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Critical Care Update

Resuscitation Part 2: Trauma and Burn Injury

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With the release of new versions of Advanced Trauma Life Support (ATLS) and Advanced Burn Life Support (ABLS), a recurring theme is a reduced role for crystalloid administration in initial care. Reasons for this de-emphasis on crystalloid vary with the source of traumatic insult. In some situations, inadequate tissue perfusion complicates inappropriate crystalloid use. Some data suggest that excessive crystalloid use may be associated with increased mortality. I review and cite recent statements regarding initial resuscitation from the trauma and nontrauma burn community along with key articles from those documents.

Committee on Trauma. *Advanced Trauma Life Support*. 10th ed. Chicago, IL: American College of Surgeons; 2018.

Cotton BA, Au BK, Nunez TC, et al. Predefined massive transfusion protocols are associated with a reduction in organ failure and postinjury complications. *J Trauma*. 2009;66:41-49.

Holcomb JB, Wade CE, Michalek JE, et al. Increased plasma and platelet to red blood cell ratios improves outcome in 466 massively transfused civilian trauma patients. *Ann Surg*. 2008;248:447-458.

Nunez TC, Young PP, Holcomb JB, Cotton BA. Creation, implementation, and maturation of a massive transfusion protocol for the exsanguinating trauma patient. *J Trauma*. 2010;68:1498-1505.

Riskin DJ, Tsai TC, Riskin L, et al. Massive transfusion protocols: the role of aggressive resuscitation versus product ratio in mortality reduction. *J Am Coll Surg*. 2009; 209:198-205.

Shrestha B, Holcomb JB, Camp EA, et al. Damage-control resuscitation increases successful nonoperative management rates and survival after severe blunt liver injury. *J Trauma Acute Care Surg*. 2015;78: 336-341.

Dries DJ. Hypotensive resuscitation. *Shock*. 1996;6:311-316.

Moore HB, Moore EE, Chapman MP, et al. Plasma-first resuscitation to treat haemorrhagic shock during emergency ground transportation in an urban area: a randomised trial. *Lancet*. 2018;392:283-291.

Sperry JL, Guyette FX, Brown JB, et al. Prehospital plasma during air medical transport in trauma patients at risk for hemorrhagic shock. *N Engl J Med*. 2018; 379:315-326.

Myers SP, Kutcher ME, Rosengart MR, et al. Tranexamic acid administration is associated with an increased risk of posttraumatic venous thromboembolism. *J Trauma Acute Care Surg*. 2019;86:20-27.

Kamyszek RW, Leraas HJ, Reed C, et al. Massive transfusion in the pediatric population: a systematic review and summary of best evidence practice strategies. *J Trauma Acute Care Surg*. 2019;86:744-754.

Bleeding is the most common factor in early mortality secondary to nonburn trauma. Definitive control of bleeding is essential along with appropriate replacement of intravascular volume. The Committee on Trauma continues to recommend 2 large-bore peripheral venous catheters to administer fluid, red cells, plasma, and platelets as appropriate. When peripheral intravenous sites cannot be obtained, intraosseous infusion, central venous access, or venous cutdown may be used depending on the clinical situation.

Aggressive and continued volume resuscitation is not a substitute for definitive hemorrhage control. Shock associated with nonburn injury is most often hypovolemic (ie, blood loss). In such cases, initiate intravenous fluid therapy with crystalloids. All intravenous solutions should be warmed either by storage in a warm environment (37°C-40°C) or administered through fluid warming devices. A bolus of 1 L of an isotonic solution should be required to achieve an appropriate response in the adult patient. In children under 40 kg, 20 mL/kg is a recommended initial crystalloid dose. If a patient is unresponsive to initial crystalloid therapy, transition should be made to blood product infusion as soon as possible. A growing body of data supports early blood administration strategies. Fluids are administered judiciously because more recent data suggest that aggressive resuscitation before control of hemorrhage may increase morbidity and mortality.

Severely injured patients are at risk for coagulopathy, which may be fueled by resuscitative measures. Coagulopathy establishes a cycle of ongoing bleeding, which can be mitigated by the use of transfusion protocols with blood components administered at specified ratios. One study evaluating nonburn trauma patients receiving fluid in the emergency department found that crystalloid administration in excess of 1.5 L independently increased the odds of death. Some severely injured patients arrive with established coagulopathy, leading to consideration of tranexamic acid.

Physiologic effects of hemorrhage are divided into 4 classes in the ATLS framework based on clinical signs that facilitate estimation of acute blood loss. Class I hemorrhage has minimal associated clinical symptoms. Typically, class I hemorrhage is associated with 15% or less blood volume loss. Generally, there is minimal tachycardia and no

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measurable change in blood pressure, pulse pressure, or respiratory rate. Clinical signs of class II hemorrhage include tachycardia, tachypnea, and decreased pulse pressure. The current ATLS classification associates class II hemorrhage with 15% to 30% blood volume loss. Decreased pulse pressure is associated with a rise in diastolic blood pressure because of an increase in circulating catecholamines with an increase in peripheral vascular tone. In early hemorrhagic shock, systolic blood pressure changes minimally. Thus, it is important to evaluate pulse pressure rather than systolic pressure. Other pertinent clinical findings associated with class II hemorrhage include central nervous system changes such as anxiety, fear, and hostility. Urinary output is only mildly affected. Measured urine flow is usually 20 to 30 mL/h in an adult with class II hemorrhage. Class III hemorrhage involves 30% to 40% blood volume loss. Typically, these patients have classic signs of inadequate perfusion including tachycardia, tachypnea, mental status changes, and a fall in systolic blood pressure. In an uncomplicated case, this is the least amount of blood loss that is consistent with a decrease in systolic blood pressure. The priority of initial management is to stop bleeding by emergency operation or embolization. These patients will require packed red blood cells and possibly other blood products. Finally, class IV shock involving greater than 40% blood volume loss is immediately life-threatening. Symptoms include marked tachycardia, decrease in systolic blood pressure, very narrow pulse pressure, and unmeasurable diastolic blood pressure. Bradycardia is a preterminal event. Urine output is negligible, and mental status is markedly depressed. The skin is cold and pale. These patients require rapid transfusion and surgical intervention.

Persistent infusion of large volumes of fluid, blood, and vasoactive medications in an attempt to normalize blood pressure is not a substitute for definitive control of bleeding. In the patient with penetrating trauma associated with hemorrhage, delaying aggressive fluid resuscitation until definitive control of hemorrhage may be achieved could blunt additional bleeding. Balancing the goal of organ perfusion and tissue oxygenation with the avoidance of rebleeding by acceptance of a lower than normal blood pressure has been termed *controlled or hypotensive resuscitation*. This approach may be a bridge to, but not a substitute for, definitive control of bleeding.

Patterns of response to initial fluid administration are divided into 3 groups by the ATLS curriculum: 1) rapid response, 2) transient response, and 3) minimal or no response. Patients in the rapid response group quickly respond to the initial fluid bolus and become hemodynamically normal without signs of inadequate tissue perfusion or oxygenation. As this occurs, clinicians slow fluids to maintenance rates. Typically, these patients have lost less than 15% of their blood volume. Patients in the second group, the transient responders, respond to the initial fluid bolus. However, these individuals begin to show deterioration of perfusion indices as initial fluids are slowed to maintenance levels, indicating either ongoing blood loss or inadequate resuscitation. Most of these patients have lost an estimated 15% to 40% of their total blood volume (class II and class III hemorrhage). Transfusion of blood products is indicated but even more important is operative or angiographic control of bleeding. Transient response to blood administration identifies patients who are still bleeding and require rapid intervention. Failure to respond to crystalloid or blood administration dictates the need for immediate definitive intervention such as operation or angiography to control exsanguinating hemorrhage. Occasionally, failure to respond to fluid resuscitation is caused by pump failure from blunt cardiac injury, tamponade, or tension pneumothorax. Nonhemorrhagic shock should be considered as part of the differential diagnosis in this group of patients with class IV hemorrhage. Massive transfusion should be initiated in these patients.

When blood is needed, ideally crossmatched products are available. If crossmatched blood is unavailable, type O packed red cells are indicated for patients with exsanguinating hemorrhage. AB plasma is given when uncross-matched plasma is needed. To avoid sensitization and future complications, Rh-negative packed red cells are preferred for females of childbearing age. When available, unmatched, type-specific packed cells are preferred over type O packed red cells. Adaptations of tube thoracostomy collection devices sometimes allow for sterile collection and transfusion of shed blood. This blood generally has only low levels of coagulation factors, so plasma and platelets may still be needed. Processed plasma products may be a more effective early resuscitation tool than multicomponent blood transfusion. Processed plasma is easily stored and used without many of the technical concerns tied to traditional blood components.

A smaller subset of patients will require massive transfusion defined as greater than 10 U packed red blood cells within the first 24 hours of admission or more than 4 U in 1 hour. Early administration of packed red blood cells, plasma, and platelets in a balanced ratio to minimize excessive crystalloid administration may improve patient survival. This approach has been termed *hemostatic or damage control resuscitation*. Simultaneous efforts are required to control bleeding and reduce the effects of coagulopathy, hypothermia, and acidosis. Severe injury and hemorrhage result in consumption of coagulation factors and early coagulopathy. This complication may be present in up to 30% of severely injured patients at the time of admission even without anticoagulation use.

In some settings, tranexamic acid is administered in the prehospital setting for severe injury. This approach is driven by recent data showing improved survival when this drug is administered within 3 hours of injury. The first dose is usually given over minutes and administered in the field. A follow-up infusion is given over 8 hours. The impact on coagulation complications with tranexamic acid is under evaluation.

Fluid resuscitation for injured children is weight based with a goal of replacing lost intravascular volume. Evidence of hemorrhage may be evident with a loss of 25% of a child's circulating blood volume. Initial fluid resuscitation for injured children recommended previously in ATLS has consisted of intravenous administration of warmed isotonic crystalloids as an initial 20-mL/kg bolus followed by 1 or 2 additional similar boluses of isotonic crystalloid and evaluation of the child's physiologic response. If there is evidence of ongoing bleeding after the second or third crystalloid bolus, 10 mL/kg packed red blood cells may be given.

Recent advances in trauma resuscitation in adults with hemorrhagic shock have resulted in movement away from large-volume crystalloid resuscitation in favor of damage control resuscitation using blood products. This approach in adults is also thought to be effective in children as a means to interrupt the lethal triad of hypothermia, acidosis, and coagulopathy. Thus, there is a movement in pediatric trauma centers in the United States toward crystalloid-restrictive balanced blood product resuscitation strategies in children with evidence of hemorrhagic shock although published studies supporting this approach are less common. The results of massive transfusion in children are inconsistent, with some reports citing no mortality benefit or an increased complication rate. Basic principles of this strategy are an initial 20-mL/kg bolus of isotonic crystalloid followed by a weight-based blood product resuscitation with 10 to 20 mL/kg packed red blood cells and 10 to 20 mL/kg fresh frozen plasma and platelets. If a facility lacks ready access to blood products, cautious administration of crystalloid remains an alternative. A favorable response is seen by slowing of heart rate, clearing of sensorium, improvement in skin color, and greater warmth in

extremities. Urine output and pulse pressure should also increase. Children have 3 typical response patterns to fluid resuscitation as seen in adults.

Burn Size Evaluation

Harshman J, Roy M, Cartotto R. Emergency care of the burn patient before the burn center: a systematic review and meta-analysis. *J Burn Care Res*. 2019;40:166-188.

Pham C, Collier Z, Gillenwater J. Changing the way we think about burn size estimation. *J Burn Care Res*. 2019;40:1-11.

Retrospective data from multiple burn centers show that many patients referred for large injuries actually were discharged within 24 hours. As many as 70% of patients referred with overestimated burn size were discharged within 48 hours. Only 30% of referred patients required surgery. Many referred individuals were more likely to have been appropriately triaged to a follow-up clinic rather than undergoing direct interhospital transfer. International burn centers have similar experiences. One study from Australia showed that in children 33% of total referrals had not correctly estimated the total body surface area (TBSA) injury, 25% of referrals did not meet standard transfer criteria, and up to 40% of transfers were not indicated. A study in England noted that 37% of transfers had misestimated TBSA injuries such that transfer may not have been indicated. When multiple studies are reviewed, on average, 45% to 77% of small burns (< 20% TBSA injuries) and 26% to 37% of larger burns (> 20% TBSA injuries) did not meet American Burn Association criteria to warrant transfer to a burn center.

The most important concern with burn size overestimation is excessive and potentially dangerous resuscitation. Although expert burn providers understand the nuances of postburn resuscitation and are wary of the dangers of excessive fluid administration, referring providers often explicitly follow the Parkland formula without consideration of unique patient and burn characteristics. When combined with the high incidence of burn size overestimation that is presently reported, application of the Parkland formula may negatively affect clinical outcomes. Studies of patients receiving excessive fluid administration during the first 24 hours of resuscitation reveal a 3-fold increase in the likelihood of abdominal compartment syndrome.

Given the significant risk of overestimation of burn size, patients with relatively minor injuries who present to nonburn institutions often undergo unnecessary interventions and receive excessive amounts of fluid. The issue of excessive resuscitation is relevant in light of changes in the ABLS approach (summarized later), which decrease the amount of fluid administered relative to TBSA burned. Growing evidence suggests that transitioning to computer-based imaging technology is the most reliable and reproducible means through which burn size can be estimated. Using computer technology, now available on mobile devices such as tablets, as a component of a telemedicine system, burn triage may be further enhanced. Many burn providers suggest that a more robust telemedicine system may bring about a necessary shift in referral-based burn care that will significantly enhance the ability of providers to provide rapid and appropriate burn care of the highest quality.

Burn Resuscitation

American Burn Life Support (ABLS) Advisory Committee. *American Burn Association Advanced Burn Life Support Course, Provider Manual, 2016 Update.* Chicago, IL: American Burn Association; 2016.

Navar PD, Saffle JR, Warden GD. Effect of inhalation injury on fluid resuscitation requirements after thermal injury. *Am J Surg*. 1985;150:716-720.

Chung KK, Wolf SE, Cancio LC, et al. Resuscitation of severely burned military casualties: fluid begets more fluid. *J Trauma*. 2009;67:231-237.

Pham TN, Cancio LC, Gibran NS. American Burn Association practice guidelines burn shock resuscitation. *J Burn Care Res*. 2008; 29:257-266.

The goal of burn resuscitation is to maintain adequate tissue perfusion and organ function while avoiding complications of over- or underresuscitation. Burn fluid resuscitation is guided by critical care principles and managed on a near continuous basis to promote best outcomes. Edema forming in burn-injured tissue reaches a maximum in the second 24 hours after burn injury. The administration of excessive volumes of resuscitation fluid magnifies edema formation, leading to various types of resuscitation-related morbidity including extremity, orbital, and abdominal compartment syndromes as well as pulmonary and cerebral edema. Shock and organ failure, most commonly manifest by acute kidney injury, may occur as a consequence of hypovolemia in a patient with an extensive burn who is untreated or receives inadequate amounts of fluid. The increase in capillary permeability caused by burn injury is greatest in the immediate postburn period, and reduction in the effective blood volume is the most rapid at that time. Prompt administration of adequate amounts of resuscitation fluid is essential to prevent decompensated burn shock and organ failure. A delay in initiating resuscitation often leads to higher subsequent fluid requirements. Inhalation injury has also been associated with increased fluid requirements. It is essential that resuscitation commence as close to the time of injury as feasible. Crystalloid fluid, in reduced amounts as described later, remains essential to the initial resuscitation of burn patients.

A number of fluid resuscitation formulas have been devised to estimate fluid needs in the first 24 hours after burn injury. All burn resuscitation formulas account for the surface area burned and body weight. The patient weight in kilograms is obtained or estimated and only second- and third-degree TBSA burned areas are calculated using the “Rule of Nines” or any of several commonly available burn diagrams. First-degree burns should not be included in fluid resuscitation calculations. Approaches dating to 2008 established the upper and lower limits from which 24-hour postburn fluid estimates could be calculated. These limits were derived from 2 commonly applied resuscitation formulas: the Parkland formula (4 mL/kg/% TBSA burned/24 h) and the modified Brooke formula (2 mL/kg/% TBSA burned/24 h). For traditional formulas, it was estimated that one half of the calculated total 24-hour volume would be administered within the first 8 hours after burn injury, with the remaining half of the calculated total 24-hour resuscitation volume given over the subsequent 16 hours in the first postburn day. Fluid administration is titrated based on urinary output and clinical response.

A more recent statement regarding initial fluid rates reflected in the current content from the ABLS curriculum is particularly relevant to providers caring for burn-injured patients before arrival at the burn center. In the prehospital and early hospital settings, before formally calculating the percent TBSA burned, fluid administration guidelines are based on patient age with a fixed initial fluid rate as a starting point as follows:

1. 5 years and younger: 125 mL lactated Ringer/h
2. 6 to 13 years of age: 250 mL lactated Ringer/h
3. 14 years and older: 500 mL lactated Ringer/h

Once the patient weight in kilograms is obtained and the percent of second- and third-degree burns is carefully determined in the secondary survey, the ABLS 2016 fluid resuscitation fluid calculations may be used to determine an adjusted fluid rate. For

adults with thermal and chemical burns, fluid is administered at 2 mL lactated Ringer/patient body kg/% TBSA second- and third-degree burns with half of the fluid for the initial 24-hour total in milliliters infused over the first 8 hours. Multiple recent reports indicate that resuscitation based on the historic 4 mL lactated Ringer/kg/% TBSA burn commonly results in excessive edema formation and other complications of over-resuscitation. If initial resuscitation is delayed, the first half of the resuscitation volume is given over the number of hours remaining in the first 8 hours after burn injury. If fluid resuscitation is delayed beyond 6 hours after burn injury, a burn center should be consulted for the most appropriate catch-up fluid administration strategy. In general, the administration of crystalloid fluids via bolus infusion should be avoided unless the patient is hemodynamically unstable.

Adult patients with high-voltage electrical injuries with evidence of myoglobinuria as reflected by pigment in the urine should receive 4 mL lactated Ringer/kg/% TBSA second- and third-degree burns with half of the 24 hour total in milliliters infused over the first 8 hours. In the setting of electrical injury, once the adjusted fluid rate based on weight and burn size is infusing, the most critical consideration is careful titration of hourly fluid administration based on patient urinary output and physiologic response. Frequently, cutaneous changes will not reflect the degree of deep injury with electrocution.

When the body weight and TBSA second- and third-degree burns are reliably calculated in a child, 3 mL lactated Ringer is given per kilogram $\times$ % TBSA second- and third-degree burns. Again, half of this fluid is given in the first 8 hours as per the adult fluid administration calculation. Because children have a greater body surface area per unit mass than adults, they will require relatively greater amounts of resuscitation fluid. The surface area/body mass relationship of a child also suggests a smaller intravascular volume per unit surface area burned, which makes the burned child more susceptible to fluid overload and hemodilution. Infants and young children should receive lactated Ringer with 5% dextrose at a maintenance rate, in addition to burn resuscitation as noted earlier. Standard burn resuscitation dogma defines young children and infants as weighing $\leq$ 30 kg. The addition of 5% dextrose is caused by an increased risk of hypoglycemia because of limited glycogen stores in infants and children.

Urine output obtained from an indwelling bladder catheter is a generally reliable guide to resuscitation adequacy in patients with normal renal function. Typical goals are as follows:

1. Adults: 0.5 mL/kg/h (or 30-50 mL/h)
2. Young children ($\leq$ 30 kg): 1 mL/kg/h
3. Pediatric ($>$ 30 kg) up to age 17 years: 0.5 mL/kg/h
4. Adult patients with high-voltage electrical injuries with evidence of pigment in the urine consistent with myoglobinuria should receive fluids targeting a urine output of 75 to 100 mL/h until urine clears

The fluid infusion rate may be increased or decreased based on urine output. The expected output should be based on ideal body weight rather than actual preburn weight. After a starting point has been determined for fluid administration using ABLS parameters, the infusion rate may be increased or decreased by up to one third if the urinary output falls below or exceeds the desired level by more than one third every hour.

Patients with high-voltage electrical injury present a special case because cutaneous effects may not reflect the degree of deep tissue injury. Thus, patients with high-voltage electrical injury associated with deeper injury may have significant amounts of myoglobin and hemoglobin in the urine. The administration of fluids at a rate sufficient to maintain a urinary output of 1 to 1.5 mL/kg/h in the adult (approximately 75-100 mL/h) should produce clearing of urine pigments with sufficient rapidity to eliminate the need for a diuretic. When adequate urinary output has been established and the pigment density decreases, the fluid rate may be decreased. It is important to note that the persistence of dark red-tinged urine may also reflect a compartment syndrome.

Summary Points

- Both the Committee on Trauma and the Advanced Burn Life Support Advisory Committee have clearly de-emphasized the amount and the role of crystalloid in initial resuscitation after various forms of injury.
- Burn resuscitation is clearly complicated by failure to effectively estimate burn size. Software programs are now available to improve burn size estimation. The American Burn Association also proposes standard fluid administration rates before arrival at a burn treatment facility.
- Trauma resuscitation, after conservative crystalloid administration, moves rapidly to the early administration of plasma or balanced blood product resuscitation. If blood products are not immediately available, conservative crystalloid administration, sometimes described as hypotensive resuscitation, may be considered.
- Fluid resuscitation rates in the burn center are clearly reduced relative to historic burn resuscitation protocols.

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