Surgical Critical Care

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24.1 Introduction

In the past two decades, tremendous advances have been made in the area of surgical critical care. Advances in resuscitation strategies, improvements in our understanding of multiple organ failure, and the increasing focus on the utilization of evidence-based medicine have all contributed to improved outcomes for traumatically injured patients. One of the distinguishing features of ICU care is the ability to provide continuous, intensive physiologic monitoring of the patient. In the setting of vascular trauma, this includes the ability to invasively monitor blood pressure and perform frequent neurovascular checks. Any change in a patient's clinical status should prompt further investigation.

Management of critically injured trauma patients is best performed in the setting of a multidisciplinary intensive care unit (ICU) team. Patients suffering from vascular trauma, whether blunt or penetrating, often have other associated injuries that require coordination of care from multiple specialists including the ICU team. In addition, many patients will have preexisting medical conditions that can further complicate their clinical management. All of these factors increase the complexity of patient management and further emphasize the need for comprehensive care delivered by a critical care specialist. It is beyond the scope of this chapter to discuss all of the potential critical care issues that critically injured trauma patients may face. However, we have attempted to identify those clinical

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situations that are most commonly encountered in the ICU in patients suffering from vascular trauma. This includes monitoring for extremity compartment syndrome, pharmacologic management of blunt aortic injury, and medical management of blunt cerebrovascular injuries.

24.2 Monitoring for Extremity Compartment Syndrome

Compartment syndrome is defined as increased pressure within an osteofascial compartment which limits perfusion to its contents, including muscles and nerves [1]. This increased pressure can be generated by a variety of mechanisms, the majority of which are secondary to trauma. These include long bone fracture, vascular injury with associated ischemia and reperfusion, as well as hematoma formation, burns, and crush injury. In the non-trauma population, compartment syndrome has been described secondary to spontaneous hematoma formation, external compression of the limb, small thrombotic or embolic events, envenomation, IV infiltration, and muscle overuse [2]. Delayed compartment syndrome, although rare, can develop without injury secondary to aggressive resuscitation [3].

Compartment syndrome is a clinical diagnosis, which must begin with a high level of suspicion. Patients will often describe pain out of proportion and paresthesias. Physical exam will reveal tense muscle compartments and increased pain with passive motion of the affected muscle group. Pain is often the first sign of compartment syndrome and the most sensitive finding. The pain is associated with pressure inside the musculofascial compartment and associated muscle damage. Paresthesias also become evident early in the development of compartment syndrome, as nerves within the compartment are especially sensitive to ischemia. Damage to these nerves will result in the loss of sensory function first [2]. Although the physical exam finding of tense compartments is often that which raises initial suspicion, it is important to remember that this is a subjective finding and that not all compartments are easily palpable, including the deep posterior compartment of the lower leg and the deep flexor compartment of the forearm. It is important to note that the presence of palpable distal pulses does not rule out compartment syndrome. Findings of ischemia including pallor, poikilothermia, and pulselessness are late and ominous findings [4].

Diagnosis of compartment syndrome can be especially challenging in the polytrauma patient who is unable to participate in the physical exam. Although significant clinical suspicion is adequate to form a diagnosis, more objective means of diagnosis are often considered. There are a variety of techniques through which intracompartmental pressures can be measured, though this is most commonly measured through the use of an electronic pressure monitor (Stryker Quick Pressure monitor instrument, Stryker Surgical, Kalamazoo, MI). This small, portable tool measures compartment pressures by placing a needle directly into the compartment of concern. Its accuracy has been confirmed with comparison trials to other methods and reliability related only to the user's understanding of anatomical location of the compartments of concern [5]. There are two ways in which compartment syndrome can be viewed numerically: as an absolute compartmental pressure or as a pressure relative to the systemic blood pressure. Normal capillary pressure ranges between 20 and 30 mmHg. When compartment pressures rise above 30 mmHg, the patient is at risk of developing compartment syndrome [6]. The classic description of compartment syndrome relative to systemic pressure involves a compartment pressure that is within 30 mmHg of the diastolic blood pressure [7]. This definition is preferred by some as it takes into consideration the hemodynamic status of the patient. Hypotensive patients by definition will have decreased perfusion pressures and therefore will tolerate less increase in the compartment pressure before ischemia is a concern.

The exact mechanism of tissue damage in compartment syndrome has not been confirmed, though it is thought to be related to the reperfusion injury which is initiated by the development of oxygen free radicals [8]. There is also a local inflammatory response which develops

subsequent to reperfusion secondary to the release of breakdown products from injured cells. Cell and tissue edema develops, resulting in an increase in pressure within the compartment which is limited by its fascial encasement. It is also theorized that reperfusion can result in the development of venous thrombosis secondary to procoagulant release from necrotic tissue. This thrombosis then spreads from the necrotic tissue to the marginal zones of perfusion, leading to further muscle necrosis, release of inflammatory mediators, and propagation of the cycle of increased pressure and necrosis [9]. The amount of pressure increases, and the duration of its presence affects the amount of tissue injury which occurs. Canine models have demonstrated that prolonged elevation of pressures, as well as the degree of pressure elevation within the compartment contributed to decreased nerve conduction velocities, consistent with the effects of ischemia [10].

Recognition of compartment syndrome is the first crucial step in treatment of the affected extremity. The longer the diagnosis of compartment syndrome goes unrecognized, and the compartment pressure is allowed to rise, the more significant the nerve and muscle damage and subsequent necrosis. If discovered early in its course, significant tissue damage can be prevented. Treatment of compartment syndrome requires fasciotomy of the affected compartments. Prophylactic fasciotomies should also be considered in the setting of significant ischemia (greater than 4–6 h), in the setting of combined orthopedic and vascular injuries, or in a patient with whom there is significant concern for the development of compartment syndrome, where monitoring of the compartment may be difficult [2]. The most common locations for development of compartment syndrome are the calf and forearm, though compartment syndrome can develop in the thigh, foot, and hand as well [11]. Lower extremity fasciotomy begins with recognition that there are four compartments which require decompression: anterior, lateral, superficial posterior, and deep posterior. The anterior compartment is most often affected and, with ischemia to the superficial peroneal nerve, results in the classically described paresthesias in the web space between the first and second toes. Although there are a variety of techniques in performing fasciotomy of the lower extremity, the gold standard is a two-incision, four-compartment fasciotomy. The anterior and lateral compartments are released from an anterior lateral incision. The medial incision will decompress the deep posterior and superficial posterior muscle compartments [12]. Release of the fascia overlying the muscles of affected compartments will reveal a bulging of the affected muscles which should be evaluated for necrosis and debrided as indicated. Skin incisions are left open, with the use of either a negative pressure dressing or moist gauze dressings, with a goal of delayed primary closure once the edema has resolved. If the patient is unable to undergo delayed primary closure, a split thickness skin graft is often used for closure.

Fasciotomy is not a benign procedure, with postoperative complications including infection, nerve injury, chronic pain, and disfiguring wounds. Despite this, failure to perform fasciotomy when needed is perhaps the most feared complication. Eight hours after onset of total ischemia, irreversible muscle and peripheral nerve damage exists [13]. Patients who require revision of fasciotomies or performance of delayed fasciotomies were associated with higher rates of muscle excision, amputation, and mortality. Casualties from the Iraq and Afghanistan campaigns, who underwent delayed fasciotomy, were shown to have had twice the rate of amputation and a threefold increase in mortality. Increase in myonecrosis puts the patient at increased risk of infection as well as increased risk of acute kidney injury from rhabdomyolysis [14].

24.3 Medical Management Considerations in Blunt Thoracic Aortic Injury

Blunt thoracic aortic injury (BTAI) is the second leading cause of death from blunt trauma after head injury [15]. BTAIs have been associated with falls from heights, auto vs. pedestrian accidents, and motorcycle crashes. By far, however,

the most common cause of blunt thoracic aortic injury is motor vehicle crashes, which account for more than 70 % of such injuries. The incidence of BTAI increases with age and is rarely seen in the pediatric population [16]. The overall incidence of patients with these injuries who survive to receive hospital care is less than 0.5 % [17], while the actual incidence of BTAI is much higher [18]. In fact, an autopsy study of 304 deaths from traffic accidents in Los Angeles County found that 33 % of patients had a rupture of the thoracic aorta. Eighty percent of these deaths occurred at the scene, and only 20 % reached the hospital prior to death [19]. For those who survive to reach hospital care, prompt diagnosis and aggressive management of blood pressure are critical in preventing free rupture of the previously contained aortic rupture. The most common location for aortic injury is the medial aspect of the lumen, just distal to the left subclavian artery, often referred to as the aortic isthmus. Injury to the aortic isthmus is found in about 93 % of hospital admissions with BTAI and 80 % of autopsy studies [18]. In terms of the injury type, the most common is creation of a false aneurysm (58 %), aortic dissection (25 %), and intimal tear (20 %) [17].

Although CT angiography is now the gold standard in diagnosing BTAI with both a sensitivity and negative predictive value approaching 100 %, there are classically described findings on initial chest x-ray which may increase the suspicions of the care team [20]. These findings include a widened mediastinum, obliteration of the aortic knob, loss of perivertebral pleural stripe, depression of the left mainstem bronchus, deviation of a nasogastric tube to the right, a left apical pleural hematoma ("apical cap"), and a massive left hemothorax. The presence of fractures of the clavicle, upper ribs, scapula, or sternum are markers for increased risk of BTAI [18].

Patients with active extravasation from an aortic injury require immediate operation. Starnes et al. demonstrated that hypotension at the time of presentation to the emergency department, loss of vital signs prior to arrival, as well as rupture as the type of injury were predictive of death secondary to BTAI [21]. Most patients who survive to hospital care have a contained aortic injury. The goal in management of these patients is preventing free rupture via aggressive blood pressure control. Ninety percent of ruptures will occur within the first 24 h of injury [18]. Because of this, immediate repair of all aortic injuries was the standard of care for many years. Recent studies have demonstrated that with strict blood pressure control, the majority of these injuries could be repaired in a delayed fashion [22, 23]. With blood pressure control, the risk of rupture is 1.5 %/h; without control of blood pressure, the risk remains at 12 % [24]. In 2007 the results of the American Association for the Surgery of Trauma prospective study demonstrated a significantly higher mortality in the early repair group vs. delayed repair with an adjusted odds ratio of 7.78, 95 % CI 1.69–35.7, $p=0.008$. This study also confirmed prior studies which demonstrated that despite lower mortality, delayed repair was associated with significantly longer ICU and hospital length of stay [25].

The medical management of BTAI is derived primarily from the management of nontraumatic aortic dissections. The goals of antihypertensive therapy in the management of aortic injury are to prevent further dissection or free rupture of the injury. This frequently is referred to as anti-impulse control, which is lessening the pulsatile load, or aortic stress (dP/dT), in order to slow the propagation of the injury and prevent rupture [26]. Propagation of aortic injury is thought to be not only secondary to elevated blood pressure itself, but on the velocity of the left ventricular contraction [26]. For this reason, optimal therapy is considered to consist of a beta-blocker, with the addition of a vasodilator for refractory hypertension. Contraindications to medical management in addition to evidence of free rupture include impaired perfusion to the gastrointestinal tract or legs and the inability to control hypertension despite medical treatment [27]. Goals for therapy are a heart rate of 55–65 beats per minute and systolic blood pressure 100–120 mmHg, or as low as the patient can tolerate [28].

The foundation of anti-impulse therapy begins with the use of beta-blockers. Esmolol is the

preferred drug as it has rapid onset and a short half-life, making it easily titratable. Its onset of action is less than 60 s, and short half-life contributes to duration of action between 10 and 20 min. Esmolol is a pure β1 receptor blocker, which, in addition to decreasing blood pressure through an inotropic effect, has a chronotropic effect of decreased heart rate [29]. Labetalol has a longer half-life than esmolol and therefore has a longer duration of action. It has a slower onset of action, 2–5 min, but longer duration of action, peaking at 5–15 min and lasting 2–4 h. Labetalol blocks both α and β receptors, thereby affecting blood pressure and contractility. Although labetalol does have a negative chronotropic effect secondary to the blocking of β receptors, it does not decrease the heart rate as substantially as esmolol, making labetalol a better choice for patients who present with lower heart rates [29]. Propranolol and metoprolol are beta-blockers which are not recommended in the acute phase of treatment. They have a longer duration of action (6–8 h), and there is no way to quickly reverse the beta-blockade should the patient go into shock. These are good choices of treatment in the subacute phase when they can be given as additional boluses as the patient is transitioned to oral regimens [29].

Vasodilators are good adjuncts to beta-blocker therapy when multidrug therapy is required for blood pressure control. Sodium nitroprusside is a potent vasodilator of both the arterial and venous systems. It has a long history of use in management of hypertensive crisis and aortic dissection. It has a rapid onset of action and a half-life of 3–4 min. It does however require close monitoring and requires frequent dose adjustments. Nitroprusside also increases intracranial pressure and in the trauma population is often contraindicated for this reason. It has also been associated with coronary steal, decreased oxygen circulation, and reflex tachycardia. For these reasons and the risk of cyanide toxicity, nitroprusside should only be used as a medication of last resort [28].

In lieu of nitroprusside, many advocate for the use of fenoldopam. Fenoldopam is a dopamine-1 agonist and selective arteriolar/renal dilator. It has a rapid onset and short duration of action (half-life 5 min). It has been shown to increase creatinine clearance and does not exhibit coronary steal. Fenoldopam can however produce reflex tachycardia and EKG changes including nonspecific T-wave changes. After long-term infusion, it produces a mild tolerance [28].

Nicardipine is a dihydropyridine calcium channel blocker. It causes relaxation of the arterial smooth muscle resulting in peripheral vasodilation and resultant blood pressure reduction. Nicardipine causes cerebral and coronary vasodilation with minimal negative inotropic or chronotropic effect and has been shown in cardiac surgery patients to have little effect on ventricular preload or cardiac output. It is easily and rapidly titratable, and it has minimal effect on the atrioventricular nodal conduction. Oxygen delivery to the cells is maintained, and there is no effect on oxygen requirements. An added benefit is that nicardipine is metabolized by the liver and is therefore safe to use in patients with renal insufficiency. As a calcium channel blocker, it is also useful in patients with COPD and asthma where β-blockade may be contraindicated [28].

Non-dihydropyridines such as verapamil or diltiazem have fallen out of favor over the last several years. The non-dihydropyridine group functions via strong chronotropic and inotropic effects, with minimal effect on the systemic blood pressure. It is the large effect on decreasing cardiac contractility which has made them a less commonly used class of drugs in the treatment of hypertension in the face of blunt thoracic aortic injury [28, 29].

24.4 Critical Care Management of Blunt Cerebrovascular Injury

Blunt carotid injury (BCI) and blunt vertebral injuries have been collectively referred to as blunt cerebrovascular injuries (BCVI). Over the last two decades, significant advances in screening, diagnosis, and treatment of BCVI have occurred. Initial estimates predicted blunt carotid artery injury-associated mortality rates of 23 %,

with 48 % of those survivors have significant permanent, severe neurologic sequela [30]. Advancements in the field of BCVI can largely be attributed to the institution of screening programs and resultant increase in diagnosis of initially asymptomatic patients. Initial estimates of suggested BCI rates of 0.1 % of blunt trauma victims admitted to trauma centers. With increased detection as a result of screening programs, the incidence has now been estimated between 0.4 and 1 % of all blunt trauma admissions [30].

Significant investigation has been put forth into the development of screening programs in the detection of BCVI. Early detection of injuries, while the patient remains asymptomatic, provides a window for intervention in hopes of preventing the subsequent morbidity and mortality associated with the occurrence of a stroke. Trauma patients who present with arterial hemorrhage from the neck, mouth, nose, or ears; large or expanding cervical hematomas; cervical bruits in a patient less than 50 years old; and focal or lateralizing neurologic defects including hemiparesis, transient ischemic attack, Horner's syndrome, oculosympathetic paresis, or vertebrobasilar insufficiency, or evidence of cerebral infarction on CT or MRI are presumed to have a BCVI until proved otherwise [30]. There is evidence to suggest that stroke rates are significantly lower in patients treated for BCVI, when compared with those untreated [31–33]. Furthermore, when screening is limited to the at-risk population, screening and treatment have been demonstrated to be cost effective [34]. The identification of a high-risk group prompting screening has gone through much debate and evolution over the last decade. Fundamental mechanisms associated with carotid artery injury include cervical hyperextension or hyperflexion with rotation and stretching of the carotid artery over the lateral articular processes of the cervical vertebral bodies C1–C3, direct cervical trauma, intraoral trauma, and basilar skull fracture involving the carotid canal [35, 36]. The vertebral artery is associated with cervical spine injuries, especially subluxations and fractures of the foramen transversarium [37]. Further analyses have suggested the following as high-risk factors for BCVI which should prompt screening: injury mechanism compatible with severe cervical hyperextension with rotation or hyperflexion; Lefort II or III midface fractures; basilar skull fracture involving the carotid canal; closed head injury consistent with diffuse axonal injury with Glasgow Coma Scale score less than 6; cervical vertebral body or transverse foramen fracture, subluxation, or ligamentous injury at any level, or any C1–C3 level fracture; near-hanging resulting in cerebral anoxia; or seatbelt or other clothesline-type injury associated with significant pain, swelling, or altered mental status [38]. Cothren et al. studied 244 patients, with a 34 % positive screening yield. In patients who were initially asymptomatic, but had contraindications to antithrombotic therapy, there was a 21 % rate of ischemic neurologic events, compared to 0.5 % in those who were asymptomatic and treated with heparin or antiplatelet agents [39]. This data has been used to justify the screening of asymptomatic patients who are at high risk because of associated injuries or mechanisms of injuries as discussed above.

The manner in which patients are screened has also evolved over the last decade with the associated advances in technology. Four-vessel cerebral arteriography has been considered the gold standard for diagnosis of BCVI. It is, however, invasive, with associated risk of complication, and is resource intensive. While the initial comparisons with 4-slice computed tomography revealed disappointing results, the widespread adoption of 16-slice CT scanners has demonstrated superior results. CT angiography has demonstrated 100 % sensitivity for carotid injury and 96 % sensitivity for vertebral artery injury [40]. Other studies have suggested a relatively high false-positive rate, suggesting that 16-slice CTA may be oversensitive. Cerebral arteriography is still warranted in the setting of high clinical suspicion and a normal CTA to definitively exclude an injury [41].

Management strategies for blunt cerebrovascular injuries include observation, surgical repair, antithrombotic drugs, and endovascular strategy. Secondary to the high morbidity and mortality associated historically with untreated

Table 24.1 Blunt carotid and vertebral arterial injury grading scale (Biffl et al. [42])

Injury grade	Description
I	Luminal irregularity or dissection with <25 % luminal narrowing
II	Dissection or intramural hematoma with ≥25 % luminal narrowing, intraluminal thrombus, or raised intimal flap
III	Pseudoaneurysm
IV	Occlusion
V	Transection with free extravasation

BCVI, namely, ischemic and thrombotic cerebrovascular accidents, observation should only be employed as a method of treatment when there are contraindications to alternate therapies [41]. The treatment of choice for a given patient is determined by the location and grade of the injury (Table 24.1) as well as the patient symptomatology [39]. Surgical management is limited for BCVI. Grade I injuries are associated with a low stroke risk, which cannot justify surgical repair. Repair is often considered for higher-grade injuries; however, the anatomical location of most injuries in relation to the skull base makes surgical access difficult [41]. Because of these reasons, nonsurgical management is currently the mainstay of treatment for BCVI. That being said, if there is a Grade II–V injury which is surgically accessible, operative repair should be considered [30]. Initial studies in the treatment of BCVI demonstrated improved neurologic outcomes in symptomatic patients and stroke prevention in asymptomatic patients with anticoagulation via heparin. Protocols for heparin therapy have been modified over time to minimize the risk of bleeding in the patient population which often has multisystem trauma. Current recommendations include initiation of heparin drip without bolus, at 10 units/kg/h with a goal partial thromboplastin time of 40–50 s [41, 42]. More recent reports including large cohorts of patients suggest that systemic heparinization and antiplatelet therapy (clopidogrel 75 mg daily or aspirin 325 mg daily) have equivalent efficacy in the prevention of stroke [43, 44]. To date there are no randomized control trials proving superiority of either anticoagulation or antiplatelet therapy, though many choose to initially treat with heparinization when multiple surgical procedure with high risk of bleeding are indicated for the patients other associated injuries. It is also important in patients with concomitant traumatic brain injuries that the decision regarding anticoagulation and antiplatelet therapy be discussed in conjunction with the neurosurgery teams, in order to balance the risk of potential stroke with the risk of intracranial hemorrhage. Although they were unable to demonstrate statistical significance, a large study from the Denver group suggests that heparin may be a superior therapy to antiplatelet therapy in stroke prevention and in improvement of neurological symptoms following cerebral ischemia [41]. Grade V injuries are associated with high mortality and require immediate attempts at obtaining control, through surgical repair if accessible, or via endovascular means if inaccessible.

Follow-up imaging in the case of BCVI has proven to be instrumental in the treatment of such injuries both in terms of evaluating for progression of the injury and resolution. Most authors recommend repeat CT angiography in 7–10 days, or with any deterioration in neurologic status. Follow-up imaging resulted in a change of therapy for 65 % of grade I injuries and 51 % of grade II injuries [41]. In a follow-up study, Cothren et al. repeated imaging at 10 days after the initial diagnosis of BCVI was made, which demonstrated a healing rate of 46 % when treated with aspirin and/or clopidogrel, 43 % for aspirin, and 39 % for heparin. Alternatively, injury progression rates for BCVIs were 10 % for aspirin, 12 % for heparin, and 15 % for aspirin and/or clopidogrel. Approximately half of all grade I BCVIs fully healed, whereas less than 10 % of grade II, III, or IV injuries healed in same time period [34, 39].

In the case of progressive vessel narrowing, or enlargement of pseudoaneurysm, the use of endovascular stenting has been employed in an effort to maintain patency of the vessel [41]. Initial studies suggested a 17 % incidence of stent-related complications, including a 45 % occlusion rate, initially suggesting that the risk of endovascular stenting outweighs the benefits [34, 39].

Subsequent studies however reported good safety and patency results, though their application of stents also include antiplatelet therapy [33]. Continued studies are required to determine the true efficacy of stents in the acute setting.

Patients who continue to demonstrate injury after the follow-up imaging are recommended to continue long-term antithrombotic therapy, as stroke has been reported as long as 14 years after injury. To date, the therapy of choice and duration of treatment have not been determined [41]. Warfarin was initially recommended for long-term anticoagulation; however, with demonstrated efficacy of antiplatelet therapy, this is now the preferred treatment [42]. Recommendations for antiplatelet therapy are derived from knowledge gained with cardiac stents and percutaneous interventions. Dual therapy (aspirin with clopidogrel) is indicated for cardiac indications; however, only single-agent therapy is recommended for stroke prevention secondary to the increased bleeding risk, and no demonstrated benefit in mortality [43–45]. More studies are necessary to determine the optimal therapy in the management of BCVI. Aspirin is the current therapy of choice in treatment of BCVI in patients with persistent lesions when acute bleeding risks from associated injuries have resolved.

24.5 Venous Thromboembolism Prophylaxis

Multisystem trauma patients have a significant risk of developing deep venous thrombosis (DVT). Without prophylaxis, the rates of DVT may exceed 50 % in high-risk patients. After major trauma the risk of pulmonary embolism ranges from 0.4 to 50 % [46]. In trauma patients there is level I evidence supporting DVT prophylaxis with LMWH or LDUH as soon as resuscitation is complete and the bleeding risk acceptable [47]. The challenge in clinical decision making centers around the timing of initiation of prophylaxis based on assessment of bleeding risk. Reasonable concern exists regarding the appropriate time to begin prophylaxis, specifically in patients suffering from high-risk injuries including intracranial hemorrhage (ICH), blunt solid organ injury, and spinal cord injury. Mechanical prophylaxis, in the form of intermittent compression pumps, is recommended instead of or as an adjunct to pharmacologic prophylaxis, depending on the bleeding risk and the VTE risk for the given patient [48].

Few studies exist which evaluate the failure of nonoperative management (NOM) of blunt solid organ injuries in patients treated with LMWH. Alejandro et al. found no change in the failure of NOM and no increase in blood transfusion requirements for patients with blunt splenic trauma who received early (≤48 h) and late (>48 h) prophylaxis [49]. Eberle et al. studied failure of NOM in patients with splenic, liver, and kidney injuries treated with early and late administration of LMWH. They found no differences in the failure rates or PE/DVT rates between early (≤3 days) and late (>3 days) administration of LMWH. A smaller study of 22 patients with solid organ injury receiving LMWH within the first 24 h found that 0 of 10 patients with liver injures, and 2 of 12 patients with splenic injuries receiving LMWH failed NOM [50]. Limitations of this study, and others assessing the management of blunt trauma, include failure to document specific risks for failure of NOM including contrast extravasation, pseudoaneurysm, or large hemoperitoneum. Further studies are necessary to assess organ-specific failure rates. Studies are ongoing, though seem to indicate that prophylactic LMWH is safely administered between 48 and 72 h, in patients who have demonstrated cessation of acute bleeding.

Perhaps more worrisome than solid organ bleeding is that of worsening intracranial hemorrhage in patients with traumatic brain injury. Patients with brain injury are especially at risk for venous thromboembolism (VTE) compared to the general trauma population [51]. Reported rates of progression of hemorrhage after LMWH range from 1.46 to 14.5 %, depending on exclusion criteria [52]. Although Kwiatt et al. present a higher progression rate than other studies secondary to broad inclusion criteria, they also concluded that the timing for initiation of LMWH did not alter the rebleed rate, when comparing

LMWH administered at ≤48 h, >48 h, and after 7 days [52]. Although not standardized, the majority of studies assessing the timing of initiation of VTE prophylaxis in patients with intracranial hemorrhage suggest documentation of stable head CT, which are monitored every 24 h after admission until stability is documented. These decisions are often made in conjunction with neurosurgical specialists and tend to start 24 h after documentation of stable CT head findings [53]. Following a similar protocol Dudley et al. demonstrated a low incidence of VTE (7.3 %), and 0.4 % symptomatic rebleed rate, when LMWH was started 48–72 h after initial trauma, provided stability of intracranial hemorrhage was documented [54]. Further studies are needed to evaluate the rates of progression, as well as rates of VTE in this population to better determine the safety and efficacy.

Determining the appropriate timing for initiation of chemoprophylaxis for VTE often requires a multidisciplinary evaluation in the polytrauma patient. Clinicians should take into consideration the patients' clinical risk factors relative to specific organ injured and presence of risk factors for bleeding. This should be weighed against the known relative increase in VTE in the trauma population and associated morbidity and mortality.

24.6 Antiplatelet Therapy

Cardiovascular disease, including acute coronary syndrome, remains the leading cause of death in industrialized countries, despite evolving therapeutic targets [55]. Platelets serve as a major therapeutic target, as the use of antiplatelet therapy allows for the inhibition of platelet aggregation [56]. Research is ongoing into the effect of such irreversible platelet inhibitors, without adequate reversal agents in the trauma population. Within the first 24 h after injury, posttraumatic intracranial hemorrhage increased in more than half of patients with traumatic brain injuries. Exacerbation secondary to inhibition of platelet activity is most likely to occur during this time period, and withdrawal of antiplatelet agents must be considered [57]. However, cessation of medication will not have an immediate impact on bleeding as the effect of the antiplatelet agents is not rapidly reversed. Cessation of antiplatelet therapy is also not without risk. After coronary stent placement, the risk of thrombosis is increased 30-fold if clopidogrel is discontinued within the first 30 days [58]. Stopping clopidogrel within the first 6 months of stent placement is an independent determinant of stent thrombosis [59]. At the same time, it is recognized that there is an increased risk of bleeding in patients on antiplatelet therapy. The risk of stent thrombosis must be carefully weighed against the risk of worsening intracranial hemorrhage. Bridging therapy with heparin was shown to be ineffective in reducing cardiac events after cessation of antiplatelet therapy [60]. In a review of 1,236 patients hospitalized for acute coronary syndrome, 4.1 % of cases were secondary to withdrawal of antiplatelet therapy, with a mean delay of 10 ± 1.9 days [61]. The rate of delayed intracranial hemorrhage is found in approximately 1–1.4 % of patients on antiplatelet therapy [62].

Wong et al. performed a retrospective case-controlled study comparing patients with traumatic brain injury who were receiving clopidogrel, aspirin, or warfarin compared to a control group. The results demonstrated a 14.7-fold increase in mortality in patients on clopidogrel [63]. Although the studies assessing morbidity and mortality are limited, primarily related to small sample size and retrospective nature, concern exists that patients on antiplatelet therapy are at a higher risk of mortality and morbidity following traumatic brain injury. Subsequent studies may also benefit from measurement of platelet function, rather than absolute presence of absence of medication as it related to bleeding risk. Nonetheless, extreme caution and liberal use of CT imaging should be employed in patients treated with antiplatelet therapy. No evidence exists at this time regarding the timing for resuming antiplatelet therapy in patients with multisystem trauma. Care should be taken in patients with closed-space injuries, where delay in recognition of delayed bleed can be catastrophic. This risk of surgical or traumatic

bleeding must closely be balanced with the risk of stent thrombosis. Patient history, including timing of stent placement, type of stent, and reason for initiation of antiplatelet therapy, although often unavailable in the acute traumatic setting, is of significant value in this decision-making process. Further studies are ongoing in this evolving arena.

References

1. Feliciano DV, Cruse PA, Spjut-Patrinely V, Burch J, Mattox KL. Fasciotomy after trauma to the extremities. Am J Surg. 1988;156(6):533–6.
2. Percival TJ, White JM, Ricci MA. Compartment syndrome in the setting of vascular injury. Perspect Vasc Surg Endovasc Ther. 2011;23(2):119–24.
3. Tremblay LB, Feliciano DV, Rozycki GS. Secondary extremity compartment syndrome. J Trauma. 2002;53: 833–7.
4. Mattox KL, Moore EE, Feliciano DV. Trauma. 7th ed. Chicago: McGraw-Hill Professional; 2013. p. 819–21.
5. Uliasz A, Ishida JT, Fleming JK, Yamamoto LG. Comparing the methods of measuring compartment pressures in acute compartment syndrome. Am J Emerg Med. 2003;21:143–5.
6. Hargens AR, Schmidt DA, Evans KL, et al. Quantitation of skeletal-muscle necrosis in a model of compartment syndrome. J Bone Joint Surg Am. 1981;63:631–6.
7. Kosir R, Moore FA, Selby JH, et al. Acute lower extremity compartment syndrome (ALECS) screening protocol in critically ill trauma patients. J Trauma. 2007;63:268–75.
8. Ricci MA, Graham AM, Corbisiero R, Baffour R, Mohamed F, Symes JF. Are free radical scavengers beneficial in the treatment of compartment syndrome after acute arterial ischemia? J Vasc Surg. 1989;9:244–50.
9. Blaisdell FW. The pathophysiology of skeletal muscle ischemia and the reperfusion syndrome: a review. Cardiovasc Surg. 2002;10:620–30.
10. Ricci MA, Corbisiero RM, Mohamed F, Graham AM, Symes JF. Replication of the compartment syndrome in a canine model: experimental evaluation of treatment. J Invest Surg. 1990;3:129–40.
11. Hope MJ, McQueen MM. Acute compartment syndrome in the absence of fracture. J Orthop Trauma. 2004;18:220–4.
12. Fildes J. Advanced surgical skills for exposure in trauma. 1st ed. Chicago: American College of Surgeons; 2010. p. 28–36.
13. Whitesides TE, Heckman MM. Acute compartment syndrome: update on diagnosis and treatment. J Am Acad Orthop Surg. 1996;4:209–18.
14. Finkelstein JA, Hunter GA, Hu RW. Lower limb compartment syndrome: course after delayed fasciotomy. J Trauma. 1996;40:342–4.
15. Clancy TV, Gary MJ, Covington DL, Brinker CC, Blackman D. A statewide analysis of level I and II trauma centers for patients with major injuries. J Trauma. 2001;51:346–51.
16. Demetriades D, Murray J, Martin M, et al. Pedestrians injured by automobiles: relationship of age to injury type and severity. J Am Coll Surg. 2004;199:382–7.
17. Demetriades D, Velmahos GC, Scalea TM, et al. Operative repair or endovascular stent graft in blunt traumatic thoracic aortic injuries: results of an American Association for the Surgery of Trauma multicenter study. J Trauma. 2008;64:561–70.
18. Demetriades D. Blunt thoracic aortic injuries: crossing the Rubicon. J Am Coll Surg. 2012;214(3):247–59.
19. Teixeira PG, Inaba K, Barmpara G, et al. Blunt thoracic aortic injuries: an autopsy study. J Trauma. 2011;70:197–202.
20. Mirvis SE, Shanmuganathan K. Diagnosis of blunt traumatic aortic injury 2007: still a nemesis. Eur J Radiol. 2007;64:27–40.
21. Starnes BW, Lundgren RS, Gunn M, Quade S, Hatsukami TS, Tran NT, Mokadam N, Aldea G. A new classification scheme for treating blunt aortic injury. J Vasc Surg. 2012;55(1):47–54.
22. Fabian TC, Davis KA, Gavant ML, et al. Prospective study of blunt aortic injury and helical CT is diagnostic and antihypertensive therapy reduces rupture. Am Surg. 1998;227:666–77.
23. Mattox KL, Wall MH. Historical review of blunt injury to the thoracic aorta. Chest Surg Clin N Am. 2000;10:167–82.
24. Hemmila MR, Arbabi S, Rowe SA, et al. Delayed repair for blunt thoracic aortic injury: is it really equivalent to early repair? J Trauma. 2004;56: 13–23.
25. Demetriades D, Velmahos GC, Scalea TM, et al. Blunt traumatic thoracic aortic injuries: early or delayed repair- results of an American Association for the Surgery of Trauma prospective study. J Trauma. 2009;66(4):967–73.
26. Varon J, Marik PE. The diagnosis and management of hypertensive crisis. Chest. 2000;118:214–27.
27. Golledge J, Eagle K. Acute aortic dissection. Lancet. 2008;372:55–66.
28. Khoynezhad A, Prestis K. Managing emergency hypertension in aortic dissection and aortic aneurysm surgery. J Card Surg. 2006;21:S3–7.
29. White A, Broder J, Mando-Vandrick J, et al. Acute aortic emergencies – part 2: aortic dissections. Adv Emerg Nurs J. 2013;35:28–52.
30. Biffl WL, Cothren CC, Moore EE, et al. Western trauma association critical decisions in trauma: screening for and treatment of blunt cerebrovascular injuries. J Trauma. 2009;67:1150–3.
31. Biffl WL, Hr. Ray CE, Moore EE, et al. The unrecognized epidemic of blunt carotid arterial injuries: the importance of routine follow-up arteriography. Ann Surg. 2000;235:699–707.
32. Miller PR, Fabian TC, Croce MA, et al. Prospective screening for blunt cerebrovascular injuries: analysis

of diagnostic modalities and outcomes. Ann Surg. 2002;236:386–95.
33. Edwards NM, Fabian TC, Claridge JA, et al. Antithrombotic therapy and endovascular stents are effective treatment for blunt carotid injuries: results from long-term follow-up. J Am Coll Surg. 2007;204:1007–15.
34. Cothren CC, Moore EE, Ray Jr CE, et al. Screening for blunt cerebrovascular injuries is cost effective. Am J Surg. 2005;190:845–9.
35. Crissey MM, Bernstein EF. Delayed presentation of carotid intimal tear following blunt craniocervical trauma. Surgery. 1974;75:543–9.
36. Zelenock GB, Kazmers A, Whitehouse Jr WM, et al. Extracranial internal carotid artery dissections: non-iatrogenic traumatic lesions. Arch Surg. 1982; 117:425–30.
37. Biffl WL, Moore EE, Elliott JP, et al. The devastating potential of blunt vertebral arterial injuries. Ann Surg. 2000;231:672–81.
38. Biffl WL, Moore EE, Ryu RK, et al. The unrecognized epidemic of blunt carotid arterial injuries: early diagnosis improves neurologic outcome. Ann Surg. 1998;228:462–70.
39. Cothren CC, Moore EE, Ray Jr CE, et al. Carotid artery stents for blunt cerebrovascular injury: risks exceed benefits. Arch Surg. 2005;140:480–6.
40. Eastman AL, Chason DP, Perez CL, McAnulty AL, et al. Computed tomographic angiography for the diagnosis of blunt cervical vascular injury: is it ready for primetime? J Trauma. 2006;60:925–9.
41. Biffl WL, Ray Jr CE, Moore EE, et al. Treatment related outcomes from blunt cerebrovascular injuries: the importance of routine follow-up arteriography. Ann Surg. 2002;235:699–707.
42. Biffl WL, Moore EE, Offner PJ, et al. Blunt carotid arterial injuries: implications of a new grading scale. J Trauma. 1999;47:845–53.
43. Fabian TC, Patton Jr JH, Croce MA, et al. Blunt carotid injury: importance of early diagnosis and anticoagulant therapy. Ann Surg. 1996;223:513–25.
44. Cothren CC, Moore EE, Biffl WL, et al. Anticoagulation is the gold standard therapy for blunt carotid injuries to reduce stroke rate. Arch Surg. 2004;139:540–6.
45. Hermosillo AJ, Spinler SA. Aspirin, clopidogrel, and warfarin: is the combination appropriate and effective or inappropriate and too dangerous. Ann Pharmocother. 2008;42:790–805.
46. Eberle B, Schnuriger B, Inaba K, et al. Thromboembolic prophylaxis with low-molecular-weight heparin in patients with blunt solid abdominal organ injuries undergoing nonoperative management: current practice and outcomes. J Trauma. 2011;70:141–7.
47. Geerts WH, Jay RM, Code KI, et al. A comparison of low-dose heparin with low-molecular-weight heparin as prophylaxis against venous thromboembolism after major trauma. N Engl J Med. 1996;334:701–7.
48. Guyatt GH, Akl EA, Crowther M, et al. American College of Chest Physicians Antithrombotic Therapy and Prevention of Thrombosis Panel CHEST guidelines. 2012. http://journal.publications.chestnet.org/issue.aspx?journalid=99&issueid=23443&direction=P.
49. Alejandro KV, Acosta JA, Rodriguez PA. Bleeding manifestations after early use of low-molecular weight heparins in blunt splenic injuries. Am Surg. 2003;60:1006–9.
50. Norwood SH, McAuley CE, Berne JD, et al. A potentially expanded role for enoxaparin in preventing venous thromboembolism in high risk blunt trauma patient. J Am Coll Surg. 2001;192:161–7.
51. Knudson MM, Ikossi DG, Khaw L, et al. Thromboembolism after trauma: an analysis of 1602 episodes from the American College of Surgeons National Trauma Data Bank. Ann Surg. 2004;240: 490–8.
52. Kwiatt ME, Patel MS, Ross SE, et al. Is low-molecular weight heparin safe for venous thromboembolism prophylaxis in patients with traumatic brain injury? A Western Trauma Association multicenter study. J Trauma Acute Care Surg. 2011;73:625–8.
53. Saadeh BS, Gohil K, Bill C, et al. Chemical venous thromboembolic prophylaxis is safe and effective for patients with traumatic brain injury when started 24 hours after the absence of hemorrhage progression on head CT. J Trauma Acute Care Surg. 2012;73: 426–30.
54. Dudley RR, Ishtiaque A, Bonnici A, et al. Early venous thromboembolic event prophylaxis in traumatic brain injury with low-molecular-weight heparin: risks and benefits. J Neurotrauma. 2010;27: 2165–72.
55. Lopes RD. Antiplatelet agents in cardiovascular disease. J Thromb Thrombolysis. 2011;31:306–9.
56. Benyon C, et al. Clinical review: traumatic brain injury patients receiving antiplatelet medication. Crit Care. 2012;16:228–35.
57. Narayan RK, Maas AIR, Servadei F, et al. Progression of traumatic intracerebral hemorrhage: a prospective observational study. J Neurotrauma. 2008;25: 629–39.
58. Moussa ID, Colombo A. Antiplatelet therapy discontinuation following drug eluting stent placement: dangers, reasons, and management recommendations. Catheter Cardiovasc Interv. 2009;74: 1047–54.
59. Airoldi F, Colombo A, Morici N, et al. Incidence and predictors of drug-eluting stent thrombosis during and after discontinuation of thienopyridine treatment. Circulation. 2007;116:745–54.
60. Vincenzi MN, Meislitzer T, Heitzinger B, et al. Coronary artery stenting and non-cardiac surgery. A prospective outcome study. Br J Anaesth. 2006;96: 686–93.
61. Ferraris VA, Ferraris SP, Moliterno DJ, Camp P, Walenga JM, Messmore HL, Jeske WP, Edwards FH, Royston D, Shahian DM, Peterson E, Bridges CR, Despotis G, Society of Thoracic Surgeons. The Society of Thoracic Surgeons practice guideline series: aspirin and other antiplatelet agents during

operative coronary revascularization. Ann Thorac Surg. 2005;79(4):1454–61.
62. Peck KA, Sise CB, Shackford SR, Sise MJ, Calvo RY, Sack DI, Walker SB, Schechter MS. Delayed intracranial hemorrhage after blunt trauma: are patients on preinjury anticoagulants and prescription antiplatelet agents at risk? J Trauma. 2011;71(6):1600–4.
63. Wong DK, Lurie F, Wong LL. The effects of clopidogrel on elderly traumatic brain injured patients. J Trauma. 2008;65:1303–8.