Damage Control: From Principles to Practice

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Introduction

Trauma patients present with unique physiology and anatomy that challenge the trauma team. Multiple cavities can be involved, and prioritizing operative interventions must be undertaken with little patient or clinical data. Further complicating the clinical picture is the delayed presentation of the trauma patient whether due to environmental, transport, or patient factors. This can lead to physiologic derangements from uncontrolled bleeding and/or contamination. Historically, the surgeon would complete the operation, including all bowel and vascular anastomoses, and close the abdomen. Complications such as abdominal compartment syndrome and later multisystem organ failure would ensue [1, 2]. As discussed in the preceding chapter, this lead surgeons to challenge the traditional approach by aborting the operation early and creating a staged approach in a concept termed "damage control" (Fig. 15.1). First described in 1983 [3], damage control demonstrated improved outcomes in 1993 [4]. Subsequently, improvements in certain stages have been described, and recognition that many physiologic challenges begin the moment injury occurs has led to implementing changes in the prehospital setting [5, 6]. Initially, damage control surgery was applied to intra-abdominal injuries, but now has been expanded to include thoracic, vascular, and extremity injuries [7, 8]. The military uses damage control across theaters—temporizing on the front lines, resuscitating and stabilizing at a forward operating base, and then transporting to a higher level of care at a well-established military base, sometimes in another country or even continent [9–11]. This chapter will build on the principles discussed in Chap. 14 and highlight their application to real-life scenarios.

Indications for Damage Control Surgery

The goal of damage control surgery is to recognize patients who are physiologically deranged, need second explorations, or are at risk for complications if the traditional approach with closure is undertaken. The lethal triad of hypothermia, coagulopathy, and acidosis appears as the patient reaches physiologic exhaustion, so waiting for the triad to develop and then undertaking damage control defeats the purpose of damage control. Bleeding and contamination are controlled in the first operation. Then, the patient is taken to the intensive care unit (ICU) for resuscitation, allowing time to recapture the patient's physiology.

Identification of patients who benefit from damage control surgery is an art that requires experience and communication. Emergency medical services (EMS) can communicate valuable information prior to patient arrival, such as prehospital hypotension, hypothermia, blood loss, and ongoing hemorrhage that can trigger the trauma team to entertain damage control. Even a single episode of prehospital hypotension that resolves with resuscitation can be indicative of a severely injured patient with little reserve for a lengthy operation [12]. Intraoperatively, hypothermia less than 36 °C, an acidosis less than 7.25 or base deficit greater than 8, clinical coagulopathy or based on laboratory values with an international normalized ratio (INR) greater than 1.5 or fibrinogen <200 mg/dl (<2 g/l) are indications for damage control. Constant and effective communication with anesthesia is necessary to ensure frequent monitoring, guide resuscitation,

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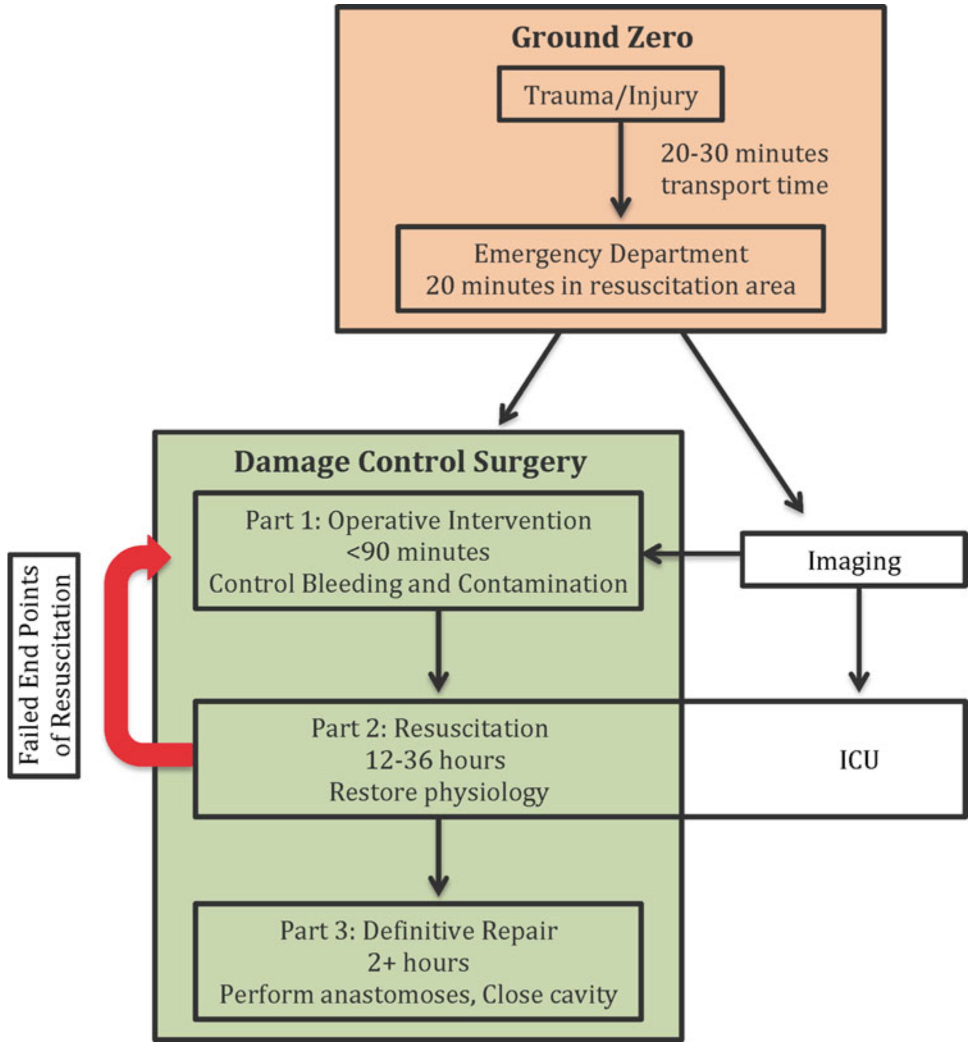

Fig. 15.1 Damage control sequence. Part 2 occurs in the ICU. Parts 1 and 2 may be repeated multiple times over several days to a week prior to Part 3 definitive repair

and communicate the decision to abort the operation and rapidly proceed to the ICU.

Patients with multiple cavity injuries are ideal candidates for damage control. Ongoing bleeding can hasten physiologic exhaustion, so hemorrhage control across cavities must be expeditiously treated with no opportunity for definitive repair. For example, a patient with a thoracoabdominal injury or multiple stab wounds may need both the abdomen and mediastinum or thorax explored, and the surgeon must make a judgment about which cavity is the primary source of bleeding or life-threatening injury. Once bleeding is controlled in one cavity, the surgeon must rapidly examine the next. Other situations that lend themselves to damage control are those where endovascular techniques may achieve hemorrhage control more effectively such as severe liver or pelvic bleeding. While waiting for the endovascular team to arrive, the surgeon may explore the abdomen and pack the liver or pelvis and even isolate and temporarily occlude the porta hepatis or internal iliac arteries. Once the endovascular team is available, the surgeon and radiologists can work together to combine operative and endovascular interventions to stop bleeding. Patient selection also plays a role; the elderly, those with more comorbidities, and pediatric patients have less reserve, and thus, the team should have a lower threshold for damage control. Ultimately, the earlier the decision is made to undertake damage control, the better chance of salvaging the patient.

Ground Zero: Scene to Emergency Department

Advanced Trauma Life Support (ATLS) is the backbone of prehospital treatment. Transport to a definitive trauma center without delay is the primary goal of ATLS and prehospital care with a goal of less than 30 min from call initiation to arrival at the trauma center. An airway must be established if a patient cannot protect his own. Needle decompression or tube thoracostomy may be performed for hypoxia and loss of

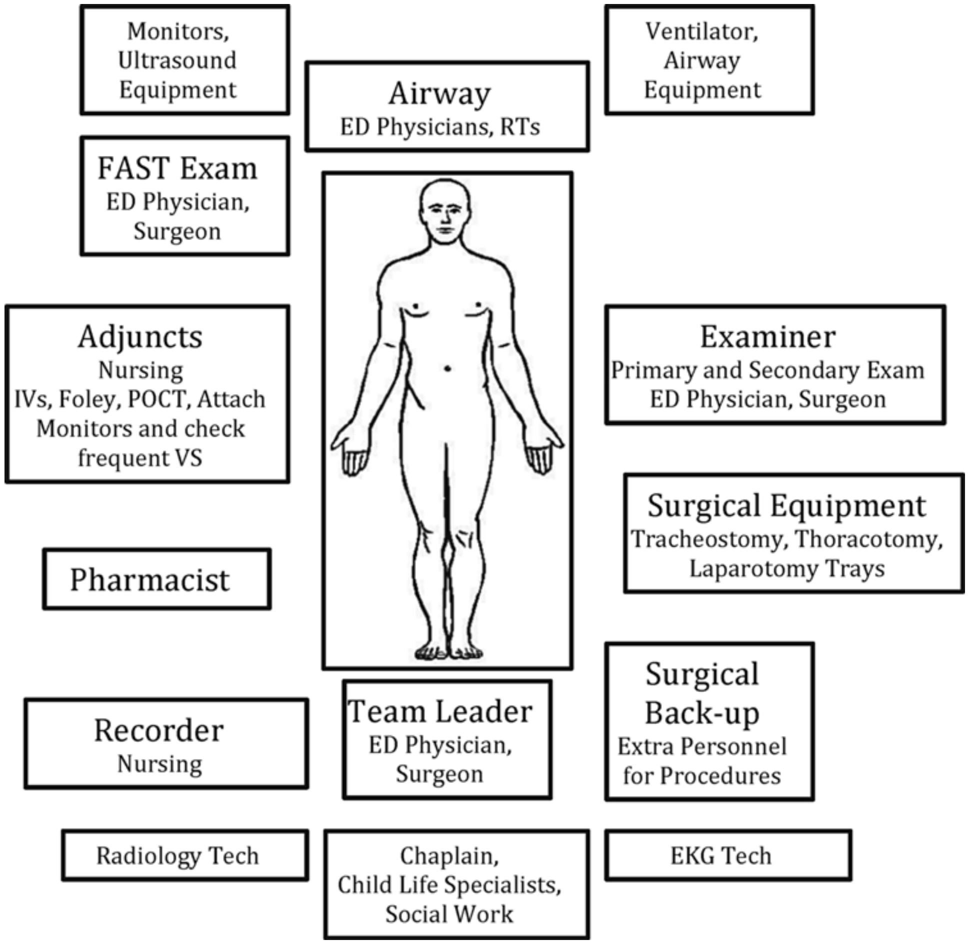

Fig. 15.2 Arrangement of Emergency Department resuscitation area conducive to effective communication. Note that the Recorder is adjacent to the Team Leader to read back information. Examiner should be on patient's left side to facilitate Emergency Department (ED) thoracotomy and other surgical procedures if necessary. Supply carts and medication dispensers/storage should be in close proximity if not in the same room along the walls. RT = Respiratory Therapist, POCT = Point of Care Testing, VS = Vital Signs, EKG = Electrocardiogram

breath sounds. Large-bore IVs should be placed, and resuscitation begun with isotonic crystalloid. Hemorrhage can be controlled with tourniquets or digital pressure. Fractures can be splinted to provide stability and decrease ongoing bleeding. Previously, 2 l of isotonic crystalloid were given followed by either more crystalloid or blood products if available to achieve a desired response in vital signs. As discussed in Chap. 14, under certain circumstances, a systolic blood pressure of 80–90 mmHg may be more ideal until hemorrhage is controlled [13]. This practice of "permissive hypotension" primarily applies to penetrating trauma with a short anticipated transport time to definitive care and only in the absence of head injuries and significant patient comorbidity.

Frequent, effective communication is imperative between the prehospital and emergency department teams. Updates on vital signs and physical findings allow emergency department personnel to mobilize resources. Necessary equipment can be gathered and procedure trays opened. Radiology technicians can be at the bedside waiting with portable X-rays and can expedite any other radiological interventions such as computed tomography (CT). The blood bank can be notified if a massive transfusion is planned in order to begin thawing products. Most importantly, roles during the triage are assigned and performed in an organized manner. Mobilization of the team prior to patient arrival decreases evaluation time and eliminates delay to imaging or the operating room.

The patient should ideally spend as little time as possible—certainly no more than 20 min—in the emergency department resuscitation/trauma area including procedures and adjuncts (Fig. 15.2). The trauma team must decipher what the life-threatening injuries are which determines the next stage of damage control. In trauma patients with blunt mechanisms, multiple cavities may be involved, and the sources of hemorrhage difficult to identify as they may not be visible. Penetrating traumas are much easier to triage, given the external wound. It is important to determine trajectory; the external wound may appear to lie within a single cavity, but trauma may involve multiple cavities. It is important to place a marker such as a paperclip or electrocardiogram (EKG) lead on the external wound prior to imaging in order to approximate trajectory.

The majority of trauma patients who are hypotensive are in hemorrhagic shock. A patient may exsanguinate externally or internally (thorax, abdomen, pelvis, retroperitoneum, soft tissues). If life-threatening bleeding is ongoing in one of the above mentioned cavities and/or the patient unstable, the surgeon should proceed rapidly to the operating room. Should a patient arrest just prior to arrival or in the resuscitation bay, an emergent resuscitative thoracotomy may be performed to release a cardiac tamponade and/or occlude the aorta in order to maintain perfusion to the heart and brain. Since endovascular technology has further evolved, the use of resuscitative endovascular balloon occlusion of the aorta (REBOA) in trauma is being revisited [14]. While it cannot relieve a cardiac tamponade, REBOA can be used in blunt or penetrating trauma prior to arrest to manage non-compressible hemorrhage at multiple levels of the aorta without the morbidity of a large chest wound [15]. The femoral artery may be accessed percutaneously or by cut down, and balloon placement does not require fluoroscopy [14, 15].

Depending on patient stability and resource availability, the team may elect to obtain a CT to gain further information. If a liver injury or pelvic fracture with bleeding is found, the team may proceed to a hybrid operating and endovascular room (when available) to control hemorrhage operatively while mobilizing the endovascular team.

Again, effective communication is of utmost importance in efficient patient flow. The CT technologist should be notified that the patient will be arriving imminently. The ordered scans should be discussed and clarified. It helps the technologist and radiologist reading the imaging to know the history (including mechanism) and physical exam findings as well as the suspected injuries as they may recommend arterial and venous phased scans, thinner slices through worrisome areas, or additional scans while the patient is still on the table. If there is a possibility the patient may be proceeding to the operating room, notifying the operating room team at the earliest opportunity is ideal. Some centers place the operating room (OR) staff on standby when the trauma team is activated in the emergency department. While a trauma-ready operating room is always available at a Level 1 center, the lights can be turned on, the room and bed warmed, and the nurse, scrub technician, and anesthesia team mobilized to prepare for a case. A trauma cart with basic supplies (shunts, staplers, tubes, drains, vacuum dressings) and various trays (vascular, thoracotomy, laparotomy) as well as a trauma suture tree should already be available in the room or just outside. Finally, the massive transfusion protocol should be implemented as soon as deemed necessary to ensure products are available as soon as possible whether it be in the ICU or operating room.

Damage Control Part 1: Operative Intervention

There are two goals in damage control Part 1: control of bleeding and contamination. Upon arrival to the room, the surgeon may give the team a brief history, interventions undertaken thus far, lines and tubes in place or needed, and the overall plan for the operation. It can be extremely helpful if anticipated problems are vocalized, so that anesthesia staff can prepare for the resuscitation and have rapid transfusers and cell savers available, while the OR staff can ready an abundant supply of sponges, basins, and adequate suction. In extreme situations, intubation may be occurring while prepping and draping the patient. In some instances, time will only permit splash prep.

Positioning the patient is dependent on which cavities or extremities need to be explored as previously determined in the emergency department. Any extremity may be prepped, draped, and included in the operative field. If a vascular injury is suspected, both legs from the inguinal ligament to knees should be prepped in case vein graft is needed. Generally, the trauma patient is supine with both arms abducted at 90° and prepped from chin to knees and laterally to the bed. If a combined thoracotomy and laparotomy is entertained and the hemithorax previously determined, a modified taxi cab hailing position is ideal. The patient is primarily supine, but on the ipsilateral side of the thorax to be entered, the chest wall is rotated medially about 30° to the coronal plane and supported with a roll. The ipsilateral arm is abducted at 90° and elbow flexed at 30°.

Once a cavity is opened, hematoma and blood should be evacuated (usually manually) and the cavity packed with lap sponges. If exsanguination is temporized, anesthesia should be allowed to aggressively resuscitate the patient until bleeding restarts or until the systolic blood pressure is 80–90 mmHg. All injuries must be fully exposed to localize hemorrhage and contamination. Bleeding organs on a pedicle (spleen, kidney) should ideally be sacrificed. Liver and lung resections are non-anatomical and usually performed with staplers. Finger occlusion of a pedicle and the Pringle maneuver for the liver or twisting the lung at its hilum are fast techniques to control significant bleeding. Various maneuvers (Kocher, Mattox, Cattell-Braasch) expose the retroperitoneum. Most vessels may be ligated. If a vessel supplies an end organ or extremity, the vessel should be shunted [16–19]. However, in life-threatening situations, even the inferior vena cava may be ligated at its bifurcation. Visceral contamination is controlled by stapling and removing the injured segment of bowel or simply whip stitching the injury closed. If a segment is removed, the patient is left in discontinuity due to time and the need for a second look given the possibility of further necrosis. A temporary abdominal, chest, or extremity dressing is placed, allowing for rapid reentry or examination while preserving the fascia and skin for definitive closure. These may be manufactured or homemade with negative pressure applied. Incorrect counts are common due to the emergent nature of the operation. While attempts are made to count the number of sponges and instruments left in a packed, open cavity, the count should never delay placement of a temporary dressing and transport to the ICU.

Again, communication with bed control to ensure an ICU bed is available and with the ICU nurses and physicians eases the transition to the next stage of damage control. It may take time to move another patient out of an ICU room, clean the room, and bring the hospital bed to the operating room. Report can be called about 20–30 min prior to leaving the operating room which allows the ICU staff time to set up suctioning, warming, and massive transfusion equipment, gather pumps, tubing and supplies, and prepare for the patient as well as notify respiratory therapy to bring a ventilator to the ICU room.

Damage Control Part 2: Resuscitation

The goal of Part 2 is to continue aggressive resuscitation in a rapid fashion in order to correct the physiologic derangements. Upon arrival to the ICU, the surgical team should communicate the brief history, interventions, the definitive plan, and any specific concerns. A full laboratory panel should be sent upon arrival to the ICU including a complete blood count (CBC) with differential, complete metabolic panel (CMP) with all electrolytes, creatine kinase (CK), lactic acid (LA), arterial blood gas (ABG), and coagulation panel including fibrinogen and repeated at minimum every 4–6 h (up to every 1–2 h in certain circumstances) to guide resuscitation and organ perfusion endpoints. Serial troponins and electrocardiograms may also be included. Core temperature should be monitored and rewarming measures such as blankets and warmed fluids used because hypothermia can inactivate the clotting cascade and impede the body's ability to coagulate blood.

While the resuscitation ratio is debated, a 1:1 or 1:2 ratio of packed red blood cells (pRBCs) to fresh frozen plasma (FFP) is the current recommendation. The goal of resuscitation is to achieve a hemoglobin ≥ 7 g/dL (>70 g/l) (>9 g/dl, 90 g/l in an actively bleeding patient), INR <1.5, maintain platelets >100,000, and cryoprecipitate may need to be given if the fibrinogen is <200 mg/dl (<2 g/l). If these goals are met, isotonic crystalloid may be used, but be mindful that normal saline may lead to a non-anion gas metabolic acidosis, worsening coagulopathy.

There is no single resuscitative endpoint. Clinically, urine output may be measured and stabilization in vital signs with titration of pressors off is indicative that end-organ perfusion is being achieved. The characteristic of the output from the temporary vacuum dressing and the amounts from the drains and tubes should be monitored. Ultrasound can help guide resuscitation, as intravascular volume can be based on inferior vena cava (IVC) collapsibility and cardiac contraction. This will be discussed further in Chap. 22. Corrections of the coagulopathy, hypothermia, and acidosis are guidance parameters.

Another important role of the ICU provider is to perform a thorough tertiary survey including physical examination and review of pertinent imaging and blood work to ensure that no injuries or wounds have been missed. Once resuscitation endpoints are met ideally within 24–36 h, the patient is returned to the operating room for a second look, or Part 3—definitive repair. If at any point during Part 2 the acidosis or coagulopathy is not correcting or was trending in the correct direction, but then regresses, or if there is clinical evidence of ongoing, rapid hemorrhage, the patient should be immediately returned to the operating room as this is indicative of a missed injury or ongoing, uncontrolled bleeding.

Finally, complications of resuscitation can arise. Acute respiratory distress syndrome (ARDS) and transfusion-related acute lung injury (TRALI) can result from aggressive resuscitation and blood product administration. One should, however, consider other differential causes for persistent hypoxemia, i.e., abdominal compartment syndrome. In the event of persistent hypoxemia, lung protective strategies such as ARDSNet ventilation should be implemented.

Compartment syndrome may develop in the abdomen even with a temporary dressing in place. It should be suspected if cardiac return is low, the IVC is collapsed on ultrasound, and the urine output decreases when previously appropriate or in the event of persistent hypoxia or hypercarbia with climbing ventilation pressures. Bladder pressures should be measured frequently or even continuously. If pressures remain high, the dressing may need to be modified, loosened, or reapplied.

For extremities, a Stryker needle can be used to objectively quantify the pressure; rapid, significant increases in compartment pressures, a measured compartment pressure >30 mmHg, or <30 mmHg difference in the diastolic blood pressure and measured compartment pressure should prompt fasciotomies.

Damage Control Part 3: Definitive Repair

Once the patient is resuscitated as defined by meeting end-organ and hemodynamic endpoints, the patient is returned to the operating room for definitive repair. The temporary dressing and all packs are removed. The cavity should be thoroughly explored. If at any point the patient becomes hemodynamically unstable or physiologically deranged as in Part 1, begins re-bleeding, or demonstrates they are unable to undergo a lengthy operation, the temporary dressing may be reapplied and the patient returned to the ICU for further resuscitation. Definitive repair entails restoring bowel continuity, tissue debridement, and vascular grafts and anastomoses. Prior to closing the abdomen, an X-ray should be obtained and confirmed with radiology that no foreign bodies remain in the cavity. If multiple cavities are left open in Part 1, all cavities may be closed in Part 3 or only one and Part 3 repeated for each cavity.

Damage Control Strategy Under Special Circumstances

The following represents specific treatment strategies for unique conditions. The ultimate goal of each strategy is to implement the damage control concept early in care, combat the lethal triad, and transport victims safely for definitive management.

Blast Injuries

Blast injuries are challenging as patients can suffer from both penetrating and blunt mechanisms. Treatment goals remain the same, and ABCs initially assessed. The provider should not become distracted by the often unsightly injury, but rather focus on treatment according to protocol and standard practice. Cricothyroidotomy may be necessary with a blast to the face. Damage control with the blast-injured patients is done in large part by controlling hemorrhage. Hemorrhage sites are either anatomically compressible (e.g., extremity, or axillary/groin vascular injuries) or completely non-compressible (e.g., truncal injuries). Patients with noncompressible hemorrhage sources receive the highest priority for immediate transport to a hospital. Compressible hemorrhage sites are amenable to direct digital pressure or tourniquet control, which can be instituted by first responders. Control of bleeding with proximally arterial compression is not advised as it does not address venous hemorrhage. Using large stacks of gauze or additional dressings in lieu of manual compression should be avoided, as this technique dissipates the pressure applied directly to the bleeding site and may delay identification of ongoing bleeding [20].

While use of tourniquets has been controversial in the damage control situation, multiple reports in the literature of tourniquet use have defined their advantages [21–26]. These include improved hemorrhage control upon patient arrival, decreased incidence of shock in those casualties treated with tourniquets, improved survival, and acceptably low tourniquet-related complications. Tourniquets should be applied to exsanguinating extremities as soon as possible in damage control situations. It is generally recommended that restoration of arterial blood supply must be completed within 6 h from placement of the tourniquet [20]. Prior to patient arrival, it is helpful for the emergency department personnel to know if a tourniquet was placed and when, the characteristic of bleeding (dark non-pulsatile versus bright red, pulsatile), and a description of the injuries. When giving report at patient arrival, the transport team should include the time of injury and approximate amount of blood loss at the scene.

If the patient's bleeding is controlled upon arrival, the primary and secondary surveys should be rapidly conducted in the usual fashion, and the four remaining cavities assessed for hemorrhage with the usual adjuncts. Blast injuries can create penetrating wounds from shrapnel, but can throw a patient with great force, causing blunt injuries as well. This is the ideal situation for damage control. When proceeding to the operating room, the staff should be told to obtain a sterile pneumatic tourniquet and prepare for abdominal and extremity exploration and temporary dressings. If extremity hemorrhage is controlled with a tourniquet and the patient's FAST is positive and if two teams are available, both the extremity and abdomen may be explored concurrently; in the case of a single operative team, however, one should begin with abdominal exploration if the extremity hemorrhage is controlled with a tourniquet. All exsanguination must be expeditiously stopped.

Should blood supply to an extremity be compromised for greater than 4–6 h, or if there is already concern for compartment syndrome, fasciotomies should be undertaken in Part 1. If fasciotomies are not performed, it should be relayed to the ICU team to clinically assess the compartments hourly.

Burns

Many providers hesitate to treat burn patients, as they are not comfortable and confident. The same ATLS principles apply. Burn patients, too, can suffer from multiple mechanisms as an explosion may cause a burn, produce shrapnel and penetrating injuries, and throw the patient causing a blunt mechanism. The standard primary and secondary survey, as with any other trauma patient, should be followed.

Burn care commences at the scene. As in all circumstances, personal protection is paramount. The provider must ensure that the scene is safe. Personal protection equipment should be applied. Patients should be immediately placed on 100 % O_2 as the adequacy of the airway is evaluated. The provider should pay particular attention to signs of impending airway edema or collapse, such as hoarseness. Patients will often have singed nasal and facial hair or eyebrows. While these findings are important to note and represent a significant injury to the face, they are not specific for airway compromise. Hoarseness, on the other hand, is representative of vocal cord injury or edema and should prompt rapid intubation in the setting of significant mechanism.

After an airway is established, it is important to check the adequacy of ventilation by watching the chest rise and fall. Patients may have circumferential third-degree burns which ultimately limit the expansion of the chest. In some circumstances and under the direction of a physician, sharp release of the constricting skin may be necessary to allow for adequate chest expansion [27].

The American Burn Association (ABA) recommends that if prehospital personnel are unable to establish IV access, hospital transport should not be delayed. Intraosseous access should be considered to expedite timeliness of resuscitation and transport. IVs must be frequently assessed because aggressive resuscitation can lead to rapid edema, IV dislodgement, and subsequent subcutaneous infiltration.

The patient should be completely exposed. A clean dry dressing should be applied. The patient should be wrapped in warm blankets to prevent heat loss. The trauma resuscitation area should be warmed above 80 °F (26 °C). No attempt should be made to cool the patient to counter the burning process; this may be a potentially lethal intervention. Patients have lost the barrier needed for thermoregulation, and despite the appearance of burned skin, patients are often hypothermic [27, 28].

Burn patients at the extremes of age, with significant or multiple comorbidities, obvious second- and third-degree burns that are >10 %, inhalational injury, or burns to sensitive areas such as the face, hands, feet, or genitalia, should be directly transported to a burn center if possible. Again, communication between the care components and damage control parts is imperative. A good report from the transport crew includes if the burn occurred in a closed space (potential inhalation injury), if an explosion occurred (multiple mechanisms), if the patient experienced a loss of consciousness (carbon monoxide poisoning or anoxic brain injury), and most importantly, the time of the injury to calculate resuscitation recommendations. The airway and face should be described as intubation may need to rapidly be undertaken and may be extremely difficult due to edema. Knowledge prior to the patient's arrival allows for extra supplies to be gathered including a tracheostomy tray and wide range of endotracheal tube sizes. A Rule of Nines figure (used to calculate burned body surface area) should be posted in the emergency department and should be reviewed prior to patient arrival. A paper copy to go in the patient's chart should be precisely completed.

Resuscitation in burn patients is based primarily on urine output (0.5 cm^3/kg/h in adults, 1 cm^3/kg/h in children <30 kg), so an indwelling bladder catheter is required. The Parkland formula—4 cm^3/kg/percentage of second- and third-degree burns of Lactated Ringer's with half given in the first 8 h from the time of injury and the remaining in the following 16 h—is a guideline of how to initiate resuscitation and may be adjusted to achieve urine output goals. It is imperative that all team members monitor end-organ perfusion, recognize the goals of resuscitation, and communicate about changes needed to achieve the goals.

If a burn patient is found to have a concomitant life-threatening injury such as intra-abdominal hemorrhage, the patient should be taken to the operating room, explored, and undergo the damage control sequence as any other trauma patient would. The goals of resuscitation must be clarified with anesthesia, because these patients require a significant amount of fluid and run the risk of leaving the operating room under-resuscitated if treated like a standard, unburned trauma patient.

Head Injury

Traumatic brain injury (TBI) continues to lead trauma statistics with high mortality rates and long-term disabling outcomes [29, 30]. Primary injury occurs at the time of the traumatic event, but secondary injuries to surrounding brain tissue can ensue and by avoiding further insults can be minimized. As always, no interventions should delay transfer to a neurotrauma center. While the Brain Trauma Foundation (BTF) guidelines [31] support advanced life support as opposed to basic life support transport, no data supports this statement. Ultimately, transport should be efficient and uphold the two main principles of the BTF guidelines: preventing hypoxia (SpO_2<90 %) and hypotension (SBP <90 mmHg). A large prospective database has demonstrated that a single episode of hypotension or hypoxemia, the strongest independent predictors of outcome, can double mortality and increase morbidity [32–35].

Management of the prehospital airway in a TBI patient is controversial and is dependent on the initial assessment of the patient. If the patient is being transported by ground in an urban environment and able to maintain SpO_2>90 % with only supplemental oxygen, data suggest that intubation with paralytics demonstrates equivocal or even worse outcomes [36–38]. Unfortunately, much of the remaining data on the topics of intubation and paralytics are observational, retrospective, and controversial leading to no best practice guidelines [39]. Risks of intubation include esophageal intubation with possible failure to recognize aspiration and delay in transport. This may also place personnel who do not frequently intubate in a high stress situation with potential for worsening patient outcome. Hypotension with induction medications and respiratory arrest should intubation fail are the downfalls of prehospital rapid sequence intubations (RSI).

These risks should not deter intubation in a severely injured TBI patient (GCS <9) as on-scene intubation may improve outcomes in the sicker patient [40, 41]. Should the patient require intubation, the responder with the most experience should intubate and use RSI if needed [42].

Historically, ketamine has not been used in TBI patients as it was thought to elevate ICPs. However, recent data suggests it may be a viable option to etomidate which causes vasodilatory effects leading to hypotension [43, 44]. Successful intubation should be confirmed both with clinical exam and with end-tidal carbon dioxide (CO_2) confirmation.

Traditionally, TBI patients would be hyperventilated to a partial pressure of carbon dioxide ($PaCO_2$) <30 mmHg, thus inducing vasoconstriction. We now know that maintaining a normal $PaCO_2$ of 35–40 mmHg improves outcomes. Only in the setting acute neurological change or impending herniation with signs such as unequal or fixed and dilated pupils, extensor posturing, or a decrease in Glasgow Coma Scale (GCS) >2 points should hyperventilation briefly be undertaken with a goal of $PaCO_2$ of 30–35 mmHg. While continuous end-tidal CO_2 monitoring is recommended, it still is not widely available in the prehospital setting. If not available, generally, 20 breaths per minute for an adult or 25 breaths for a child will achieve these goals.

Ideally, a Glasgow Coma Score (GCS) should be determined prior to administering sedatives or paralytics to the patient. Pupil exam should also quickly be performed, noting orbital trauma, asymmetry (>1 mm difference in diameter), or fixed pupils (<1 mm change with bright light). Resuscitation should be undertaken utilizing isotonic fluids. In a patient with a GCS <8 or with signs of impending herniation, mannitol (0.5–1 g/kg) or hypertonic saline (7 %, 1–2 cm^3/kg or 3 %, 3 cm^3/kg) may be given. Other maneuvers that can be beneficial in the treatment of TBI patients include minimizing noise and light stimulation, elevating of the head of bed/stretcher using reverse Trendelenburg, and loosening a constricting cervical collar (C-collar) to encourage venous drainage. Ultimately, outcomes following TBI are dependent on rapid transport to a neurotrauma facility with CT-scanning capability, intracranial pressure (ICP) monitoring and treatment, and available neurosurgical care.

Crush Injury

Crush syndrome is greatly underappreciated in trauma care. Specific compartments or the entire body may be crushed. It is the second most common cause of death after an earthquake, following asphyxia [45]. Much of the literature is a result of world-wide learning experiences following mass casualties such as earthquakes.

When approaching a victim of a crush injury, medical personnel should ensure their own safety first. If multiple victims are involved, medical attention should be directed to patients already freed, allowing rescue providers to extricate additional victims. First-line providers should be familiar with basic life support measures and ATLS principles. If the patient can be reached prior to extrication without endangering the medical provider or hindering rescue efforts, ideally, the patient should be assessed prior to extrication and frequently reassessed. Rescue deaths are patients that appear stable prior to extrication, but rapidly deteriorate following extrication thought to be due to reperfusion and systemic dissemination. Attention should first be directed at establishing large-bore intravenous access. Any limb may be utilized, intraosseous (IO) access if no IV can be established, and even subcutaneous infusion is possible at 1 cm^3/min if absolutely no other options exist. Isotonic saline should be used because even the minimal potassium in Lactated Ringer's can contribute to life-threatening hyperkalemia. While trapped, adults should be given 1 l/h of normal saline, children 15–20 cm^3/kg/h. If extrication takes longer than 2 h, fluids should be reduced to 0.5 l/h. The elderly, children, and patients with congestive heart failure and chronic kidney disease require less fluid. Other patient factors that may need more fluid include higher body mass indices, severely injured patients, delayed extrication, and higher fluid losses due to bleeding or hot weather.

On-scene amputation should not be performed to prevent crush injury—only to free a patient in a threatening situation such as impending structural collapse. A tourniquet may be placed just proximal to the amputation site to control bleeding. The most distal guillotine amputation should be performed, and intravenous ketamine may be used.

Communication with rescue personnel must be precise and extrication deliberate as life-threatening situations (bleeding, airway compromise) can arise. Patients who are trapped in Trendelenburg positions are especially at risk for rapid pulmonary edema and airway compromise. Once extricated, tourniquets may be applied for lethal bleeding, not to prevent the release of metabolites from the crushed tissue, and the usual precautions (spinal, airway, etc.) with rapid transport may commence.

Upon arrival to the trauma facility, assessment should follow the standard approach of ATLS. All wounds should be considered dirty with antibiotics and tetanus administered appropriately. Hypothermia should be avoided or corrected.

Consequences of crush syndrome include rhabdomyolysis, acute kidney injury (AKI), hyperkalemia, and compartment syndrome. Routine labs, specifically including basic metabolic function (BMP), lactic acid (LA), creatine kinase (CK), and urine pH, should be checked frequently, usually every 4–6 h. A creatine kinase >5,000 is an independent risk factor for acute kidney injury [46]. Hence, an indwelling bladder catheter should be placed to accurately measure urine output. Urine output for adults should be a minimum of 50 cm^3/h, ideally 100 cm^3/h. Normal saline is the preferred resuscitative fluid, and there is no data to support alkalinization of the urine with a bicarbonate drip or administration of mannitol to prevent AKI. Mannitol should not be used in anuric or hypotensive patients, but may have a role as a free radical scavenger and in decreasing compartment pressures. If given, assess the response to a small (25–50 g) dose; maximum benefit is achieved in about 40 min. Hyperkalemia is treated in the usual fashion, administering calcium to stabilize cardiac cell membranes. EKGs should be frequently utilized. Emergent dialysis may be necessary. Improved mortality has been demonstrated in trauma patients when dialysis has been started prior to a BUN >60 mg/dL (21.4 mmol/l) [47]. Nephrotoxic agents, hypotension, bleeding, and anemia should all be avoided in the oliguric phase.

Surgical treatment of crush injury includes fasciotomies and amputations. Fasciotomies can result in infection, thus increasing the risk of amputation, serous drainage and bleeding, and sensory and motor loss. Measurement of compartment pressures (>30 mmHg or <30 mmHg difference between the compartment and diastolic pressure) is the only objective indication for a fasciotomy. Subjectively fasciotomies may be performed if pain is out of proportion on exam or with passive flexion, loss of pulses, paresthesias, or if debridement of necrotic tissue is needed. If there is an underlying fracture, performing a fasciotomy converts this to an open fracture, and orthopedic consultation may be indicated. Delaying fasciotomies can lead to muscle loss and permanent sensory and motor deficits.

Amputations are performed in extremis situations—overwhelming rhabdomyolysis, myoglobin release, hyperkalemia, sepsis, or impending death. They should not be performed to prevent crush syndrome and the sequelae. If guillotine amputation is to be undertaken, it should be performed as soon as the above is recognized and often at the bedside due to patient instability. If the patient is too unstable, a tourniquet can placed and the extremity iced for a physiological amputation. Elective amputations may also be performed if major extremity trauma is present.

Conclusions

Damage control was first described as a surgical concept in an attempt to intercede prior to a patient reaching physiological exhaustion. This concept has since evolved into a resuscitative strategy from time of injury until definitive surgical repair. Of utmost importance to employing damage control as a concept is team collaboration that ensures efficient flow and care of the severely injured patient. It is essential to adhere to the damage control concept especially during special situations such as blast, burn, and crush injuries where the soft tissue destruction may distract from the life-threatening injuries.

Key Points

- Damage control surgery is the concept of staging interventions with early implementation to provide the best opportunity of salvaging a critically ill trauma patient.
- Effective communication is the cornerstone of providing a seamless transition from Ground Zero at the scene to the emergency department, control of bleeding and contamination in Part 1, resuscitation in Part 2 to achieving definitive repair in Part 3.
- Special circumstances such as burns, blast injuries, and traumatic brain injuries are evaluated in the same methodical manner, recognizing multiple cavities and life-threatening injuries can be present concurrently.
- Burns require aggressive resuscitation. The goal in traumatic brain injury treatment is to avoid secondary injury by preventing hypoxia and hypotension.

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