding and rebound tenderness. Colorectal perforation seeding the peritoneal cavity is a surgical emergency with poor outcomes. The patient can rapidly progress into septic shock, disseminated intravascular coagulation, multisystem organ failure, and death. Although emergent surgical intervention is often required, outcomes have been generally poor, with mortality from 6 to 33% [19].

The surgical approach is typically open exploration and thorough washout with identification of the diseased and perforated site. Even without the established diagnosis of malignancy, resection of the perforated site should adhere to the principles of oncologic resection with extended lymphadenectomy for accurate pathologic staging [12]. Despite the poor perioperative mortalities, patients presenting with perforation from a CRC, without findings of widely metastatic lesions, should still be managed with a curative intent. Resuscitation and intravenous antibiotics followed by prompt surgical intervention are warranted. The tumor should be resected when feasible. Oncologic resection typically concludes with creation of an end stoma. Primary anastomosis may be considered in carefully selected patients, provided that the anastomosis is protected with a diverting ileostomy [20].

Contained perforations may present with a phlegmon or abscess. In stable patients, clinical staging should be completed. In the absence of metastatic disease, complete resection of the tumor, *en bloc* with adjacent involved organs, is the ideal method for controlling the perforation. If metastatic disease is identified, consideration may be given to stabilizing the patient and providing antibiotics with or without percutaneous drainage [16].

Poorly contained leaks should also be expected in the event of diastatic perforations, wherein a distal obstructing carcinoma results in ischemia and perforation of the proximal bowel, most commonly the splenic flexure or cecum. Subtotal colectomy is the operation of choice in these settings. Restoration of intestinal continuity with an ileocolic anastomosis may be considered in low-risk patients [12].

15.1.3 Perforated Diverticulitis

Diverticulitis is suspected clinically when there is a triad of left lower abdominal pain, fever and leukocytosis. The typical radiological signs range from pericolic fat stranding and wall thickening to abscess, fistula formation, free perforation and feculent peritonitis [21]. Cases of perforated diverticulitis can occur at any site of the colon, although it most commonly involves the sigmoid colon. Peritonitis and free perforation have been shown to occur more often in patients with no prior history of diverticulitis.

Primary resection of the diseased part of the colon and anastomosis is commonly performed and this procedure is safe provided the peritonitis is not severe. There is still controversy about proper surgical treatment of diffuse peritonitis due to large bowel perforation, especially in the left side. Hartmann's procedure (two-stage procedure) became popular in recent decades as an alternative to colostomy alone (three-stage approach) because the latter neither eliminates the source of inflammation nor stops peritoneal soiling. Commonly, the severity of peritonitis is assessed with the staging system of complicated colonic diverticulitis proposed by Hinchey, whereas the Mannheim peritonitis index is used to grade the severity of abdominal sepsis. Furthermore, according to the World Society of Emergency Surgery (WSES) position paper on the management of perforated sigmoid diverticulitis [22], the treatment options depend on the stage of disease, based on the disease extent identified on CT scanning.

Patients with stage III-IV diverticulitis who present signs of sepsis often require an emergency operation for source control. Currently, the timing and type of source control is unclear. Patients in septic shock benefit from preoperative optimization, rather than immediate intervention [22].

15.1.4 Inflammatory Bowel Disease, Toxic Colitis and Toxic Megacolon

Large bowel perforation in inflammatory bowel disease (IBD) is rare. Free perforation in ulcerative colitis (UC) occurs in about 2% of patients and is often associated with toxic megacolon [23]. Toxic megacolon is a life-threatening complication of IBD, characterized by diffuse non-obstructive colonic dilatation associated with systemic toxicity [24]. Although most commonly recognized as a potential complication of UC, it may also complicate Crohn's disease, ischemic colitis and infectious colitis [25]. Among patients with human immunodeficiency virus (HIV), cytomegalovirus (CMV) colitis has been implicated as the most common cause of toxic megacolon. Recently, with the increasing use of broad-spectrum antibiotics, pseudomembranous colitis (PC) has become a major clinical problem and cases of toxic megacolon secondary to PC have been described [26].

Toxic megacolon involves total or segmental non-obstructive colonic distension of at least 6 cm with inflammation of the colonic wall and associated systemic toxicity. Dilatation in usually most severe in the ascending and transverse colon. CT can provide more detailed findings regarding the distribution of colonic involvement and degree of wall thickening, including abnormal haustral pattern, segmental colonic wall thinning and nodular pseudopolyps [27].

Infectious colitis has varied clinical manifestations, depending on the afflicting pathogen. The differential diagnosis for infectious colitis primarily involving the right colon includes *Salmonella*, *Yersinia*, tuberculosis and amebiasis. Diseases with propensity for left colon include schistosomiasis, shigellosis, herpes, gonorrhea, syphilis. Diffuse colonic involvement can be caused by CMV and *Escherichia coli*.

Pseudomembranous colitis is the most severe form of *Clostridium difficile* colitis. Complications can include fulminant colitis and colonic perforation. If the pathogen is not controlled by appropriate antibiotic therapy, transmural necrosis and perforation can occur [6].

Most patients have been reported to have segmental involvement, with the rectum and sigmoid colon most affected. In the same study, positive scans were associated with leukocytosis, abdominal pain and diarrhea [28].

Since many of the clinical, laboratory or radiologic findings overlap, the distinction between severe colitis, fulminating colitis and toxic megacolon is somewhat arbitrary. The association of severe colitis, systemic sepsis and colonic dilatation with an abnormal haustral pattern is generally accepted as diagnostic of toxic megacolon.

Whenever possible, high-resolution helical CT with intravenous contrast agent administration should be performed to detect complications in these acutely ill individuals. Mortality rates of 33–64% have been reported in patients developing toxic megacolon associated with PC [24]. The reported mortality rates in patients with toxic megacolon vary, depending on the time of diagnosis, quality of medical and surgical management, associated illnesses, immunologic status and early detection of the intra-abdominal complications.

Prompt surgery is indicated for patients with toxic colitis or megacolon if there is evidence of free perforation, peritonitis, or massive hemorrhage. Surgery may also be indicated to avoid perforation if no clinical improvement occurs with aggressive medical therapy management within 48–72 h [23]. If perforation occurs, mortality may be greater than 40%, whereas if surgery is completed prior to perforation the mortality is between 2% and 8% [29].

Surgical options include subtotal colectomy with ileostomy, proctocolectomy with ileostomy or diverting loop ileostomy with decompressive skin level “blowhole” colostomy. A restorative proctocolectomy is not advised in the emergency setting. The optimal operation involves subtotal colectomy with end ileostomy. This allows removal of the majority of bowel and avoids an anastomosis in a critically ill patient [30]. In patients with UC, a definitive procedure can be done once the patient is stable.

Stercoral colitis is another kind of inflammatory colitis related to increased intraluminal pressure from impacted fecal material in the colon that may lead to ulceration resulting in colonic perforation [31]. When stercoral colitis is associated with colonic perforation, a 35% mortality rate has been reported [32]. The three most common locations for stercoral ulceration are the anterior rectum just proximal to the peritoneal reflection, the antimesenteric border of the rectosigmoid junction, and the apex of the sigmoid colon. Most cases are described as occurring on the antimesenteric side of the bowel wall. A possible explanation is that blood supply is relatively poor on the antimesenteric side, predisposing to ischemia.

15.2 Large Bowel Obstruction

15.2.1 Colorectal Cancer

Obstruction is a common symptom of CRC with an incidence range of 15–29% [33]. The majority of cases of acute colonic obstruction in adults are secondary to CRC [16, 34]. Differential diagnosis includes adhesive disease, hernia, volvulus, and extrinsic obstruction. Closed loop obstruction can occur in the setting of multiple tumors or a competent ileocecal valve, placing the patient at risk for ischemia and translocation of bacteria across the intestinal wall. A high mortality rate is associated with closed-loop obstruction associated with malignancy [35].

Obstruction is also the most common indication for emergency surgery for CRC. Surgery for large bowel obstruction presenting acutely should be performed in an oncologic fashion, even if a formal diagnosis of malignancy has not yet been made. Patients presenting with obstruction and no evidence of metastatic disease should be operated on with curative intent [16].

Typical signs of large bowel obstruction are progressively worsening abdominal pain, distension, nausea and vomiting. The diagnosis is suggested on plain radiography and confirmed with CT scan or water-soluble contrast enema [36]. CT scan has become the imaging modality of choice for patients presenting with symptoms suggestive of colonic obstruction. Obstructing colon cancers can be defined as occurring either proximal or distal to the splenic flexure, with the site of disease having a significant impact on treatment options. The left colon is more prone to obstruction, most commonly in the sigmoid [37].

The general consensus for the management of right-sided colonic obstruction involves one-stage resection and anastomosis for almost all patients but the frailest, thereby avoiding a stoma [38]. The emergency management of left-sided colonic obstruction remains controversial. There are several treatment options, also according to the WSES guidelines on the management of obstructing cancer of the left colon [39].

15.2.2 Malignant Intussusception

Intussusception is defined as the telescoping of a proximal segment of bowel into an adjacent distal segment, usually resulting in a mechanical obstruction. Intussusception represents only 5% of all cases of obstruction in adults and some studies demonstrate that 60% of patients with intussusception of the large bowel had a pathologic lead point that was malignant, suggesting that malignancy should be suspected in all adults presenting with obstruction due to intussusception [16].

15.2.3 Volvulus

Sigmoid volvulus is an emergent disease that typically causes closed-loop obstruction by abnormal twisting of the sigmoid colon along its mesenteric axis. Prompt diagnosis can be made with CT, with a diagnostic accuracy approaching 100% by demonstrating an abrupt transition between a normal and dilated colon as well as convergence of both ends of the dilated loop toward the fulcrum point [40, 41].

Urgent endoscopic detorsion of the volvulus is the primary treatment of choice, and thereafter elective surgery becomes the second treatment of choice to prevent recurrent volvulus in patients with simple sigmoid volvulus. The progression toward complicated volvulus results in irreversible colonic ischemia, gangrene, and perforation as a life-threatening condition [42]. Complicated sigmoid volvulus has persistently high mortality rates up to 60% and these patients should undergo emergent laparotomy for complete therapeutic cure instead of endoscopic detorsion [40].

15.3 Hemorrhage

Severe bleeding is a rare phenomenon in IBD patients, occurring in 0–6% of cases. Despite this rarity, it accounts approximately for 10% of all urgent colectomies for UC [43].

Most patients with UC and severe hemorrhage have extensive colitis and almost all have pancolitis. Surgery remains the mainstay of treatment for IBD when massive hemorrhage is evident: surgery is indicated in those patients who either fail to show slowing of bleeding after 4–6 units of blood, have recurrent hemorrhage, or have other indications for resection of the diseased bowel. The goal of surgery is to remove the patient from life-threatening hemorrhage [23]. Subtotal colectomy and ileostomy remain the best option in UC.

With brisk bleeding, the use of angiography may be considered only if patient stability is obtained. Angiography may detect the precise location of the bleeding source. Depending on the briskness of bleeding and time of presentation, some sources have had as high as a 70% success rate in localizing the bleeding source with angiography [44]. In the case of bleeding secondary to Crohn's colitis, an abdominal colectomy may be necessary. If the rectum is free of disease and the patient is stable, an ileorectal anastomosis may be performed.

15.4 Ischemic Colitis

Ischemic colitis is the most frequent form of intestinal ischemia and has a female predominance [45]. It results from an insufficient blood supply to the colon rather than from vascular obstruction, often causing subsequent inflammation and damage which may rarely progress to necrosis and become fatal. The ischemia-induced inflammatory process initially causes injury to the mucosa as a consequence of local hypoperfusion and reperfusion, through congestion, edema and hemorrhage, producing a thicker aspect of the wall.

It mostly occurs in elderly patients (80%) that present with abdominal pain, rectal bleeding and diarrhea [46]. The diagnosis of ischemic colitis is challenging because its clinical presentation may be similar to that of other abdominal diseases such as diverticulitis, appendicitis, and IBD. CT scan is widely accepted as the primary screening method for evaluation of abdominal pain [47]. According to Cruz et al., multisegment involvement is more common than single segment involvement, and a pattern of contiguous multisegment involvement is more common than a pattern of skipped segment. Overall, the left colon is involved more than three times as often as the right colon. The segment most frequently involved individually and in combination with others is the descending-sigmoid colon. The characteristic CT findings in ischemic colitis are pneumatosis, free fluid and dilatation. Wall thickening, fat stranding and abnormal wall enhancement are the most frequent findings on CT. Contrary to conventional teaching about an increased risk of ischemia in the watershed between the superior and inferior mesenteric artery circulation, the splenic flexure was not found to be a site of disproportionate risk for ischemic colitis [46]. Even though previous studies have shown a high specificity for ischemic colitis, there are many other conditions that can present with pneumatosis, with or without accompanying portal gas, such as infection and inflammation, neoplastic damage, chemotherapy and overdistension [48, 49]. Intestinal pneumatosis can be an incidental finding in asymptomatic patients and considered a benign condition. Pneumatosis and portomesenteric venous gas are not only the least common findings in most previous studies on ischemic colitis but also the most specific features for acute bowel ischemia, approaching reported specificities of almost 100% [46].

The left colon is more frequently involved independently of the severity of ischemia. Rectal involvement is reported to be relatively less frequent than involvement of left-sided segments, maybe as a result of the abundant collateral blood supply found in the pelvis and perineum [50].

15.5 Principles of Therapy of Left Colonic Obstruction

15.5.1 Colostomy

In large bowel obstruction loop colostomy or loop ileostomy is performed in the first stage. The second stage take place a few weeks later where the tumor is resected and the colostomy/ileostomy is closed or, alternatively, the colostomy can be closed at a third stage (two- or three-stage procedure). The colostomy/ileostomy performed at the first stage may provide decompression of the colon. Loop colostomy/ileostomy should be performed in cases of dramatic scenario, when patients have a very high surgical risk.

15.5.2 Hartmann's Procedure

Primary resection for acute left-sided colonic obstruction is considered the standard treatment [38, 39], and primary resection with end colostomy is considered the safest option [51]. The main advantages are that there is no risk of anastomotic dehiscence and the operation may be performed by less experienced surgeons. The main disadvantages are the need for a second major operation to reverse the colostomy, and 40–60% of patients do not have their colostomy reversed, with a significant drop in their quality of life.

Hartmann's procedure should be preferred to loop colostomy. It offers no survival benefit compared to segmental colonic resection with primary anastomosis, and should be considered in patients with high surgical risk [39].

15.5.3 Primary Resection and Anastomosis

Primary resection and anastomosis (PRA) has an advantage since it is a definitive procedure that does not require further surgery. PRA requires a more experienced surgeon and carries a risk of anastomotic leakage from an unprepared bowel in an already ill patient. Most studies have shown Hartmann's operation to be associated with poorer outcome, which is most likely related to selection bias as anastomosis is avoided in high-risk patients [52].

PRA is generally preferred in selected patients. Another option is to perform a total or subtotal colectomy, which avoids the problem of unprepared bowel and protects against any future malignancy of the right colon.

Some studies demonstrated that there is no convincing evidence that mechanical bowel preparation is associated with reduced rates of anastomotic leakage in the elective setting. A randomized controlled trial comparing intraoperative colonic irrigation with manual decompression in acute left-sided colonic obstruction concluded that decompression is as good as colonic irrigation with no difference in morbidity and mortality.

Patients should be stratified according to perioperative risk [38].

The experience of the surgeon seems to be a primary factor in the choice of anastomosis or colostomy.

15.5.4 Colonic Stents

Endoscopic stents have been used for palliation in patients with inoperable cancer or unfit for surgery, or as a bridge to surgery when the acute obstruction is managed by the stent and the patient could have an elective operation for cancer at a later stage. Problems related to endoscopic colonic stenting include perforation, migration and re-obstruction. Most studies have shown that colonic stenting is a relatively safe technique with high success rates [53].

15.6 Conclusions

Emergency large bowel surgery continues to carry a high risk despite several developments in the provision of emergency surgical care. There are remaining grey areas, but clinical decisions will often depend on the surgeon's experience. One-stage PRA of the large bowel is a feasible option in cases of emergency large bowel obstruction caused by colonic carcinoma; it can be performed with acceptable morbidity and mortality whenever comorbidity of the patient is not a contraindication.

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16 Biliary Emergencies

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16.1 Background

The prevalence of gallstones in the general population is 10–15% and 20–40% of these patients will develop a gallstone-related complication [1].

Possible complications of gallstones are: acute calculous cholecystitis (ACC), choledocholithiasis, acute cholangitis (AC), acute biliary pancreatitis, gallstone ileus, Mirizzi syndrome, gallbladder carcinoma and porcelain gallbladder [2]. Among these complications, ACC, AC and acute biliary pancreatitis can be considered biliary emergencies because they need prompt management and therapy.

In this chapter, the diagnosis, classification and management of ACC and AC will be discussed, while the management of acute biliary pancreatitis is addressed in the relevant chapter of the book.

16.2 Acute Calculous Cholecystitis

According to the third National Health and Nutrition Examination Survey, 6.3 million men and 14.2 million women aged 20–74 years old in the United States had gallbladder disease [3]. ACC is the first clinical presentation in 10–15% of patients with a gallstone-related complication [1].

The Tokyo guidelines, first published in 2007 (TG07) and updated in 2013 (TG13) and 2018 (TG18), attempted to establish objective parameters for the

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diagnosis, classification, and management of ACC [4–6]. In 2016, the World Society of Emergency Surgery (WSES) published the first edition of its guidelines for ACC (WSES16) [7], which presented different diagnostic and therapeutic algorithms compared to TG13, in particular with regard to diagnostic criteria, severity classification and therapeutic indications. Furthermore, WSES16 included a discussion on unclear areas such as evaluation of the patients' surgical risk and appropriate management of associated common bile duct stones. TG18 reached conclusions that were closer to the recommendations of WSES16, especially in terms of a more liberal indication for surgery, also for severe ACC [8]. However, as reaffirmed in the 2020 updated WSES guidelines (WSES20) [1], some differences from TG18 on important topics remain.

16.2.1 Diagnosis

According to TG13 and TG18, a diagnosis of ACC can be made when all three of the following criteria are met [5, 6] (Table 16.1):

- the presence of local inflammation, represented by the presence of right upper quadrant pain and Murphy's sign; this sign has a high specificity (79–96%), but a poor sensitivity (50–65%);
- the presence of systemic inflammation, represented by fever or elevated white blood cell count or C-reactive protein level;
- imaging findings characteristic of ACC.

Studies have found that the diagnostic accuracy of the TG13/TG18 criteria ranges from 60.4 to 94.0% if pathological samples are used as the gold standard [6]. However, a cross-sectional study found that, among fever, inflammatory markers and ultrasound (US) findings, only neutrophil count was statistically associated

Table 16.1 Diagnostic criteria for acute calculous cholecystitis according to TG13/TG18

A.	**Local signs of inflammation**
	A-1. Murphy's sign
	A-2. RUQ mass, pain or tenderness
B.	**Systemic signs of inflammation**
	B-1. Fever
	B-2. Elevated CRP
	B-3. Elevated WBC count
C.	**Imaging findings**
	Imaging findings characteristic of acute cholecystitis
Suspected diagnosis	
	One item in A + one item in B
Definite diagnosis	
	One item in A + one item in B + item C

TG13/TG18 Tokyo guidelines 2013 and 2018, *RUQ* right upper quadrant, *CRP* C-reactive protein, *WBC* white blood cells
Modified from [6]

with the diagnosis of cholecystitis [9]. In this study, the overall accuracy of the TG13 criteria was 60.3% and TG13 overdiagnosed ACC in 62.5% cases of normal gallbladder [9]. According to WSES16 and WSES20 there is no single clinical or laboratory finding with sufficient diagnostic accuracy to establish or exclude ACC. Only a combination of detailed history, complete clinical examination, laboratory tests and imaging investigation may strongly support the diagnosis of ACC, although the best combination is not yet known [1, 7].

16.2.2 Imaging

With a sensitivity of 81% and a specificity of 83% [10], US is the gold standard imaging technique for ACC because of its lower cost, better availability and lack of invasiveness, according to both TG18 and WSES20 [1, 6]. An enlarged gallbladder, a thickened wall >5 mm, presence of stones, debris echo and the sonographic Murphy's sign are the US signs of ACC.

The diagnostic accuracy of computed tomography (CT) is poor [1, 6], but contrast-enhanced CT is recommended for diagnosing gangrenous ACC [6]. The diagnostic accuracy of magnetic resonance imaging (MRI) is comparable to that of US and the technique is useful if abdominal US does not provide a definitive diagnosis [1, 6], but it is poorly applicable in emergency settings. The hepatobiliary iminodiacetic acid (HIDA) scan has the highest sensitivity and specificity for ACC, although its scarce availability, long time required to perform the test, and exposure to ionizing radiation limit its use [1].

16.2.3 Classification

TG13 and TG18 suggest an ACC classification structured in three different levels of severity, based on the characteristics of the acute inflammatory process [6]:

1. *Grade III (Severe ACC)*: ACC associated with organ dysfunction:
   (a) Cardiovascular dysfunction: hypotension with dopamine >5 μg/kg per min, or norepinephrine, any dose
   (b) Neurological dysfunction: decreased level of consciousness
   (c) Respiratory dysfunction: PaO_2/FiO_2 ratio < 300
   (d) Renal dysfunction: oliguria, creatinine >2.0 mg/dL
   (e) Hepatic dysfunction: PT-INR >1.5
   (f) Hematological dysfunction: platelet count <100,000/mm^3.
2. *Grade II (Moderate ACC)*: ACC associated with any one of the following conditions:
   (a) Elevated white blood cell count (>18,000/mm^3)
   (b) Palpable tender mass in the right upper abdominal quadrant
   (c) Duration of complaints >72 h

(d) Marked local inflammation (gangrenous cholecystitis, pericholecystic abscess, hepatic abscess, biliary peritonitis, emphysematous cholecystitis).

3. *Grade I (Mild ACC)*: ACC that does not meet the criteria for grade III or grade II ACC; grade I can also be defined as ACC in a healthy patient with no organ dysfunction and mild inflammatory changes in the gallbladder, making cholecystectomy a safe and low-risk operative procedure.

This clinical classification was the first attempt to create an international grading system in order to standardize data and patients' characteristics and to choose the best treatment option. The assessment criteria used in the TG13/TG18 severity grading for ACC have been validated in numerous studies and they are significantly associated with parameters including mortality, length of hospital stay, conversion to open surgery, and medical costs [6]. In particular, Endo et al. showed that in grade III ACC, factors including jaundice, neurological dysfunction, and respiratory dysfunction were associated with vital prognosis [11].

However, according to some authors, these criteria are based mainly on the characteristics of the local acute inflammatory process considering less important the patient's pre-existing clinical characteristics, comorbidities, and risk factors [12].

16.2.4 Common Bile Duct Stones Associated with Acute Calculous Cholecystitis

In patients with ACC, the presence of concomitant common bile duct stones (CBDS) is reported to range from 8.7 to 25% [13]. Liver biochemistry tests, including alanine transaminase (ALT), aspartate transaminase (AST), bilirubin, alkaline phosphatase (ALP), gamma-glutamyl transferase (GGT), should be performed in all patients with ACC to assess the risk for CBDS [7]. The most reliable liver function test for CBDS is GGT, with a sensitivity of 80.6% and a specificity of 75.3%, using a cut-off of 224 U/L [14]. The specificity of serum bilirubin levels is 60% with a cut-off level of 1.7 mg/dL and 75% with a cut-off level of 4 mg/dL [15]. However, WSES20 recommends against the use of elevated liver function test or bilirubin as the only method to identify CBDS in patients with ACC, because they may be altered as a result of acute inflammation of the gallbladder and biliary tree [1]. The American Society of Gastrointestinal Endoscopy (ASGE) and the Society of American Gastrointestinal Endoscopic Surgeons (SAGES) proposed a risk stratification for CBDS (high: >50%; intermediate: 10–50%; low: <10%) based on moderate, strong and very strong predictive factors [16]. WSES20 suggests stratifying the risk of CBDS according to a modified classification from the ASGE and SAGES guidelines, with a more cautious approach: only patients with evidence of CBDS at abdominal US should be considered at high risk and should directly undergo endoscopic retrograde cholangiopancreatography (ERCP). Patients with strong or moderate risk factors should be considered at intermediate risk and should undergo second level investigations such as endoscopic ultrasound (EUS) or magnetic resonance cholangiopancreatography (MRCP), laparoscopic ultrasound (LUS) or

Table 16.2 Risk factors and classification of risk for choledocholithiasis according to WSES20 [1]

Predictive factor for choledocholithiasis	
Very Strong	Evidence of common bile duct stone at abdominal ultrasound
	Ascending cholangitis
Strong	Common bile duct diameter >6 mm (with gallbladder in situ)
	Total serum bilirubin >1.8 mg/dL
Moderate	Abnormal liver biochemistry tests other than bilirubin
	Age older than 55 years
	Clinical gallstone pancreatitis
Risk class for choledocholithiasis	
High	Presence of any Very Strong predictive factor
Low	No predictive factor present
Intermediate	All other patients

From [1] (published under the terms of the Creative Commons CC-BY license)
WSES20 World Society of Emergency Surgery 2020 guidelines

intraoperative cholangiography (IOC), depending on local expertise and availability (Table 16.2).

A Cochrane meta-analysis compared EUS and MRCP: both had good diagnostic accuracy, showing summary sensitivities of 95% for EUS and 93% for MRCP and a summary specificity of 97% and 96%, respectively [17]. Comparing ERCP and IOC, the summary sensitivity was 83% for ERCP and 99% for IOT ($p = 0.05$), the summary specificity was 99% for both ERCP and IOT [18]. IOC and LUS had the same pooled sensitivity and similar pooled specificity for CBDS [19].

The treatment of CBDS can be performed before, during or after the cholecystectomy: preoperative ERCP with sphincterotomy, intraoperative ERCP with sphincterotomy, laparoscopic or open common bile duct exploration, postoperative ERCP with sphincterotomy. A systematic review assessed the differences between these techniques in terms of morbidity, mortality, and success rate [20]. Open bile duct surgery seems superior to ERCP in its ability to achieve bile duct stone clearance, while there seem to be no significant differences in the safety and efficacy of laparoscopic bile duct exploration versus the endoscopic options.

Treatment of CBDS, if performed before the cholecystectomy, is one of the major factors implicated in the delaying of surgery.

16.2.5 Surgical Therapy

At the end of nineteenth century, precisely in 1882, the first open cholecystectomy was performed by Langenbuch and gallbladder removal during initial hospitalization became the gold standard for symptomatic cholelithiasis [21]. With the advent of laparoscopy, laparoscopic cholecystectomy became the gold standard technique.

During these years numerous reports, case series and randomized controlled trials have been published discussing the better timing for laparoscopic cholecystectomy in ACC and whether early (ELC) or delayed (DLC) laparoscopic cholecystectomy should be preferred.

16.2.5.1 Tokyo Guidelines

The Tokyo Guidelines suggest a treatment flowchart based on the clinical classification of ACC [8]. TG13 did not consider issues like physical status such as comorbidities and, until TG18, grade III ACC was considered not suitable for surgery. TG18 introduced a modified flowchart, more similar to the WSES16, based on more recent evidence, and recommended that the treatment strategy should be chosen after an assessment of cholecystitis severity, the patient's general status and underlying disease. To evaluate the patient's comorbidity and general status, TG18 suggest using the Charlson comorbidity index (CCI) and the American Society of Anesthesiologists physical status classification (ASA-PS).

(a) *Grade I ACC*: ELC is recommended if the CCI and ASA-PS scores suggest the patient can withstand surgery (CCI <6 and ASA-PS <3). If the patient cannot withstand surgery, TG18 suggest conservative management and possible DLC.
(b) *Grade II ACC*: ELC in an advanced surgical center is recommended if the CCI and ASA-PS scores suggest the patient can withstand surgery (CCI <6 and ASA-PS <3). In cases of difficult cholecystectomy, a switch to open or subtotal cholecystectomy could be considered. If the patient cannot withstand surgery, TG18 suggest conservative management and, if the patient does not respond to initial medical treatment, biliary drainage (consider DLC).
(c) *Grade III ACC*: Attempts should be made to normalize organ function through organ support, alongside administration of antimicrobials. ELC in an advanced surgical center is recommended if the patient is judged to be able to withstand surgery (no neurological and respiratory dysfunction, total bilirubin <2 mg/dL, CCI <4 and ASA-PS <3). In cases of difficult cholecystectomy, a switch to open or subtotal cholecystectomy could be considered. If the patient cannot withstand surgery, TG18 suggest conservative management and, if the patient does not respond to initial medical treatment, biliary drainage (consider DLC).

TG18 defined neurological and respiratory dysfunction and coexistence of jaundice as negative predictive factors in grade III ACC because they are associated with higher mortality [8].

Focusing on the timing of cholecystectomy, TG18 recommend ELC regardless of exactly how much time has passed since onset. Comparing ELC and DLC, ELC (both within 72 h and within 1 week) showed shorter total hospital stays and lower costs [8].

16.2.5.2 World Society of Emergency Surgery Guidelines

WSES16 and WSES20 recommend ELC as the first-line therapy for ACC, after a risk stratification for CBDS [1, 7]. The only contraindications to ELC are septic shock or absolute anesthesiology contraindications. ELC is recommended also for patients with Child A and B cirrhosis, advanced age and patients who are pregnant. WSES20 recommend laparoscopic or open subtotal cholecystectomy in situations in which anatomic identification is difficult and the risk of iatrogenic injuries is high.

Focusing on the timing of ELC, WSES20 recommend ELC to be performed as soon as possible, within 7 days from hospital admission and within 10 days from the onset of symptoms. In the event that ELC cannot be performed within this time frame, DLC beyond 6 weeks should be preferred.

Compared to ELC, intermediate laparoscopic cholecystectomy (ILC) and DLC showed a higher rate of serious adverse events [22].

A systematic review of studies reporting on the ability of prognostic factors or risk prediction models to predict outcomes in patients with ACC showed that no reliable models exist to date [23]. The only available comparison of risk assessment scores (ASA, APACHE II and POSSUM) is limited to perforated ACC and highlights a significant association of the three scores with morbidity and mortality. APACHE II seems to be the best risk predictor [24], but it is built to predict morbidity and mortality in patients admitted to intensive care units: its use as a preoperative score should be considered as an extension usage from the original concept. Therefore WSES20 do not suggest the use of any prognostic model in patients with ACC [1].

WSES20 suggest considering non-operative management (NOM) for patients refusing surgery or for those who are not suitable for surgery. NOM could include the best medical therapy with antibiotics and observation and, if initial NOM fails, alternative treatment options like biliary drainage.

Regarding the assessment of the risk for choledocholithiasis, after an evaluation for the presence of peritonitis, condition that leads the patient to an emergency operation, the WSES guidelines suggest considering the ASGE guidelines. With a low risk, if the patient is eligible for surgery, ELC should be performed as soon as possible. If the patient is not suitable for surgery he should receive antibiotic therapy and possible biliary drainage, if the medical treatment is ineffective after 48 h. Patients at high risk for choledocholithiasis should undergo ERCP directly or, if ERCP is ineffective, a surgical exploration of the common bile duct. Patients with intermediate risk have to be evaluated with MRCP, EUS, LUS or IOC, based on staff availability, to select patients who should receive ERCP. Both patients at high risk and those at intermediate risk after diagnostic evaluation, if fit for surgery, should receive ELC or, if unfit, should be treated conservatively with antibiotic therapy [1].

16.2.6 Biliary Drainage

Gallbladder drainage decompresses the infected bile or pus in the gallbladder, removing the infected collection without removing the gallbladder. Removal of the infected material, in addition to antimicrobial therapy, can result in reduced inflammation with an improvement of the clinical condition [7]. A recent randomized controlled trial (CHOCOLATE) [25] compared ELC and percutaneous gallbladder drainage (PTGBD) in high-risk patients (APACHE II score ≥7) with ACC and showed a higher major complication rate, a higher reintervention rate and a higher rate of recurrent biliary disease after PTGBD. However, in patients with ACC who are not suitable for surgery, non-surgical approaches, including PTGBD and endoscopic procedures, should be considered. According to WSES20, endoscopic transpapillary gallbladder drainage (ETGBD) or ultrasound-guided transgastric or transduodenal gallbladder drainage (EUS-GBD) could be considered safe and effective alternatives to PTGBD [1]. A recent randomized controlled trial (DRAC 1) [26] compared EUS-GBD with PTGBD in high-risk patients (age ≥80, ASA-PS score ≥3, age-adjusted CCI >5 or Karnofsky score <50) with ACC, finding improved outcomes in EUS-GBD (lower 1-year and 30-day adverse events, lower reintervention rate, lower rate of unplanned readmissions, lower rate of recurrent cholecystitis, lower pain and analgesic requirements). Furthermore, EUS-GBD with lumen-apposing self-expandable metal stents (LAMSs) should be preferred to ETGBD, with metal stent removal within 4 weeks [1].

16.2.7 Antibiotic Therapy

An open-label non-inferiority prospective controlled trial randomized 414 patients who underwent cholecystectomy for uncomplicated ACC to either no antibiotics after surgery or continuation of the preoperative antibiotic regimen for 5 days, finding no difference in the incidence of postoperative infection rate [27]. On this basis, WSES20 recommend against the routine use of postoperative antibiotics when the focus of infection is controlled by cholecystectomy [1]. Similarly, TG18 recommend antimicrobial therapy only before and at the time of surgery for patients with grade I and II ACC, and for the duration of 4–7 days after surgery for grade III ACC and for complicated ACC [28]. The antimicrobial regimen should be based on the presumed pathogens involved and the risk factors for major resistance patterns. Organisms most often involved in biliary infections are the gram-negative aerobes, *Escherichia coli* and *Klebsiella pneumonia* and anaerobes, especially *Bacteroides fragilis* [29]. In immunosuppressed patients, enterococcal infection should always be presumed and treated [30]. Health care-related infections are commonly caused by more resistant strains. For these infections, complex regimens with broader spectra are recommended, as adequate empiric therapy appears to be a crucial factor affecting postoperative complications and mortality rates, especially in critically ill patients [30]. Table 16.3 reports the antimicrobial regimens suggested by WSES for ACC.

However, microbiological analyses are helpful in designing targeted therapeutic strategies for individual patients, especially in patients at high risk for antimicrobial resistance [1].

Table 16.3 Antimicrobial regimens suggested for acute calculous cholecystitis [1]

Good penetration efficiency antibiotics (bile to serum concentration ≥5)	Low penetration efficiency antibiotics (bile to serum concentration <1)
Piperacillin/Tazobactam	Cefotaxime
Tigecycline	Meropenem
Amoxicillin/clavulanate	Ceftazidime
Ciprofloxacin	Vancomycin
Ampicillin/Sulbactam	Amikacin
Ceftriaxone	Gentamicin
Levofloxacin	Cefepime
Penicillin G	Imipenem

From [1]

16.3 Acute Cholangitis

AC occurs when biliary stenosis results in cholestasis and biliary infection with a subsequent flush of microorganisms or endotoxins into the systemic circulation, inducing a sepsis [31]. Causes of biliary obstruction are benign biliary strictures (postsurgical, acute and chronic pancreatitis, autoimmune cholangitis, primary sclerosing cholangitis, complicated stone or congenital anomalies) and malignant biliary strictures (pancreatic cancer, gallbladder cancer, cholangiocarcinoma, small intestine malignancy or liver metastases), biliary stent obstruction, hemobilia or parasitic infections. The most common cause of biliary obstruction is choledocholithiasis. Bile is sterile, and bacterial infection of the bile results from ascending migration of pathogens or portal bacteremia [32]. The mortality rate is high if the infection is not treated and the biliary obstruction rapidly resolved.

16.3.1 Diagnosis

Charcot's triad (combination of jaundice, fever and right upper quadrant abdominal pain) shows high specificity, but a low sensitivity of 50–70% [31]. The TG13 and TG18 diagnostic criteria (Table 16.4) are associated with high diagnosis rates of about 90%.

16.3.2 Imaging

Available imaging modalities that are useful in AC are US, EUS, abdominal CT, MRCP and ERCP. Their role is to assess the presence or absence of an obstruction of the biliary tree, the cause of the obstruction, such as gallstones and biliary strictures, and the level of the obstruction [32].

Table 16.4 Diagnostic criteria for acute cholangitis according to TG13/TG18

A.	**Systemic inflammation**
	A-1. Fever (>38 °C) and/or shaking chills
	A-2. Laboratory data: evidence of inflammatory response (WBC <4 or >10 × 1000/μL, CRP ≥1 mg/dL)
B.	**Cholestasis**
	B-1. Jaundice (TBil ≥2 mg/dL)
	B-2. Laboratory data: abnormal liver function tests (ALP, GGT, AST, ALT >1.5 × upper limit of normal value)
C.	**Imaging**
	C-1. Biliary dilatation
	C-2. Evidence of the etiology on imaging (stricture, stones, stent, etc.)
Suspected diagnosis	
	One item in A + one item in B
Definite diagnosis	
	One item in A + one item in B + one item in C

TG13/TG18 Tokyo guidelines 2013 and 2018, *WBC* white blood cells, *CRP* C-reactive protein, *TBil* total bilirubin, *ALP* alkaline phosphatase, *GGT* γ-glutamyltransferase, *ALT* alanine aminotransferase, *AST* aspartate aminotransferase
Modified from [31]

According to a meta-analysis by Abboud et al. [33], abdominal US has a high specificity (96–100%) and low sensitivity (38–42%) for dilated common bile duct and for CBDS. In the clinical setting, when a patient presents with acute abdominal pain, CT is often performed ahead of abdominal US as it can exclude other diseases, but its sensitivity in the detection of bile stones is 25–90%. Although MRCP has sufficient diagnostic capabilities and is recommended for identifying the cause of AC and evaluating inflammation, it is usually not the first-choice test method for reasons of availability and convenience [31].

16.3.3 Classification

The TG13 and TG18 severity grading criteria for AC are important for predicting prognosis and determining a treatment strategy. In patients with a higher severity grade, 30-day mortality was significantly higher [34]:

1. *Grade III (Severe AC)*: AC associated with the onset of dysfunction at least in any one of the following organs/systems:
   (a) cardiovascular dysfunction: hypotension requiring dopamine ≥5 μg/kg/min, or any dose of norepinephrine
   (b) neurological dysfunction: disturbance of consciousness
   (c) respiratory dysfunction: PaO_2/FiO_2 ratio <300
   (d) renal dysfunction: oliguria, serum creatinine >2.0 mg/dL
   (e) hepatic dysfunction: PT-INR >1.5
   (f) hematological dysfunction: platelet count <100,000/mm^3.

2. *Grade II (Moderate AC)*: AC associated with any two of the following conditions:
   (a) abnormal white blood cell count (>12,000/mm^3, <4000/mm^3)
   (b) high fever (≥39 °C)
   (c) age (≥75 years old)
   (d) hyperbilirubinemia (total bilirubin ≥5 mg/dL)
   (e) hypoalbuminemia (<STD × 0.7).
3. *Grade I (Mild AC)*: AC that does not meet the criteria for grade III (severe) or grade II (moderate) AC at initial diagnosis.

16.3.4 Therapy

After severity has been assessed and the patient's general status has been evaluated, a treatment strategy should be decided. Biliary drainage and antibiotics are the two key pillars of the treatment of AC. In the case of serious deterioration, appropriate organ support and respiratory/circulating management should be considered. Broad-spectrum intravenous antibiotics should be started as early as possible whenever the diagnosis of AC is suspected. Blood and bile cultures should always be carried out before antibiotic administration.

Biliary drainage can be achieved with ERCP, EUS, percutaneous transhepatic cholangiography (PTC) or open surgical drainage. Biliary drainage by ERCP could include stent placement or nasobiliary drain placement with or without sphincterotomy.

According to TG18, endoscopic transpapillary biliary drainage (ETBD), regardless of the use of nasobiliary drainage or biliary stenting, should be selected as the first-line therapy for AC. In AC, endoscopic sphincterotomy (EST) is not routinely required for biliary drainage alone because of the concern for post-EST bleeding. In the case of concomitant bile duct stones, stone removal following EST at a single session may be considered in patients with mild or moderate AC, except in patients under anticoagulant therapy or with coagulopathy. Presently, balloon enteroscopy-assisted endoscopic retrograde cholangiopancreatography (BE-ERCP) is used as the first-line therapy for biliary drainage in patients with surgically altered anatomy where BE-ERCP expertise is present. However, the technical success rate is not always high. Thus, several studies have revealed that EUS-guided biliary drainage (EUS-BD) can be one of the second-line therapies after failed BE-ERCP as an alternative to PTC, where EUS-BD expertise is present [35]. Open surgical drainage is only considered when ERCP, PTC, or EUS-BD are not successful or are contraindicated.

In a recent meta-analysis by Iqbal et al. [36], emergent biliary drainage within 48 h in patients with AC was found to be associated with lower odds of in-hospital mortality, 30-day mortality, organ failure, and a shorter length of stay. The mortality benefit persists in patients with mild-to-moderate and severe AC who underwent emergent ERCP.

The indications of TG18, based on the severity of AC, are the following:

(a) *Grade I AC*: usually medical treatment with antibiotics is sufficient and most patients do not require biliary drainage. However, ETBD should be considered in patients who do not respond to initial treatment. If required, according to etiology, EST may be performed at the same time as biliary drainage.
(b) *Grade II AC*: early endoscopic or percutaneous transhepatic biliary drainage is required. If the underlying etiology requires treatment, this should be provided after the patient's general condition has improved. EST may be performed together with biliary drainage.
(c) *Grade III AC*: urgent endoscopic or percutaneous transhepatic biliary drainage should be performed as soon as possible after the patient's condition has been improved by initial treatment. If treatment of underlying etiology is required, this should be provided after the patient's general status has improved [37].

In the case of AC due to choledocholithiasis, after resolution of AC, cholecystectomy is indicated. Data regarding the timing of cholecystectomy after AC is relatively sparse and the literature demonstrates a tendency to DLC with only 28.6–37.2% of patients receiving ELC after AC. However, a recent retrospective observational study [38] showed a lower rate of complications when cholecystectomy was performed during the index admission for AC.

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Management of Infected Necrosis in Severe Acute Pancreatitis

17

Ari Leppäniemi

17.1 Introduction

While most patients with acute pancreatitis have the mild or moderate forms of the disease, about 20–30% develop severe acute pancreatitis characterized and defined by organ failures lasting more than 48 h and associated with a mortality rate of about 15–18% [1–3]. In a retrospective analysis of 435 consecutive patients with severe acute pancreatitis requiring management in the intensive care unit, the 90-day mortality rate was 17.9%. Independent risk factors for mortality included age over 60 years, female sex, heart disease, chronic liver failure, open abdomen treatment and sterile necrosectomy during the first 4 weeks [3].

One of the main indications for surgery in patients with severe acute pancreatitis is the infection of the necrotic collections. The management of infected pancreatic necrosis has evolved over the years from invasive open surgery to less invasive methods and strategies. This chapter summarizes the current knowledge and practices regarding the management of infected pancreatic necrosis.

17.2 Incidence of Infected Necrosis

In different series, about 20–40% of the patients with severe acute pancreatitis develop infected pancreatic necrosis. Compared with patients with sterile necrosis, infection in patients with organ dysfunctions increases the mortality rate by almost two-fold [4, 5]. A systematic review and meta-analysis of 6970 patients showed that the mortality rate in patients with infected necrosis and organ failure was 35.2%, while concomitant sterile necrosis and organ failure was associated with a mortality

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of 19.8%. If the patients had infected necrosis without organ failure the mortality was 1.4% [5].

In addition to infected pancreatic necrosis, bacteremia and pneumonia are the two other common infections in these patients. Organ failure, bacteremia, and pneumonia mostly occur early in the disease, whereas infected pancreatic necrosis tends to be a later event and is associated with an increased need for invasive interventions [2, 4, 6].

17.3 Diagnostics

Because of the inflammatory character of acute pancreatitis and the other infections often present in these patients, the diagnosis of infected pancreatic necrosis can be difficult. Clinical symptoms and signs are not reliable and specific enough [7, 8].

Computed tomography (CT)-guided fine-needle aspiration and Gram-stain was frequently used in the past but has gained less favor because of the high rate of false negative findings. It can be useful, however, in selecting an appropriate individualized antibiotic regimen [9, 10].

Even if rarely encountered, the presence of retroperitoneal gas on CT is a good indicator for infected necrosis [7].

In clinical practice, following clinical improvement and decreasing CRP-values, a new increase of the CRP-value 2–4 weeks after the onset of the disease together with worsening organ dysfunctions can be a sign of infected necrosis and should lead to an active search for the source of infection. If no other causes, such as pneumonia, are found, the possibility of infected necrosis should be considered. Inserting a CT-guided catheter to the necrotic collection and taking a bacterial sample of the drainage fluid would reveal an infection. If the sample is sterile, the drain can be removed, if infected, the drain can work as a first-line treatment according to the step-up strategy [11].

Even if patients with sterile necrosis are usually managed nonoperatively, nearly half of patients operated due to ongoing organ failure without signs of infected necrosis, have a positive bacterial culture in the operative specimen [12]. It is also known that performing a necrosectomy for sterile necrosis within the first 4 weeks has a negative effect on survival [3]. Therefore, verifying the presence of possible infection should be attempted by any means available unless 4 weeks have passed from the disease onset.

17.4 Treatment

17.4.1 Antibiotics

While routine prophylactic antibiotics for every patient with acute pancreatitis are not recommended, antibiotics are always recommended for patients with infected necrosis associated with severe acute pancreatitis [13]. The empirical antibiotic regimen should include both aerobic and anaerobic Gram-negative and Gram-positive microorganisms. Routine antifungal prophylaxis is not recommended in patients with infected necrosis although *Candida spp.* are common in these patients and are associated with higher mortality [13].

17.4.2 Percutaneous Drainage

If possible, all invasive interventions should be postponed until 4 weeks from the onset of the disease when a walled-off necrotic collection has formed (Fig. 17.1). It facilitates the demarcation of necrosis from vital tissue resulting in less injuries to other structures, less bleeding and more effective necrosectomy [14]. However, as stated above, percutaneous drainage as a first step is a reasonable option even earlier, if infected necrosis is suspected.

The benefit of initial percutaneous drainage as a first step in managing infected pancreatic necrosis was demonstrated in a landmark multicenter randomized study (PANTER trial) that compared a step-up approach (percutaneous drainage followed by upsize of drain, and minimally invasive retroperitoneal necrosectomy, video-assisted retroperitoneal debridement, if needed) to primary open necrosectomy in 88 patients with infected necrotizing pancreatitis [11]. The primary endpoint consisted of death or major complications (new-onset multiple organ failure, perforation of visceral organ, enterocutaneous fistula, bleeding). Of the patients assigned to the step-up approach, percutaneous drainage alone was sufficient in 35% of the patients, and the composite endpoint of mortality or major complications favored the step-up strategy (40% vs. 69%), even if there was no difference in mortality (19% vs. 16%). The incidences on new-onset organ failure (12% vs. 40%), incisional hernia (7% vs. 24%) and new-onset diabetes (16% vs, 38%) were lower in the step-up group.

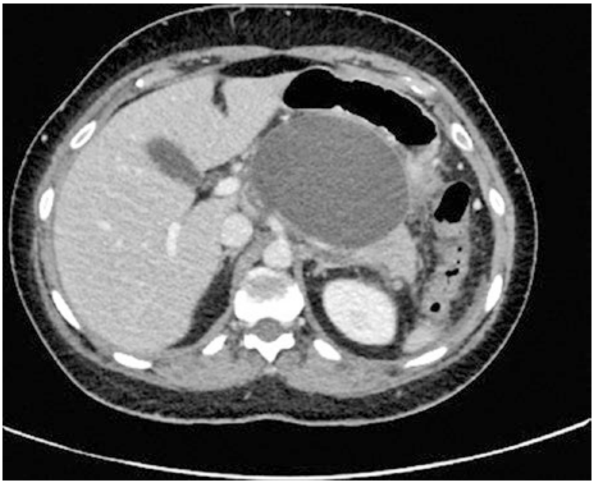

Fig. 17.1 Walled-off necrosis (WON)

In a subsequent systematic review of percutaneous catheter drainage as primary treatment for necrotizing pancreatitis, infected necrosis was confirmed in 71% of the patients, and 56% did not require surgery after percutaneous drainage [15]. It is of note, however, that treatment of infected necrosis with percutaneous drainage is less successful when the collections are extensive and heterogenous [16].

17.4.3 Endoscopic Interventions

There are two kinds of endoscopic interventions: transgastric (or transduodenal) and retroperitoneal. In the endoscopic transgastric necrosectomy or drainage, the necrotic collection is approached with a gastroscope through the posterior gastric wall, sometimes with the help of endoscopic ultrasound. The collection is drained into the stomach, necrosectomy is performed as needed and feasible, and a stent is inserted to maintain the drainage site open. In video-assisted retroperitoneal debridement, (VARD), the necrotic collection is approached percutaneously with the help of the endoscope and the collection is debrided with endoscopic instruments. If a drain has been placed into the collection beforehand, it helps in localization of the collection. The procedure is completely retroperitoneal and a drain is left in place after debridement. In both transgastric and retroperitoneal techniques, multiple interventions are often required.

In a multicenter randomized study, 98 patients were randomized to either endoscopic transluminal (gastric or duodenal) drainage (and endoscopic necrosectomy, if needed), or the surgical step-up approach (percutaneous drainage followed by VARD, if needed). The primary endpoint was a composite of death or major complications (new-onset multiple organ failure, perforation of visceral organ, enterocutaneous fistula requiring intervention, incisional hernia including burst abdomen) within 6 months after randomization. There was no difference in mortality (18% vs. 13%), occurrence of the primary endpoint (43% vs. 45%), or in any of the major complications included in the primary endpoint. The rate of pancreatic fistulas (5% vs. 32%) and length of hospital stay (mean 53 vs. 69 days) were lower in the endoscopy group. The authors concluded that there will probably be a shift to the endoscopic step-up approach as preferred treatment, based on the outcome of this trial [17].

17.4.4 Open Surgery

In selected patients, transgastric debridement can also be performed via open surgery (Fig. 17.2). In a series of 178 patients with walled-off necrosis, 96% of the patients underwent a single-stage surgical transgastric necrosectomy with postoperative mortality and morbidity rates of 2% and 38%, respectively [18]. It is also suitable for patients with a disconnected distal pancreas, since the procedure secures the drainage of the distal pancreas to the stomach, avoiding a persistent fistula.

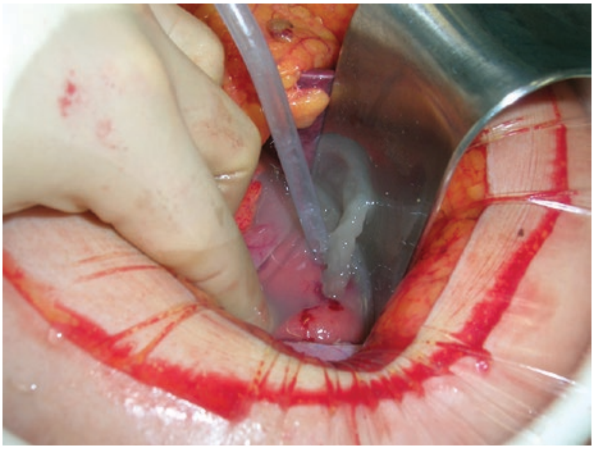

Fig. 17.2 Liquid draining from infected necrotic collection during open transgastric necrosectomy

For years the standard treatment of infected pancreatic necrosis was anterior intra-abdominal open necrosectomy with digital extraction of the necrotic material through the gastrocolic ligament or transverse mesocolon. It was usually accompanied by irrigation and drainage. Although the mortality rates after open necrosectomy in contemporary series is comparable to that of minimally invasive techniques, the possible association with increased risk of postoperative complications and organ failures has prompted the shift towards less invasive techniques.

However, in selected patients, it is still a useful option. In a retrospective series from a single center during a 12-year period, 109 consecutive patients underwent open necrosectomy [19]. The overall 90-day mortality rate was 23%. However, if necrosectomy was delayed until 4 weeks from symptom onset and the necrosis had become walled-off on preoperative imaging, the 90-day mortality rate was 11%. The risk factors for mortality included age over 60 years, pre-existing comorbidities, early (less than 4 weeks from disease onset) necrosectomy, multiple organ failure, white blood cell count over 23×10^9, and deterioration or prolonged organ failure as the indication for necrosectomy. It is of note that none or only one of these risk factors were present in 52 patients (48% of all patients), and these patients had no mortality.

17.5 Choice of Surgical Tactics

Obviously, available clinical experience and resources need to be taken into account when choosing the appropriate approach for individual patients. Furthermore, the type and location of the infected collection, the patient's condition (reflected in the ability to tolerate invasive procedures), and previous operative interventions and scars may affect the decision.

If the collection is mostly in liquid form, percutaneous or endoscopic transgastric drainage would seem to be the least invasive and thus appropriate. If the location of the collection is limited to the lesser sac and closely attached to the posterior wall of the stomach, transgastric procedures, either endoscopic or open surgical, are feasible. Transgastric techniques should also be considered in patients with disconnected distal pancreatic remnant.

In larger, heterogenous collections containing a significant amount of solid material, retroperitoneal or open (transabdominal) procedures may be more appropriate (Fig. 17.3). Clear visualization especially during open transabdominal necrosectomy allows for a more complete necrosectomy often avoiding multiple procedures. In one study it was also associated with a lower risk of bleeding (9% versus 19%) when compared with minimally invasive techniques [20].

A study of 1980 patients with necrotizing pancreatitis combining original and newly collected data compared open necrosectomy (58% of the patients), minimally invasive necrosectomy (25%), and endoscopic necrosectomy (17%) [21]. In all patients the risk of death (odds ratio) compared with open necrosectomy was 0.53 for minimally invasive necrosectomy and 0.20 for endoscopic necrosectomy, respectively. In high-risk patients, the odds ratios for risk of death were 0.70 and 0.27. The authors concluded that in high-risk patients, minimally invasive surgical and endoscopic necrosectomy are associated with reduced death rates compared with open necrosectomy.

A retrospective study comparing multidisciplinary minimally invasive step-up approach to a modern open necrosectomy cohort showed a five-fold decrease in mortality (2% versus 10%) [20]. In the minimally invasive group of 91 patients, 9% were treated with percutaneous drainage, 32% with endoscopic transgastric necrosectomy, 8% with video-assisted retroperitoneal debridement, 15% with sinus tract endoscopic necrosectomy, and 27% with a combination of techniques.

Another advantage of the minimally invasive techniques is the reduced proinflammatory response, as confirmed in a randomized trial comparing endoscopic transgastric necrosectomy to surgical necrosectomy [22].

If the initial step-up management fails, the most appropriate secondary therapy is still controversial. A meta-analysis of 21 controlled studies with a total of 2177 patients compared the outcome after retroperitoneal and open intraperitoneal necrosectomies [23]. The retroperitoneal group had a lower postoperative complication

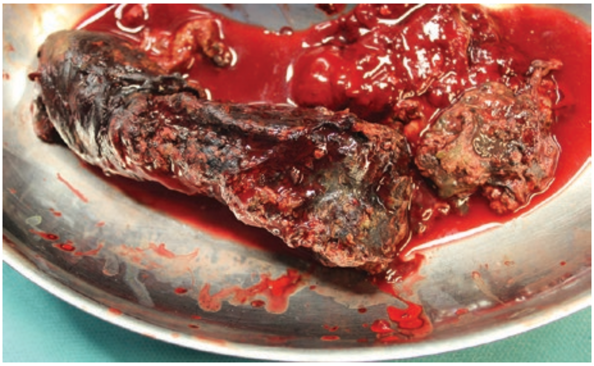

Fig. 17.3 Solid necrotic material debrided during open necrosectomy

rate, lower postoperative mortality, higher technical success rate, similar surgical reintervention rate, shorter operative time and shorter hospital stay.

The different management techniques of infected pancreatic necrosis have each their own, sometimes passionate, supporters. Most of the techniques used or selected are supported by the available data. However, as shown in a Cochrane Database Systematic Review on interventions for necrotizing pancreatitis from 2016, low- to very low-quality evidence suggested that the minimally invasive step-up approach resulted in fewer adverse effects, serious adverse effects, less organ failure and lower costs compared to open necrosectomy [24]. Furthermore, very low-quality evidence suggested that the endoscopic minimally invasive step-up approach resulted in fewer adverse effects than the video-assisted minimally invasive step-up approach but increased the number of procedures required for treatment.

When interpreting the results, it should be noted that there is significant heterogeneity in patients, organ failures, and size as well as localization of necrosis. In addition, surgical techniques and indications for interventions are not uniform. After the publication of the Cochrane review, several good quality randomized studies have been published by the Dutch Pancreatic Study Group that has advanced our knowledge significantly. It is important that other centers and study groups can confirm their results.

In summary, a multitude of approaches are available for the management of infected pancreatic necrosis. A step-up approach starting with percutaneous drainage is the obvious first step. If that is insufficient, the second step depends on patient factors, type and location of the collection, and the available expertise. In a modern center treating these challenging patients, all options should be available and the treatment should be individualized based on the assessment of a multidisciplinary team consisting of surgeons, endoscopists, radiologists and intensivists.

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Source Control in Abdominal Sepsis

18

Massimo Sartelli

18.1 Introduction

Intra-abdominal infections (IAIs) include several different pathological conditions and are usually classified into uncomplicated and complicated [1]. In uncomplicated IAIs, the infectious process only involves a single organ and does not proceed to the peritoneum. Patients with these infections can be managed with either surgical source control or with antibiotics alone. In complicated IAIs, the infectious process extends beyond the organ and causes either localized or diffuse peritonitis.

IAIs are an important cause of morbidity and mortality [1].

Treatment of patients with complicated IAIs has been usually described to achieve satisfactory results if adequate management is established [2]. However, results from published clinical trials may not be representative of the true morbidity and mortality rates of these severe infections. First of all, patients who have perforated appendicitis are usually over-represented in clinical trials. Furthermore, patients with IAIs enrolled in clinical trials often have an increased likelihood of cure and survival. In fact, the trial eligibility criteria usually restrict the inclusion of patients with comorbid diseases that would increase the death rate of patients with IAIs [1]. In the WISS study enrolling all the patients older than 18 years old with complicated IAIs worldwide, the overall mortality rate was 9.2% (416/4533) [2].

Early clinical diagnosis, adequate source control to stop ongoing contamination, appropriate antimicrobial therapy dictated by patient and infection risk factors, and prompt resuscitation in critically ill patients are the cornerstones of the management of IAIs.

The timing and adequacy of source control are currently among the most important issues in the management of IAIs because inadequate and late operation may have a negative effect on outcome [2].

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18.2 Source Control

Source control encompasses all measures undertaken to eliminate the source of infection, reduce the bacterial inoculum and correct or control anatomic derangements to restore normal physiologic function [3, 4].

IAIs are the sites where source control is more feasible and more impactful. In these settings appropriate source control can improve patient outcomes and reduce antibiotic pressure by allowing a short course of antibiotic therapy [1].

The timing and adequacy of source control are currently important issues in the management of IAIs because, when inadequate and delayed, they may have a negative effect on outcome. The optimal timing of source control has not been rigorously investigated [5, 6]. However, source control should be performed as soon as possible in patients with diffuse peritonitis, but it can be delayed for logistical reasons in stable patients with a localized infection, if appropriate antibiotic therapy is given and careful clinical monitoring is provided [7].

The level of urgency of treatment is determined by the affected organ(s), the relative speed at which clinical symptoms progress and worsen, and the underlying physiological stability of the patient. The Surviving Sepsis Campaign guidelines suggest that a specific anatomic diagnosis of infection requiring emergent source control should be identified or excluded as rapidly as possible in patients with sepsis or septic shock [8].

Control of the source of infection in patients with IAIs can be achieved using both operative and non-operative techniques. An operative intervention remains the most viable therapeutic strategy for managing surgical infections in critical ill patients.

Non-operative interventional procedures include percutaneous drainages of abscesses. Well-localized fluid collections of appropriate density and consistency (i.e., lack of extensive loculations) may be drained percutaneously with acceptable outcomes. Percutaneous drainage of abdominal and extraperitoneal abscesses performed under ultrasound or computed tomography guidance in selected patients are safe and effective [9, 10]. The principal cause for failure of percutaneous drainage is misdiagnosis of the magnitude, extent, complexity, location of the abscess.

Surgery is the most important therapeutic measure to control surgical infections. In the setting of IAIs, the primary objectives of surgical intervention include (a) determining the cause of peritonitis, (b) draining fluid collections, (c) controlling the origin of peritonitis. In patients with IAIs, surgical source control entails resection or suture of a diseased or perforated viscus (e.g., diverticular perforation, gastroduodenal perforation), removal of the infected organ (e.g., appendix, gallbladder), debridement of necrotic tissue, resection of ischemic bowel and repair/resection of traumatic perforations with primary anastomosis or exteriorization of the bowel [11].

Table 18.1 summarizes the sources of infection in the international WISS Study [2].

In recent years, laparoscopy has been gaining wider acceptance in the diagnosis and treatment of IAIs. The laparoscopic approach in the treatment of peritonitis is

Table 18.1 Source of infection in 4553 patients from 132 hospitals worldwide (15 October 2014–15 February 2015)

Source of infection	Number	%
Appendicitis	1553	34.2
Cholecystitis	837	18.5
Gastroduodenal perforations	498	11.0
Postoperative	387	8.5
Colonic non-diverticular perforation	269	5.9
Small bowel perforation	243	5.4
Diverticulitis	234	5.2
Post-traumatic perforation	114	2.5
Pelvic inflammatory disease	50	1.1
Other	348	7.7
Total	4553	100.0

Modified from [2]

feasible for many emergency conditions. It has the advantage of allowing, at the same time, an adequate diagnosis and appropriate treatment with a less invasive abdominal approach. However, because of the increase of intra-abdominal pressure resulting from pneumoperitoneum, laparoscopy may have a negative effect in critically ill patients, leading to acid–base balance disturbances, as well as changes in cardiovascular and pulmonary physiology [12].

18.3 Relaparotomy Strategies

In certain circumstances, infection not completely controlled may trigger an excessive immune response and local infection may progressively evolve into sepsis, septic shock, and organ failure. These patients can benefit from immediate and aggressive surgical reoperations with subsequent relaparotomy strategies to curb the spread of organ dysfunctions caused by ongoing peritonitis. Surgical strategies following an initial emergency laparotomy include subsequent "relaparotomy on demand" (when required by the patient's clinical condition) as well as planned relaparotomy in the 36–48-h postoperative period.

On-demand laparotomy should be performed only when absolutely necessary and only for those patients who would clearly benefit from additional surgery. Planned relaparotomies, on the other hand, are performed every 36–48 h for purposes of inspection, drainage, and peritoneal lavage of the abdominal cavity. The concept of a planned relaparotomy for severe peritonitis has been debated for over 30 years. Reoperations are performed every 48 h to reassess the peritoneal inflammatory process until the abdomen is free of ongoing peritonitis; then the abdomen is closed. The advantages of the planned relaparotomy approach are optimization of resource utilization and reduction of the potential risk for gastrointestinal fistulas and delayed hernias. The results of a clinical trial published in 2007 by Van Ruler et al. investigating the differences between on-demand and planned relaparotomy strategies in patients with severe peritonitis found few advantages for the planned relaparotomy strategy; however, the study mentioned that this latter group exhibited a reduced need for additional relaparotomies, decreased patient dependency on subsequent health care services, and decreased overall medical costs [13].

An open abdomen (OA) procedure is the best way of implementing relaparotomies. The role of the OA in the management of severe peritonitis has been a controversial issue [14].

Although guidelines recommend not to routinely utilize the OA approach for patients with severe intraperitoneal contamination undergoing emergency laparotomy for intra-abdominal sepsis, OA has now been accepted as a strategy in treating physiologically deranged patients with acute peritonitis [15].

The OA concept, which is closely linked to damage control surgery, may be easily adapted to patients with advanced sepsis and can incorporate the principles of the Surviving Sepsis Campaign. The term “damage control surgery” (DCS) for trauma patients was introduced in 1993 [16].

It was defined as initial control of hemorrhage and contamination, allowing for resuscitation to normal physiology in the intensive care unit and subsequent definitive re-exploration. Similarly to the trauma patient with the lethal triad of acidosis, hypothermia and coagulopathy, many patients with sepsis or septic shock may present in a similar fashion. For those patients, DCS can truly be life-saving. Patients progressing from sepsis with organ dysfunction into septic shock can present with vasodilation, hypotension, and myocardial depression, combined with coagulopathy. These patients are profoundly hemodynamically unstable and are clearly not optimal candidates for complex operative interventions. Abdominal closure should be temporary, and the patient is rapidly taken to the intensive care unit for physiologic optimization. This includes optimization of volume resuscitation and mechanical ventilation, correction of coagulopathy and hypothermia, and monitoring for the possible development of abdominal compartment syndrome. Over the following 24–48 h, when abnormal physiology is corrected, the patient can be safely taken back to the operating room for reoperation. Following stabilization of the patient, the goal is the early and definitive closure of the abdomen, in order to reduce the complications associated with an OA. Primary fascial closure can be achieved in many cases within few days from the initial operation. It would not be successful if early surgical source control failed.

Sequential fascial closure can immediately be started once the abdominal sepsis is well controlled. In these cases, surgeons should perform a progressive closure, where the abdomen is incrementally closed each time the patient undergoes a reoperation. Within 10–14 days the fascia retracts laterally and becomes adherent to the overlying fat; this makes primary closure impossible. Therefore, it is important to prevent retraction of the myofascial unit [17, 18].

Several materials can be used to achieve temporary closure of the abdomen: gauze, mesh, impermeable self-adhesive membrane dressings, zippers and negative pressure wound therapy (NPWT) techniques. The surgical options for management of the OA are now more diverse and sophisticated, but there is a lack of prospective randomized controlled trials demonstrating the superiority of any particular method. At present, NPWT techniques have become the most extensively used methods for temporary abdominal wall closure. NPWT actively drains toxin or bacteria-rich intraperitoneal fluid and has resulted in a high rate of fascial and abdominal wall closure.

18.4 Conclusion

IAIs are the sites where a source control is more feasible and more impactful. In these settings appropriate source control can improve patient outcomes and reduce antibiotic pressure by allowing a short course of antibiotic therapy.

Surgery is the most important therapeutic measure to control surgical infections. In the setting of intra-abdominal infections, the primary objectives of surgical intervention include (a) determining the cause of peritonitis, (b) draining fluid collections, (c) controlling the origin of peritonitis.

In certain circumstances, infection not completely controlled may trigger an excessive immune response and local infection may progressively evolve into sepsis, septic shock, and organ failure. Such patients can benefit from immediate and aggressive surgical reoperations with subsequent relaparotomy strategies, to curb the spread of organ dysfunctions caused by ongoing peritonitis.

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19 Laparoscopy and Minimally Invasive Surgery Techniques in Acute Care Surgery

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19.1 Introduction

The advantages of minimally invasive surgery (MIS) are well established (decreased postoperative pain, shorter hospital stay and earlier return to normal activities following surgery, fewer postoperative complications such as wound infection and incisional hernia), with laparoscopy widely recognized as the gold standard in the

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treatment of several surgical conditions and having international consensus on these benefits.

Despite the progress in technology, training and availability of resources, the use of laparoscopy has not yet been fully extended to urgent or emergent procedures due to its long learning curve or the longer operative time of emergency laparoscopy compared to elective laparoscopy. Additional considerations that have limited the application of laparoscopy include technical difficulties associated with diffuse peritonitis, large purulent collections, lack of visualization due to distended bowel, and the presence of extensive adhesions. Table 19.1 provides a list of "pros" and "cons" that must be considered by any program when implementing or expanding MIS for urgent or emergent conditions.

However, in 2006, the European Association for Endoscopic Surgery (EAES) published its consensus statement on laparoscopy for abdominal emergencies sustaining the advantages of the laparoscopic approach in various emergencies [1]; additionally, an increasing number of studies have been published on the feasibility of laparoscopy in acute abdominal disease outlining the ideal indications and recommendations [2–5]. Despite these clear advantages, beginning or expanding programs for laparoscopy and other MIS techniques in emergency surgery can be challenging. Table 19.2 shows a "top 10" list of recommendations and considerations that should be appreciated when developing an MIS program in trauma or acute care surgery.

Table 19.1 Pros and cons of instituting or expanding minimally invasive surgery for urgent or emergent surgical conditions

Pros of minimally invasive surgery
• Avoidance of laparotomy or other large incision • Decreased wound complications (infections, hernias) • Significantly less pain postoperatively vs open surgery • Faster recovery and time to resume full activity • Shorter hospital stays • Decreased narcotic requirement • Magnified visualization of area of interest • Better visualization in some areas • Can visualize all areas of the body cavity • Equal/shorter operative times after learning curve • Easier to video record or photo document cases • Minimal adhesions reduces SBOs, future re-entry easier
Cons of minimally invasive surgery
• Specialized equipment and training • Different skill set versus open surgery • Requires skilled assistant for more complex cases • Less control over surgical assistant/trainee • May relegate trainees to "drive camera" • Requires intubation and paralysis • Insufflation and working space variable • Cardiopulmonary effects of insufflation (usually minor) • Longer operative times during learning curve • Continuously evolving/changing technology • Harder to recognize or manage iatrogenic injuries • Decreased haptic feedback, no tactile sensation

SBOs small bowel obstructions

Table 19.2 Top 10 recommendations for integrating minimally invasive surgery (MIS) techniques for trauma and acute care surgery (ACS)

1.	MIS results in clear benefit to the patient when used appropriately and expertly. Adopt and develop MIS skills now!
2.	Most pathology in trauma and acute care surgery is amenable to an MIS approach, but not all will benefit. Know the contraindications as well as the indications
3.	Leverage the MIS expertise at your center. Observing or scrubbing on elective MIS cases will greatly enhance your MIS comfort, techniques, and expand your operative “tool box”
4.	Avoid the “peek and shriek” and immediate conversion to open: initial patience with suction/irrigation and lysis of adhesions will often pay off and avoid opening unnecessarily
5.	Initial entry: there is no rule that initial entry has to be at the umbilicus, and in the setting of prior surgery avoiding the midline for initial trocar placement is best
6.	For open surgery, you lengthen the incision to improve exposure. For MIS, the rule is to add additional assistant trocar(s) to improve exposure and ability to visualize and operate
7.	Most important MIS technical skills/devices: (1) adopt and practice a method for intracorporeal suturing/knot tying, (2) an energy device for dissection, and (3) laparoscopic stapling. Now you can do almost anything laparoscopically that you do open
8.	Convert to open when there is clear failure to progress, when operation becomes unsafe, or when an injury/pathology not amenable to MIS is identified. If unsure, consulting a colleague for a second opinion and assistance can be incredibly valuable and avoid converting to open
9.	Robotic surgery is the current “hot topic” and is here to stay. The current technology offers little proven patient benefit over laparoscopy, but the technology is advancing rapidly and will progress to greater benefit. Learning it now will ease the transition to next generation
10.	Robotics can be integrated into your trauma/ACS practice, but requires an initial dedication to training and then continued use early in the learning curve. Cholecystectomy is often the initial ACS entry case into robotics and can be used to hone your initial basic skills

Laparoscopic management of an acute abdomen is feasible, safe, and recommended in acute appendicitis, acute cholecystitis, and perforated peptic ulcers, with an increasing, but still debated, role in the use of laparoscopic lavage in perforated diverticulitis with purulent peritonitis, as well as in the approach to small bowel obstruction due to a single adhesive band, large bowel obstruction due to colon carcinoma, diffuse peritonitis with or without large intra-abdominal abscess, and acutely incarcerated or strangulated hernias [2, 4].

19.2 Contraindications

In recent decades, several studies have investigated the use of laparoscopy in abdominal sepsis to rule out the risk of bacteremia and endotoxemia and the risk of hypercapnia; published results showed that pneumoperitoneum did not appear to increase massive bacteremia and/or worsen septic shock [2].

Absolute contraindications for a minimally invasive approach in acute surgery, other than a surgeon with insufficient laparoscopic experience, are hemorrhagic or septic shock with hemodynamic instability, inability to tolerate pneumoperitoneum, massive abdominal distension related to ileus, and suspected perforated cancer.

Relative contraindications are considered fecal peritonitis, the presence of severe comorbidities and the patients' response to pneumoperitoneum, and potential development of respiratory failure with hypercapnia and toxic shock syndrome. A well-thought-out approach that weighs up both the pros and cons of a minimally invasive approach in each patient and procedure type (Table 19.1) should be performed to guide the final decision about proceeding with MIS versus open surgery.

19.3 Diagnostic Laparoscopy

In patients presenting to the emergency department with a suspicion of an acute abdominal process and undergoing an accurate diagnostic workup including a blood sample, ultrasound and/or computed tomography (CT), the underlying etiology of the symptoms may remain difficult to identify despite laboratory and radiologic investigations; when the diagnosis of continuing acute abdominal pain of less than 1-week duration remains elusive, this condition is termed "non-specific abdominal pain" (NSAP). In these cases, diagnostic laparoscopy (DL) represents a valid option to be considered, with a high rate of diagnostic accuracy ranging from 89 to 100% [1].

A non-randomized prospective study reported on 1320 consecutive patients with acute abdominal pain who underwent DL within 48 h from presentation to hospital. A definitive diagnosis was made in 90% of patients, of whom 30% underwent a therapeutic procedure.

DL is linked to a reduction of unnecessary laparotomy and improved diagnostic accuracy in these patients; it allows clear visualization of the entire abdominal cavity, the presence of intra-abdominal pathology, access to peritoneal fluid for cultures or cytology and the possibility to wash out the peritoneal cavity to decrease contamination. In addition, a wide array of therapeutic interventions can be performed laparoscopically rather than converting to open surgery. These include extensive lysis of adhesions, small bowel or colonic resections and anastomoses, creation of a colostomy or ileostomy, and resection of masses or solid organs. The role of DL in trauma is further discussed in this chapter.

19.4 Acute Appendicitis

Laparoscopic appendectomy (LA) proved to be safe and effective in the treatment of acute appendicitis and it should be considered the standard first choice when resources and skills are available. When compared to the open approach, laparoscopy appendectomy appears to require more operative time, but it results in less postoperative pain, fewer wound infections and shorter hospital stay, with an overall advantage on hospital and social costs [6–9].

Intra-abdominal collections and deep pelvic abscesses demonstrated a higher incidence but with a reassuring decrease in the last decade and in more recent randomized controlled trials, likely linked to the overall improvements in surgical skills [10, 11]. When performed by experienced surgeons, the laparoscopic approach proved safe in complicated appendicitis, with evidence of a lower wound infection rate, shorter stays, faster recovery and overall lower morbidity and mortality compared to open appendectomy (OA). Studies on the elderly (>65 years old) showed improved outcomes in patients with acute appendicitis treated with laparoscopic surgery when compared to open surgery in terms of length of stay, overall morbidity and postoperative mortality, even in patients with comorbidities and with complicated appendicitis [12, 13].

Advantages of the laparoscopic approach have been shown also for obese patients (BMI >40) with studies showing how OA in morbidly obese patients leads to increased risk of surgical wound infections and respiratory complications. LA should be preferred in all obese patients [6, 9]. Despite the fact that LA is safe and effective in young adults and children, it may not offer significant advantages when compared to the open procedure. The safety of LA in pregnancy has been a matter of debate among clinicians. A recent study analyzed four systematic reviews comparing the rate of fetal loss in LA versus OA and reporting a significantly higher rate of fetal loss after LA. However, all the systematic reviews reported how one study predominantly affected this result because of its size; excluding this single one, the remaining studies reported no significant difference between the two operative approaches for this outcome. A recommendation from the 2020 guidelines confirmed LA during pregnancy is safe in terms of risk of fetal loss and preterm delivery, with shorter length of hospital stay and lower incidence of surgical site infection when compared to OA [9, 14].

During the recent COVID-19 pandemic, the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) stated that, even though previous research has shown that laparoscopy can lead to aerosolization of blood-borne viruses, there is no evidence at the moment to consider this effect with COVID-19. Despite lack of evidence, a prudent attitude toward laparoscopy has been highlighted by the Intercollegiate General Surgery Guidance in the United Kingdom. Any policy or protocol on this topic needs to appropriately consider and balance the risks of infectious transmission as well the potential benefits versus risks of open surgery versus laparoscopy.

An open approach in acute appendicitis not suitable for non-operative management with antibiotic therapy is recommended by Di Saverio et al. in all COVID+ or suspected COVID+ patients. However, other groups and authors have recommended continuing to perform these procedures laparoscopically using appropriate precautions to prevent aerosolization and citing the fact that there has yet to be a single reported incidence of COVID-19 transmission or infection secondary to performing a laparoscopic surgery [15].

19.5 Acute Calculous Cholecystitis

Cholecystectomy is the most common digestive operation and about 30% of procedures are performed after an episode of acute cholecystitis (AC). Laparoscopic cholecystectomy (LC) is today the gold standard of treatment for acute calculous cholecystitis. Studies show shorter hospitalization for patients undergoing LC compared to open surgery. Advantages of the minimally invasive approach result in decreased postoperative pain, faster recovery and shorter hospital stay when compared to open surgery. Laparoscopy comes with higher costs due to equipment, but the overall costs seem to balance or be lower than open surgery when considering the significantly shorter hospital stay and lower complication profile [16–19].

Poor surgical candidates may be initially approached with non-operative management and antibiotic therapy and potentially a gallbladder drainage procedure before undergoing elective gallbladder surgery after the resolution of the acute inflammation and if the surgical risk decreases. The Tokyo Guidelines in 2007 and in 2013 classified the severity of AC and recommended LC for grade I (mild) and for grade II (moderate); grade III AC was considered suitable for LC only after gallbladder drainage [20, 21]. In the updated 2018 Tokyo Guidelines, grade III is considered suitable for LC when both patient and facilities meet specific conditions, including the evaluation of risk factors through predictive factors, the Charlson comorbidity index (CCI) score, and the American Society of Anesthesiologists physical status classification (ASA-PS) score. This approach to increasing the performance of LC rather than utilizing percutaneous cholecystostomy tube placement is supported by studies demonstrating the poor outcomes associated with percutaneous drainage. A prospective randomized trial (CHOCOLATE Trial) examined this question in patients with AC and categorized as "high-risk" those with an APACHE score greater than 7. The cholecystectomy arm experienced significantly fewer complications and need for reinterventions, shorter hospital stays, and decreased recurrent symptoms [22]. The strategy proposed by the recent 2018 Tokyo recommendations considered the severity of cholecystitis as well as patient general conditions and medical background [23].

- **Grade I (mild) AC**
  Early LC once the patient is suitable for surgery according to the CCI and ASA-PS scores. Poor surgical candidates undergo conservative management, and delayed surgery is considered in patients responding to treatment.
- **Grade II (moderate) AC**
  Early LC once the patient is suitable for surgery according to the CCI and ASA-PS scores and the surgery is performed in an advanced surgical center. Conversion to an open procedure or subtotal cholecystectomy should be considered depending on the findings, to avoid iatrogenic damage to the bile ducts or other surrounding structures. Poor surgical candidates undergo conservative treatment, and biliary drainage should be considered.
- **Grade III (severe) AC**
  Evaluation of the degree of organ dysfunction, antibiotics, support and resuscitation to normalize function. Predictive factors such as rapid response to resuscitation or renal impairment following the initial treatment should be considered besides the CCI and ASA-PS scores; if the patient can tolerate surgery, early LC can be carried out by a specialist surgeon with extensive experience and the availability of intensive care support. Patients who cannot withstand surgery should undergo conservative management. Early biliary drainage is advised if it is not possible to control the gallbladder inflammation.

Several studies focused on establishing the best timing of laparoscopic surgery in AC; results agreed that LC within the first week after diagnosis is associated with lower mortality rates, complication rates, incidence of bile duct injury and conversion to open surgery. Morbidity seems to be similar if the operation is performed after 6 weeks from the diagnosis, suggesting waiting until the sixth week to proceed if the first 7-day window has been missed. Within 7 days of diagnosis, the outcome appears to be better when LC is performed within 48 h of presentation [19, 24–27]. There is no agreement on the best timing to perform LC following percutaneous transhepatic gallbladder drainage (cholecystostomy) and a consensus has not been reached, with some centers performing surgery within 10 days from the drainage and others waiting longer (up to 12 weeks or more) [19]. The decision should be made based on the patient's risk factors for general anesthesia and resolution of sepsis.

Conversion to open surgery has been reported in 11.4% of cases in a recent survey [28]. Factors leading to conversion to an open approach include poor visualization within the Calot's triangle due to severe inflammation, excessive bleeding or suspicion of biliary duct damage. Borzellino et al. reported in a meta-analysis that the severity of AC was a major predictive factor of conversion to open surgery, which appeared not to affect the rate of local postoperative complications [29]. However, the safety of open conversion could be questioned if the surgeon has less experience performing open cholecystectomy.

The updated 2018 Tokyo recommendations suggested specific bailout procedures that surgeons should choose based on intraoperative findings to avoid secondary damage. Those are subtotal cholecystectomy, which consists in evacuating the contents of the gallbladder through an incision and then removing as much of the wall as possible (leaving an open gallbladder stump and the cystic duct closed from the inside or simply closing the remnant gallbladder wall) [19, 30]; conversion to open surgery; fundus first or "dome down" technique, in which the separation of the gallbladder from the liver starts at the fundus, without initially visualizing the cystic artery and cystic duct in the Calot's triangle, and is followed by a subtotal cholecystectomy. No adequate studies have been performed about this procedure and its safety concerning biliary duct damage. It has been reported that this technique may cause vascular-biliary injury due to an inadequate plane of dissection, particularly in patients with chronic inflammation associated with biliary inflammatory fusion and contraction [30, 31].

During the Covid 19 pandemic, acutely inflamed gallbladders have been initially managed conservatively with antibiotics and/or cholecystostomy at some centers, avoiding early LC. In this approach, only patients with suspected gangrene or gallbladder perforation have been considered for a laparoscopic approach [15]. In contrast, others have recommended continuing to perform LC as per standard practice during the pandemic due to the known higher complication and risk profile associated with delay to surgery or the use of percutaneous drainage. The American College of Surgeons guidelines on this topic have supported the continued performance of LC along with "fast-track" discharge programs to perform the needed surgery and then minimize the hospital length of stay for the patient.

19.6 Perforated Peptic Ulcer

Despite a decrease in the incidence of perforated peptic ulcer (PPU) due to eradication of *Helicobacter pylori* and use of proton pump inhibitors, the amount of patients requiring acute intervention for PPU has remained quite stable, probably in relation to the extensive use of non-steroidal anti-inflammatory drugs. The standard surgical procedure for PPU is gastrorrhaphy or duodenorrhaphy, with emergency gastric resection representing a rare option reserved for massive perforated gastric ulcers and/or associated bleeding.

Laparoscopic closure of PPU has been demonstrated to be safe and feasible when performed by expert surgeons, and it offers numerous advantages including confirmation of the diagnosis, identification and patch closure of the ulcer, intra-abdominal lavage, all avoiding a laparotomy [32–34]. Conversion to open surgery is most frequently related to a large perforation, inadequate ulcer localization and difficulties placing reliable sutures due to friable edges. To date, few studies compared the laparoscopic versus open approach for repair of PPU reporting no statistically significant differences in postoperative pain or complications. However, a recent meta-analysis reported advantages of laparoscopic surgery with lower surgical site infection rate, shorter nasogastric tube duration and less postoperative pain [35]. Further trials are still required to draw definitive conclusions.

19.7 Small Bowel Obstruction

Small bowel obstruction (SBO) is a frequent surgical emergency often caused by postoperative adhesions, which resolves with non-operative treatment in a large number of patients; still, an important group of patients requires emergency or urgent surgery. Open adhesiolysis has been for decades the primary surgical treatment for adhesive SBO and it still represents the first option for the operative management of strangulated SBO after an unsuccessful conservative approach. However, laparoscopy can be safe and effective in selected groups of patients when done by a skilled laparoscopic surgeon [36, 37]. Reported complications of the laparoscopic approach to SBO are iatrogenic bowel injuries, higher rates of reoperation and inadequate evaluation of compromised bowel. Age and a prior history of laparotomy seem to be predictive factors of the reported complications and this is why it is recommended that laparoscopic adhesiolysis should ideally be performed in selected patients with a maximum of two previous laparotomies presenting with a first episode of SBO and/or a single adhesive band [3, 4]. A prospective, randomized, multicenter study of laparoscopic versus open adhesiolysis for SBO (LASSO Trial) demonstrated a significantly shorter hospital stay in the laparoscopy group, with no difference in minor or major complication rates. In addition to these short-term benefits, there are also significant potential long-term benefits in terms of a decreased risk for incisional hernias and need for subsequent ventral hernia repair [38].

19.8 Acute Diverticulitis

Today the most common classification used to evaluate acute complicated diverticulitis is the Wasvary Hinchey's modification, which distinguishes four stages of severity. Patients with perforated diverticulitis and peritonitis (stage III and IV) should be evaluated early for surgical intervention.

A standardized therapeutic approach is still lacking, as the type of surgery for Hinchey III and IV are yet to be universally agreed: Hartmann's procedure, laparoscopic lavage (LL), or resection and primary anastomosis (PA) either with or without a diverting ileostomy, represent the most common therapeutic choices in these patients. LL has been shown to decrease stoma formation rate without impacting 1-year mortality, although short-term morbidity may be increased [39]; it may be considered in selected Hinchey III patients by surgeons with appropriate expertise.

Advantages offered by LL include shorter operative time, fewer cardiac complications, fewer wound infections, and shorter hospital stay; however, it comes with higher rates of intra-abdominal abscess, peritonitis, and increased long-term emergency reoperations [39]. Laparoscopic sigmoidectomy in the treatment of Hinchey III–IV diverticulitis seems to be safe and feasible in hemodynamically stable patients when performed by experienced laparoscopic colorectal surgeons.

Laparoscopic sigmoid resection and end colostomy (Hartmann's procedure) is still the preferred approach in settings where the surgeon's skill or disease factors are prohibitive for performing an anastomosis. However, in stable patients with healthy-appearing descending colon and rectal ends, the preferred approach should be to perform a primary anastomosis with or without a temporary diverting loop ileostomy. The conversion rate varies from 0 to 19%, with very low reintervention and anastomotic leakage rates [40].

Definitive conclusions on the advantages or disadvantages of the laparoscopic technique for Hinchey IV patients are still limited by the variability of practice patterns and expertise, the relatively small number of cases encountered in daily clinical practice and the challenges of conducting randomized studies in emergency situations.

19.9 Abdominal Trauma

In hemodynamically stable patients, DL has gradually been accepted as a reliable tool for diagnosing patients with penetrating and blunt abdominal injury, even though recommendations at the evidence level cannot be made due to the lack of randomized controlled trials [41, 42]. In cases of diagnostic doubt due to equivocal findings on CT or discrepancy between the clinical examination and imaging and in the presence of appropriate surgical skills, many studies have demonstrated the high accuracy of laparoscopy in precisely detecting such abdominal injuries; it has been shown to significantly decrease the incidence of non-therapeutic laparotomy, to decrease hospital stay, and to provide better respiratory management and less post-operative pain, a lower rate of adhesions, incisional hernias and surgical site infections [42, 43].

Laparoscopy may also have a therapeutic role in the treatment of several types of injuries such as the repair of diaphragmatic or hollow viscus lesions as well as the delayed approach in hepatic trauma in cases of hepatic-related complications such as bleeding, biloma, hepatic abscess or necrosis [4, 42].

Laparoscopic splenectomy can be performed in stable patients with high-grade injuries where, for example, angioembolization is unavailable or contraindicated, conservative management is not successful, or when complications of angioembolization (e.g., ischemia with suprainfection and abscess, multiple residual and/or inaccessible pseudoaneurysms) have developed during follow-up [44]. Additional ideal candidates for laparoscopic intervention are those patients with symptomatic or large post-traumatic splenic cysts, which can be managed by laparoscopic fenestration/excision or splenectomy. Absolute contraindications for the laparoscopic approach in trauma are represented by hemodynamic instability, hemorrhagic or septic shock, severe cardiorespiratory dysfunction, severe brain injury and inability to tolerate pneumoperitoneum.

19.10 Establishing or Building an Acute Care MIS Program

There are multiple factors, considerations, costs, risks, and benefits to establishing a new MIS program in the trauma/acute care surgery setting or expanding an existing program. In addition, there may be multiple unforeseen problems or obstacles, as well as unanticipated downstream second- or third-order effects that need to be managed or mitigated to achieve a safe and successful program. One example that is particularly critical for teaching programs is to consider the impact of introducing any new technology or procedure on the training of surgical residents and/or fellows. Figure 19.1 highlights the well-described problem that these procedures will

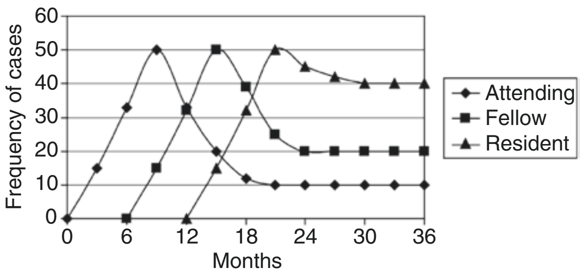

Fig. 19.1 Differential diffusion of newly introduced procedures or technology. Attendings will perform the cases initially and rapidly achieve experience and competence, with delayed diffusion to surgical trainees such as fellows or residents. (Reproduced with permission from: Ellison EC, Carey LC. Lessons learned from the evolution of the laparoscopic revolution. Surg Clin North Am. 2008;88:927–41)

typically be performed by attending surgeons during their early experience, and only later will the surgical fellows or residents be allowed to perform significant portions and acquire the required skill set. This effect can be significantly attenuated with careful planning, integrating realistic simulation training programs, and maximizing opportunities for active trainee participation even during the early learning curve phase.

A good general principle for establishing a solid MIS program is to start with modest and reasonable initial goals, ensure that all participating staff are well prepared for using MIS in this setting, and have relatively strict patient selection criteria. Once an initial satisfactory body of experience has been obtained, then the program can be expanded to more complex procedures and less restrictive patient selection criteria. Although this chapter has primarily focused on laparoscopy, there is an increasing worldwide adoption and utilization of robotic surgical platforms to perform many of these procedures, or to enable an MIS approach to procedures that may otherwise be too technically difficult or complex to perform laparoscopically. In highly select settings, robotic surgery can be safely and successfully introduced and utilized in urgent or emergent surgical or trauma situations. Table 19.3 provides a "top 10" list of high-yield procedure types and techniques in trauma and acute care surgery that are well suited for the introduction of MIS approaches.

Table 19.3 Recommended Top 10 minimally invasive surgery capabilities/procedures to integrate into an acute care surgery practice

1.	Laparoscopic exploration and repair for all simple iatrogenic hollow-viscus injuries such as duodenal perforation during ERCP, colonic perforation during colonoscopy, etc.
2.	Diagnostic laparoscopy for penetrating thoracoabdominal trauma, and laparoscopic reduction and repair of any identified diaphragm injury
3.	Video-assisted thoracoscopy for evacuation of retained hemothorax, early empyema, and for repair of diaphragm injury if associated hemothorax present
4.	Exploratory laparoscopy and lysis of adhesions for select patients with small bowel obstruction requiring operative intervention
5.	Laparoscopic reduction and repair for incarcerated inguinal hernias using transabdominal preperitoneal approach: this allows hernia repair plus full assessment of bowel
6.	Laparoscopic approach for splenectomy and/or distal pancreatectomy for trauma in highly select and stable patients with injury requiring operative intervention
7.	Video-assisted retroperitoneal debridement for necrotizing pancreatitis requiring operative drainage/debridement—typically for walled-off necrosis at >4 weeks
8.	Robotic-assisted surgery: newest platforms allow for easy multi-quadrant surgery, use of energy devices and staplers, all controlled by operating surgeon
9.	Adjuncts to robotic platform (Firefly) allow for fluorescence imaging of biliary tree to avoid iatrogenic injuries and imaging of vascular supply/perfusion for bowel surgery and anastomoses
10.	Single-incision robotic cholecystectomy—one umbilical incision only, robot adjusts for crossed instruments to recreate "normal" laparoscopic instrument motion and orientation

ERCP endoscopic retrograde cholangiopancreatography

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Emergency Management of Caustic Injuries

20

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20.1 Introduction

Ingestion of caustic agents, accidentally or with suicidal intent, is a rare event with potential devastating effects [1]. Most patients present with mild injuries of the upper gastrointestinal tract that resolve without consequences. In a small number of patients surgery is required, either as life-saving treatment in the emergency setting or as an adjunct to other treatments for the management of late sequelae [2].

The emergency management of caustic ingestion relies on the concomitant intervention and close collaboration of several specialists including emergency care physicians, anesthesiologists, radiologists, surgeons, otorhinolaryngologists, gastroenterologists, and psychiatrists [3]. Replacement of endoscopy by computed tomography for the evaluation of gastrointestinal injuries is a major paradigm shift in the emergency management of caustic injuries [4].

20.2 Epidemiology

Epidemiologic data on caustic ingestion are scarce due to under-reporting of such events [3, 5]. In France and the United Kingdom, 15,000 new cases of corrosive exposure were reported yearly but it is unclear how many occurred by ingestion [2, 6]. In the United States, some 1000 children are admitted to hospital every year and the related hospital costs exceed 22 million dollars [6].

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Ingestion is usually intentional in adults (75%) and this population is more likely to experience life-threatening complications. In contrast, accidents are more frequent in children [3, 5, 7, 8], and the incidence is increasing steadily in this population, especially in developing countries which lack effective regulatory measures and structured prevention programs [3, 9, 10].

20.3 Corrosive Agents

Most frequently ingested products are acids, alkalis, and oxidizing agents (e.g., bleach). Strong acids have been reported to produce coagulation necrosis which lessens tissue penetration; it has been suggested that acids spare the esophagus and are mostly responsible for severe injuries to the stomach [8]. In contrast, alkalis are thought to produce liquefaction necrosis resulting in immediate severe injuries at all levels of the gastrointestinal tract [3, 5, 7, 8]; nevertheless, transmural necrosis has been recorded at all levels of the gastrointestinal tract after major ingestion of both alkalis and acids [11].

The pattern of ingestion is different across the world, being conditioned by local customs and access to different kinds of corrosives. Acids are frequently ingested in India and Taiwan, while bleach and alkalis are the leading cause in Europe and North America [1, 6].

Some corrosives may induce severe systemic effects such as severe hypocalcemia (phosphoric, hydrofluoric acids), hyponatremia (strong acids/alkalis), hypokalemia and severe acidosis [1, 6]. The quantity of ingested caustic agent is the major determinant of the extent of digestive injury, but this information is seldom available [3, 5].

20.4 Emergency Management

During the initial approach the main goals include avoiding aggravating the degree of caustic lesions, obtaining control of organ failures, addressing potential systemic effects and evaluating the transmural character of the caustic damage.

20.4.1 Pre-hospital Management

During this phase it is important to establish the diagnosis of caustic agent ingestion and try to identify the ingested substance [12]. Whenever feasible, the ingested agent should be collected on the scene and brought to the emergency department. It is important to determine whether the ingestion was accidental or intentional and detect co-ingestion of alcohol and/or drugs. The delay between ingestion and treatment initiation is a major prognostic factor in the case of massive ingestion of strong corrosives [13]. Identification of the form of the ingested agent (solid, liquid, gel, vapors-concomitant aspiration) and of additional risk factors such as extreme ages (young children, elderly), pregnancy, underlying diseases (cancer, cirrhosis) is paramount as they condition further management and outcomes [13].

Maneuvers that are likely to induce a second esophageal passage of the corrosive agent (strict supine position, provoked vomiting, gastric lavage, ingestion of diluents) should be avoided as they might aggravate existing injuries and lead to severe pharyngeal and respiratory sequelae. Attempts at pH neutralization by ingestion of weak acids or alkalis should be prohibited as they are likely to increase damage by exothermic reactions [6, 13].

20.4.2 In-hospital Management

After emergency department or intensive care unit admission symptomatic treatment should be pursued while waiting to evaluate the severity of gastrointestinal damage. In the case of massive ingestion and respiratory failure securing the airway is a major issue; fiberoptic laryngoscopy is preferable to blind intubation in this setting [13]. If uncertainty persists regarding potential systemic toxicity, poison control centers should be contacted. Nasogastric tubes increase risks of caustic pneumonia and gastric perforation and should be prohibited [13]. The efficacy of proton-pump inhibitors, H2 blockers, corticosteroids and broad-spectrum antibiotics has not been proven. Their systematic use outside controlled trials should be avoided [1, 5, 7].

20.4.3 Severity Assessment of Caustic Damage

20.4.3.1 Clinical Presentation

The clinical presentation depends on the type, amount and physical form of the ingested substance. Solid agents adhere to the mouth and pharynx producing maximum damage at this level while liquids transit rapidly and maximum damage is located in the esophagus and the stomach. Clinical signs of digestive perforation (i.e., abdominal tenderness/rebound, subcutaneous emphysema, hemodynamic instability) are infrequent but their presence should prompt immediate surgery [2, 14]. Hoarseness, stridor and dyspnea are suggestive of aspiration and of laryngeal/epiglottis involvement. The presence of dysphagia, drooling and odynophagia usually reflect esophageal damage while epigastric pain and hematemesis suggest gastric injuries. Most authors agree that symptoms correlate poorly with the extent of gastrointestinal damage [3, 5, 7].

20.4.3.2 Laboratory Studies

The performance of a wide range of laboratory tests is recommended in the emergency setting (liver function tests, Na^+, K^+, Cl^+, urea, creatinine, Ca^{2+}, Mg^+, leukocytes, hemoglobin, platelets, TP, lactates). β-HCG should be measured in young women, and alcohol levels in all patients [13]. Correlations have been established between some laboratory parameters and the severity of caustic injuries. High leukocyte and low platelet counts, elevated serum C-reactive protein levels, severe acidosis (pH <7.22), renal failure, perturbation of liver function tests were associated with transmural digestive necrosis and poor outcomes [3, 5, 7]. Laboratory tests are useful in monitoring patients eligible for initial non-operative management [15].

20.4.3.3 Computed Tomography

Computed tomography (CT) is currently the cornerstone of the evaluation of damage extent after caustic ingestion [16]. CT of the neck, thorax and abdomen should be performed before and after intravenous injection of a non-ionic contrast agent (2 mL/kg) with an 18- to 25-second acquisition time and a 90-s scan delay. CT should be done preferably 3–12 h after ingestion and oral contrast is not recommended. Recent studies have shown that CT outperformed endoscopy in selecting patients for surgery [17–19] and in predicting risks of esophageal stricture [4].

A simple and highly reproducible CT classification [1] of caustic injuries has been recently proposed (Fig. 20.1a):

- *Grade I* injuries show normal-appearing organs (homogenous wall enhancement, absence of wall edema and adjacent tissue stranding);
- *Grade II* injuries show wall edema, surrounding soft tissue inflammation and increased postcontrast wall enhancement;
- *Grade III* injuries show absence of postcontrast wall enhancement which indicates the presence of transmural necrosis.

In order to allow prediction of the risks of esophageal stricture, the classification of Grade II esophageal injuries has been further refined [4] into (Fig. 20.1b):

- *Grade IIa* injuries, which display a "target" pattern of the esophageal wall enhancement;

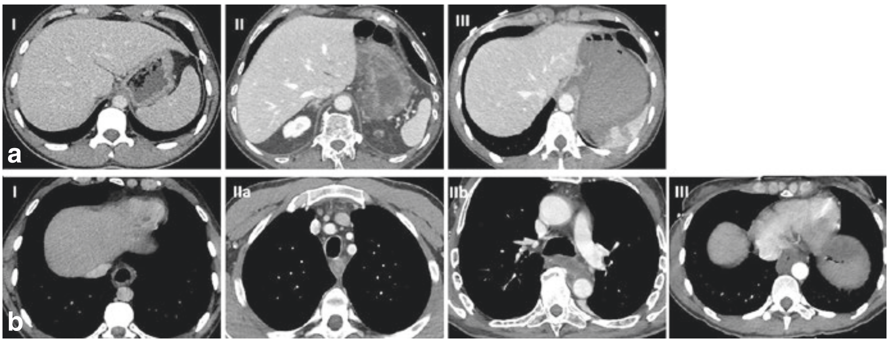

Fig. 20.1 Computed tomography classification of caustic injuries of the stomach (**a**) and the esophagus (**b**)

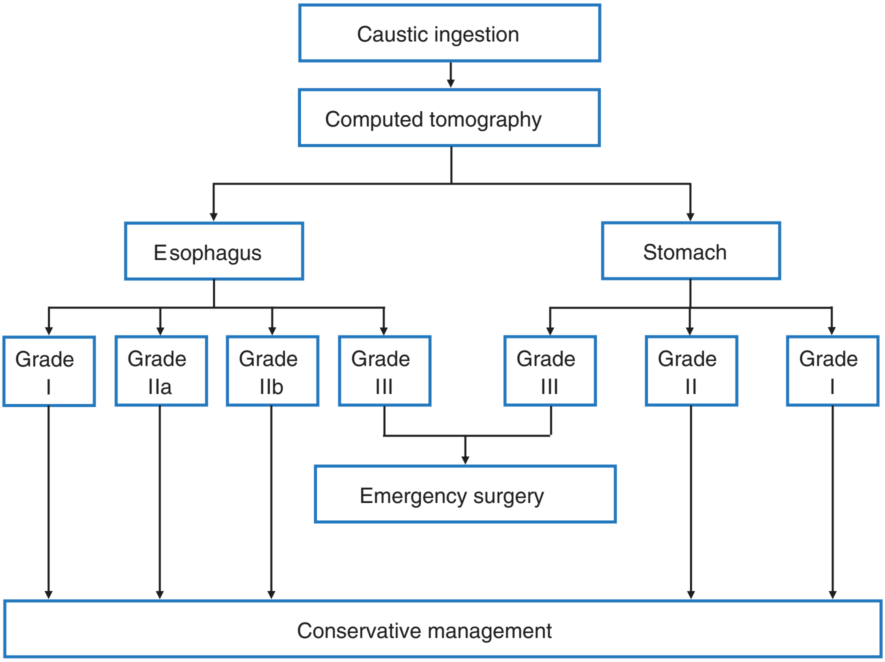

Fig. 20.2 Computed tomography-based algorithm for the management of caustic ingestion

– *Grade IIb* injuries, which display a fine rim of external wall enhancement with the esophageal lumen showing liquid density.

A CT-only management algorithm of caustic ingestion is presented in Fig. 20.2. Between 2015 and 2020, 294 patients were managed according to this algorithm at the Saint Louis Hospital in Paris and their outcomes were similar to those of 120 patients managed between 2012 and 2015 by a combined CT-endoscopy algorithm (unpublished data).

20.4.3.4 Endoscopy

Esophagogastroduodenoscopy used to be the cornerstone of caustic ingestion management algorithms worldwide [3, 5, 8]; inability to predict the depths of intramural necrosis resulting in futile surgery has currently limited its indications in the emergency setting. Upfront endoscopy is still used in children [6] and in patients with contraindications for CT (i.e., severe iodine allergy, renal failure) [1]; if endoscopy shows severe injuries, CT confirmation of transmural necrosis is still recommended prior to surgery, especially if esophageal resection is considered. Endoscopy remains the mainstay for the diagnosis and upfront treatment of caustic strictures [4].

20.4.4 Non-operative Treatment

A non-operative approach can be offered to 70–80% of patients after caustic ingestion [1]. Patients eligible for non-operative treatment may resume oral alimentation as soon they are able to swallow. After psychiatric consultation, fit patients with low-grade injuries (Grade I–IIa) can be discharged as soon as they eat normally [16]. Patients with more severe injuries require close monitoring; deterioration of clinical and/or laboratory tests (abdominal pain, rebound tenderness, shock, need for ventilatory support, renal failure, peripheral blood leukocytosis, and/or acidosis) should prompt repeat CT evaluation [17]. Follow-up should be conducted for at least 4 months to detect stricture formation [4].

20.4.5 Emergency Surgery

Emergency surgery is indicated in patients in whom CT shows transmural digestive necrosis in order to prevent perforation, peritonitis and death [2]. In a recent report, emergency surgery was required in 24 (20%) of 120 consecutive caustic ingestion patients [18]. Fiberoptic bronchoscopy should be performed on a systematic basis before surgery to rule out airway involvement. Laparotomy is the mainstay approach, but laparoscopic exploration is feasible and safe [20]. The main emergency operations performed for the treatment of caustic injuries are detailed bellow.

20.4.5.1 Esophagogastrectomy

Esophagogastrectomy (EGT) through a combined abdominal and cervical approach using the esophageal stripping technique is the most frequently employed resection procedure [2]. EGT is indicated when CT suggests transmural esophageal necrosis and laparotomy confirms transmural gastric necrosis. Jejunostomy construction at the end of the operation allows enteral nutrition while waiting for reconstruction [2]. The existence of isolated esophageal necrosis has been recently challenged [15, 18]. Esophagectomy is not recommended if the CT findings are suggestive of transmural esophageal necrosis but laparotomy shows the absence of transmural gastric necrosis [18]; close monitoring should be attempted under such circumstances.

20.4.5.2 Gastrectomy

Transmural necrosis of the stomach requires total gastrectomy [21]; partial gastric resections are not recommended because ongoing necrosis might compromise outcomes. Immediate digestive reconstruction by esophagojejunostomy (EJ) can be attempted in stable patients; otherwise, damage control esophageal exclusion or external drainage should be favored [21]. Leakage of the EJ in this setting is rare [21]. Most of these patients develop severe esophageal strictures and require delayed esophageal reconstruction; a feeding jejunostomy should be constructed at the time of gastrectomy to allow enteral nutrition during the waiting period.

20.4.5.3 Extended Resections

Following massive ingestion of strong caustic agents, resection of other abdominal organs may be required [22]. All transmural necrosis injuries should be resected during the initial procedure; second-look procedures should only be performed if clinical and biological data suggest ongoing necrosis [22]. Concomitant pancreato-duodenectomy (PD), colectomy, splenectomy and bowel resections were reported in up to 20% of patients who underwent EGT [2]. If the patient's condition allows, immediate pancreato-biliary reconstruction is recommended after PD [23]. Bowel necrosis is usually related to intraluminal passage of the caustic agent; massive bowel necrosis contraindicates resection because of poor patient survival and compromised nutritional and reconstructive issues. The decision to abort a potentially life-saving resection procedure in the emergency setting should not rely on quality of life-related issues [24, 25]. Perceived inability to perform future esophageal reconstruction should not influence emergency surgical decisions as patients may eventually lead quite normal lives while being on lifelong enteral nutrition [24, 25].

20.4.5.4 Tracheobronchial Necrosis

On rare occasions, esophageal necrosis may extend directly to the posterior aspect of the tracheobronchial tree. If tracheobronchial necrosis (TBN) is certified, esophagectomy should be performed by a right thoracic approach to avoid further injuries and allow airway repair with a pulmonary patch technique [26].

20.4.5.5 Results of Emergency Surgery

The extent of surgery is the major determinant of operative outcomes. In a recent report, the mortality of gastrectomy, EGT, PD and TBN for caustic injuries reached 11%, 14%, 39% and 45% and the morbidity rates were 63%, 65%, 94% and 100%, respectively [2]. The standardized mortality ratio (SMR) after emergency surgery for caustic injuries was 21.5 when compared with the general French population [2]. In patients managed since 2015, the SMR after emergency surgery dropped to 12.9, reflecting significant progress in patient selection and perioperative management (unpublished data). Factors that have a negative impact on long-term survival and functional outcomes include advanced age and the extent of caustic necrosis [2].

20.5 Conclusion

Caustic ingestion has a dramatic impact on patient survival, functional outcomes and quality of life. Efforts to improve outcome should be directed at improving patient selection for surgery in parallel with the development of public health programs directed at public education and the implementation of effective measures limiting access to strong corrosive substances.

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