Perioperative Management

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General Aspects of Perioperative Trauma Management

The Patient

Although anyone can be a trauma patient, traumatic injury predominately affects the younger population. However, the elderly are also at risk due to increasing mobility and activity later in life. The etiologies of injury are as diverse as their comorbidities. Therefore, a patient admitted to the trauma bay at any time of day may be of any age and may have any combination of injuries and resulting problems, as well as preexisting disease, which may complicate the course of the hospital stay.

The Team

The best management of trauma patients is achieved through a coordinated and multidisciplinary approach. To achieve this goal, the combined workload of the initial assessment, primary resuscitation, diagnostic procedures, and immediate response to life-threatening situations must to be distributed. Because time is crucial, especially in the first phase after admission, joint action on diagnostic procedures and urgent treatment are necessary. Therefore, trauma surgeons, anesthesiologists, and radiologists work simultaneously and in close cooperation. Specialized assistants such as nurses or technicians provide support. The specific division of duties reduces the field of activity for each single provider and enables a better focus on individual aspects of care. Thus, the potential risks of personal overload and of resulting mistakes may be decreased. The duties and responsibilities of each team member must be defined by consensus in advance and must be communicated to the entire team. Ideally, all team members know each other, including their strengths and weaknesses. However, in large trauma centers, this may not be the case. Whenever possible, the team members should briefly introduce themselves and wear color-coded vests to help organize and identify the team members.

The Team Leader

All teams need a leader, especially if different specialties and multiple levels of hierarchy are involved. A predesignated team leader is responsible for oversight and coordination of the multidisciplinary treatment of the trauma patient. All relevant information should be communicated to the team leader. Requests posted from any member of the team (e.g., an urgent need for transfer to the OR) will influence the decision making on sequential management and priority setting. The

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clinical condition of a trauma patient is dynamic, and changes may occur quickly (e.g., a pneumothorax turns into a tension pneumothorax with hemodynamic changes). The response to any alteration of patient's condition must be immediate and targeted. Therefore, priorities should be set dynamically and flexibly.

Use of Algorithms

Various methods to optimize medical and logistic processes in trauma care have been developed worldwide. Algorithm-based guidelines help to maintain an organized workflow and allow for dynamic, situation-based, and comprehensive teamwork. The most popular international course system is Advanced Trauma Life Support (ATLS) of the American College of Surgeons [1]. Trauma physicians from various disciplines are educated and trained together as a team. Basic knowledge of such concepts is necessary for any physician involved in trauma care. However, local conditions and possible structural limitations of each trauma center may hamper the implementation of such concepts. Local standard operational procedures (SOPs) must be formulated to guarantee best practices and care.

Taking Over the Patient

The emergency medical technician (EMT) and/or emergency physician who transports the patient to the emergency department has the earliest contact with the patient. During the initial treatment at the scene, EMTs spend more time with the patient than any member of the trauma team. They perform a systematic physical examination and obtain comprehensive information on the medical history of the patient. By contact with bystanders who observed the patient's accident, they may have gathered and organized valuable information. These data may provide clues to facilitate the identification of specific injuries by providing details on the injury mechanism and kinematics. Therefore, this information must not be lost at the interface between prehospital and clinical management. The EMTs verbally describe the patient to the entire trauma team at a defined time point, in a clear and orderly manner. The team should focus on this brief overview that includes the details listed in Table 2.1. Active listening avoids unnecessary queries or misunderstandings. The team leader calls on the EMT to provide the briefing either just before or after the repositioning of the patient. Furthermore, all relevant details on prehospital findings and treatment must be documented in an adequate manner for later access.

Table 2.1 Important information from the pre-hospital phase

Scene and situation	
Kinematics and mechanisms	Height of fall, death of other passengers
Use of safety devices	Airbag, helmet or other protective gear
Time of injury	
Initial patient status	
Vitals including	ABC
Mental status (GCS or AVPU)	D: Prior to anesthesia or sedation
Treatment and progress	
Measures performed	Compression bandage applied
Medication given	Analgesics, sedatives, fluid
Were these measures successful?	Vitals and mental status, external bleeding control
Concomitant medical information	AMPLE
Difficulties at scene	Entrapment in car, difficult airway
Personal data (patient and affiliated)	Who can be contacted for more information?

A airway, *B* breathing, *C* circulation, *D* disability, *GCS* Glasgow Coma Scale, see also Table 2.9; *AVPU* alert, verbal, pain, unresponsive, see also Table 2.10; *AMPLE* allergies, medications, past medical history, last oral intake, events preceding

Initial Assessment and Treatment

The focus of the initial assessment and treatment is on identifying life-threatening conditions as soon as possible and initiating the right treatment at the right time. It is advisable to follow a standardized procedure such as the ABCDE

Table 2.2 Common reasons for obstructed airway

Tongue	Severe cognitive impairment following brain injury, cerebral hypoperfusion, intoxication or sedation
Gastric content	Aspiration
Blood	Hemorrhage from mouth or nose
Distorted anatomy	Direct trauma to the head
Foreign body	E.g., dental prosthesis, broken teeth, misapplied oral airway devices

approach and thereby to focus to the most critical disorder first. Otherwise, important information needed to deliver lifesaving therapy may be missed. "Treat first what kills first!" is an advisable principle [2].

Airway

First, it is essential to ensure an open and patent airway. A lack of oxygen is the most urgent threat to life. If the upper airway is obstructed, all further efforts to transport oxygen to the lungs will inevitably fail. Insufficient oxygenation of the blood will result in a critical undersupply to organs. The brain is most susceptible to permanent damage due to hypoxemia, and trauma patients are at risk for airway obstruction (Table 2.2). A patient who gives vocal responses will most probably have a patent airway up to that time point. If not, a simple chin lift or jaw thrust may quickly reopen the airway. The gentle insertion of nasopharyngeal or oropharyngeal airways into semiconscious patients may further secure the airway as bridging therapy. Patients with intact gag reflexes may not tolerate these devices. If they are tolerated, they may assist oxygen insufflation with non-rebreather masks in spontaneously breathing patients. Furthermore, they often facilitate bag-valve mask ventilation that may be indicated. If the patient is unconscious or has otherwise lost protective airway reflexes, a secure airway must be established immediately to prevent aspiration and ensure proper oxygenation. Whenever feasible, the patient's airway should be assessed in advance for potential difficulties with airway maneuvers. The mnemonic LEMON (look, evaluate, mallampati, obstruction, neck) [3] may be helpful. Factors predictive of difficulties are listed in Table 2.3.

Table 2.3 Some findings that may suggest the presence of a difficult airway

Long upper incisors
Short interincisor distance (<3 cm)
Extreme relation of maxillary to mandibular incisors (e.g., prominent "overbite")
Short thyromental distance (<6.5 cm or < 3 ordinary finger breadths)
Restricted visibility of uvula (e.g., Mallampati class > II)
Macroglossia
Short and/or thick neck
Limited neck mobility (chin to chest or extension)
Highly arched or very narrow palate
Obesity
History of difficult airway
Acute injury to the face, mandible or neck

The table is not intended as an exhaustive list

Endotracheal intubation is considered the gold standard but is also known to be potentially difficult, particularly in trauma patients. Furthermore, all trauma patients are non-fasting, and there is a high risk of aspiration. Orotracheal intubation should be performed using a standardized rapid sequence induction (RSI) technique. This includes preoxygenation [4–7] with 100 % oxygen to wash out nitrogen and maximize the oxygen pool and to delay arterial desaturation during successive apnea. All equipment required in the subsequent process must be at hand and tested for functionality. Next, medication to induce anesthesia is administered through a patent IV access. Bag-valve mask ventilation before intubation should be avoided unless the patient's ventilation is inadequate. The vocal cords are visualized by direct laryngoscopy, and the endotracheal tube (ET) is gently passed through them. If the first attempt to correctly place the ET fails, a re-saturation of the patient by manual ventilation (100 % oxygen with a tight-fitting mask including reservoir) is required. If fluids such as blood or saliva occlude the visual field, cautious suctioning of the mouth and pharynx may improve conditions for the next attempt.

Table 2.4 Common indications for endotracheal intubation

Cardiac or respiratory arrest
Airway obstruction
Respiratory insufficiency
Severe hypoxemia (despite supplemental oxygen)
Severe cognitive impairment (GCS < 8) requiring airway protection
Need for deep sedation or analgesia (also preoperative management)
Severe hemorrhagic shock
Increased intracranial pressure (transient hyperventilation)
Delivery of 100 % oxygen to patients with carbon monoxide intoxication
Facilitation of management (e.g., diagnostics) in combative or intoxicated patients

Immediately after successful intubation, the correct endotracheal position of the tube must be verified by the use of a carbon dioxide detector, ideally by capnography. If capnography is not available, a colorimetric CO_2 monitoring device may indicate proper intubation of the airway or false esophageal intubation. Because neither device is capable of detecting main-stem bronchus intubation, a physical examination including a thorough auscultation in search of bilateral ventilation and thoracic excursion is required. Radiographic imaging can also identify an excessively deep intubation. Securely fixing the ET helps to prevent tube dislocation during later patient movement (e.g., transfer to computer tomography). During the entire airway maneuver, monitoring of oxygen saturation, cardiac rhythm, and blood pressure is mandatory. Common indications for endotracheal intubation are listed in Table 2.4.

Additionally, trauma patients with suspected cervical spine injury require gapless immobilization of the cervical spine until a radiographic diagnosis can securely rule out an injury. Therefore, an additional assistant is required to properly provide manual inline immobilization (MILS) of the cervical spine during the entire airway maneuver [8]. The anterior portion of the cervical collar may be opened while strictly maintaining MILS, but conventional laryngoscopy may still be difficult.

Difficult Airway

There is no standard definition of a difficult airway in the literature. A difficult airway is complex and challenges all physicians involved in airway management. Multiple factors derived from the patient, the clinical setting, and the expertise of the practitioner contribute to difficulty. The "Practice Guidelines for Management of the Difficult Airway" [9] developed by the American Society of Anesthesiologists Task Force on Difficult Airway Management [10] suggests the use of the following descriptions:

1. Difficult face-mask ventilation
2. Difficult laryngoscopy
3. Difficult tracheal intubation
4. Failed intubation (after multiple intubation attempts)

Repeated intubation attempts (>2) are independently associated with increased adverse events such as hypoxemia, dysrhythmia, cardiac arrest, regurgitation or aspiration, airway or dental trauma, and main-stem bronchus or unrecognized esophageal intubation [11, 12]. Hence, the use of alternative airway devices should be considered if multiple attempts to secure the patient's airway by conventional direct laryngoscopy techniques fail. A difficult airway cannot always be anticipated and can easily surprise an unprepared emergency team. Everyone who is or who may become responsible for securing the airway must have a predesigned strategy to cope with an expected or unexpected difficult airway. Standardized protocols tailored to the specific setting of each trauma center facilitate decision making in situations with time constraints and enable the trauma team to be ahead of the emergency. In case of a suspected difficult airway, the difficult airway protocol in effect should be followed immediately. The accepted standard of care for an anticipated difficult intubation is conscious intubation using a flexible bronchoscope.

In addition, numerous supraglottic/extraglottic airway devices are available. Most are part of routine daily anesthesia care, but they are also considered rescue devices in difficult airway scenarios. These devices can be blindly inserted to an extraglottic position, and they allow for indirect ventilation through a glottic opening. Some devices allow for the placement of a stylet, exchange catheter or flexible fiberscope through the airway device into the trachea. An endotracheal tube can then be railroaded over the provided guide wire to secure the airway.

A variety of fiber-optic or video-assisted rigid laryngoscopes allow for direct visualization of the intraglottic airway in real time to securely place an endotracheal tube. These commercially available devices differ in size and quality with respect to attached or remote video screens, and they have the option of tube guidance. One instrument's particular feature may be advantageous in certain circumstances but disadvantageous in others (e.g., the size of video screen aids viewing but limits portability). Whereas video laryngoscopy generally offers better glottic visualization than conventional laryngoscopy [13–15], the success rates of endotracheal intubation are not necessarily higher due to the difficulties of tube insertion with some devices [15]. Furthermore, blood, emesis, or airway injury may occlude the optical portion of the device and limit the video-laryngoscopic view in trauma patients.

Patients with suspected or known cervical spine injury do not necessarily have a difficult airway, but they may need a technique with the least cervical motion to prevent further injury to the spine. There is ongoing debate about best practices in the traumatized patient [16–18]. A conscious fiber-optic intubation is preferable in cooperative, hemodynamically stable patients who are not in immediate respiratory distress [19]. While the use of flexible fiber-optic bronchoscopes has some advantages, it is time-consuming. If time is essential to securing the airway, more rapid alternatives, such as those described above, should be used.

The clinicians will have to choose among the broad variety of tools and techniques depending on the actual situation and/or algorithm. The physicians responsible for airway management should have experience with at least two or three different instruments. To become familiar with these techniques, the tools can be used in routine cases to prepare for the management of difficult airways. To discuss all available and suitable alternative airway devices here would go beyond the scope of this chapter; they are described elsewhere [8, 13–16, 18–26].

If all options fail to intubate, ventilate, or oxygenate the patient, cricothyrotomy may be the final lifesaving procedure. These final options include needle cricothyrotomy, percutaneous cricothyrotomy, or surgical cricothyrotomy with emergency tracheostomy.

If a patient is admitted with an airway device in place, its correct positioning must immediately be confirmed by capnography and auscultation. Once the airway is secured and thoroughly confirmed or the conscious patient offers a patent airway, high-flow oxygen should be insufflated before the assessment of breathing and ventilation.

Breathing

The quality as well as the quantity of breathing and ventilation are essential parts of the initial assessment. In spontaneously breathing patients, the evaluation of the respiratory rate, rhythm, and effort to breathe provides a quick overview of the patient's condition. While approaching the patient, the examination should note signs such as nose flaring, agitation, labored respiration, or the inability to speak several words coherently. Any abnormalities may indicate respiratory distress and compromised air exchange. In addition, the respiratory rate should be counted or at least assessed. A slow (<10) or high (>20) respiratory rate urgently needs attention. Changes in the respiratory rate require immediate treatment, as they are reliable markers for insufficient ventilation. The supply of oxygen by a non-rebreather face mask with a reservoir may not be enough to compensate for insufficient ventilation. In these cases, assisted bag-valve mask ventilation facilitates ventilation, optimizes oxygenation, and may avert further deterioration of the patient's respiratory condition. A respiratory rate within the normal range combined with a shallow depth of breathing also indicates that assistance is needed. This type of breathing is considered to be hypoventilation causing respiratory hypercarbia/hypercapnia, and it has the potential to influence mental status (e.g., somnolent or very fatigued patients). The responsible physician should look for symmetry of chest raises (e.g., flail chest) and thoroughly auscultate for bilateral lung sounds in patients that are spontaneously breathing or on mechanical ventilation (if not performed during airway management). Audible respiratory sounds indicate upper airway obstruction, whereas decreased or absent lung sounds are highly suspicious of a pneumothorax or hemothorax. The suspicion should be ruled out or confirmed and diagnosed more precisely with a chest x-ray [27]. Painful or irregular breaths may be trauma-related and should be monitored to identify any thoracic injuries. Severe impairment of breathing and ventilation is suspected in the presence of a tension pneumothorax, injuries to the spinal cord, or traumatic brain injury with alterations to the regulatory respiration center. Clinical signs of a pneumothorax include rather unspecific findings such as tachypnea and tachycardia but also more specific findings as pulsus paradoxus, decreased breath sounds, and hyperresonance on percussion on the affected side. In addition to these signs and symptoms, some patients present with diminished mental status caused by hypoxia. Audible breath sounds do not rule out a pneumothorax. A hypoxic, cyanotic patient with increased jugular venous distention is highly susceptible to a tension pneumothorax and needs urgent treatment. A tension pneumothorax increases the intrathoracic pressure. Therefore, the need for unusually high airway pressure in patients on mechanical ventilation is another sign of a life-threatening tension pneumothorax. Lifesaving decompression of the chest should be initiated immediately in hemodynamically instable patients (obstructive shock). Rapidly performed needle decompression can bridge therapy until a chest tube can be inserted to restore an air-free pleural space. Whereas radiographic imaging corroborates the diagnosis of a pneumothorax and allows for differentiation of a hemothorax, a tension pneumothorax must be treated without delay, i.e., without waiting for radiologic confirmation. The diagnosis can be made mainly on the basis of clinical examination findings and attentive observance of the patient.

Table 2.5 Causes of inadequate ventilation

Pneumothorax or hemothorax
Direct trauma to chest wall
Injury of the airway (trachea or mainstem bronchi)
Lung contusion
Decreased respiratory drive (resulting from traumatic brain injury, shock, hypothermia, intoxication or excessive sedation)
Aspiration (blood, gastric content)
Cervical spine injury
Toxic lung edema (following gas inhalation)

Inadequate ventilation may also be caused by the other factors listed in Table 2.5. It is important to note that a patient may suffer from various conditions in parallel that interfere with ventilation. Therefore, all possible reasons for inadequate ventilation must be assessed if the patient is in respiratory distress. An intubated patient may also rapidly deteriorate. As a first step, the patient is taken off the ventilator, and manual ventilation is performed. This change adds the sense-based information derived from the use of the bag. At the same time, the use of the mnemonic DOPE [26] to quickly assess the most common causes of an acute decline in patients on mechanical ventilation may be helpful:

D. **Displaced tube**? Bilateral breath sounds still present? Positive capnography?

O. **Obstructed tube**? Does thick mucus obstruct the tube? If so, perform suctioning. Does the patient bite on the tube? Ensure adequate anesthesia depth.

P. **Pneumothorax**? Positive pressure ventilation may exacerbate the valve effect of an existing pneumothorax and progressively build up further pressure in the pleural space. Auscultate and check for elevated airway pressure.

E. **Equipment failure**? Check for oxygen supply. Does the ventilator function correctly? If in doubt, replace any questionable equipment.

Circulation

Once a patent or secured airway and optimized conditions for breathing and ventilation are established, gas exchange and oxygenation of the blood can take place. Subsequently, sufficient circulation is a mandatory precondition to transport oxygen to the tissues on demand. Although initial monitoring of a trauma patient includes standard monitoring (i.e., ECG, pulse oximetry, and noninvasive blood pressure measurement), a brief, easy-to-perform, and focused clinical examination will provide valuable information on the patient's perfusion and circulatory condition. This includes pulse palpation and an assessment of cardiac rhythm. The absence of a palpable pulse on an uninjured extremity may indicate the decompensated phase of shock. Pale, cold, and damp skin is also associated with shock and severely diminished perfusion and can be evaluated within seconds. Furthermore, a prolonged capillary refill time (>2 s) is suggestive of affected perfusion. However, trauma patients are disproportionately young and without limiting comorbidities [28]. Therefore, they can often compensate severe blood loss for a certain period of time without being hemodynamically compromised. Once the blood loss overcomes the compensatory capacities, a rapid and potentially fatal breakdown of circulation occurs. To assess the severity of insufficient circulation and shock, lactate and/or base excess measurement is recommended [29]. To prevent circulatory collapse and avoid secondary damage to the patient, bleeding control at the earliest possible moment is crucial.

Bleeding Control

Control of ongoing hemorrhages should be initiated on arrival and without delay. Manual pressure or pressure dressings may control continuous external bleeding. If direct pressure fails to arrest life-threatening blood loss from extremities, a tourniquet may be applied early as a lifesaving measure [30–32]. Most evidence for the beneficial use of tourniquets is derived from battlefield injuries [31–36]. However, that type of injury and the injury circumstances differ from the mangled extremities observed in civilian life. Tourniquets can be used temporarily to allow further diagnostics and aid resuscitation until surgery is possible. To avoid potential side effects from tourniquets, such as limb ischemia or nerve paralysis, the duration of tourniquet application should be as short as possible [37, 38]. Furthermore, the use of operative tourniquet systems that are commonly employed in elective surgery is favored over field tourniquets with regard to adverse events [39]. If available, it is advisable to switch to pneumatic devices with an appropriate inflation (above systolic pressure) in case the EMT has applied a field tourniquet to stop a life-threatening hemorrhage.

Severe bleeding may also occur from pelvic fractures. Several circumferential pelvic binders are available for temporary and rapid pelvic closure. In some types of fracture patterns, external pressure applied to the pelvis successfully reduces the pelvic volume. This compression may be sufficient to arrest bleeding from lacerated vessels (mainly veins and smaller arteries) and cancellous bone. The stabilization of pelvic fractures in the emergency department with commercial compression devices or simple bed sheets in hemodynamically instable patients is advised in the Advanced Trauma Life Support guidelines [40]. All of these measures are temporary and are considered adjunct treatment options to minimize blood loss until definitive control of bleeding is achieved.

Whereas surgery is the mainstay of bleeding control, transcatheter angiographic embolization (TAE) is an alternative to arrest hemorrhage in a certain subgroup of patients. TAE is an established, minimally invasive technique to control arterial bleeding from solid organ injury or pelvic fracture [41–45]. In general, TAE is associated with low morbidity [44–47], but complications such as necrosis of the distal colon, ureter, uterine, and bladder as well as perineal wound sepsis [48], ischemic damage of the gluteal muscle[49], and paresis [50] have been reported. These risks should be considered if angiography and embolization are an option for the diagnosis and acute treatment of the bleeding patient and may outweigh the published success rates of over 90 % in arresting pelvic hemorrhage [45, 51–54]. TAE should be performed soon after admission in hemodynamically unstable patients with ongoing or suspected bleeding [55] because mortality rates increase from 14 to 75 % if intervention is delayed (>3 h) [51]. However, there are still ongoing debates regarding how to identify patients who will benefit from early TAE and how to determine the most beneficial sequence of angiographic embolization to control bleeding relative to surgical interventions [56, 57]. At this time, there are no homogeneous results from clinical studies that precisely aid clinical decision making and refine the optimal timing of TAE versus surgery. Depending on institutional resources, each physician or institution will have to decide which treatment to perform first to control bleeding and avoid further deterioration, such as hemorrhagic shock.

Hemorrhagic Shock

Significant blood loss following trauma may sequentially lead to hemodynamic instability, decreased tissue perfusion, cellular hypoxia, organ damage, and death. According to ATLS [1], the mechanism of injury in combination with the severity of injury, the patient's physiological condition, and the response to volume resuscitation may be used to guide the initiation of surgical bleeding control. For the degree of hemorrhagic shock and subsequent interventions, it is therefore essential to estimate blood loss. Definitions of blood loss are displayed in Table 2.6 [58]. Early signs of shock are: altered level of consciousness as a result of reduced cerebral perfusion, delayed capillary refilling, mottled skin as a consequence of reduced peripheral perfusion, as well as oliguria. An accurate estimation of total fluid loss is further aggravated by urinary loss, insensible perspiration, and tissue edema. Thus, it is important to remember that the average adult blood volume represents approximately 7 % of body weight and that older individuals have a smaller blood volume. In comparison, children have an average of 8–9 % blood volume of body weight, whereas infants have a total blood volume of 9–10 % of their total body weight. An acute blood loss of up to 750 mL is considered as non-shock, whereas a class IV shock is a preterminal state requiring immediate therapy (Table 2.7) [59, 60].

Predictors of Shock and Coagulopathy

Measurements of hematocrit are routinely obtained in bleeding patients. A considerable limitation of the hematocrit is the influence of fluid administration and RBC transfusion [61, 62]. Although frequently measured hematocrit may be an indicator for ongoing blood loss, traumatized patients with significant blood loss may also show a stable hematocrit.

Thus, serial measurements of serum lactate and base excess are more sensitive markers to estimate the extent of bleeding. The level of lactate generated by anaerobic glycolysis and tissue hypoperfusion is an indirect marker for hemor-

Table 2.6 Definitions of massive severe blood loss

Loss of an entire blood volume equivalent within 24 h; or
Loss of 50 % of blood volume within 3 h; or
Continuing blood loss at a rate of 150 mL/min; or
Continuing blood loss at a rate of 1.5 mL/kg/min over 20 min; or
Rapid blood loss leading to decompensation and circulatory failure, despite the support of blood products, volume replacement, and all accepted surgical and interventional treatments to stop bleeding

Modified according to Grottke et al. [58]

Table 2.7 Classification of hemorrhagic shock

	Class			
Parameter	I	II	III	IV
Blood loss (mL)	<750	750–1,500	1,500–2,000	>2,000
Blood loss (%)	<15	15–30	30–40	>40
Heart rate (beats/min)	<100	>100	>120	>140
Blood pressure	Normal	Decreased	Decreased	Decreased
Respiratory rate (breaths/min)	14–20	20–30	30–40	>35
Urine output (mL/h)	>30	20–30	5–15	Negligible
CNS symptoms	Normal	Anxious	Confused	Lethargic

Modified from American College of Surgeons Committee on Trauma [60]
CNS central nervous system

rhagic shock, as shown by Manikis et al. [63]. In this study, initial lactate levels of patients with significant trauma were increased in non-survivors. Aside, it was shown that a prolongation of normalization of elevated lactate levels was also associated with the development of organ failure. Accordingly, base deficit has been shown to be also a potential predictor of mortality in patients with hemorrhagic shock following major trauma [64]. For instance, both in adult and pediatric patients, the base deficit was sensitive for the degree of hemorrhagic shock and mortality [65, 66].

The degree of coagulopathy correlates with the severity of trauma and shock [67]. The high mortality associated with hypothermia, metabolic acidosis, and coagulopathy is also referred to as the "lethal triad" or the "bloody vicious cycle." The metabolic derangements and acidosis affect the coagulation system [68]. A prolongation of clotting time, reduced clot strength, and an increase of the degradation of fibrinogen have been observed after the induction of acidemia induced by hydrochloric acid [69, 70].

The causes of hypothermia are multifactorial and interdependent, including altered central thermoregulation, decreased heat production due to tissue hypoperfusion in hemorrhagic shock, exposure to low ambient temperature, and infusion of inadequately warmed resuscitation fluids and blood components [71]. Apart from an impairment of enzyme activity, lower temperatures correlate with reduced synthesis of coagulation factors and also lead to an alteration of platelet function. Thus, mortality in injured patients with temperatures below 32 °C is increased [72]. Clinically significant effects on coagulation, platelet function, and clinical bleeding are already seen at moderately hypothermic temperatures below 34 °C [73]. TF-FVIIa complex activity is reduced linearly with temperature showing only 50 % of the original activity at 28 °C as compared to normothermia [74]. The effect of hypothermia on platelets is addressed to an impaired signal transduction from initial adhesion to activation of platelets mediated by von Willebrand factor traction on glycoprotein Ib/IX receptors [75].

Fluid Administration and RBC Transfusion

The primary goal of volume resuscitation in traumatized patients is to restore tissue perfusion to maintain end-organ function and to avoid inadequate tissue perfusion manifested by anaerobic metabolism as well as lactic acidosis. Generally, crystalloid or colloid solutions are available. Crystalloids may be categorized as hypotonic, isotonic, or hypertonic. For volume resuscitation, only isotonic and hypertonic fluids are employed because hypotonic solutions do not stay in the intravascular space. Crystalloids are inexpensive and resuscitate both the intravascular and interstitial space. Disadvantages include the formation of edema in patients with capillary leak, and higher volumes are needed to achieve equivalent intravascular volume effects compared to colloids.

Colloids are classified into protein and nonprotein solutions. The colloids with protein are albumin (5 % and 25 %) and gelatin solutions. Available nonprotein colloids are starches with various molecular weights (6 % hetastarch, 10 % pentastarch) and dextrans (e.g., dextran-40). In comparison to crystalloids, colloids remain longer in the intravascular space, exhibit greater volume expansion, and presumably cause less edema. The primary drawbacks include the potential for anaphylaxis (especially with dextrans and gelatin solutions) and a negative impact on coagulation, and they have the potential to cause negative effects on renal function by tubular injury. Despite several studies in the last two decades, it is still unclear what type of volume should be employed as primary resuscitation fluid. Numerous studies have documented an increased risk of death in patients treated with colloids compared with patients treated with crystalloid solutions [76, 77]. This effect was even more pronounced in trauma patients [78, 79]. In contrast, a meta-analysis performed by Roberts et al. showed no difference in mortality between treatment with colloids and crystalloids [80]. The infusion of hypertonic solutions has been shown to lower intracranial pressure and improve survival in patients with penetrating torso injuries requiring fluid resuscitation [81].

Generally, various resuscitation regimes, the heterogeneity of the study populations, and different outcome parameters complicate the accurate analysis of available studies. However, currently, the use of crystalloids in bleeding patients for initial therapy is advised [29]. Hypertonic solutions may also be considered, although the evidence for increased survival is inconclusive. In hemodynamically unstable patients, the infusion of modern hydroxyethyl starch or gelatin can be considered.

Transfusions of red blood cells (RBCs) are a mainstay in trauma management. The concept of specific component therapy was developed during the 1960s. Whole units of blood are separated into plasma, platelets, and RBCs, and these components may be separated further (e.g., by cryoprecipitation). This strategy allows for resource allocation according to the individual needs of the patient, resulting in both economic and logistical benefits. One disadvantage is that substitution with plasma-free and thrombocyte-depleted RBCs may lead to coagulopathies at an earlier stage compared to the substitution of whole blood. For example, an analysis from the Vietnam War showed that platelet counts did not fall below 10×10^9/L, despite massive transfusions of 6 L of whole blood [82].

RBC transfusions are used to treat hemorrhage and anemia and to improve oxygen delivery to tissues. Erythrocytes also contribute to hemostasis by influencing the biochemical and functional responsiveness of activated platelets via the rheological effect on platelet margination and by supporting thrombin generation [83]. To date, no prospective randomized trials are available that have determined the optimal transfusion trigger in the resuscitation of traumatized patients. Reanalyzed data from the Transfusion Requirements in Critical Care trial showed that critically ill patients could tolerate hemoglobin levels as low as 7 g/dL [84, 85]. The restrictive transfusion regimen (transfusion trigger <7 g/dL) resulted in a reduced number of RBCs transfused compared to a liberal regimen (transfusion trigger <10 g/dL). Although the analysis did not show a beneficial effect of a restrictive transfusion approach, as reflected by similar incidences of multiorgan failure (MOF) and post-traumatic infections, the approach may still have provided benefits because the study was not primarily designed or powered to answer this question. In contrast, an observational study with 15,534 patients by Malone et al. revealed different results; in this trial, 1,703 trauma victims received on average 6.8 ± 6.7 units of RBCs [86]. After controlling for potential confounders—injury severity score (ISS), Glasgow coma score (GCS), shock variables, age, and race—RBC transfusion was associated with increased mortality, admission to ICU, and ICU length of stay. Until further RCTs adequately address these issues, it is generally agreed that hemoglobin levels in bleeding patients should be maintained at 7–8 g/dL. Although many centers transfuse patients with traumatic brain injury (TBI) to achieve hemoglobin levels of 10 g/dL, there is no strong evidence for this approach. Thus, targeting a higher hemoglobin level in patients with TBI compared to other critically ill patients is not recommended. In multiple studies, transfusions of RBCs have been shown to be associated with increased mortality, acute lung injury, incidence of post-traumatic infections, and renal failure (Table 2.8) [87, 88]. These adverse events may

Table 2.8 Acute and delayed complications of transfusion

Acute complications
Acute hemolytic transfusion reaction
Febrile non-hemolytic transfusion reactions
Transfusion-related acute lung injury
Allergic reactions
Bacterial sepsis
Hypocalcemia
Hyperkalemia
Acidosisa
Hypothermia
Dilutional coagulopathy
Delayed complications
Delayed hemolytic transfusion reactions
Transfusion-related immmunomodulation; Post-traumatic infections
Multi organ failure
Transfusion-transmitted diseases
Post-transfusion graft-versus-host disease
Post-transfusion purpura

be particularly important with RBC transfusions stored for more than 14 days [89].

Permissive Hypotension in Traumatized Patients

Traditional concepts of volume resuscitation in the actively hemorrhaging trauma patient emphasize maintenance of a normal systolic blood pressure. This approach may increase the risk of the dissolution of blood clots from the wound by increasing the hydrostatic pressure. The strategy to avoid this negative impact on early aggressive volume resuscitation while maintaining sufficient organ perfusion is called "permissive hypotension". Although the evidence from large RCTs is still missing, studies have shown a positive impact of permissive hypotension in patients with penetrating trauma [90, 91]. Aside, a Cochrane meta-analysis showed no negative effects of this regime as compared to early or larger volume resuscitation [92]. In patients with proven or signs of traumatic brain injury and spinal injuries, the low-volume approach is contraindicated. Lower blood pressures bear the risk of insufficient perfusion pressure, which is necessary to ensure tissue oxygenation of the injured central nervous system.

Conclusively, a systolic blood pressure of 80–100 mmHg should be maintained until major bleeding has been terminated in the initial phase of treatment of injured patients without injuries of the central nervous system.

Use of Vasopressors

Although fluid resuscitation is the first approach to restore sufficient mean arterial pressure in hemorrhagic shock, the use of vasopressor therapy may be required as adjunctive therapy to maintain tissue perfusion and sustain life. Aside, some severely injured patients may be nonresponsive to fluid resuscitation. Although larger studies from humans in the field of hemorrhagic shock are missing, current evidence from experimental studies suggests the use of norepinephrine vasopressor therapy [93]. Norepinephrine is a potent α1[alpha1]-adrenergic receptor agonist with modest β[beta]-agonist activity. The stimulation of α1[alpha1]-receptors predominantly exhibits vasoconstriction and less direct inotropic properties. Thus, norepinephrine primarily increases systolic, diastolic, and pulse pressure and with minimal impact on net cardiac output and chronotropic effects. The increase of the sympathetic tone may also be favorable in the face of the potential negative sympathetic tone effects of medications used for sedation. In cases of poor response to fluid resuscitation or any signs of cardiac trauma, a close evaluation of cardiac function is needed. To maintain cerebral perfusion in patients with TBI, the mean arterial pressure should be maintained at 80 mmHg, whereas a systolic pressure of 80–100 mmHg is advised in traumatized patients without TBI [29].

Disability

The assessment of the patient's mental status or cerebral function may be used in the early evaluation as a surrogate parameter for cerebral perfusion. The brain is very sensitive to an acute undersupply of oxygen. Therefore, any acute changes in the patient's level of consciousness or behavior must be noted and monitored carefully while searching for the underlying cause. Neurological alterations are often an early, if not the first, sign of severe deterioration (e.g., the initiation of shock or hypoxia). Changes in mental status must to be interpreted based on the initial neurological findings. This assessment begins with a critical look at the patient's behavior; for example, an aggressive, combative trauma patient who is reluctant to cooperate in any way is highly susceptible to an acute hypoxemia or a traumatic brain injury. In addition to observation, neurological scoring systems such as the Glasgow Coma Scale (GCS; Table 2.9) or the simple mnemonic AVPU (alert, verbal, pain, unresponsive; Table 2.10) [94] offer quantifiable scoring rates. To detect any changes over time, the neurological examination should be performed repeatedly. Both assessment tools rate the patient's response to external stimuli such as verbal commands and pain. The evaluation of mental status using the AVPU scheme is simple but also less detailed than that using the GCS. The AVPU focuses on

Table 2.9 Glasgow Coma Scale

Parameter	Score	Response
Eye-opening	4	Spontaneous
	3	To speech
	2	To pain
	1	None
Best verbal response	5	Oriented
	4	Confused
	3	Inappropriate words
	2	Incomprehensible sounds
	1	None
Best motor response	6	Obeys commands
	5	Localizes pain
	4	Withdraws from painful stimuli
	3	Abnormal flexion (decorticate posturing)
	2	Abnormal extension (decerebrate posturing)
	1	None

Table 2.10 AVPU

AVPU level	Response and assessment findings	
Alert	Spontaneous	
	Alert and oriented × 4	Person, place, time, and event
	Alert and oriented × 3	Person, place, and time
	Alert and oriented × 2	Person and place
	Alert and oriented × 1	Person only
Verbal	Responds to verbal stimuli	
Pain	Responds to painful stimuli	
Unresponsive	No response	

Modified according to Aehlert [94]

awareness as demonstrated by orientation to person, place, and time. For example, a patient who is aware of his own person as well as time and place is considered to be alert and oriented ×3. An APVU grade lower than three characterizes a patient who is confused or disoriented. The GCS is a more comprehensive and effective tool to assess neurological function. A score for each patient's response to eye opening (*E*) and best verbal (*V*) and motor response (*M*) is documented. The scores sum to a total score ranging from 3 (poorest) to 15 (best), for example, $E=2$, $V=3$, and $M=5$, total GCS score of 10. Significant changes in mental status (beginning in the prehospital setting; see Table 2.1) are reflected in changes in the documented scores. A score of 8 or less is usually considered an indication for endotracheal intubation. Both neurological assessment tools help to determine the patient's neurological status, but they share one major limitation: they do not account for pupillomotoric responses. Adequately functioning pupils are equal in size, round, and promptly reactive to stimulation with light. Unilateral dilatation and/or unequal reactivity to light in an unconscious trauma patient may be a consequence of brain herniation (i.e., pressure on cranial nerve III, oculomotor).

In summary, there are four principal reasons for a diminished state of consciousness in trauma patients:

- Reduced cerebral oxygenation (caused by hypoxemia and hypoperfusion)
- Injury to the central nervous system
- Drug or alcohol abuse
- Metabolic and neurological deviation (diabetes mellitus, epilepsy)

These causes may be present in any combination and may interrelate. They may have caused the trauma itself (e.g., a road accident due to drug intoxication). Every patient with a conspicuously altered mental state should receive a thorough neurological examination. A cranial computer tomogram should be considered in any unconscious (or intubated) patient who cannot be examined and/or who arouses suspicion of a brain injury.

Exposure

The final step in the initial assessment is the complete exposure of the patient. All clothing is removed to allow for a physical examination. Apparent injuries tend to attract attention by their graphic appearance, with the risk of underdiagnosing less obvious but sometimes more threatening issues. Therefore, a rapid head-to-toe or a more focused exam depending on the acute situation of the patient is necessary to detect any further injuries or deformities. This examination must also include the patient's back. To avoid hypothermia and for ethical reasons, the patient is covered with blankets once the physical examination and the complete initial assessment are finished.

Key Points

- The perioperative management of trauma patients can be challenging, especially in the initial phase of care, when multiple diagnostic procedures and urgent treatment are necessary to be performed in parallel. The multidisciplinary approach of the initial care can be coordinated best by standardized, algorithm-based procedures that are practiced by the entire team.
- Airway management is crucial in the treatment of emergency patients because a lack of oxygen is the most urgent threat to life. An insufficient oxygenation puts the patient at imminent risk and will inevitably inhibit an effective treatment in the further course. Therefore, every care provider must be proficient in standard techniques for securing the airway.
- Airway management can be difficult, particularly in trauma patients. Because a difficult airway cannot always be anticipated, the trauma team must have a predesigned strategy to cope with difficulties in securing the airway, and alternative airway devices must be immediately available.
- Bleeding control at the earliest possible moment is fundamental to prevent circulatory collapse/shock and avoid secondary damage to the patient. Serial measurements of serum lactate and base excess are sensitive markers to estimate the extent of bleeding.
- The best volume resuscitation regime is still under debate, but currently the use of crystalloids in bleeding patients for initial therapy is advised.
- RBC transfusions are used to treat hemorrhage and anemia and to improve oxygen delivery to tissues, whereas the optimal transfusion trigger in the resuscitation of traumatized patients has still to be determined.
- Neurological alterations are often an early, if not the first, sign of severe deterioration (e.g., initiation of shock or hypoxia) and may be used as a surrogate parameter for cerebral perfusion during the very early evaluation of the patient.
- Hypothermia increases mortality and morbidity in injured patients and must be avoided/corrected by any means.

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