LESSONS FOR PRACTICE:

- Fluid resuscitation is a vital component of the initial management of pediatric trauma care
- Venous access in the pediatric trauma patient should be established in the quickest, most effective manner
- Careful monitoring of patients after fluid resuscitation can prevent future complications

Introduction

A vital aspect of the successful management of a traumatically injured child involves appropriate fluid resuscitation and monitoring. Careful consideration should be given to the type of fluid, access needed and possible complications that may be encountered in these patients. While fluid boluses and management strategies for ongoing shock can be standardized in adults, weight-based techniques are needed in children. This includes customization of a massive transfusion protocol. Appropriate, timely fluid resuscitation may also reduce the need for surgical intervention.

Options for Fluid Type & Vascular Access

Importance. Fluid resuscitation for hypovolemia is integral to the acute medical management of critically ill patients. Although recent studies have suggested that the timing of volume replacement deserves careful consideration, when it comes to selecting the resuscitation fluid type, doctors are faced with a range of options. At the most basic level the choice is between a colloid or crystalloid solution.

Crystalloid. Crystalloids, or balanced salt solutions, are the most commonly used resuscitative fluids, and their use to restore extracellular volume significantly decreases the transfusion requirements after hemorrhagic shock. Examples of crystalloid solutions are Lactated Ringer (LR) or normal saline (NS). Lactated Ringer solution is isotonic and rapidly replaces the depleted interstitial fluid compartment and does not aggravate any preexisting electrolyte abnormalities. Normal saline is also effective for resuscitation of hypovolemic patients. These fluids are attractive for use in fluid resuscitation as they are both inexpensive, readily available and do not cause sensitivity reactions.

Colloid. Colloid solutions contain relatively large molecules that remain in the intravascular compartment hours longer than isotonic crystalloids. As a result, they are more efficient intravascular volume expanders than crystalloid solutions. Colloids are commonly used for volume expansion in hypovolemia and include albumin, dextran 70, dextran 40 and hydroxyethyl starch. Colloid solutions have distinct disadvantages for the acute resuscitation of a child in hypovolemic shock. They are less widely available than crystalloids and may take time to prepare. Blood-derived colloid solutions may cause sensitivity reactions. Synthetic colloids may cause coagulopathies. One advantage of the use of colloids is the decreased volume necessary, which is helpful in cases of head trauma or when lung contusions are present.

Blood products. Blood is recommended for replacement of volume loss if the child’s perfusion is inadequate despite administration of 2 to 3 boluses of 20 mL/kg of isotonic crystalloid. Under these circumstances administer 10 mL/kg PRBCs as soon as available.

- **type O blood.** Type O blood is immediately available without a cross match. Because type O blood contains no AB cellular antigens, administration of packed red blood cells is relatively safe in patients of any blood type. Use type O blood if there is an immediate need for blood to prevent cardiac arrest. O-negative blood is preferred in females of childbearing age to avoid Rh sensitization. Either O-negative or O-positive blood may be administered to males.

- **type-specific blood.** Unmatched, type-specific blood may be used if ongoing blood loss results in hypotension despite administration of crystalloid. Most blood banks can supply type-specific blood within 10 minutes. Type-specific blood is ABO and Rh compatible, but, unlike fully crossmatched blood, incompatibilities of other antibodies may exist.
Mass transfusion. In pediatric patients (< 50 kg), when the estimated blood loss is equal to or greater than 30 mls/kg and bleeding continues, a mass transfusion protocol (MTP) should be initiated. This volume loss criteria, as opposed to Hgb/Hct measurements for estimating blood loss, is more effective in the pediatric patient as rapid exsanguination may not be reflected in Hgb or Hct levels until fluid resuscitation catches up. When the MTP is activated, pediatric trauma patients are transfused, based on weight, with a 1:1:1 transfusion of RBC, plasma and platelets. C.S. Mott’s pediatric specific MTP is shown below in Figure 1.

**Massive Transfusion Protocol (MTP) – Pediatric < 50 KG**

**Appropriate Initial Interventions:**
- Intravenous access – by weight (kg):
  - 1-5 kg: 22-24 gauge
  - 6-10 kg: 20-24 gauge
  - 11-25 kg: 18-22 gauge
  - 25-50 kg: 16-20 gauge
- Admission weight (kg)

**Admission labs:**
- T&c, CBC, INR/PT, PTT, Fibrinogen, Electrolytes, BUN/Cr, ionized calcium, ABG, lactate
- Continuous monitoring of vital signs
- Aggressive re-warming
- Prevent / Reverse acidosis
- Minimize crystalloid – avoid dilutional coagulopathy

**Other considerations:**
- Warfarin Reversal: 4 Factor PCC Koentra INR 2-4 25 units/kg, INR>4-6, 35 units/kg, INR>6, 50 units/kg, repeat doing not recommended
- Antifibrinolytic therapy:
  - Amicar 100 mg/kg bolus then 33.3 mg/kg/hour
- Cell salvage: Anes Tech via Mott OR Front Desk 76-32430

**Additional help:**
- Anesthesia: pager 1534
- Pediatric Surgical Fellow – pager via web or operator
- Rapid Response Team pager 90147 or call stat paging 141

**General Guidelines for Lab-based Blood Component Replacement in Children with Massive Bleeding:**

<table>
<thead>
<tr>
<th>Product</th>
<th>Consider For</th>
<th>Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBCs (360 ml/unit)</td>
<td>N/A</td>
<td>30 ml/kg</td>
</tr>
<tr>
<td>FFP (250 ml/unit)</td>
<td>INR &gt; 1.5</td>
<td>20 ml/kg</td>
</tr>
<tr>
<td>Platelets (50 ml/bag)</td>
<td>&lt; 100,000</td>
<td>20 ml/kg</td>
</tr>
<tr>
<td>Cryoprecipitate</td>
<td>Fibrinogen &lt; 100</td>
<td>0.2 units/kg</td>
</tr>
</tbody>
</table>

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**Identify and Manage Bleeding**
- (Surgery, Angiographic Embolization, Endoscopy)
- ≥ 30 mls/kg and ongoing uncontrolled bleeding

**Clinical Team Activates MTP & Designates Clinical Contact**

**Clinical Contact phones Blood Bank (BB) at 936-6888 and:**
- Provides name of clinical contact person to BB
- Provides MR#, sex, name, location and weight of patient
- Records name of BB contact, calls if location/contact information changes
- Sends person with patient name and MRN to pick up the cooler
- Ensures that MTP protocol electronic order is entered in CareLink

**BB Prepares Peds MTP Pack per weight**
- Transfuse as 1:1:1 Ratio (e.g. 1 rbc. 1 plasma 1 single platelet)

**Stop MTP**
- Notify BB & return any unused blood ASAP
- Resume standard orders
- DIC MTP Electronic order

If persistent coagulopathy consider:
- rFVIIa 90 µ/kg dose
Vascular Access of the Pediatric Patient

Importance. Obtaining vascular access in a pediatric trauma patient offers unique challenges. These issues include obtaining the cooperation 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. 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. 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.

Central access lines. When considering venous access for resuscitation, use IV/IO access. Central lines can be difficult to place in the pediatric patient, as the femoral vein is underdeveloped in the younger child and access to the neck/chest would be difficult if not impossible without adequate sedation. As a resuscitative line, the central line has too much resistance, secondary to its length and usually not of adequate size to bolus large volumes in a child. Sites for central catheterization include the femoral vein as well as the subclavian and internal jugular veins. The neck/chest locations have decreased risk of infection and dislodgement with movement, as well as an increased accuracy in monitoring central venous pressures; however, access may be difficult to obtain in an emergency. When placing central lines, the femoral line placement can be aided by the use of ultrasound, 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 (IJ) vein access in these patients. Also, in young children < 3 years of age, the femoral vein is quite small. Consider utilizing the IJ or subclavian sites for these patients. Common complications associated with these lines include higher risks of pneumothorax. The presence of unilateral pneumothorax, if already treated with a chest tube, should direct a clinician to place central access on the same side as the child would already be treated for this complication.

IO vs. IV. Rapid intravascular (IV) access is a vital component of emergency care and resuscitation. Rapidly securing vascular access may be a considerable challenge in the presence of shock or hypovolemia, causing peripheral venous shutdown. If peripheral vascular access cannot be readily obtained in a child with symptoms of shock (within 90 seconds), intraosseous (IO) access should be established. Current Advanced Trauma Life Support guidelines suggest IO access should be established after two failed IV attempts. IO cannulation is a relatively simple and effective method of rapidly establishing vascular access for emergency fluids or medications. It provides access to a non-collapsible marrow venous plexus, which serves as a rapid, safe and reliable route for administration of drugs, crystalloids, colloids and blood during resuscitation. IO access can be established in children of all ages, often in about 30 to 60 seconds. Fluids and medications can reach the central circulation within seconds when delivered via an IO route. It is recommended that the dose used for intravenous fluids and medications remain unchanged when the IO route is used. The primary site of IO insertion in children is the proximal tibia (Picture 2). Other insertion sites in infants and children include the humerus, distal ulna, distal femur and distal tibia. Contraindications for IO placement are: fractures and crush injuries near the access site, conditions with fragile bones (eg, osteogenesis imperfecta), previous attempts to establish access in the same bone and presence of infection in overlying tissue.
Standard Approach

**Resuscitation algorithm.** Following a defined algorithm as it relates to resuscitative efforts of the pediatric patient can avert confusion and prevent unnecessary surgery. A predetermined and systematic approach to the injured child guarantees recognition of life-threatening injuries and provides a method for rapid stabilization. See Fig 2 for a resuscitation algorithm example.

Figure 2

*TARGETS: Urine Output (UO) 1 – 2 mL/kg/hr

<table>
<thead>
<tr>
<th>Age</th>
<th>Systolic BP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 1 years</td>
<td>&gt; 60 mmHg</td>
</tr>
<tr>
<td>2 to 5 years</td>
<td>&gt; 70 mmHg</td>
</tr>
<tr>
<td>6 to 12 years</td>
<td>&gt; 80 mmHg</td>
</tr>
<tr>
<td>&gt;12 years</td>
<td>&gt; 90 mmHg</td>
</tr>
</tbody>
</table>

**Calculating FENa (Fraction Excretion of Sodium)**

\[
\text{FENa} = \frac{\text{U}_\text{Na} \times \text{P}_\text{Cr}}{\text{P}_\text{Na} \times \text{U}_\text{Cr}}
\]

- Urine Sodium (U\text{Na})
- Urine Creatinine (U\text{Cr})
- Plasma Sodium (P\text{Na})
- Plasma Creatinine (P\text{Cr})

- Post-Renal
  - 1 PLUGGED FOLEY (FLUSH TO CLEAR)
- Renal
  - 2 INJURY TO KIDNEY/URETER/BLADDER
- Pre-Renal
  - 3 NEEDS FLUIDS or PRESSORS

- Normotensive with Urine Output 1-2 mL/kg/hr
  - Run IVF at maintenance rate
- Not Hypotensive But ↓ Urine Output
  - Consider reasons for low UO
- Hypotensive
  - Bolus NS or LR 20mL/kg
  - Still hypotensive?
    - No Maintenance fluid rate
    - Yes Place Central Line & Assess CVP
      - If CVP is low <8, Consider OR
      - If CVP is high >8-10, Start pressors
      - Dobutamine 2 -20 mcg/kg/min IV & titrate to urine output of 1mL/kg/hr
      - Still hypotensive?
        - Yes Consider Vasopressin 0.003 units/kg/min
        - Is CVP at goal?
          - Yes Increase fluid rate by 33% and consider repeat bolus
          - No

- C.S. Mott Children’s Hospital Pediatric Trauma Program

**Add Dopamine 2-20 mcg/kg/min or Epinephrine 0.1-1.0 mcg/kg/min or Levophed 0.02 mcg/kg/min (Levophed as last resort in burn injury d/t ↓ peripheral perfusion)**

**IF hypotension persists, look for missed injury & initiate hydrocortisone 2mg/kg/dose every 8 hours (Max. 100 mg/ dose)**
Monitoring

Importance. Though much of the resuscitation and diagnosis occurs in the first few hours for most trauma patients, several patients will continue to need ongoing resuscitation and monitoring beyond the initial “golden hour”. In these patients, the level of monitoring varies with their clinical picture. We will discuss the following monitoring modes/devices to ascertain the situations in which they are most useful: base deficit and lactate, urine output, arterial blood pressure and blood gases, central venous pressure, Swan-Ganz catheters, and echocardiography.

Hemodynamic assessment. Hemodynamic assessment should include evaluation of the rate and character of the pulse and the blood pressure. Tachycardia is a normal response to volume loss but also to pain, anxiety, and fear, all of which are commonly present in children. Assessment of the pulse (full and strong or weak and thready) may be helpful in determining the proper resuscitative efforts. Because the body’s ability to compensate for hypovolemia, changes in blood pressure do not occur reliably until 20% to 30% of blood volume has been lost. This is especially true in the pediatric patient. The pulse pressure, however, usually narrows, even in compensated shock, because of the effects of vasoconstriction on the diastolic blood pressure. Importantly, the CVP reflects the adequacy of and not the true blood volume, and the state of the venous tone. Changes in CVP in response to treatment or from continuing hemorrhage are more revealing than a solitary measurement.

Base deficit & lactate. Biochemical markers are valuable as a means to identify shock in its early stages and evaluate effectiveness of resuscitative measures. This is based on a shift from aerobic to anaerobic metabolism in under perfused tissues. Increased lactate production is associated with tissue hypoperfusion. In addition, lactate appears to be prognostic in several different shock states including hypovolemia. Effective resuscitation of shock results in a decrease in serum lactate levels. Another biochemical marker is the base deficit. This is defined as the amount of fixed base (or acid) that must be added to an aliquot of blood to restore the pH to 7.40. Base deficit values have been categorized as normal (2 to –2), mild (<3 to –5), moderate (<6 to –9), and severe (>–10). Changes in base deficit toward normal with volume infusion can be used to judge the efficacy of resuscitation.

Urine output. Urine output is the easiest measure of resuscitation and one of the most reliable. In a patient with pelvic fracture, scrotal hematoma, hernia, or a penile/rectal/perineal injury, caution should be taken to exclude urethral injury before placement of a catheter. A retrograde urethrogram is indicated in these select instances, though a cystoscopy or urological consultation would also be appropriate management strategies. If a urethral injury is identified, a suprapubic catheter could be placed with or without image guidance; however, a pelvic hematoma or intraabdominal injury could affect the management strategy. In neonates, a risk of urethral stricture with a Foley insertion is not unheard of and many of these patients can be managed without a catheter with just weighing of diapers based on clinical situation. Urine output in children should be at least 1-2 ml/kg/hr. If a drop in urine output is identified, causes can be categorized into prerenal, renal, and postrenal causes (see figure for algorithm). A Foley can be flushed to identify functionality. A FENa can help differentiate prerenal from renal causes.

Arterial line. An arterial line can be the most useful monitoring device during resuscitation. The arterial catheter addresses two needs: ability to continuously monitor a blood pressure and ability to frequently draw lab work including serial hematocrits and blood gas measurements. The arterial catheter has risks of thrombosis and infection, though these are usually not seen during temporary uses (within a few days). In children, placement of an arterial line can occasionally be difficult and time-consuming. The use of an ultrasound can be immensely valuable. Our first choice is usually a radial location, followed by a femoral line using guidance. Though we have infrequently needed to use a cutdown approach, this has become rare in the ultrasound era. Finally, be cautious about using an ulnar artery approach as this could lead to ischemia of the digits, especially in the setting of an absent or spasmodic radial artery.

Central line. Central lines are useful for monitoring central venous pressure as well as providing access for fluids, nutrition, and medications including those requiring continuous infusion such as vasoressors and sedatives/analgesics/paralytics. As most pediatric patients do not have major heart disease, Swan-Ganz catheters have become largely obsolete. In most children, routine use of echocardiography (Pic 3) to determine cardiac function and evaluate for valvular injury is adequate for traumatic injuries. In the rare instance where additional information is needed a transesophageal echocardiogram or cardiac catheterization are performed electively. In the setting of ongoing resuscitation, the central line can provide access to a mixed venous blood gas or decent substitute if near the right atrium. This measure can be used in conjunction with an arterial blood gas to determine if oxygen delivery is adequate.
Complications of Fluid Resuscitation

**Hypothermia.** Hypothermia (core temperature <35°C) is common during traumatic injury and shock. In addition to immobilization, both prehospital and post admission exposure can lead to conductive, convective, and evaporative heat loss, which should all be minimized. In addition, the administration of room temperature intravenous fluids and of cold-stored blood also contributes to hypothermia. Hypothermia increases fluid requirements and independently increases acute mortality rates. As the core temperature decreases, the rate of oxygen consumption also decreases to approximately 50% of normal at 28°C. Hypothermia may also adversely affect cardiovascular function and coagulation and may compromise several metabolic functions, including metabolism of citrate, which is present in stored blood. Inadequate citrate clearance in turn causes ionized hypocalcemia. Treatment for hypothermia can be done in several ways:

- **Passive warming:** warm blankets, hot packs, warming blankets, etc.
- **Active warming:** warming of inspired ventilator gas, warming of intravenous fluid
- **Severe hypothermia:** continuous mechanical arteriovenous rewarming, lavage of heated saline through nasogastric and thoracostomy tubes, heated peritoneal lavage.

**Abdominal compartment syndrome.** Abdominal compartment syndrome is a highly morbid complication of reperfusion injury to the splanchnic viscera. This syndrome appears to be increasingly prominent due to aggressive resuscitation techniques that enable salvage of profoundly hypotensive and hypovolemic patients. Splanchnic ischemia and reperfusion result in extensive visceral capillary leak and interstitial edema of the bowel. Excessive volume resuscitation during this phase leads to grossly edematous viscera within the closed space of the abdomen, which dramatically increases intra-abdominal pressure, and compromises intra-abdominal organ function, increases renovascular resistance, limits diaphragmatic excursion and may decrease cardiac output and elevate intracranial pressure. The clinical hallmarks of abdominal compartment syndrome are a distended and tense abdomen, diminished tidal volume, pulmonary edema, decreased cardiac output, oliguria and elevated urinary bladder pressure. Presence of all or a major part of this syndrome should prompt consideration of an urgent operative laparotomy to decompress the abdomen and treat by leaving the abdomen open.

“What good is the warmth of Summer without the cold of Winter to give it sweetness”  
Author Unknown
Post Resuscitation Fluid

**Maintenance fluid.** Determining maintenance fluid in a child can be challenging. Careful consideration and calculation of the maintenance fluid rate is necessary to prevent overhydration in pediatric patients. A simple formula can be utilized to determine an hourly rate. Commonly referred to as the 4:2:1 rule, the formula is utilized using the patient’s weight as a guide. Volumes are calculated using a weight-based infusion rate: for the first 10 kg, 4 mL/kg/h, for the next 10 kg, 2 mL/kg/h and 1 mL/kg/h for each kilogram thereafter. Examples of the application of the 4:2:1 rule are shown in Figure 4.

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**WHAT WOULD YOU DO?**

**ACTUAL CASE REVIEW**

**Situation:** A 2 1/2 yo male who was found by mom to be lethargic and crying after “falling out of bed” twice earlier in the day. He was not appropriately responsive and was vomiting. An ambulance was called. He was transferred to Mott Children's Hospital via EMS. En route he was reportedly hypotensive to 50/30 just prior to arrival at Mott’s ED.

**Assessment:** Child presents to Emergency Department lethargic, tachypneic with grunting respirations, LCTA, old bruising noted to left cheek and left eye, multiple scattered bruises noted to abdomen and back. Abdomen is soft, non-distended. Skin pale and dusky, cool extremities noted. BP is 65/36 RR 40 HR 161 Temp 38.3

**NOW WHAT?**

**Management:** IV started x 2 and a bolus of 320 mL was begun (pt weight 16 kg) and bolus was repeated x 2 for continued hypotension. Laboratory values and radiology testing were ordered. FAST scan at the bedside revealed free fluid in Morrison’s pouch in the splenorenal recess as well as posterior to the bladder. CT of the abdomen, pelvis and lumbar spine revealed a Grade 5 liver laceration (hepatic vasculature, portal system & IVC appeared intact), splenic lacerations, multiple bilateral Grade 2 kidney lacerations, hemoperitoneum & acute bilateral lower rib fractures. Head and C-Spine CTS were negative. Due to continued hypotension and increasing abdominal girth and distention, a decision was made by the Pediatric Trauma Surgeon to take the patient to the OR for operative management. He remained tachycardic at 165 bpm. A blood transfusion of PRBC was initiated en route to the OR.

**NOW WE OPERATE, RIGHT?**

**Course of Care:** The patient was transported to the operating room with the Pediatric Trauma Surgeon. After infusion of blood products, the patient became more responsive, vital signs stabilized (BP was 141/89, HR 121 and RR 34) and the surgeon opted to attempt PICU observation before proceeding with operative intervention. The patient received an NG tube and arterial line prior to transport to PICU.

**LESSONS LEARNED**

**Outcome:** Following a defined algorithm can avert confusion and prevent unnecessary surgery. This patient did not require resection of solid organs in an unstable state and was able to be resuscitated with crystalloid and blood. Non-operative management allowed the patient to tamponade the injuries and recover uneventfully without a laparotomy. If the patient did not respond to the blood transfusion, further operative management would likely be needed. In this situation, however, the algorithm was successful in avoiding a potentially difficult surgery with major morbidity. It was later discovered that this child was injured after being kicked and beaten. Charges were filed against the perpetrator.
Trauma and Child Abuse

Although child abuse affects children of all ages, genders, cultures and socioeconomic strata, certain children are statistically predisposed to increased risk. Some of the indicative characteristics include the child’s age (infants and preschoolers) and whether the child was born premature, is developmentally delayed, possesses special health needs or succumbs to behavioral problems. Also, given that greater than 80% of documented abuse cases are perpetrated by parents or caregivers, these victims’ home or care environments demonstrate other clear risk factors (Figure 5).

Signs for concern. Certain information surrounding the patient’s presentation for treatment should raise a level of concern for possible abuse. Those signs are:

- There is a lack of or inadequate explanation for the injury or condition
- The details of the explanation change
- There are differing accounts from witnesses
- The explanation does not fit the child’s developmental capacity
- The explanation does not fit the pattern, age, or severity of the injury
- There are delays in seeking medical attention for the injury or condition
- The concern expressed by the caregivers is inappropriate for the condition or injury sustained

If abuse is suspected, other tests may be appropriate to assess for additional injuries or to elucidate other medical etiologies for injuries. These diagnostic studies may be more easily determined in consultation with child abuse specialists.

“Snowflakes are one of nature’s most fragile things, but look what they do when they stick together”  Vera M. Kelly

Article references:
Advanced Trauma Life Support: Student Course Manual. 9th ed. Chicago, IL: American College of Physicians; 2012: 253

Figure 5

RISK FACTORS FOR CHILD ABUSE

PARENTAL OR CAREGIVER CHARACTERISTICS
- Poverty
- Unemployment
- Lack of or minimal education
- Single parenting or unrelated caregivers

CAREGIVER HISTORY
- Substance abuse
- Domestic violence
- Mental illness
- Their own neglect or abuse

NURSES: Remember 1 CME = 1 CEU credit for nursing! This activity WILL count toward your 25 hours/2yrs of required CEU for licensure