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Vascular access, fluid resuscitation, and blood transfusion in pediatric trauma

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ABSTRACT

Trauma care in the general population has largely become protocol-driven, with an emphasis on fast and efficient treatment, good team communication at all levels of care including prehospital care, initial resuscitation, intensive care, and rehabilitation. Most available literature on trauma care has focused on adults, allowing the potential to apply concepts from adult care to pediatric care. But there remain issues that will always be specific to pediatric patients that may not translate from adults. Several new devices such as intraosseous (IO) needle systems and techniques such as ultrasonography to cannulate central and peripheral veins have become available for integration into our pre-existing trauma care system for children. This review will focus specifically on the latest techniques and evidence available for establishing intravenous access, rational approaches to fluid resuscitation, and blood product transfusion in the pediatric trauma patient.

Key Words: Pediatric, resuscitation, transfusion, trauma

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INTRODUCTION

The optimal resuscitation of a pediatric trauma patient presents unique challenges and age-specific issues that do not exist in the adult population. Care providers must use similar, but in some cases very different strategies to appropriately resuscitate a pediatric trauma patient. Specifically, unique approaches to vascular access, fluid management, and blood transfusion should be considered.

VASCULAR ACCESS

Obtaining vascular access in a pediatric trauma patient offers unique challenges. These issues include obtaining the cooperativeness of the child for IV placement, potential for psychological trauma, smaller veins, and more subcutaneous fat in children making both palpating and visualizing veins more difficult. When considering IV placement in a pediatric *trauma* patient, additional issues such as higher likelihood of hypovolemia upon presentation,[1] lower success rates of IVs by first responders[1] with consequent hematomas, bruises, and non-availability of these punctured veins for IV placement, fractures in the extremity bones, and

hypothermia causing peripheral vasoconstriction, the challenge becomes even more difficult.

Flow of fluids through intravenous catheters is governed by the Hagen-Poiseuille equation which characterizes the flow through a long cylindrical pipe [Figure 1]. Flow is inversely proportional to the length of tubing, viscosity of fluid, proportional to the pressure drop across the
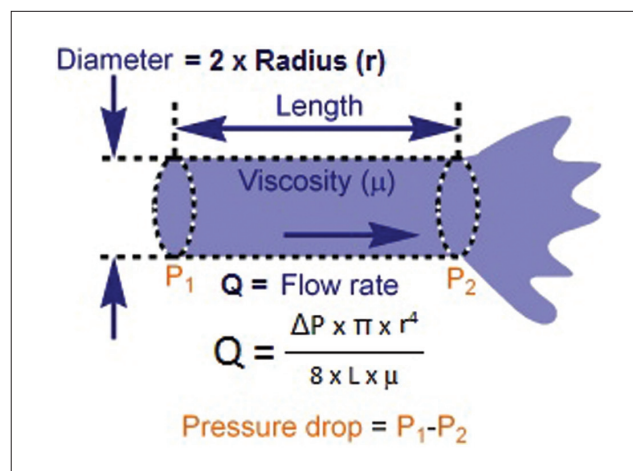

Figure 1: Flow through a pipe, adaptation of Hagen-Poiseuille law (modified from calctool.org)

IV catheter, and proportional to the fourth power of the radius of the IV catheter. Maximum flow rates for each IV catheter are published and written on the package of each IV. The values from BD© (Franklin Lakes, NJ), a common IV catheter manufacturer in the US, are shown in Table 1. These values generally correspond with flows when using an IV under normal conditions as using a rapid infusion system can result in higher values. Rapid infusion systems increase the pressure drop across the IV catheter and increase the temperature of the infusate which effectively decreases viscosity to allow for greater flow rates.

Size and length of intravenous catheters must be considered in pediatric trauma patients. Even within the pediatric population, what would be considered a "small catheter" for a teenager would be considered a "volume line" for an infant. It has been reported that using a rapid infusion system and an 8.5 French central line in an adult, one can achieve flow rates of approximately 850 ml/min.[3] For a 70-kg male, this would result in replacing his normal circulating blood volume in just under 6 minutes. To achieve replacement of one circulating volume in the same time in a 20-kg 7-year old, one could use two 20 gauge IVs with a rapid infusion system. To have the same capability in a 5-kg infant, one could use one 22 gauge IV and a 10 cc syringe as a pump.

Quick and efficient intravenous access is vital to appropriately resuscitating a trauma patient. Clinical practices have changed in the last 10 years considerably, arguably resulting in better outcomes for pediatric trauma patients. Special techniques have been used to facilitate IV placement by improving the visualization of the veins and include local warming,[5] transillumination,[6] epidermal nitroglycerin,[7] and ultrasound. Improved local anesthetic techniques such as use of EMLA (a eutectic mixture of lidocaine and prilocaine) with or without sonophoresis,[8,9] amethocaine (Ametop),[10] and use of the J-Tip Needle Free Injection System [Figure 2] (National Medical Products, Irvine, CA)[11] help in establishing an IV access with little or no pain. While the use of EMLA cream can be effective to provide analgesia for IV placement, it can take 20−30 minutes before it takes effect. The use of the J-Tip, an FDA-approved device that delivers an air-powered needleless injection of lidocaine, provides local anesthesia at a given site with less pain when compared to EMLA cream alone.[11]

In the stable pediatric patient, it is ideal to have at least one, if not two, working peripheral IVs. The preferred access sites would be those in uninjured extremities with common favorites being the antecubital, external jugular (in patients without suspected cervical spine injury), and saphenous veins. In the hemodynamically unstable pediatric trauma patient, with potential hypovolemia, the preferred IV access site is one that can be most easily obtained. While the aforementioned sites should be sought after, percutaneous access of the femoral vein, internal jugular vein, subclavian vein, axillary vein, and the umbilical vein (if still patent) should also be considered [Figure 3].[12] Accessing the superior sagittal sinus has been reported as a means of emergency blood transfusion in a 2-week-old infant whose fontanel had not yet fully closed.[13]

Delay in appropriate intravenous access will, without question, delay needed treatment in pediatric trauma patients which is why alternatives to intravenous access, such as IO access, are being more readily used [Figure 4]. Success rates for first time IO lines are higher than umbilical venous lines in the newborn population[15] and are in general gaining more widespread use,[16] but given

Figure 2: J-Tip air-powered injection system, Jtip.com

Gauge	Published flow rate (ml/min)*	Flow rate gravity (ml/min)[2]	Flow rate level 1 (ml/min)[3]	Flow rate RIS (ml/min)[3]	10 cc syringe pump (ml/min)[4]
4 Fr	Not published	286	450	516	Not published
5 Fr	Not published	380	533	667	Not published
6 Fr	Not published	480	548	702	Not published
7 Fr	Not published	Not published	564	772	Not published
8.5 Fr	Not published	674	596	857	Not published
14	330	Not published	488	584	Not published
16	220	Not published	368	412	Not published
18	105	92	209	205	Not published
20	60	51	140	144	Not published
22	35	37	Not published	Not published	106
24	17	Not published	Not published	Not published	78

Table 1: Maximum flow rates for peripheral intravenous catheters of different internal diameters

*All values are for crystalloid solutions, published flow rate from BD packaged IV catheters

the discomfort associated with them and their limitations, they will likely never replace intravenous lines as first-line access. Both Pediatric Advanced Life Support (PALS) and Advanced Trauma Life Support (ATLS) now recommend placement of an IO line if adequate IV access cannot be established within three attempts or 90 s, whichever is sooner.[17] The placement of IO lines has been aided by the invention of battery-powered drills to assist with placement, such as the EZ-IO [Figure 4] (Vidacare, San Antonio, TX), which boasts a 93% success rate with 82% being placed on the first attempt in a pediatric emergency department population.[18] Several anatomical sites may be used for IO cannulation. The most commonly used include the proximal tibia, the distal tibia, the proximal humerus, and the distal femur. The anterior–superior iliac spine is used less commonly. The sternum and distal radius have been identified for use in adults but not in children.[19] Flow rates through IO lines are lower than intravenous lines, and there are no clear published flow rates in pediatric patients specifically, but rates as high as

204 ml/min have been reported in the adult tibia, provided the assistance of a pressure bag.[20] This is much higher than the best attempt to "model" the pediatric tibia, as one group did with hypovolemic dogs, only reporting rates of 29 ml/min with the use of a pressure bag.[21]

Since the emphasis is on fast access, the antiquated practice of surgical cutdown has been replaced by percutaneous central venous access, sometimes aided by ultrasound guidance and IO access. These latter methods routinely take less time than a surgical cutdown, which can take more than 10 min in an infant, even in skilled hands.[22] Undertaking a surgical cutdown does not guarantee success in establishing intravenous access, and serious complications such as cellulitis, venous thrombosis, arterial transection, and nerve damage have all been reported.[23]

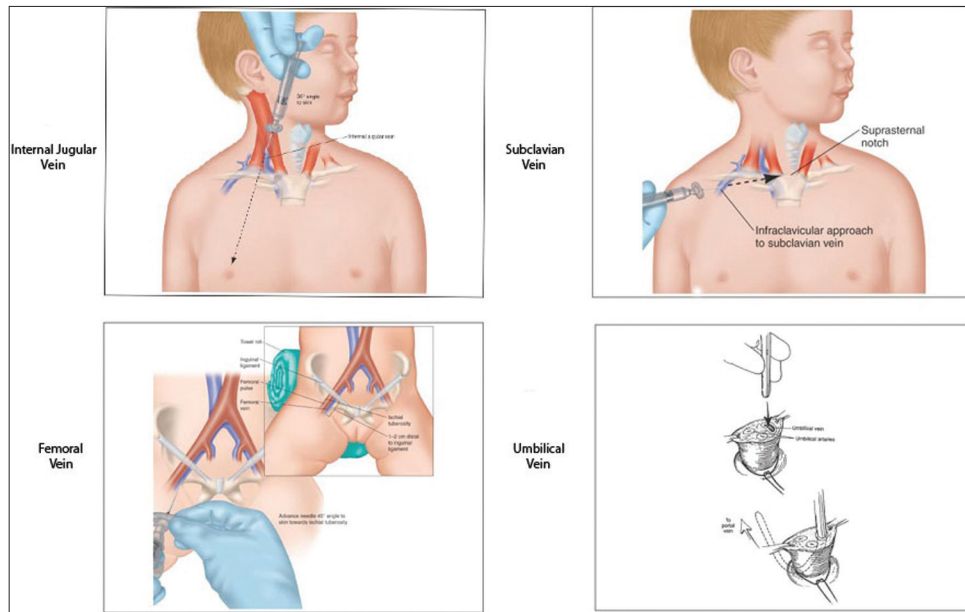In a pediatric trauma resuscitation, IV access that can be placed most easily with the lowest rate of immediate

Figure 3: Central IV line sites, from the pediatric emergency medicine resource
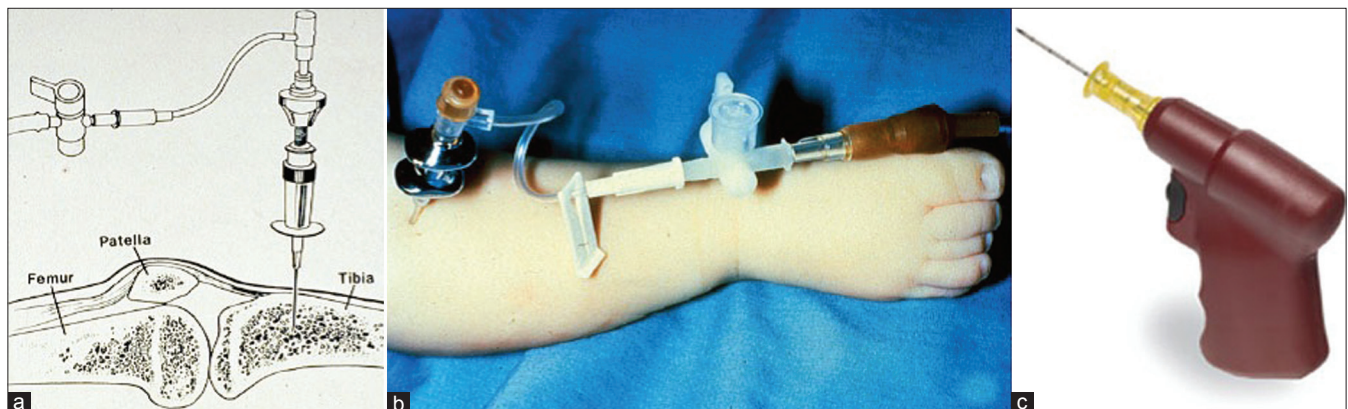

Figure 4: (a) Drawing IO line, (b) proximal tibia IO line, (c) EZ-IO drill; adapted from Ramaiah and Sharar[14]

life-threatening complications would be the femoral vein line. Femoral line placement can be aided by the use of ultrasound [Figure 5], but can also be placed based on landmarks as the femoral vein runs through the groin just medial to the femoral artery which can usually be detected by a palpable pulse. The presence of serious abdominal or pelvic trauma with suspected injury to the IVC is a contraindication for a femoral line, and clinicians should strongly consider subclavian or internal jugular vein access in these patients. Common complications associated with these lines include higher risks of pneumothorax. The presence of unilateral pneumothorax, if already treated with chest tube, should direct a clinician to place central access on the same side as the child would already be treated for this complication.

FLUID MANAGEMENT

The goal of resuscitation in trauma victims is to provide adequate oxygen delivery to vital organs and prevent shock. Inadequate volume resuscitation (when combined with inadequate IV access) has been shown to be the leading cause of preventable trauma-related mortality in children in a recent study.[24] Recognizing shock in the pediatric trauma patient can be more difficult as the signs of shock can be more subtle than in adult patients. A child that appears only as irritable initially may have lost as much as 30% of his or her blood volume [Table 2]. Rapidity with which children can get hypovolemic should not be underestimated and hence PIV access with two age-appropriate IV cannulae should be achieved in all polytrauma patients.

Clinically, it is useful to separate shock into three clinical categories: compensated shock, decompensated shock, and cardiopulmonary failure in order to prioritize the resuscitation strategies [Table 2]. A quick physical exam can provide vital information which should lead to appropriate treatment thereafter. Key elements of this exam will include assessing heart rate, presence and strength of pulses, blood pressure, respiratory rate, mental status, color and temperature of extremities, and capillary refill. Tracking urinary output and blood pH can help provide guidance with further resuscitation efforts, although these variables are not always available on immediate assessment.

While every child is different and presents with his or her own unique issues, most trauma centers apply simple algorithms to treat pediatric trauma patients. A clinician must continue to reassess vital signs and objective
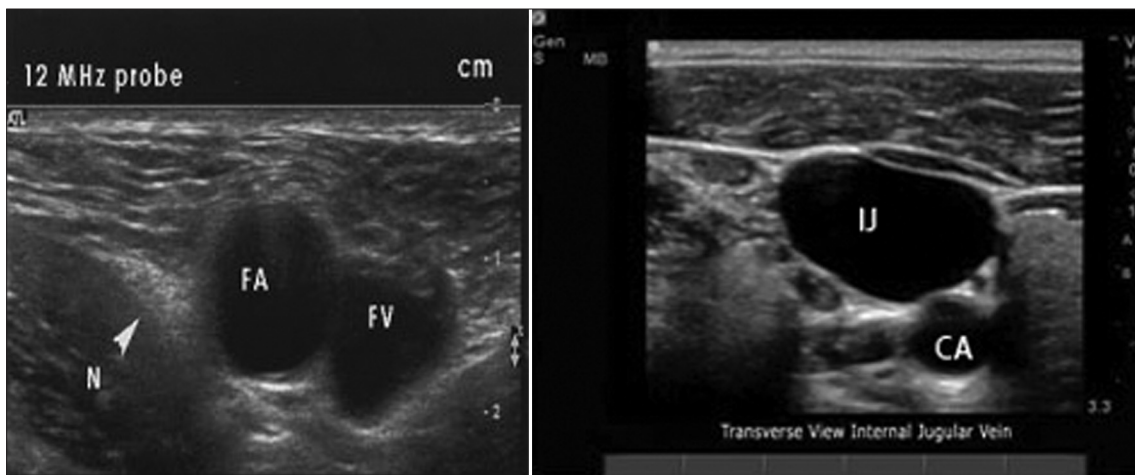

Figure 5: Ultrasound images of femoral and internal jugular venous sites

Table 2: Categories of shock, adapted from PALS, 2011, and ATLS, 2008			
System	**Mild Hemorrhage** **Compensated Shock** **(<30% blood volume loss)**	**Moderate Hemorrhage** **Decompensated Shock** **(30-45% blood volume loss)**	**Severe Hemorrhage** **Cardipulmonary Failure** **(>45% blood volume loss)**
Cardiovascular	Mild tachycardia Weak peripheral pulses Strong central pulses Mild acidosis	Moderate tachycardia Weak peripheral pulses Weak central pulses Moderate acidosis	Severe tachycardia No peripheral pulses Weak central pulses Hypotension *(SBP < 70 + [2 × age in years])* Severe acidosis
Respiratory	Mild Tachypnea	Moderate Tachypnea	Severe Tachypnea
CNS	Irritable, anxious	Agitated, lethargic	Obtunded, comatose
Skin	Cool extremities, mottling. Cap refill > 2 s	Cool extremities, pallor. Cap refill > 3 s	Cold extremities, cyanosis. Cap refill > 5 s
Urinary	Mild oliguria	Marked oliguria; increased BUN	Anuria

laboratory parameters to guide volume replacement and deviate from the published standards if situation demands. ATLS, a program created and developed by the American College of Surgeons, has developed such guidelines in taking care of the pediatric trauma patient. According to ATLS practice, when a child presents in shock, after adequate IV/IO access is established, if there are any signs of inadequate tissue perfusion, administer a rapid (<20 minutes) bolus of 20 cc/kg of lactated Ringer's solution or 0.9% saline solution. If there are continued signs of inadequate perfusion after the bolus is completed, ATLS suggests a second rapid infusion of 20 cc/kg of lactated Ringer's solution or 0.9% saline solution. If there are still signs of inadequate tissue perfusion after a second bolus, a third one is suggested, but at this point, one should also start to consider using blood products for resuscitation, especially if the blood loss is suspected to be ongoing. Particularly in younger children of smaller weights, a buretrol is highly recommended to prevent over-resuscitation of a child. The management of glucose levels in these patients is a topic that has not been examined closely in the literature, but one study suggests that glucose levels are abnormal 77% of the time.[25] For this reason, blood glucose should be closely monitored in pediatric patients to prevent hypoglycemia, especially those under 6 months of age. Glucose should be kept out of resuscitative fluid to prevent hyperglycemia, but routinely monitored, and hyperglycemia should be treated in high-risk groups such as traumatic brain injury patients.[26] Hyperglycemia has also been associated with increased risk of infection and increased length of stay[27] in pediatric trauma patients suggesting that the control of hyperglycemia may lead to better patient outcomes.

In the pediatric trauma patient with suspected or known traumatic brain injury, additional treatment goals center around preventing secondary brain injury, maintaining adequate cerebral perfusion pressure, and keeping intracranial pressure low. In addition to maintaining an adequate circulating volume, appropriate fluid management also includes appropriately using hyperosmolar therapy (mannitol, hypertonic saline) when indicated. Because maintaining normal intracranial pressure is a primary goal in managing these patients, hypovolemia and hypervolemia must be avoided.

When considering the choice of resuscitation fluid (crystalloid versus colloid administration), there is still a lack of strong evidence in the literature to justify the use of more expensive non-blood product colloids (e.g. albumin, starches) when compared to cheaper and more commonly used crystalloid solutions.[28] In certain patient populations, such as traumatic brain injury patients, the use of albumin has been associated with worse outcomes when compared to crystalloid solutions.[29]

Fluid management devices, such as rapid infusion systems

(e.g. Belmont RIS®; Belmont Instrument Corporation; Billerica, MA), continue to be developed in the last decade and have shown promise in the adult trauma population. These allow us to infuse fluid faster than traditional methods and keep patients more normothermic than time-tested methods, such as the Level 1® (Smith Medical; Dublin, OH) system. While more modern infusion systems can provide the benefit of not having to de-air fluid bags before placement in the Level 1 and keeping infused fluid warmer, a major advantage has yet to be shown in the pediatric trauma population.[4] Such infusion systems tend to show an advantage once IV catheters of size 16 G or greater are used. Thus, if a patient would benefit from having a larger IV placed and can feasibly have one placed, a rapid infusion system may provide some benefit. Otherwise, the difference in temperature can be made up for with alternative methods of warming.[4] In the resuscitation of infants, toddlers, and small children <20 kg, the most efficient pump may be a 10 cc syringe, operated by a clinician, attached to traditional IV pump tubing, provided a one-way valve is in place.[3] Using an infusion system may be harmful as blood can be infused too fast leading to complications such as pulmonary edema or hyperkalemia.[30]

While trauma care does not stop after the initial resuscitation, careful attention needs to be applied to the fluid management of these patients after an initial resuscitation to help prevent further secondary iatrogenic injuries and maintain adequate perfusion throughout the acute phase of recovery. The "4-2-1 rule" is what is most commonly used and practiced when estimating maintenance requirements for pediatric (and some adult) patients. The rule recommends 4 cc/kg/h for a patient up to 10 kg. For patients between 10 and 20 kg, the rule establishes 40 cc/hr + 2 cc/kg/h (for every kg above 10 kg), and 60 cc/h + 1 cc/kg/h (for every kg above 20 kg) in patients greater than 20 kg. This rule is purely a guideline and should not be used in all patients, but rather as a starting point for maintaining fluid management in the trauma patient.

BLOOD TRANSFUSION

In patients who have more severe injuries or patients who do not respond to initial IV crystalloid boluses, the use of blood products should be strongly considered as the primary resuscitative fluid until hemorrhage can be controlled. While whole blood might be an ideal fluid to transfuse in the trauma patient, it is not readily available in all countries and situations. Transfusing individual blood products remains the standard of care in pediatric trauma resuscitation mainly because this is what is available from blood centers. ATLS recommends considering transfusion if a patient still has signs of shock after two boluses of 20 cc/kg of a crystalloid have

been administered [Figure 6]. The decision to transfuse blood products is not one that should be taken lightly, as transfusion of stored packed red blood cells may have deleterious side effects on oxygen delivery[31,32] and has in some populations of pediatric patients been associated with increased mortality, prolonged use of mechanical ventilation, and increased length of ICU stay.[33] It can also be difficult to determine how much blood loss has occurred when a patient has arrived making the decision more difficult. While laboratory analysis such as serial hematocrits, lactate, and base deficit may prove useful to help guide fluid and blood product administration, there are no clear hemoglobin thresholds for pediatric patients other than those extrapolated from studies looking at adult outcomes.[32] Additionally, laboratory analysis can take time and it can be difficult in the acute resuscitative period to obtain samples that will be reflective of accurate hematologic values for that patient at that point in time.

When time allows a clinician to measure individual parameters associated with each blood product (hematocrit, PT/INR, platelets, fibrinogen, or other complex methods such as thromboelastography), transfusion can be directed toward objective laboratory

values. These laboratory values will vary by age and the age-specific average should be considered when titrating blood products to laboratory values. Additionally, the blood bank should be notified when a pediatric trauma patient is less than 4 months of age so that these patients can preferentially receive blood that has been recently collected, freshly irradiated, and is "CMV-safe." If time cannot be allowed for delivery of such blood, using the emergency uncrossmatched O-negative blood until the appropriate units can be delivered is a better alternative than delaying transfusion in such a patient.

In clinical situations when there is not sufficient time or it is not feasible to wait for laboratory tests to guide therapy, using an empiric approach to blood transfusion must be employed. While there is no clear answer about which empiric approach to take in adults regarding ratios of packed red blood cells, fresh frozen plasma, platelets, and cryoprecipitate, it is clear that all of these products should be used in a massive transfusion protocol. Dosing blood products is traditionally weight based and when an accurate weight cannot be measured, using a length-based resuscitation tape [Figure 7] can help estimate the weight. One transfusion protocol has been recently proposed for children less than 30 kg [Figure 8], which also suggests use of recombinant Factor VIIa in cases where multiple blood volumes have been lost. This recommendation is based on several case reports where rFVIIa has been successfully used outside of its FDA-approved indications, and doses administered have ranged from 20 to 180 mcg/kg.[32] Before its routine use can be recommended in children, more studies should be undertaken to look at the potential complications, specifically in children, of administering rFVIIa, but its potential benefit cannot be debated.

COMPLICATIONS

Under-resuscitation could lead to multiple-organ dysfunction, with the kidney and liver being the most susceptible organs. Procedure-related complications for IO and central access include, but are not limited to,
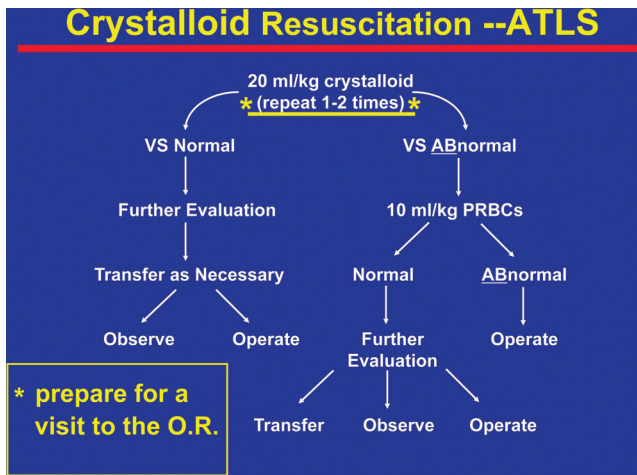

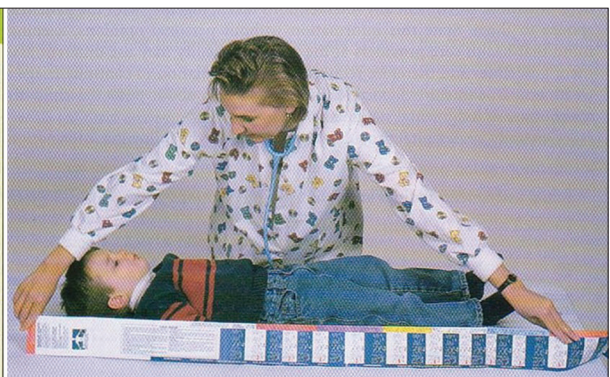**Figure 6:** Advanced trauma life support resuscitation algorithm

Figure 7: Broselow length-based resuscitation tape guide for pediatric patients, adapted from pediatric advanced life support
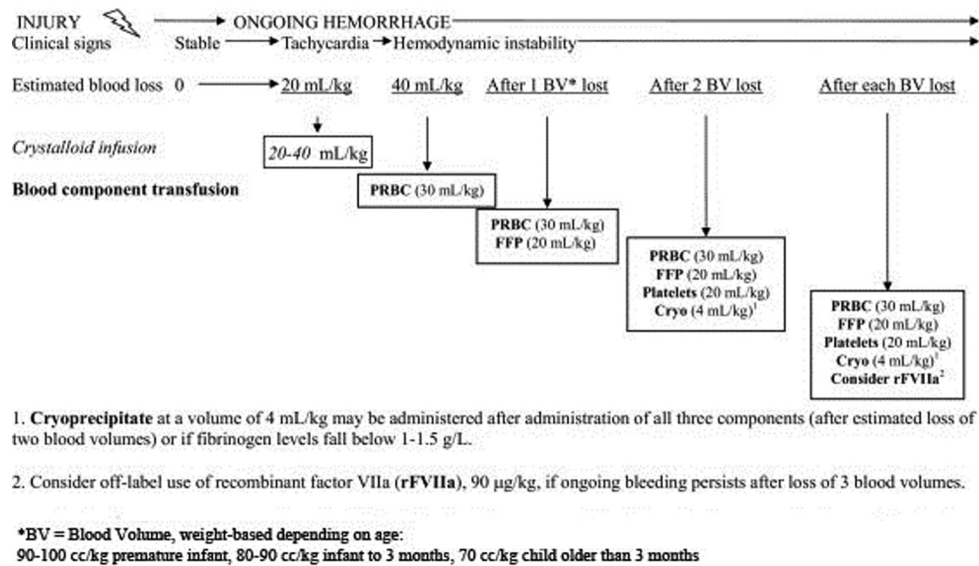
Figure 8: Suggested transfusion practice in massive hemorrhage (adapted from Dehmer *et al.*[32] with permission and modified from Barcelona *et al.*[34])

extravasation, infection, pneumothorax, and perforation of the heart. Over-resuscitation can lead to pulmonary and/or peripheral edema, especially in children with pre-existing cardiac or renal disease. Children must be monitored for common complications of blood transfusion including hyperkalemia, hypocalcemia, and hypothermia (if blood products are not sufficiently warmed during transfusion). Additionally, other potential iatrogenic complications include hypothermia, air embolism, transfusion reactions when blood products are used, and subcutaneous infiltration of IV fluid. Some of these complications can be severe enough to be life threatening on their own.

The key to excellent trauma care starts with good preparation, rapid assessment, re-assessment, team communication, and close monitoring throughout the acute phase of traumatic injury. Using appropriate methods in establishing IV/IO access, fluid management, and blood transfusion is an integral part of providing quality care for pediatric trauma patients.

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