Hemorrhagic Shock in Pediatric Trauma

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Introduction

Hemorrhage is the commonest form of shock in injured patients. Hemorrhagic shock is one of the leading causes of morbidity and mortality in pediatric trauma. Exsanguination on scene and massive blood loss accounts for nearly 40% of trauma related deaths. Multiple injuries or polytrauma secondary to motor vehicle collision, falls, blunt injuries to abdomen and pelvis, open or multiple bone injuries, penetrating injuries and vascular injuries account for the majority of cases of hemorrhagic shock.

This article describes the pathophysiology of hemorrhagic shock, challenges in the evaluation of hemorrhagic shock, principles of resuscitation and management, discuss the controversies and provide a massive transfusion protocol in the context of pediatric trauma.

Pathophysiology of Hemorrhagic shock in trauma:

The blood volume in a child is approximately 8-9% of body weight, 80-90ml/kg. Clinical manifestations of shock may not occur till there has been a loss of more than 20% of circulating blood volume in pediatric trauma. Massive transfusion (major hemorrhage) in children and neonates is often defined transfusion of >50 % total blood volume (TBV) in 3 hours, transfusion >100 % TBV in 24 hours or transfusion support to replace ongoing blood loss of >10 % TBV per min.

Acute blood loss following trauma leads to hypovolemia and anemia. Tissue injury following trauma activates the inflammatory cascade leading to production and release of cytokines. As a result, there is increased capillary permeability in the endothelium leading to massive fluid shifts, tissue edema and further intravascular volume depletion. Tissue trauma and hypoperfusion leads to an early endogenous process described as acute trauma induced coagulopathy mediated by activation of protein C pathway. Depending on the extent of trauma, there is varying degree of hyperfibrinolysis, dysfibrinogenemia and impaired platelet activity. Hemodilution, hypothermia and acidosis may exacerbate coagulopathy leading to further bleeding. Hypothermia, acidosis and coagulopathy are often described as a lethal triad and each of these is an independent marker of mortality in hemorrhagic shock in trauma.

Understanding the pathophysiology of hemorrhagic shock and the mechanisms of trauma induced coagulopathy is vital for treatment strategies.

How do I evaluate a child in traumatic hemorrhagic shock?

Early identification of a child in hemorrhagic shock is a priority to reduce the preventable mortality in trauma management. However, the clinical assessment for hemorrhagic shock in pediatric trauma is challenging.
Children have increased physiological reserves compared to adults and compensate by preserving normal blood pressure in the early stages of shock but deteriorate rapidly if not reversed early. Clinical signs and symptoms do not emerge till there is a blood loss of >20% of blood volume. The systemic responses in children manifest based on the degree of blood loss as outlined in Table 1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Class I</th>
<th>Class II</th>
<th>Class III</th>
<th>Class IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Blood loss</strong></td>
<td>Very mild</td>
<td>Mild</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>% blood volume</td>
<td>&lt;15%</td>
<td>16% - 25%</td>
<td>26% - 38%</td>
<td>&gt;40%</td>
</tr>
<tr>
<td><strong>Hemodynamics</strong></td>
<td>Normal Heart rate</td>
<td>Tachycardia</td>
<td>Significant tachycardia</td>
<td>Severe tachycardia</td>
</tr>
<tr>
<td></td>
<td>Normal pulse volume</td>
<td>Reduced pulse volume</td>
<td>Poor peripheral pulse volume</td>
<td>Poor central pulse volume</td>
</tr>
<tr>
<td></td>
<td>Normal BP</td>
<td>Narrow pulse pressure</td>
<td>Reduced BP</td>
<td>Significant Hypotension</td>
</tr>
<tr>
<td></td>
<td>Warm, pink extremities</td>
<td>Cold extremities</td>
<td>Cold, mottled extremities</td>
<td>Cold, mottled extremities</td>
</tr>
<tr>
<td>Capillary refill time</td>
<td>Delayed Capillary refill time</td>
<td>Prolonged Capillary refill time</td>
<td>Very prolonged Capillary refill time</td>
<td>Very prolonged Capillary refill time</td>
</tr>
<tr>
<td><strong>Respiratory Rate</strong></td>
<td>Normal</td>
<td>↑</td>
<td>↑ ↑</td>
<td>↑ ↑ ↑</td>
</tr>
<tr>
<td><strong>Mental State</strong></td>
<td>Anxious</td>
<td>Irritable</td>
<td>Irritable/drowsy</td>
<td>Drowsy/unresponsive</td>
</tr>
<tr>
<td><strong>Urine output</strong></td>
<td>Normal</td>
<td>Reduced, concentrated</td>
<td>Oliguria with high Blood urea</td>
<td>Anuria</td>
</tr>
<tr>
<td><strong>ABG</strong></td>
<td>Normal pH</td>
<td>Normal pH</td>
<td>Metabolic acidosis</td>
<td>Significant metabolic acidosis and high lactate</td>
</tr>
</tbody>
</table>

Table 1: Classification of Hemorrhagic Shock in pediatric trauma Adapted from ATLS, 9th Ed.

The child's ability to compensate in the early phase of blood loss creates an impression of hemodynamic stability or normality. Tachycardia is often seen initially often with cooler extremities. However, this is a non-specific sign and may be attributed to pain or fear. Hypotension is a late sign and the deterioration is often rapid and precipitous. It is important to understand the mechanism of injury, possible exsanguination at scene. A thorough evaluation for source of bleeding is vital during the initial assessment of a child in shock. Consider non-hemorrhagic causes of shock such as tension pneumothorax, pericardial tamponade and neurogenic shock during the initial assessment.

Evaluate heart rate, respiratory rate, peripheral pulse volume, blood pressure and specifically pulse pressure of >20mmHg, capillary refill time and sensorium as part of initial circulatory assessment and reassessment following any intervention.

### How to identify the source of bleeding?

Source of potential blood loss, internal or external, must be aggressively sought for by a rapid physical examination of chest, abdomen, pelvis, retro peritoneum, extremities and external bleeding.

### FAST Scan – Focused Assessment with Sonography in Trauma

FAST scan of abdomen to look for free fluid in abdomen and intra-abdominal injuries has been practiced in trauma centers. However, caution must be exercised in the interpretation of FAST scan. At least 200-400ml of blood loss in peritoneum is essential to get a positive FAST result. A negative FAST examination does not exclude bleeding and may add to loss of time especially in the hands of untrained staff.

### Computerized Tomography Scan:

CT scan of abdomen and chest adds value especially in detecting the source of bleeding and is preferred as a
diagnostic modality when there is hemodynamically stable window of opportunity or a transient response. However, CT scan is not an emergency diagnostic modality for a hemodynamically unstable bleeding child. It is important to stabilize the hemodynamics and consider damage control resuscitation than diagnostic investigations during the management of hemorrhagic shock.

Other investigations:
Other studies include X-rays of chest, pelvis and extremities. Laboratory investigations such as Hemoglobin, Clotting profile – Prothrombin time (PT), activated partial thromboplastin time (APTT), international normalized ratio (INR), arterial blood gas and lactate can aid in initial assessment in the emergency department.

Prognostic Indicators:
The independent predictors of adverse outcome or mortality in hemorrhagic shock in trauma are higher Injury Severity Score (ISS >20), metabolic acidosis (Base deficit >8), high lactate and INR >1.5 at admission. Other scores described in literature to predict mortality due to shock in trauma are pediatric trauma BIG score and age adjusted pediatric Shock Index. Pediatric trauma BIG Score is calculated by the formula: Base deficit + (INRX2.5) + (15-Glasgow Coma Scale) at admission. A score of >16 reliably predicted the non survivors. Shock index (Heart rate/Systolic Blood Pressure) reflects vascular and myocardial dysfunction.

Management of hemorrhagic shock in Pediatric Trauma
Damage control strategies prioritize physiological and biochemical stabilization over the full anatomical repair of all injuries and forms the mainstay of the management of hemorrhagic shock in pediatric trauma. The key components are to aggressively stop the bleeding, replace the lost blood volume and to prevent the lethal triad of hemorrhagic shock – hypothermia, acidosis due to hypo perfusion and coagulopathy. The approach is CABC – Control of hemorrhage followed by stabilizing Airway, Breathing and Circulation.

Control of hemorrhage
The source of bleeding must be identified and controlled in a timely fashion. Consider direct compression or haemostatic dressings for external injuries, tourniquets and application of splints to exsanguinating limb injuries, application of pelvic binders in open pelvic fractures to tamponade and contain the bleeding within the pelvis. Embolisation of bleeding vessels via interventional radiology in a timely fashion can be useful for vascular injuries and other injuries where the above methods cannot be applied.

Damage Control Surgery
Damage control surgery is done as an emergency procedure for rapid control of bleeding in the hemodynamically unstable children. It is emphasized that the team trained in damage control surgery should manage the procedure. In the absence of trained personnel, it is essential that the child be shifted immediately to a tertiary trauma centre without any loss of time due to attempted procedures locally. The approach and sequence has been summarized in Table 2.

<table>
<thead>
<tr>
<th>Part 0 – DC I</th>
<th>Pre-hospital or Emergency Department</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognise injury pattern and potential candidate for damage control resuscitation</td>
<td></td>
</tr>
<tr>
<td>Tournate on scene time</td>
<td></td>
</tr>
<tr>
<td>Abbviate Emergency Department time for stabilisation</td>
<td></td>
</tr>
<tr>
<td>Early intubation (Rapid sequence), early rewarming</td>
<td></td>
</tr>
<tr>
<td>Expedit transport to Operation theatre</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Part 1 – DC I</th>
<th>Operation Theatre (OT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate exploratory laparotomy</td>
<td></td>
</tr>
<tr>
<td>Rapid control of bleeding and contamination</td>
<td></td>
</tr>
<tr>
<td>Abdominal packing</td>
<td></td>
</tr>
<tr>
<td>Temporary wound closure</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Part 2 – DC II</th>
<th>Intensive care Unit (ICU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ongoing resuscitation</td>
<td></td>
</tr>
<tr>
<td>Stabilise physiological and biochemical parameters</td>
<td></td>
</tr>
<tr>
<td>Advanced investigations to identify all injuries</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Part 3 – DC III</th>
<th>ICU/Ward</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re-exploration in OT, definitive repair</td>
<td></td>
</tr>
<tr>
<td>Multiple visits to OT</td>
<td></td>
</tr>
<tr>
<td>Involvement of other specialists</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Damage Control (DC) Surgery – Suggested Sequence


Fluid resuscitation

The goal of fluid resuscitation is to replace the blood loss and maintain adequate oxygenation and perfusion of the end organs. Intravenous or intraosseous access must be obtained rapidly. In trauma, the hypovolemia is predominantly due to blood loss and is complicated by coagulopathy in trauma.

If the child is actively bleeding, administer blood. Ensure a bolus of Tranexamic acid 15mg/kg is given. Pre-warmed Normal saline is given as 10ml/kg

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Rapid responder</th>
<th>Transient responder</th>
<th>Non-responder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vital signs</td>
<td>Return to normal</td>
<td>Transient response and reappearance of tachycardia and poor perfusion</td>
<td>Remain abnormal</td>
</tr>
<tr>
<td>Estimated blood loss</td>
<td>Minimal (10-20%)</td>
<td>Moderate and ongoing (20-40%)</td>
<td>Severe &gt; 40%</td>
</tr>
<tr>
<td>Need for more crystalloids</td>
<td>Low</td>
<td>Low as high risk of exacerbating coagulopathy</td>
<td>Moderate as bridge to transfusion</td>
</tr>
<tr>
<td>Need for blood</td>
<td>Low</td>
<td>High</td>
<td>Immediate</td>
</tr>
<tr>
<td>Blood preparation</td>
<td>Type and crossmatch</td>
<td>Immediate</td>
<td>Emergency blood release (O negative)</td>
</tr>
<tr>
<td>Need for operative intervention</td>
<td>Possibly</td>
<td>Likely</td>
<td>Highly likely</td>
</tr>
</tbody>
</table>

Table 3: Responses to initial fluid resuscitation Adapted from ATLS, 9th Ed.

In adult trauma, hypotensive resuscitation has been advocated as a key strategy. Hypotensive resuscitation does not appear physiological in children since hypotension occurs late and is a sign of irreversible shock. In children, the physiology driven fluid resuscitation have different endpoints and seem to advocate permissive tachycardia. It is important to consider age related variation in vital parameters. Reduction in heart rate, widening of previously narrow blood pressure, improvement of peripheral perfusion and warm peripheries are the targets for fluid resuscitation. Table 3 summarizes the response to fluid administration.

Massive transfusion protocol

Massive transfusion is described as the administration of Packed red blood cells (PRBC) >40ml/kg in 3 hours

bolusto rapidly correct hypovolemia and prevent hypothermia. Ringer Lactate and Plasmalyte have been tried too. The response to fluid bolus must be reassessed promptly. A positive response is an improvement in sensorium, peripheral perfusion, widening of pulse pressure and pulse volume and decrease in heart rate. Overzealous crystalloid administration to replace the blood loss does not achieve the expected result of improving perfusion, may exacerbate coagulopathy and actually worsen outcomes. The role of colloids such as human albumin and HES – hetastarch is limited considering the risk of exacerbating coagulopathy.

In adult trauma, hypotensive resuscitation has been advocated as a key strategy. Hypotensive resuscitation does not appear physiological in children since hypotension occurs late and is a sign of irreversible shock. In children, the physiology driven fluid resuscitation have different endpoints and seem to advocate permissive tachycardia. It is important to and >80ml/kg in 24 hours or transfusion requirement of ongoing blood loss at > 10% blood volume per min. In a study by London Air Ambulance, about ten percent of trauma cases had serious hemorrhage. Following introduction of a “code red - massive hemorrhage policy” in 2012, emergency O negative blood was administered on-scene for traumatic cardiac arrest due to hypovolemia. The return of spontaneous circulation rates improved but did not result in survival benefit. A systematic review of pre-hospital blood product resuscitation for trauma could not conclude on the efficacy due to limited clinical literature and poor quality evidence.

Adult studies in military trauma settings and a few civilian trauma settings suggest administration of a balanced ratio of PRBC: Fresh frozen plasma (FFP): platelets in the ratio of 1:1:1 to be associated with good outcomes. However, studies that can guide transfusion practices in children are very few.

The incidence of major hemorrhage in children is low...
but carries the highest mortality. In a study on transfusion practices by the authors in a single center tertiary pediatric trauma center in London, about 6% had major hemorrhage requiring massive transfusion, associated with ISS >35 (full form) and carried a mortality of 62%. Majority of deaths occurred in the emergency department, surgeons, anesthetists, operating theatre and intensive care. Regular simulation exercises are done to ensure team awareness and preparedness (especially of Laboratory staff, blood bank, porters, operation theatres) and common team goals.

![Figure 1 - Massive Transfusion protocol (Adapted from Paediatric Code Red Policy -Courtesy, Adult and Pediatric Trauma Service, Royal London Hospital, Whitechapel, London, UK)](image-url)

Emergency department, surgeons, anesthetists, operating theatre and intensive care. Regular simulation exercises are done to ensure team awareness and preparedness (especially of Laboratory staff, blood bank, porters, operation theatres) and common team goals.

Coagulopathy has been traditionally monitored by tests such as PT, APTT and INR. An INR >1.3 has been associated with higher mortality of nearly 25% especially in trauma. However, these parameters do not reflect the actual pathophysiological changes often seen. Thromboelastometry is sensitive in identifying hypercoagulable states by investigating the interaction of coagulation factors, their inhibitors, anticoagulant drugs, blood cells, specifically platelets, during clotting and subsequent fibrinolysis. Thromboelastometry may be applied as a point of care device to identify coagulopathy in trauma for goal directed transfusion of blood products in major hemorrhage setting in trauma. The risks of massive transfusion are transfusion

**Emergency Department**

Suspected or actual active bleeding or Transient or Non responders to fluid resuscitation

Start PRBC - 10-20 ml/kg (O negative till crossmatch or type specific blood available) & FFP 15ml/kg

If ongoing bleeding - continue blood transfusion till bleeding stops (No crystalloids or colloids)

PRBC - 10-20ml/kg aliquots & FFP - 15 ml/Kg aliquots & Platelets - 15 ml/kg SDP preferred (RDP - 1 unit per 5 Kg) aliquots Cryoprecipitate - 10 ml/Kg aliquots

Send samples for CBC, Group and crossmatch, PT, APTT, Fibrinogen, ABG, Lactate; Consider ROTEM (Thromboelastometry)

**Early Damage Control Surgery**

Targets: Hb > 10g/dl, Platelets > 100,000, INR >1.2, Fibrinogen > 1.5;
Serum K <5.8, ionised Ca’ >1; lactate<2;
Improving metabolic acidosis, normal pH, Normothermia
Blood - In aliquots till bleeding stops; ensure adequate supply. Communicate with blood bank the urgency. Nominate one team member to coordinate.

PRBC - Packed Red Blood cells; FFP - Fresh frozen plasma; SDP- Single Donor Platelets; RDP - Random Donor Platelets; PT - Prothrombin time; APTT - Activated Thromboplastin time
INR - International Normalised Ratio. Hb - Hemoglobin. ABG- Arterial blood gas
associated lung injury – TRALI, Transfusion reactions and infections.

Other interventions for management of coagulopathy in trauma:

Tranexamic acid is an anti-fibrinolytic agent and acts by inhibiting lysine binding sites thus preventing conversion of plasminogen to plasmin. The prevention of clot break-down reduces the risk of further bleeding and is felt to play a role in the management of coagulopathy in trauma. Tranexamic acid was found to reduce mortality when given within 3 hours of major trauma as found in CRASH 2 trial. Tranexamic acid is widely used by British and US army in trauma. There is no published study of its use in pediatric major trauma but is worth considering as an important intervention since the risks of adverse effects are low. Tranexamic acid is given as 15mg/kg bolus in all cases of suspected major hemorrhage and has become a part of the protocol of pre-hospital care prior to administering blood products. Infusions have been deferred due to questionable benefit and an increased risk of deep vein thrombosis in adult studies. Factor VIIa has been observed to reduce the requirement of blood products compared to standard or placebo therapies though not statistically significant. It is expensive and there is no published supportive evidence for its application in pediatric trauma.

Prothrombin concentrates and other agents have been studied but have not been practiced clinically.

Key Messages:
- Hemorrhagic shock is a preventable mortality in pediatric trauma.
- Assess rapidly and identify the source of bleeding. Hypotension is a late sign.
- Avoid CT scan and other investigations in a hemodynamically unstable child.
- If actively bleeding, administer blood early. Avoid excessive crystalloid bolus.
- Damage Control Surgery must be attempted by trained personnel. Aim to shift to the nearest trauma center without wasting time with too many interventions.
- A local massive transfusion protocol for timely administration of blood products is beneficial.
- The exact ratio of blood products and the survival benefit is still not clear in pediatric trauma.

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