Notable Grand Rounds
of the
Michael & Marian Ilitch
Department of Surgery

Wayne State University
School of Medicine

Detroit, Michigan, USA

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TRAUMA ANESTHESIA AND
PERIOPERATIVE VOLUME RESUSCITATION

July 17, 2024

About Notable Grand Rounds

These assembled papers are edited transcripts of didactic lectures given by mainly senior residents, but also some distinguished attending and guests, at the Grand Rounds of the Michael and Marian Ilitch Department of Surgery at the Wayne State University School of Medicine.

Every week, approximately 50 faculty attending surgeons and surgical residents meet to conduct postmortems on cases that did not go well. That "Mortality and Morbidity" conference is followed immediately by Grand Rounds.

This collection is not intended as a scholarly journal, but in a significant way it is a peer reviewed publication by virtue of the fact that every presentation is examined in great detail by those 50 or so surgeons.

It serves to honor the presenters for their effort, to potentially serve as first draft for an article for submission to a medical journal, to let residents and potential residents see the high standard achieved by their peers and expected of them, and by no means least, to contribute to better patient care.

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Trauma Anesthesia and Perioperative Volume Resuscitation

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Grand Rounds presentation

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Introduction

Trauma is the leading cause of death for individuals up to the age of 45 and the third leading cause of death across all age groups. In the United States, trauma results in over 180,000 deaths annually, more than 3 million non-fatal injuries, and approximately 2.8 million hospital admissions. Anesthesia plays a critical role from the emergency department (ED) through the operating room (OR) to the intensive care unit (ICU), encompassing airway management, pain control, and patient resuscitation.

Challenges for Anesthesia

Trauma anesthesia presents several unique challenges. Cases are often urgent or emergent, occurring during off-hours with limited resources. Patient history is typically unavailable, and the patient's NPO (nil per os) status is unknown, necessitating the assumption of a full stomach. The potential use of illicit drugs is also unknown. Access to the patient is limited, and immediate surgical intervention is often required in severe trauma cases. Secondary examinations for additional injuries are limited due to the urgency of surgery and the need for general anesthesia. Occult injuries, such as tension pneumothorax or cardiac tamponade, may not present until later, leading to rapid patient deterioration.

Advanced Trauma Life Support (ATLS)

A cornerstone of the ATLS curriculum is the ABCDE (airway, breathing, circulation, disability, exposure) approach to the rapid initial evaluation of injured patients. Despite adaptations for combat and disaster settings, ATLS continues to emphasize the prioritization of life-threatening airway and breathing problems before circulation issues, though this remains controversial. Rapid assessment of the airway, including the patient's ability to speak and answer questions, as well as verification of adequate ventilation and circulation, is a critical component in the management of trauma patients.

Airway

Initial Evaluation

The first step in managing a trauma patient is to assess airway adequacy, ensuring that the patient can maintain sufficient oxygenation and ventilation. Continuous monitoring with pulse oximetry is crucial to keep track of oxygen levels. Minute ventilation, calculated by multiplying the respiratory rate by the tidal volume, helps assess the patient's breathing efficiency. Additionally, observing the work of breathing can provide clues about potential respiratory distress.

Several factors can compromise airway adequacy in trauma patients. Altered consciousness due to head trauma or the influence of drugs and alcohol can impair airway maintenance. Direct trauma to the maxillofacial region, neck, or larynx may also pose significant risks. Severe blood loss leading to a low Glasgow Coma Scale (GCS) score, as well as respiratory failure from blast injuries, inhalation injuries, or chemical exposure, are other critical considerations. Studies indicate that between 7% and 30% of trauma patients will require definitive airway management, either through endotracheal intubation (ETT) or surgical airway intervention.

Identifying airway obstruction involves a multi-faceted approach. Visually, signs such as obtundation, tachypnea, agitation, cyanosis, retraction or use of accessory muscles, and asymmetric chest rise may indicate fractures or pneumothorax. Auditory assessment includes listening to the patient's voice for abnormalities and detecting stridor, abnormal breath sounds, crackles, or gurgling. Palpation can reveal crucial information such as a deviated trachea, severe fractures, or subcutaneous emphysema.

In trauma situations, it is essential to assume all patients have a compromised airway until it is conclusively ruled out. Ensuring supplemental oxygen and cervical stabilization is a standard protocol for all patients. If time allows, a more detailed airway assessment for anesthesia can be performed. This includes evaluating the mouth opening for size and signs of trauma or blood, measuring the thyromental distance (less than three fingerbreadths indicating a possible difficult airway), assigning a Mallampati score (ranging from grades 1 to 4), checking for obstructions, and assessing neck mobility, which is often limited in trauma patients due to cervical collars.

Following the airway evaluation, the ability to mask ventilate the patient is assessed. (See **Fig. 1** on next page for difficult intubation guidelines.) Predictors of difficult mask ventilation are summarized by the BONES acronym: Beard, Obesity, No teeth, Elderly (over 55 years), and Snorer. Based on this comprehensive assessment, the medical team can decide on the appropriate intervention, whether it involves continuing with supplemental oxygen or proceeding with definitive airway management using an ETT or surgical airway.

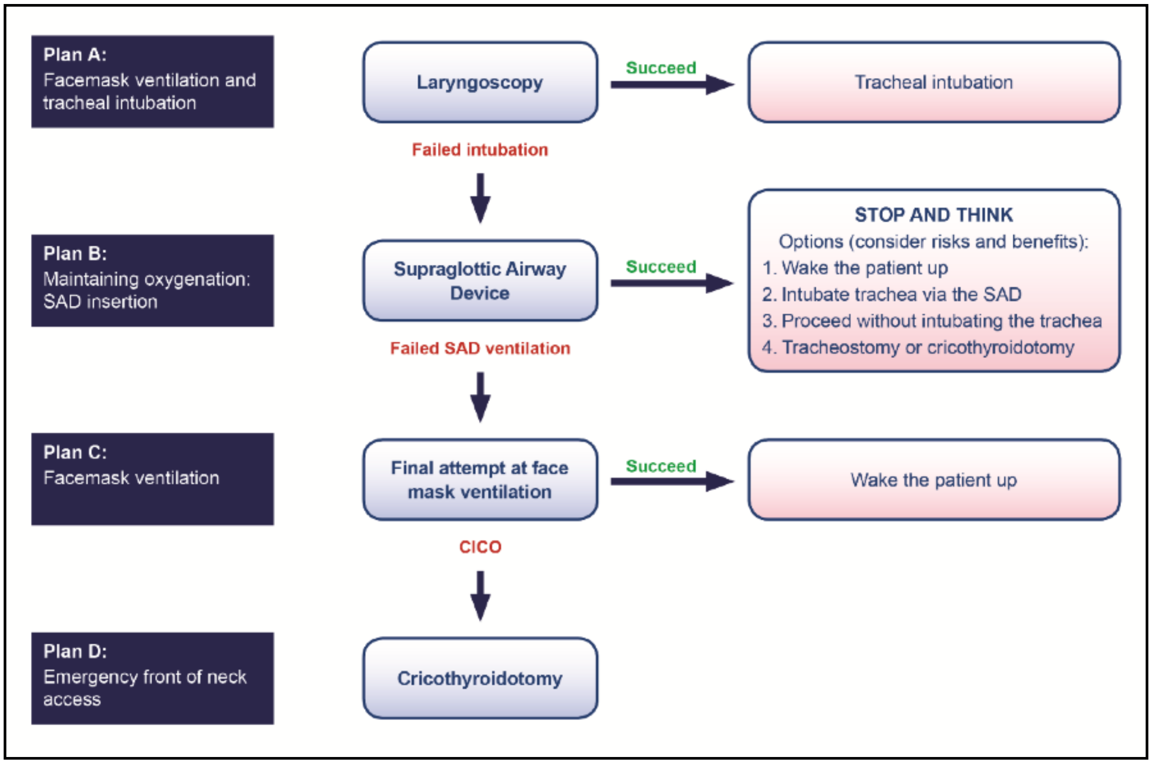


Fig. 1. Difficult Intubation Guidelines
Source: Adapted from Reena. (2021). Retrograde intubation: largely ignored technique in difficult airway algorithms. *Ain-Shams Journal of Anesthesiology*. 13. 10.1186/s42077-021-00155-5.

Securing the Airway

If the patient meets criteria for definitive airway management, endotracheal intubation can be performed in several ways depending on available equipment, including direct laryngoscopy, video laryngoscopy (Glidescope), fiberoptic intubation (nasal or oral), intubating LMA (with an 80-90% success rate), retrograde intubation, or blind nasal intubation. If these methods fail, a surgical airway will be required.

Induction of Anesthesia

Since all trauma patients are considered to have a "full stomach," a rapid sequence approach is utilized for securing the airway. This approach aims to provide rapid intubating conditions while maintaining hemodynamic and cervical spine stability.

Steps:

1. Ensure the presence of a person skilled in surgical airway techniques.
2. Ensure suction and ventilation equipment are readily available.
3. Preoxygenate the patient with 100% oxygen.
4. Administer medication:
    - Etomidate 0.3 mg/kg or a maximum of 20 mg
    - Ketamine 1-2 mg/kg
    - Succinylcholine 1 mg/kg actual body weight
    - Rocuronium 1.2 mg/kg

Once the patient is relaxed, avoid mask ventilation and attempt intubation. Ensure CO2 return and begin ventilation. Secure the ETT with a device. If rocuronium is used, the patient may require sedation as paralysis will last up to 90 minutes, depending on the dose.

Breathing and Ventilation

The next step after assessing the airway is to evaluate breathing and ventilation. This involves focusing on the respiratory rate and breathing pattern, looking for pathologies such as flail chest or signs of a pneumothorax. Chest expansion is observed, and breath sounds across the chest are assessed for reduction or absence. Life-threatening injuries like tension pneumothorax, particularly from penetrating or blunt trauma, must be identified. Signs include reduced chest movement, diminished breath sounds, tracheal deviation (initially towards the injured side and later away from it), tachycardia, hypotension, and neck vein distension. Open chest injuries, penetrating trauma, or massive hemothorax (indicated by dull percussion, hemodynamic instability, and reduced chest movements) are critical to detect.

For non-intubated patients, maintaining supplemental oxygen is vital, with a target pulse oximetry reading above 92%, assuming a good waveform. Continuous monitoring for respiratory distress is essential. If the patient has been intubated or a surgical airway has been performed, initial ventilator settings typically include tidal volumes of 6-8 mL/kg, a respiratory rate of 12-16 breaths per minute, PEEP of 5 cm H2O, and starting oxygen at 100%, titrating down as necessary. For paralyzed patients, direct volume or pressure control ventilation is used, completely managing minute ventilation. Non-paralyzed patients are often placed on assist-control modes, which help synchronize patient effort with the ventilator and require less sedation.

Ventilator-induced lung injury (VILI) is a significant concern and can manifest in various forms. Barotrauma occurs due to high peak or plateau pressures, which are ideally maintained below 35 cm H2O in the operating room. Volutrauma results from the use of large tidal volumes, typically those exceeding 8 mL/kg. Atelectrauma arises from the repeated opening and closing of alveoli. Oxygen toxicity can result from prolonged exposure to high oxygen concentrations. Biotrauma refers to the cellular inflammatory response triggered by mechanical injury. To mitigate these risks, it is crucial to attempt weaning and extubation as soon as it is safely possible.

Circulation

The principal cause of death among trauma patients within the first 24 hours of injury is hemorrhagic shock. Optimal fluid resuscitation strategies have been studied for nearly a century without a clear consensus. Vascular disruption, blood pressure, volume resuscitation, and the time between injury and hemostasis all influence hemorrhage severity. Four key principles in initial trauma management include controlling bleeding, restoring tissue perfusion, minimizing iatrogenic injury from resuscitation, and promoting hemostasis.

Hypovolemic shock is a state of poor circulating volume leading to tissue ischemia, anaerobic metabolism, and subsequent lactic acidosis, characterized by hypotension, tachycardia, and reduced pulse pressure. Initially, compensatory mechanisms increase cardiac rate and

Class of haemorrhagic shock				
	I	II	III	IV
Blood loss (mL)	Up to 750	750–1500	1500–2000	> 2000
Blood loss (% blood volume)	Up to 15	15–30	30–40	> 40
Pulse rate (per minute)	< 100	100–120	120–140	> 140
Blood pressure	Normal	Normal	Decreased	Decreased
Pulse pressure (mm Hg)	Normal or increased	Decreased	Decreased	Decreased
Respiratory rate (per minute)	14–20	20–30	30–40	> 35
Urine output (mL/hour)	> 30	20–30	5–15	Negligible
Central nervous system/ mental status	Slightly anxious	Mildly anxious	Anxious, confused	Confused, lethargic

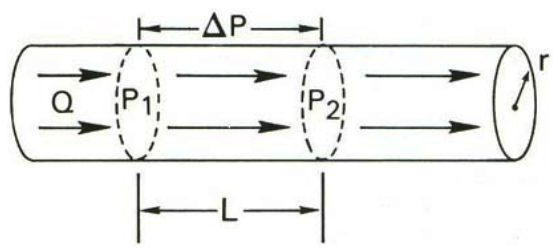
Table 1. Classes of Hemorrhagic Shock

contractility, raising cardiac output to maintain perfusion. However, this increases myocardial oxygen demand, potentially causing an imbalance between oxygen demand and supply, particularly problematic in older patients or those with cardiovascular disease.

Causes of hemorrhagic shock include acute blood loss from trauma, severe GI losses (diarrhea or vomiting), burns, excessive sweating, and dehydration. Hemorrhagic shock is classified from I to IV. Class I involves up to 750 mL (about 15% of blood volume) loss, with high-normal pulse rates (<100 bpm), maintained blood pressure, respiratory rate, and urine output, and minimal CNS dysfunction. Class IV involves a loss of about 40% of blood volume, with tachycardia, decreased pulse pressure and blood pressure, increased respiratory rate (to compensate for acidosis), little to no urine output, confusion, lethargy, obtundation, and likely the need for definitive airway management. (See **Table 1**.)

Flow and IV Access in Trauma Resuscitation

The flow equation $Q = \Delta P \cdot \frac{\pi r^4}{8\eta l}$



illustrates the importance of catheter size and length in fluid administration. Increasing the radius of the IV catheter significantly enhances flow, as flow is proportional to the fourth power of the radius. For trauma patients requiring rapid volume resuscitation, larger bore IVs (e.g., 16-gauge) are preferred. Doubling the radius can increase flow by 16 times, assuming viscosity and length remain constant. Shorter catheter length also improves flow rates.

When choosing IV lines, consider the purpose: volume resuscitation or multiple infusions for ICU patients. Standard 20-gauge IVs provide about 60 mL/min, while 16-gauge IVs can deliver approximately 220 mL/min. Bilateral 16-gauge IVs can achieve around 400 mL/min. Triple lumen catheters, while useful for multiple infusions, are suboptimal for volume resuscitation due to their longer length, providing only 100-130 mL/min across all ports.

MAC (Multi-Lumen Access Catheter) catheters, with two large bore ports, can deliver 500-800 mL/min through the proximal catheter, and up to a liter with rapid infuser assistance. Double lumen catheters offer a balance, providing around 300 mL/min while allowing for additional infusions.

Damage Control Resuscitation in Trauma

Initially developed in the Iraq and Afghanistan wars, damage control resuscitation focuses on hemostatic methods, minimizing crystalloid use, and using warmed fluids and blood products in a 1:1:1 ratio of RBCs, platelets, and FFP. This approach allows permissive hypotension, targeting systolic pressures in the 90s and MAPs of 60, reducing blood loss without increasing mortality. It is contraindicated in traumatic brain injury, spinal cord injury, or known cardiovascular disease but beneficial in healthy, young trauma patients, especially soldiers.

Immediate damage control surgery, whether operative or angiographic, and goal-directed correction of coagulopathy are critical. This method aims to avoid the lethal triad of dilutional coagulopathy, acidosis, and hypothermia. Reducing crystalloid use minimizes tissue swelling and dilutional coagulopathy, improving outcomes.

Massive Transfusion Protocol (MTP)

MTP is often initiated for severe trauma, especially penetrating injuries, before reaching the operating room. Indications include an ABC score (pulse >120, systolic pressure <90, positive FAST exam, and penetrating torso injury), persistent hemodynamic instability despite fluid resuscitation, active bleeding requiring surgery or angiointervention, or active transfusion in the trauma bay. During massive transfusion, the primary focus is to maintain cardiac output and minimize tissue hypoxia, preventing the lethal triad of acidosis, coagulopathy, and hypothermia. Prioritizing the delivery of RBCs along with platelets and FFP, and sometimes cryoprecipitate, is crucial.

The 1:1:1 transfusion ratio aims to prevent dilutional coagulopathy, reduce tissue swelling, and promote faster recovery. Research on the timing of cryoprecipitate varies; some advocate for early administration, while others delay until the second cooler. I usually have cryoprecipitate thawed early if heavy transfusion is anticipated, as it takes 20-30 minutes to be ready. Proactive ordering ensures availability when needed.

Calcium supplementation is vital during MTP to prevent hypocalcemia, which can exacerbate coagulopathy. Aim to keep ionized calcium above 0.9 mmol/L by administering 1 gram of calcium chloride with the first unit and then one gram for every three units transfused. Continuous monitoring through arterial blood gases (ABGs) every 20-30 minutes can help

Coagulation status	TEG tracing	R value	K and α value	Maximum amplitude	Treatment algorithm
Normal hemostasis		Normal	Normal	Normal	Attain surgical hemostasis using sutures
Hemodilution or clotting factor deficiency		High	Low or normal	Low or normal	Administer fresh frozen plasma if indicated
Fibrinogen deficiency		Normal or high	Low	Low or normal	Administer cryoprecipitate
Low or dysfunctional platelets		Normal	Normal	Low	Administer platelets
Primary fibrinolysis		Normal	Normal	Low	Administer antifibrinolytics or tranexamic acid as indicated
Secondary fibrinolysis: hypercoagulopathy with fibrinolysis		Low	High	High	Treat disseminated intravascular coagulopathy
Thrombosis		Low	High	High	Administer anticoagulant indicated

Table 2. Common Clotting Disorders, Thromboelastography (TEG) Tracing Example, Characteristic Values, and

Fig 2. TEG Tracing

Source: Table 2 in Collins, Shawn Bryant et al. "Update for Nurse Anesthetists Thromboelastography : Clinical Application , Interpretation , and Transfusion Management." (2016).

manage acid-base status and ionized calcium levels.

Monitoring and Goals Post-MTP

In the OR, placing an arterial line for major trauma cases allows frequent checks of pH, blood gases, electrolytes, metabolites, glucose, and lactate levels. While high-stat cartridges provide rapid lactate checks, sending samples to the lab for formal analysis is more accurate. Thromboelastography (TEG) is invaluable for assessing coagulation status, platelet function, clot strength, and fibrinolysis. Dynamic monitoring with TEG helps guide resuscitation decisions more effectively than the standard 1:1:1 ratio alone. (See **Fig. 2**.)

Post-MTP, the goals include maintaining MAP between 60-65 mmHg, hemoglobin between 7-9 g/dL, INR below 1.5, normal fibrinogen levels (1.5-2 g/L), platelet count above 50,000/μL, normal pH, and core temperature above 35°C. Ensuring these parameters are met stabilizes the patient and promotes recovery.

Effective trauma anesthesia and perioperative volume resuscitation require meticulous planning, swift and adaptive responses, and a collaborative approach. Monitoring and dynamic decision-making are crucial for improving outcomes in critically injured patients.

Traumatic Brain Injury (TBI) Management

The pathophysiology of TBI involves primary and secondary brain injuries. Primary injury results from the initial trauma—mechanical impact on brain tissue and the skull due to acceleration, deceleration, and rotational forces, leading to skull fractures, brain contusions, or expanding hematomas. Secondary injuries arise from surgery and anesthesia-related factors such as hypotension, hypoxemia, hypercarbia, fever, glucose changes, or increased intracranial pressure (ICP).

Avoiding glucocorticoids in TBI patients is standard practice. Anesthetic management goals include maintaining cerebral perfusion pressure (CPP). CPP is calculated as mean arterial pressure (MAP) minus ICP or central venous pressure (CVP). For trauma patients, assuming an elevated ICP, maintaining CPP above 50 mmHg is critical. If ICP is assumed to be 30 mmHg, MAP should be kept at least at 80 mmHg.

Surgical Considerations for TBI

Prompt surgical intervention is crucial for TBI patients. Delays are minimized to expedite operative conditions, reduce secondary insults, and provide adequate analgesia. Upon opening the dura or inserting an ICP monitoring device, real-time ICP measurements allow adjustment of blood pressure goals. Lowering blood pressure may be considered once ICP is accurately assessed and managed.

Critical Site Bleeding and Anticoagulation Reversal

In cases of critical site bleeding—such as intracranial, spinal cord, intraocular hemorrhages, or pericardial tamponade—reversal of anticoagulation may be necessary. Hemodynamic instability (systolic BP <90 mmHg, MAP <40 mmHg), orthostatic changes, or decreased organ perfusion (indicated by lactic acidosis or significant hemoglobin drop) prompt reversal.

Reversal Strategies

For warfarin reversal, vitamin K (1-10 mg IV) and four-factor prothrombin complex concentrate (PCC) like KCentra, which contains factors II, VII, IX, and X, are used. Dosage is often INR-based, with higher INR requiring more units. Fresh frozen plasma (FFP) is less efficient for rapid reversal, especially for achieving lower INR targets.

For direct thrombin inhibitors like dabigatran, specific reversal agents like idarucizumab (Praxbind) are available. Cryoprecipitate may also be used to maintain fibrinogen levels above 200 mg/dL.

Special Considerations for TBI Patients

In managing TBI patients, preventing secondary injury is paramount. This includes avoiding factors that increase ICP, maintaining normotension and normocapnia, and ensuring adequate CPP. Rapid surgical intervention and precise anesthetic management are critical to optimizing outcomes.

Anticoagulation Reversal for Heparin and Other Agents

Heparin reversal involves using protamine sulfate. The dosing is typically 1 mg of protamine per 100 units of heparin, with a maximum dose of 50 mg. Calculating the dose of protamine requires knowing the last dose and the time elapsed, considering heparin's half-life of 60-90 minutes. For example, if a patient received 5000 units of heparin three hours ago, approximately 2500 units remain, requiring 25 mg of protamine.

Low molecular weight heparin (LMWH), like enoxaparin, is partially reversed with protamine. If the last dose was 8-12 hours ago, 0.5 mg of protamine per 1 mg of enoxaparin is administered, achieving about 60% reversal. Protamine is usually unnecessary if the last dose was over 12 hours ago. For ongoing bleeding or prolonged PTT, a second dose of protamine (same dosing) can be given 2-4 hours later.

Reversing fondaparinux, used frequently at Karmanos, involves recombinant factor VIIa (90 mcg/kg IV) or activated PCCs (50 units/kg IV), with reassessment for hemostasis.

For newer anticoagulants like rivaroxaban (Xarelto) and apixaban (Eliquis), four-factor PCC (25-50 units/kg) or activated PCCs (25 units/kg) are recommended. Specific reversal agents like andexanet alfa are used based on the last dose and time elapsed, with higher doses for unknown or high-dose scenarios.

Reversal of Antiplatelet Agents

For patients on antiplatelet agents like aspirin or clopidogrel (Plavix), platelet transfusion (2-3 units) is recommended despite mixed efficacy results in studies. Desmopressin (0.4 mcg/kg IV) can enhance platelet function, particularly when combined with platelet transfusion.

Heparin Reversal

Protamine sulfate is the reversal agent for heparin. The typical dose is 1 mg per 100 units of heparin, with a maximum dose of 50 mg. The half-life of heparin is 60-90 minutes, so the dose of protamine should be adjusted based on the time elapsed since the last heparin administration. For example, if a patient received 5000 units of heparin three hours ago, approximately 2500 units would remain, requiring 25 mg of protamine. Low molecular weight heparin (LMWH) such as enoxaparin can be partially reversed with protamine. If the last dose was 8-12 hours ago, 0.5 mg of protamine per 1 mg of enoxaparin is administered, achieving about 60% reversal. Protamine is usually unnecessary if the last dose was over 12 hours ago. For ongoing bleeding or prolonged PTT, a second dose of protamine (same dosing) can be given 2-4 hours later.

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Anticoagulation Reversal Strategies

Heparin reversal with protamine sulfate involves calculating the appropriate dose based on the last heparin dose and its half-life of 60-90 minutes. For LMWH like enoxaparin, protamine can partially reverse its effects. Fondaparinux reversal may require recombinant factor VIIa or activated PCCs. Newer anticoagulants such as rivaroxaban and apixaban have specific reversal agents like andexanet alfa.

For antiplatelet agents, platelet transfusion and desmopressin can be used to enhance platelet function and address acute life-threatening bleeding.

Ensuring hemostasis and avoiding complications such as hypothermia and dilutional coagulopathy are critical in the acute management of trauma patients. Proper resuscitation and timely intervention can significantly improve outcomes in these critically injured patients.

Conclusion

Effective management of trauma patients requires a multifaceted approach, encompassing rapid assessment, timely interventions, and vigilant monitoring. Trauma anesthesia presents unique challenges, often necessitating urgent or emergent care with limited patient history and resources. The principles of Advanced Trauma Life Support (ATLS) provide a structured approach to initial evaluation, emphasizing the importance of airway management, breathing assessment, and circulation stabilization.

In trauma cases, airway management is crucial, involving continuous monitoring and various techniques to secure the airway, especially in patients with compromised conditions. Rapid sequence induction is essential for trauma patients considered to have a "full stomach," ensuring quick and safe intubation. Assessing and supporting breathing and ventilation, particularly in the presence of life-threatening conditions like tension pneumothorax or flail chest, is vital for patient stability.

Ventilator-induced lung injury (VILI) remains a significant concern, necessitating careful management of ventilator settings and timely weaning. Circulation management focuses on addressing hemorrhagic shock, optimizing fluid resuscitation, and employing damage control resuscitation strategies to prevent the lethal triad of acidosis, coagulopathy, and hypothermia.

For patients with traumatic brain injury (TBI), maintaining cerebral perfusion pressure and avoiding secondary injuries are paramount. Prompt surgical intervention and precise anesthetic management help mitigate the risks associated with elevated intracranial pressure.

Critical site bleeding requires immediate reversal of anticoagulation, employing specific strategies for various anticoagulants and antiplatelet agents. Ensuring hemostasis and avoiding complications like hypothermia and dilutional coagulopathy are crucial for successful outcomes.

In conclusion, the intricate management of trauma patients demands a collaborative, multidisciplinary approach, combining advanced medical techniques, rapid decision-making, and continuous reassessment. By adhering to established protocols and adapting to the dynamic needs of critically injured patients, healthcare providers can significantly improve survival rates and patient outcomes in trauma care.

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