Navigating the Challenges of Managing Pediatric Trauma: Current Trends, Evidence, and Practical Pathways

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ABSTRACT

Background

Pediatric trauma care is shifting toward physiology-first, outcome-focused management that balances rapid hemorrhage control with judicious diagnostics across resource settings.

Objectives

To synthesize contemporary evidence and provide practical guidance on hemostatic resuscitation, radiation stewardship and vascular screening, abdominal trauma pathways and operative strategy, traumatic brain injury (TBI) care, and system-level readiness.

Methods

Narrative review of recent guidelines, consensus statements, and pivotal studies in pediatric trauma, emphasizing practices with demonstrable outcome benefit and de-implementation of low-value care.

Major Findings

Hemostatic resuscitation should prioritize early recognition of hemorrhagic shock, rapid access to blood, and preferential use of low-titer group O whole blood; when unavailable, employ balanced component therapy approximating a 1:1:1 ratio. Monitor and correct ionized calcium during large-volume transfusion. Evidence for tranexamic acid is mixed, supporting selective use and viscoelastic guidance with thromboelastography/rotational thromboelastometry. Radiation stewardship favors age-sensitive rules: clinical clearance with the Pediatric Emergency Care Applied Research Network (PECARN) cervical-spine criteria when risk is very low, magnetic resonance imaging for suspected ligamentous injury in younger children, and chest computed tomography only when results will change management. For blunt cerebrovascular injury, the Utah and McGovern scores support selective CT angiography with grade-tailored antithrombotic therapy. Abdominal trauma pathways combine serial examinations, screening laboratories, and focused assessment with sonography for trauma (FAST) to guide selective imaging and admission; American Pediatric Surgical Association guidance prioritizes hemodynamics over CT grade, encourages early mobilization, and favors symptom-driven follow-up. Operative strategy includes indications for damage-control surgery and the open abdomen with planned re-look and timely fascial closure. For TBI, 2019 Brain Trauma Foundation guidance emphasizes stepwise intracranial pressure control, age-appropriate

cerebral perfusion pressure targets, early nutrition, seizure prophylaxis, and avoidance of secondary insults. Greater pediatric readiness at the hospital and system level is associated with improved survival.

Conclusions

A physiology-first, evidence-aligned approach that prioritizes interventions with measurable benefit and de-implements low-value care can improve outcomes for injured children across diverse clinical environments.

Keywords: Pediatric trauma, whole blood, damage-control resuscitation, imaging stewardship, TBI, pediatric readiness

Introduction

Injured children are physiologically distinct from adults and benefit from pediatric-tailored resuscitation, imaging, and operative thresholds. Over the past decade, pediatric trauma care has shifted toward hemostatic resuscitation, judicious use of ionizing radiation, physiology-based non-operative management of solid organ injuries, and system-level emphasis on pediatric readiness. This review synthesizes high-impact, up-to-date literature and clinical guidelines to support clinicians managing traumatic injuries in children practicing across resource spectra.

Hemostatic Resuscitation

Hemorrhage accounts for about 20% of death in trauma with nearly half of hemorrhage-related deaths being preventable by more timely management [1]. Strategies to improve outcomes for children with traumatic hemorrhage include rapid hemorrhage control, balanced component resuscitation, and strategic coagulation adjuncts such as tranexamic acid. Following recent updates in adult traumatic hemorrhagic shock management, pediatric practice has shifted towards low-titer group O whole blood (LTOWB) transfusion, when available, followed by balanced component therapy approximating a 1:1:1 plasma:platelet:RBC ratio. These pediatric volume resuscitation practices have shifted away from large-volume crystalloid infusion given its association with hemodilution, coagulopathy, and acidosis. Prospective evidence evaluating 24-hour all-cause mortality from traumatic hemorrhagic shock with the use of LTOWB versus component therapy and tranexamic acid (TXA) is forthcoming from the MATIC-2 trial (Massive Transfusion in Children) [2]. While results are pending, observational cohorts and a recent meta-analysis suggest that early use of low-titer group O whole blood is associated with improved early survival compared with component therapy, particularly when delivered during the initial resuscitation phase [3-5]. This is similar to findings in adult hemorrhagic shock literature [6,7].

Although time to transfusion and hemorrhage control are likely to improve outcomes among injured children and adolescents, few studies have evaluated the impact of time to hemorrhage control/resuscitation in this age cohort [1]. In one study, earlier blood transfusion was associated with decreased length of stay and hospital related morbidity but not mortality [8]. While no benefit on mortality was observed, this study was not powered to analyze outcomes in children who were transfused, only a small cohort of patients in this study were transfused, and time was not a confounder among those transfused. In adults, timely management of hemorrhage is associated with less products required to restore intravascular volume, lower mortality, and a decrease in postinjury complications such as multiorgan failure, severe sepsis, and pneumonia (Sullivan). When time to transfusion was directly assessed in adult studies of hemorrhagic shock, each 10-minute delay to the first unit of packed red blood cells (PRBCs) transfused increased the odds of 30-day mortality [9,10]. These findings are likely to be similar to the pediatric population. Several factors have been proposed that may contribute to transfused-related delays including challenges in the identification of hemorrhagic shock in children, the availability of blood products, and challenges in delivering these products into the child [1,11].

Most trauma providers cite their clinical judgement as the primary driver to identify hemorrhagic shock and to decide to transfuse. However, experienced clinicians often over and underestimate transfusion need and have cited uncertainty as a leading cause of preventable delays to transfusion [12-14]. Several clinical decision tools have been developed to assist providers in the identification of hemorrhagic shock and the likelihood of transfusion, including the pediatric age-adjusted shock index (SIPA), reverse shock index with Glasgow Coma Scale score (rSIG), and transfusion probability after injury (TRAIN) [15]. Despite these triage tools, they have several limitations that impair the clinical applicability of these tools. Future studies and triage tools are necessary to assist providers in the timely identification of hemorrhagic shock and assist in early transfusion decisions.

Following the recognition of hemorrhage and need for transfusion, many centers do not have readily available blood in their emergency department. As discussed previously, delays in transfusion are associated with

worse survival outcomes among children and adults with uncontrolled hemorrhage or hemorrhagic shock. At adult and pediatric centers, several studies have demonstrated the ability to reduce the time to transfusion by increasing the availability of blood products including storing blood at the site of delivery, using 'runners' to go to and from the blood bank, and tubing systems [1]. Each center to assess the financial costs and benefits as the cost benefit may vary for each institution.

Across pediatric trauma series and guidance documents, initial resuscitation commonly uses weight-based PRBC boluses of 10–20 mL/kg, with many centers favoring ~10 mL/kg as an initial dose followed by reassessment within massive transfusion protocols [16-18]. If LTOWB is available, an initial 10–20 mL/kg bolus provides balanced resuscitation in a single product and is supported by pediatric whole-blood experience and reviews [3,19,20]. Across pediatric transfusion references, plasma is commonly administered in 10–15 mL/kg increments per cycle [21]. Platelet dosing is frequently reported at ~10–15 mL/kg for older children, with 15–20 mL/kg cited for neonates [17,21]. When fibrinogen is low or bleeding persists, cryoprecipitate is typically described at ~10 mL/kg within massive hemorrhage protocols (**Figure 1**)[17]. Across pediatric massive transfusion reports and protocol descriptions, product administration is titrated to hemostasis, often approximating a 1:1:1 ratio by volume, with repeat dosing guided by serial laboratory indices and, where available, viscoelastic testing. Many programs define "massive" transfusion as ≥40 mL/kg within the first 24 hours, however, this threshold varies and is not clinically relevant in real time [22,23]. Where available, thromboelastography (TEG) and rotational thromboelastometry (ROTEM) can guide component replacement, though pediatric trauma evidence is limited to pilot and retrospective cohorts [24]. Because citrate in blood products chelates calcium and can precipitate hypotension and coagulopathy during large volume transfusion, the literature describes early and repeated ionized calcium assessment during high-volume resuscitation, and reports that hypocalcemia on arrival and during resuscitation correlates with higher mortality and greater product requirements [25,26]. When hypocalcemia is identified, pediatric references commonly describe dosing such as calcium chloride 5 to 10 mg/kg intravenous (IV) when central access is available or calcium gluconate 15 to 30 mg/kg IV when using a peripheral line, with avoidance of infusing through the same line as blood products [27]. In centers using antifibrinolytics, the pediatric literature on TXA is mixed. A 2022 systematic review reported no overall survival benefit in civilian pediatric trauma after adjustment, and a 2023 narrative review noted mortality associations in selected subgroups [28]. When TXA is used, reported regimens commonly mirror perioperative practice, for example 15 mg/kg intravenously (maximum 1 g) within 3 hours of injury followed by 2 mg/kg per hour for as long as 8 hours, and several sources note that routine use is generally not pursued for isolated traumatic brain injury without hemorrhagic shock [28].

Figure 1: Pediatric Hemorrhagic Resuscitation: Products & Dosing at a Glance

Product	Typical Dose
Packed Red Blood Cells	10-20 mL/kg
Whole Blood	10-20 mL/kg
Fresh Frozen Plasma	10-15 mL/kg
Platelets (neonate)	15-20 mL/kg
Platelets (older child)	10-15 mL/kg
Cryoprecipitate	~10 mL/kg
Tranexamic Acid	15 mg/kg (Max 1 g)

Delays to obtaining vascular access are more common in children than adults likely attributed to the inherit smaller vein diameter in children compared to adults, a factor exacerbated by hemorrhagic shock. Several studies have observed additional factors that contribute to delays to vascular access including the peripheral intravenous (PIV) and intraosseous (IO) placement expertise of the team, presence of family members, and misperception of time during placement [29,30]. One study proposed an inherit self-serving bias that providers have when obtaining vascular access that may result in repeated and prolonged attempts at one specific access technique rather than transitioning to another route of access[1]. First-attempt PIV placement has been observed to be as low as 53% among non-injured and injured children [31]. For children in shock, it is appropriate to proceed to IO access after two failed IV attempts or when IV access cannot be rapidly obtained[32,33]. Preferred sites are the proximal tibia in infants/young children, with distal tibia or distal femur as alternatives. In larger children/adolescents, the proximal humerus may be considered when anatomy and positioning permit [34]. Blood products, crystalloids, and medications can be safely delivered via a properly placed IO. Early pediatric trauma series specifically documented successful infusion of blood boluses through IO lines during resuscitation [34,35]. Reports describe the use of pressure bags or rapid infusers to achieve adequate flow, with placement typically confirmed by easy

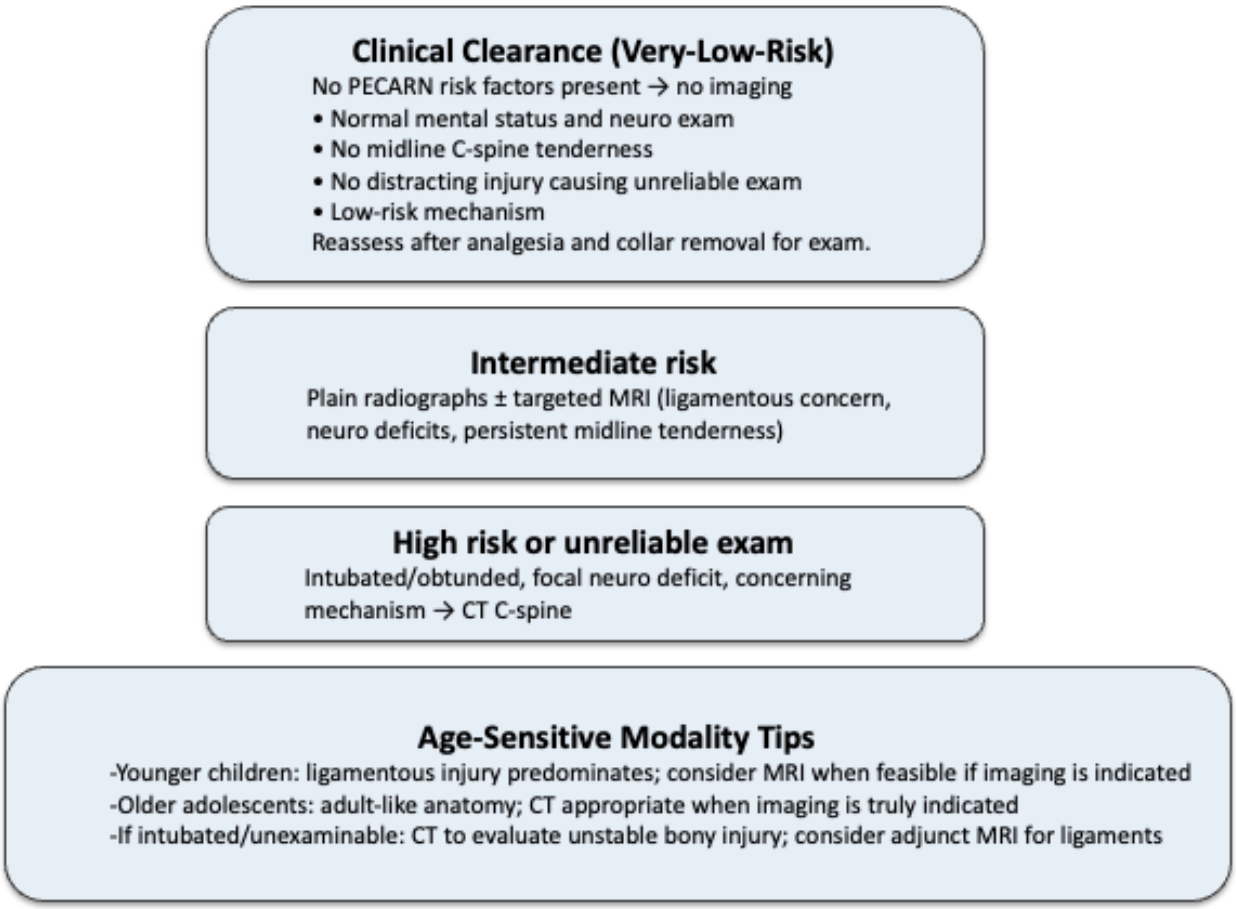
flush and aspiration, mechanical stability, and secure limb positioning, followed by close monitoring for extravasation. Complications are uncommon but reported, including extravasation in approximately 3.7%, compartment syndrome in approximately 0.6%, and osteomyelitis in approximately 0.4%, which supports vigilant site checks and prompt line removal when swelling or pain occurs[36,37]. In awake children, lidocaine can be considered through the IO before pressure infusions to reduce pain[34]. IO access should be utilized as a temporary bridge with transition to durable peripheral or central venous access once the patient is stabilized. In parallel, ultrasound-guided peripheral cannulation for difficult access populations has been associated with higher first-pass and overall success [38].

Minimizing Radiation: C-Spine and Chest Imaging

The 2024 Pediatric Emergency Care Applied Research Network (PECARN) cervical-spine prediction rule identifies children at very low risk for C-spine injury and can substantially reduce imaging, supporting clinical clearance when no risk factors are present (**Figure 2**)[39]. Modality selection is age sensitive. In younger children, where ligamentous injury predominates and ossification is incomplete, magnetic resonance imaging (MRI) can substitute for computed tomography (CT) in selected cases, particularly when neurologic deficits or persistent midline tenderness are present and when sedation is feasible. In contrast, older adolescents with more adult-like anatomy are more often cleared with CT when imaging is strictly indicated [40,41]. From a practical standpoint, the literature describes the use of CT when a child is intubated, has depressed consciousness, or cannot be reliably examined, to assess for unstable osseous injury. For children younger than about 10 years who are clinically evaluable, studies and guidelines generally support clinical clearance or targeted MRI rather than routine CT when this can be accomplished safely [39,40].

For the chest, routine CT adds little value in a hemodynamically stable child with a normal chest radiograph and no concerning clinical features. Multiple pediatric studies show it increases radiation without changing acute management in most cases [24,42-44]. When imaging is necessary, use shared decision-making and dose optimization. Childhood CT exposure is associated with a small but

Figure 2: PECARN Pediatric Cervical Spine Clearance



measurable increased risk of leukemia and brain tumors, so scans should answer a specific clinical question; if a CT is needed to guide care, obtain it, but avoid "just-in-case" imaging [45].

Children experience pulmonary contusions more often than rib fractures because of a compliant chest wall. Management is typically supportive with analgesia, pulmonary toilet, and incentive spirometry, with escalation for respiratory failure when indicated. Routine chest CT is seldom required when the chest radiograph and clinical examination are reassuring. Operative fixation such as surgical stabilization of rib fractures is uncommon and reserved for select patterns in older children and adolescents. Multimodal analgesia is emphasized, and regional techniques including paravertebral or erector spinae plane blocks may be considered for refractory pain in adolescents [42,46-48].

Chest and neck vascular imaging should be selective. In a hemodynamically stable child with a normal chest radiograph and reassuring exam, computed tomography angiography (CTA) chest is rarely useful [42,43]. By contrast, screening for blunt cerebrovascular injury (BCVI) should rely on pediatric-specific tools (McGovern, Utah) rather than adult Denver/Memphis criteria [49,50]. The Utah and McGovern scores share the same core predictors but differ in performance and intent. The Utah score assigns points to five variables present at emergency department (ED) arrival or on initial imaging: Glasgow Coma Scale (GCS) ≤ 8 (1 point), focal neurologic deficit (2), carotid canal fracture (2), petrous temporal bone fracture (3), and cerebral infarction on CT (3); a total score ≥ 3 is "high risk" and warrants CTA, whereas ≤2 corresponds to a low post-test probability (~8%) [51,52]. In the multicenter validation cohort, Utah's sensitivity was about 59% with specificity 85% and NPV 97%, supporting its utility to "rule in" BCVI when positive while recognizing that a negative score can still miss injuries [51]. The McGovern score retains all five Utah variables and adds mechanism of injury (high-speed motor vehicle collision or auto-pedestrian) as an additional 2-point item; using the same ≥3 threshold, McGovern increases sensitivity (single-center 81% vs 52% for Utah) with some loss of specificity (~71%) and, in multicenter validation, maintains >80% sensitivity and >98% NPV, aligning with its purpose as a sensitive pediatric-specific screen to guide selective CTA neck rather than indiscriminate imaging [49,50]. When BCVI is confirmed, antithrombotic therapy (aspirin or heparin/low molecular-weight heparin) appears safe in children and may reduce stroke/progression; regimen should be individualized to injury grade, hemorrhage risk, and neurosurgical input (**Figure 3**) [53].

Abdominal Injuries

In blunt torso trauma, the literature supports the use of careful serial examinations together with screening laboratories such as aspartate aminotransferase (AST), alanine aminotransferase (ALT), lipase, and urinalysis,

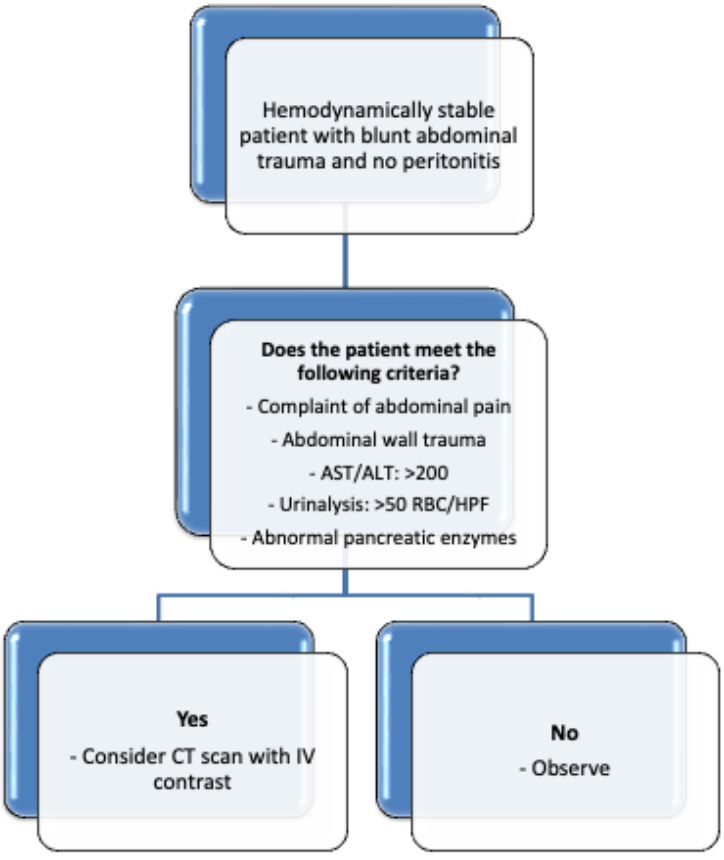
Figure 3: Pediatric Blunt Cerebrovascular Injury Recommendations

Grade	CTA Finding	First-line therapy	Alternatives/When to escalate
I	Intimal irregularity or intramural hematoma, <25% stenosis	Aspirin 3-5mg/kg/day (max 81mg)	If aspirin contraindicated or lesion progresses: therapeutic anticoagulation
II	Dissection/intramural hematoma ≥ 25% stenosis or intraluminal thrombus	Aspirin 3-5mg/kg/day (max 81mg) or therapeutic anticoagulation	Switch to/continue therapeutic anticoagulation if progression or neuro symptoms; involve cerebrovascular team for carotid lesions
III	Pseudoaneurysm	Aspirin 3-5mg/kg/day (max 81mg) or therapeutic anticoagulation; early neuro/vascular consult	Endovascular repair if enlarging or flow-limiting, or symptomatic
IV	Vessel Occlusion	Aspirin 3-5mg/kg/day (max 81mg); neuro involvement recommended for carotid	Consider revascularization/endovascular repair in symptomatic cases
V	Transection	Emergent operative or endovascular control	Multidisciplinary approach

along with adjunct focused assessment with sonography for trauma (FAST). Children who are well-appearing with negative screens are frequently observed without CT. In contrast, concerning examination findings, abnormal laboratories, or evolving symptoms usually warrant CT and admission (**Figure 4**). Children who are hemodynamically unstable (i.e., persistent age-adjusted hypotension/tachycardia with poor perfusion despite initial resuscitation) should bypass CT and proceed to definitive hemorrhage control [54-56]. FAST should be viewed as a supportive tool rather than a sole rule-out in stable children, with disposition guided by the total clinical picture alongside these screening elements [54,55].

In solid organ injury, American Pediatric Surgical Association (APSA) guidance emphasizes a physiology-first approach. Admission decisions are based on hemodynamic status rather than CT grade. Mandatory bed rest is minimized or omitted, early mobilization is encouraged, and discharge is considered once hemoglobin and vital signs are stable. Routine follow up imaging is not required [57]. Many centers now avoid using CT grade alone to determine level of care or length of stay. Even with contrast blush, splenic salvage is common in stable children. For return to activity, many follow APSA's "grade + 2 weeks" guidance for contact sports, with no routine follow-up imaging unless symptoms recur [57].

Figure 4: Blunt Abdominal Trauma Evaluation



Damage Control Surgery & Open Abdomen in Children

Damage-control surgery in children is reserved for situations in which rapid hemorrhage control or contamination control must take precedence over definitive reconstruction. Typical triggers include ongoing bleeding despite resuscitation, physiologic exhaustion with hypothermia, acidosis, or coagulopathy, evolving abdominal compartment syndrome, and the need for an abbreviated exploration with deferred reassessment of bowel viability. The operative goals are to pack and control bleeding**,** control contamination, avoid prolonged hypothermia and coagulopathy, and place a temporary abdominal closure that protects the viscera and permits a second look. When the child is stable and contamination is controlled, resection with primary anastomosis for small-bowel perforation is often feasible at the index operation. For colon injuries, primary repair or resection-and-anastomosis is appropriate when physiology allows and the field can be adequately decontaminated, reserving diversion or delayed reconstruction for unstable patients or destructive injuries with heavy contamination [58-63]. Temporary abdominal closure with negative-pressure systems supports edema control, prevents visceral desiccation, and facilitates planned re-exploration. Pediatric series, although smaller than adult cohorts, report acceptable fascial-closure rates and complication profiles when standardized protocols are followed[58,63]. Best practice is to return for a planned re-look within 24–48 hours, aim for early primary fascial closure once temperature, acid–base status, and coagulopathy have normalized, and to minimize the duration of the open abdomen to reduce risks of enteroatmospheric fistula, infection, fluid/protein losses, and ventral hernia [58,63]. Throughout the open-abdomen phase, prioritize meticulous thermal management, judicious but adequate resuscitation, early enteral nutrition when bowel continuity and perfusion permit, frequent assessments for evolving compartment physiology, and vigilant skin/soft-tissue care around the dressing. These principles help translate the damage-control intent into favorable pediatric outcomes[58,63].

Traumatic Brain Injury

Traumatic brain injury care in children follows the 2019 Brain Trauma Foundation guidance with an emphasis on

preventing hypoxia and hypotension, early analgesia/sedation, stepwise intracranial pressure (ICP) management, and maintenance of age-appropriate cerebral perfusion pressure (CPP) [64,65]. Treat sustained intracranial pressure elevations, often above 20 mm Hg, with a stepwise approach that includes keeping the head and neck in a midline position, using controlled ventilation to maintain normocapnia while avoiding routine prophylactic hyperventilation and reserving brief hyperventilation for impending herniation, providing adequate sedation and analgesia with neuromuscular blockade when needed, and delivering hyperosmolar therapy (**Figure 5)**. A typical regimen is 3% hypertonic saline given as a bolus of 2-5 mL per kg or as an infusion with serum sodium and osmolality targets set by protocol. Mannitol can be considered as an alternative when hemodynamic conditions permit [64]. Cerebrospinal fluid (CSF) diversion with an external ventricular drain can both monitor and treat ICP, and decompressive craniectomy is reserved for refractory intracranial hypertension after stepwise measures fail [64]. Maintain age-specific CPP (younger children at the lower end of ~40–50 mm Hg, older children/adolescents at the higher end) and avoid secondary insults such as fever, anemia, and hyper/hypoglycemia [64]. Start early nutrition, preferably enteral, within 72 hours when feasible, and provide seizure prophylaxis to reduce early post-traumatic seizures in severe TBI [64]. Corticosteroids are not recommended given adult evidence of harm and lack of pediatric benefit [64]. Routine scheduled repeat head CT is generally not required in a stable child [64]. With respect to fluids and products, prioritize avoidance of hypotension and coagulopathy. Balanced blood-first resuscitation should be used only when hemorrhagic shock coexists, as plasma or whole blood is not a TBI-specific therapy per se.

Systems: Pediatric Readiness, Triage, and Team Design

Nationally, higher pediatric readiness of emergency departments is associated with lower in-hospital and 1-year mortality for injured children, with the survival benefit persisting after adjustment for patient and hospital factors [66]. Readiness work commonly includes the availability of pediatric-appropriate equipment and drug dosing tools, routine interprofessional team training and simulation to offset high-acuity/low-volume realities, clear activation criteria with clinician override, defined

Figure 5: Practical ICP Management in Children

Intervention	Typical Regimen	Monitoring/Targets	When to use/Escalate	Key Cautions
Hypertonic Saline 3% (Bolus)	2-5 mL/kg IV over 10-20 min; may repeat for ICP spikes	Check Na^+ and serum osmolality q4-6 hours; Na^+ ~145-155mmol/L, Osmolality ≤ 320 mOsm/kg	First line for suspected/confirmed intracranial hypertension or acute ICP spikes	Hypernatremia, hyperchloremic acidosis; extravasation risk via peripheral lines
Hypertonic Saline 3% (Infusion)	0.1-1.0 mL/kg/h IV, titrated to ICP/clinical response	Same as above	Ongoing control when repeated boluses are needed or ICP lability persists	Fluid overload if not balanced; wean gradually to avoid rebound ICP
Mannitol	0.5-1 g/kg IV over ~10 min	Serum osmolality ≤ 320 mOsm/kg	Alternative or adjunct when hemodynamics permit and volume status can be maintained	Avoid in hypotension, hypovolemia, AKI; watch for electrolyte shifts
CSF Diversion (Extraventricular Drain)	Ventricular catheter for monitoring/drainage; drain for ICP > 20mmHg sustained (~ >5min)	ICP waveform/values; CSF output, neuro exam	Failure of medical therapy or need for direct ICP monitoring/therapeutic drainage	Infection, hemorrhage, over-drainage, ensure transducer leveling and sterile care
Decompressive Craniectomy	Surgical decompression after tiered measures fail	ICU monitoring of ICP, CPP, and complications	Rescue for refractory ICP >20-25mmHg despite optimized sedation, ventilation, HTS/mannitol, temperature control, and EVD	Lowers ICP reliably; functional outcomes variable; risks: hygromas, wound issues, external brain herniation

transfer/consult pathways, and ongoing quality improvement with feedback on triage accuracy and time-to-disposition [66-68]. When feasible, preferential transport to pediatric-ready centers improves survival. In regions where transport times are long, raising readiness across all EDs may yield the greater population benefit [66].

Prehospital triage should align with the 2021 National Guideline for the Field Triage of Injured Patients, recognizing regional variation in age cutoffs (commonly ≤14 y pediatric, ≥15 y adult) and emphasizing transport to the most appropriate trauma center for the sickest patient when pediatric and adult casualties co-occur [69]. Importantly, pediatric survival is strongly linked to the pediatric readiness of the receiving ED (**Figure 6**). Matching children to trauma centers with high ED pediatric readiness confers lower mortality and remains beneficial even when transport times extend beyond 30 minutes, although raising readiness everywhere may save even more lives [66,70]. Ensure prehospital teams have pediatric dosing references, equipment, and clear destination protocols consistent with state/regional systems [69].

Pediatric Trauma in Resource Limited Environments

In many low- and middle-income settings, pediatric trauma care is constrained by shortages of essential medications (e.g., antibiotics, analgesics), lack of pediatric-appropriate airway, monitoring, and resuscitation equipment and reliable blood products, limited pediatric specialists, and fragmented prehospital and interfacility systems. Surveys and facility assessments in Africa document frequent gaps in equipment and drugs for injured children and identify training deficits as major barriers to quality care [71-73]. Broader systems work highlights governance problems and the need for nationally coordinated trauma systems [74], while pediatric surgery capacity studies show near-absence of pediatric surgeons and anesthesiologists at district hospitals and unreliable infrastructure, underscoring the scarcity of pediatric expertise outside tertiary centers [75]. Reviews focused specifically on pediatric trauma in Africa echo these themes and call out the cumulative impact on preventable morbidity and

Figure 6: Pediatric Trauma Bay at Children's Hospital of Richmond

mortality [76]. Prehospital care across low- and middle-income countries is typically under-developed and uncoordinated, with limited trained responders and transport, further compounding time-critical care for injured children [77]. Safe blood supply is consistently limited, and failures across recruitment, storage, and distribution translate into delayed or inadequate hemorrhage control[78].

These constraints translate into concrete bedside risks: delayed resuscitation and shock, undertreated pain, and higher infection risk when antimicrobial supply or stewardship is suboptimal. Pediatric pain remains systematically undertreated in many African settings due to training gaps, opioid access barriers, and supply limitations[79]. Practical steps include using streamlined, resource-appropriate pediatric trauma protocols and checklists, embedding basic competencies in national and emergency training, equipping EDs with minimums carts and weight-based aids, deploying low-cost monitoring with standardized triage, creating regional referral and prehospital responder networks, and reinforcing the entire blood pathway from donor recruitment to point-of-care supply [73,74,77,78]. Collectively, these system and bedside adaptations are repeatedly cited as feasible ways to narrow outcome gaps for injured children where resources are limited.

Ethical Considerations

Emergency pediatric trauma often requires time-critical decisions under uncertainty and with limited ability to obtain traditional informed consent. In life-threatening situations, implied consent permits interventions necessary to prevent death or serious harm (e.g., airway management, hemorrhage control, emergency transfusion). When feasible, clinicians should seek parental permission and, in developmentally appropriate children, assent, while documenting the emergent nature of care and any discussions held.

Blood product use raises specific issues: families may have religious objections to transfusion. Policies should outline pathways for emergency transfusion in minors, involvement of hospital leadership and ethics consultation, and documentation of best-interest determinations. For low-titer group O whole blood, institutions should include these modalities in consent templates and family information materials when time allows.

Radiation stewardship and sedation for imaging require balancing diagnostic yield against long-term risk and immediate procedural risks. Shared decision-making is recommended when imaging is discretionary, with clear explanations of why a computed tomography scan will, or will not, change management, and discussion of alternatives such as magnetic resonance imaging.

For blunt cerebrovascular injury, initiation of antithrombotic therapy in children entails bleeding risk. Decisions should be individualized with neurosurgery input and explicit discussion of risks, benefits, and uncertainties. Pain management should be equitable and evidence-based. Efforts to reduce undertreatment of pediatric pain should be embedded in protocols, particularly in resource-limited environments.

Limitations of the Evidence

Much of pediatric trauma practice extrapolates from adult data as high-quality pediatric randomized trials are scarce. Evidence for whole blood**,** viscoelastic-guided resuscitation, and tranexamic acid in children is dominated by retrospective cohorts and heterogeneous registries, limiting causal inference and dose-response precision. Prediction tools show variable performance across settings and can misclassify shock in very young children or those with traumatic brain injury.

Imaging stewardship recommendations are supported by observational data and center-level protocols; generalizability may be constrained by resource availability (e.g., access to pediatric MRI/sedation, 24/7 radiology). Implementation barriers include blood product logistics, limited point-of-care ionized calcium testing, wide variation in IO/ultrasound IV expertise, and uneven pediatric readiness outside children's hospitals. In low- and middle-income settings, gaps in equipment, analgesia, trained staff, prehospital systems, and safe blood supply complicate adoption of best practices. These limitations underscore the need for context-sensitive protocols and cautious interpretation of effect sizes.

Conclusion

Pediatric trauma care has moved decisively toward physiology-first management: early hemostatic resuscitation, radiation stewardship anchored by age-sensitive decision rules and targeted MRI/CT use, and nonoperative solid-organ pathways that emphasize early mobilization and symptom-driven imaging. Damage-control strategies and open abdomen remain life-saving when physiology dictates, using planned re-exploration and timely fascial closure. TBI care continues to follow

Brain Trauma Foundation guidance with stepwise ICP/CPP targets, early nutrition, seizure prophylaxis, and disciplined avoidance of secondary insults. At the system level, ED pediatric readiness and appropriate destination choice in prehospital triage are consistently associated with improved outcomes.

Looking forward, priorities include completing multicenter randomized and pragmatic trials comparing low-titer group O whole blood with component therapy (e.g., MATIC-2) and testing viscoelastic-guided algorithms; prospectively defining ionized calcium thresholds and dosing during massive transfusion; clarifying indications, timing, and dosing for tranexamic acid; externally validating and embedding in electronic health records pediatric shock prediction tools and blunt cerebrovascular injury screening scores; conducting comparative-effectiveness studies of MRI-first cervical-spine strategies and selective chest CT; and evaluating pediatric-readiness interventions (simulation, blood stored in the emergency department, weight-based dosing aids) by rolling them out to different hospitals in random order and comparing before-and-after results.

These steps will refine de-implementation of low-value care, scale practices with measurable benefit, and advance safer, more effective trauma care for children across diverse clinical environments.

References:

1. Sullivan TM, Gestrich-Thompson WV, Milestone ZP, Burd RS. Time is tissue: Barriers to timely transfusion after pediatric injury. *J Trauma Acute Care Surg*. Jan 1 2023;94(1S Suppl 1):S22-S28. doi:10.1097/TA.0000000000003752

2. ClinicalTrials.gov. Massive Transfusion in Children: A Platform RCT of Whole Blood Compared to Component Therapy and Tranexamic Acid to Placebo in Life-threatening Traumatic Bleeding (MATIC-2) [ClinicalTrials.gov identifier NCT06070350]. Accessed 10/9/25, https://clinicaltrials.gov/study/NCT06070350

3. Gaines BA, Yazer MH, Triulzi DJ, et al. Low Titer Group O Whole Blood In Injured Children Requiring Massive Transfusion. *Ann Surg*. Apr 1 2023;277(4):e919-e924. doi:10.1097/SLA.0000000000005251

4. Morgan KM, Abou Khalil E, Feeney EV, et al. The Efficacy of Low-Titer Group O Whole Blood Compared With Component Therapy in Civilian Trauma Patients: A Meta-Analysis. *Crit Care Med*. Jul 1 2024;52(7):e390-e404. doi:10.1097/CCM.0000000000006244

5. Petersen EM, Fisher AD, April MD, et al. The effect of the proportion of low-titer O whole blood for resuscitation in pediatric trauma patients on 6-, 12- and 24-hour survival. *J Trauma Acute Care Surg*. Apr 1 2025;98(4):587-592. doi:10.1097/TA.0000000000004564

6. Torres CM, Kenzik KM, Saillant NN, et al. Timing to First Whole Blood Transfusion and Survival Following Severe Hemorrhage in Trauma Patients. *JAMA Surg*. Apr 1 2024;159(4):374-381. doi:10.1001/jamasurg.2023.7178

7. Ngatuvai M, Zagales I, Sauder M, et al. Outcomes of Transfusion With Whole Blood, Component Therapy, or Both in Adult Civilian Trauma Patients: A Systematic Review and Meta-Analysis. *J Surg Res*. Jul 2023;287:193-201. doi:10.1016/j.jss.2023.02.010

8. Polites SF, Moody S, Williams RF, et al. Timing and volume of crystalloid and blood products in pediatric trauma: An Eastern Association for the Surgery of Trauma multicenter prospective observational study. *J Trauma Acute Care Surg*. Jul 2020;89(1):36-42. doi:10.1097/TA.0000000000002702

9. Powell EK, Hinckley WR, Gottula A, Hart KW, Lindsell CJ, McMullan JT. Shorter times to packed red blood cell transfusion are associated with decreased risk of death in traumatically injured patients. *J Trauma Acute Care Surg*. Sep 2016;81(3):458-62. doi:10.1097/TA.0000000000001078

10. Meyer DE, Vincent LE, Fox EE, et al. Every minute counts: Time to delivery of initial massive transfusion cooler and its impact on mortality. *J Trauma Acute Care Surg*. Jul 2017;83(1):19-24. doi:10.1097/TA.0000000000001531

11. Sullivan TM, Sippel GJ, Gestrich-Thompson WV, Burd RS. Strategies to Obtain and Deliver Blood Products Into Critically Injured Children: A Survey of Pediatric Trauma Society Members. *Pediatr Emerg Care*. Feb 1 2024;40(2):124-127. doi:10.1097/PEC.0000000000003118

12. Pommerening MJ, Goodman MD, Holcomb JB, et al. Clinical gestalt and the prediction of massive transfusion after trauma. *Injury*. May 2015;46(5):807-13. doi:10.1016/j.injury.2014.12.026

13. Dente CJ, Mina MJ, Morse BC, et al. Predicting the need for massive transfusion: Prospective validation of a smartphone-based clinical decision support tool. *Surgery*. Nov 2021;170(5):1574-1580. doi:10.1016/j.surg.2021.04.034

14. Tran A, Lamb T, Taljaard M, et al. Current practices and challenges in assessing traumatic hemorrhage: An international survey of trauma care providers. *J Trauma Acute Care Surg*. May 1 2021;90(5):e95-e100. doi:10.1097/TA.0000000000003081

15. Sullivan TM, Sippel GJ, Burd RS. What Scoring System Should We Use to Evaluate for Hemorrhage-Related Interventions in Pediatric Trauma Patients? In: Slidell MB, Henry MCW, eds. *Difficult Decisions in Pediatric Surgery*. Springer Nature Switzerland; 2025:95-106.

16. Mokhtar G, Adly A, Baky AA, et al. Transfusion of blood components in pediatric age groups: an evidence-based clinical practice guideline adapted for the use in Egypt using 'Adapted ADAPTE'. *Ann Hematol*. Apr 2024;103(4):1373-1388. doi:10.1007/s00277-024-05657-4

17. New HV, Berryman J, Bolton-Maggs PH, et al. Guidelines on transfusion for fetuses, neonates and older children. *Br J Haematol*. Dec 2016;175(5):784-828. doi:10.1111/bjh.14233

18. New HV, Stanworth SJ, Gottstein R, et al. British Society for Haematology Guidelines on transfusion for fetuses, neonates and older children (Br J Haematol. 2016;175:784-828). Addendum August 2020. *Br J Haematol*. Dec 2020;191(5):725-727. doi:10.1111/bjh.17109

19. Abou Khalil E, Morgan KM, Gaines BA, Spinella PC, Leeper CM. Use of whole blood in pediatric trauma: a narrative review. *Trauma Surg Acute Care Open*. 2024;9(Suppl 1):e001127. doi:10.1136/tsaco-2023-001127

20. Shea SM, Mihalko EP, Lu L, et al. Doing more with less: low-titer group O whole blood resulted in less total transfusions and an independent association with survival in adults with severe traumatic hemorrhage. *J Thromb Haemost*. Jan 2024;22(1):140-151. doi:10.1016/j.jtha.2023.09.025

21. Kahn S, Chegondi M, Nellis ME, Karam O. Overview of Plasma and Platelet Transfusions in Critically Ill Children. *Front Pediatr*. 2020;8:601659. doi:10.3389/fped.2020.601659

22. Spinella PC, Leonard JC, Marshall C, et al. Transfusion Ratios and Deficits in Injured Children With Life-Threatening Bleeding. *Pediatr Crit Care Med*. Apr 1 2022;23(4):235-244. doi:10.1097/PCC.0000000000002907

23. Neff LP, Cannon JW, Morrison JJ, Edwards MJ, Spinella PC, Borgman MA. Clearly defining pediatric massive transfusion: cutting through the fog and friction with combat data. *J Trauma Acute Care Surg*. Jan 2015;78(1):22-8; discussion 28-9. doi:10.1097/TA.0000000000000488

24. Abou Khalil E, Gaines BA, Morgan KM, Leeper CM. Admission maximum amplitude-reaction time ratio: Association between thromboelastography values predicts poor outcome in injured children. *J Trauma Acute Care Surg*. Feb 1 2023;94(2):212-219. doi:10.1097/TA.0000000000003834

25. Abou Khalil E, Feeney E, Morgan KM, Spinella PC, Gaines BA, Leeper CM. Impact of hypocalcemia on mortality in pediatric trauma patients who require transfusion. *J Trauma Acute Care Surg*. Aug 1 2024;97(2):242-247. doi:10.1097/TA.0000000000004330

26. Rollins L, Bertero E, Hunter L. Developmental differences in the visual processing of emotionally ambiguous neutral faces based on perceived valence. *PLoS One*. 2021;16(8):e0256109. doi:10.1371/journal.pone.0256109

27. Khalid S, Iwanaga J, Loukas M, Tubbs RS. Split Femoral Nerve Due to Psoas Tertius Muscle: A Review with Other Cases of Variant Muscles Traversing the Femoral Nerve. *Cureus*. Aug 9 2017;9(8):e1555. doi:10.7759/cureus.1555

28. Kornelsen E, Kuppermann N, Nishijima DK, et al. Effectiveness and safety of tranexamic acid in pediatric trauma: A systematic review and meta-analysis. *Am J Emerg Med*. May 2022;55:103-110. doi:10.1016/j.ajem.2022.01.069

29. Kuhlenschmidt KM, Choi E, Moonmoon K, et al. Provider Perception of Time During Trauma Resuscitation: A Prospective Quantitative Trauma Video Review Analysis. *J Surg Res*. Jun 2022;274:207-212. doi:10.1016/j.jss.2021.12.048

30. Voigt J, Waltzman M, Lottenberg L. Intraosseous vascular access for in-hospital emergency use: a systematic clinical review of the literature and analysis. *Pediatr Emerg Care*. Feb 2012;28(2):185-99. doi:10.1097/PEC.0b013e3182449edc

31. Lininger RA. Pediatric peripheral i.v. insertion success rates. *Pediatr Nurs*. Sep-Oct 2003;29(5):351-4.

32. Chiang T, Teichman AL. Resuscitation and Evaluation With Intraosseous Access: A Review of the Literature in Trauma and Non-Trauma Patients. *Am Surg*. Jun 2024;90(6):1608-1617. doi:10.1177/00031348241227169

33. Topjian AA, Raymond TT, Atkins D, et al. Part 4: Pediatric Basic and Advanced Life Support: 2020 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. Oct 20 2020;142(16_suppl_2):S469-S523. doi:10.1161/CIR.0000000000000901

34. Nagler J, Krauss B. Videos in clinical medicine. Intraosseous catheter placement in children. *N Engl J Med*. Feb 24 2011;364(8):e14. doi:10.1056/NEJMvcm0900916

35. Guy J, Haley K, Zuspan SJ. Use of intraosseous infusion in the pediatric trauma patient. *J Pediatr Surg*. Feb 1993;28(2):158-61. doi:10.1016/s0022-3468(05)80263-5

36. Hallas P, Brabrand M, Folkestad L. Complication with intraosseous access: scandinavian users' experience. *West J Emerg Med*. Sep 2013;14(5):440-3. doi:10.5811/westjem.2013.1.12000

37. Reinhardt RA, Tussing GJ, Kalkwarf KL. Endocarditis prophylaxis for patients with periodontal disease. *Am Fam Physician*. Jan 1983;27(1):129-34.

38. Mitchell EO, Jones P, Snelling PJ. Ultrasound for Pediatric Peripheral Intravenous Catheter Insertion: A Systematic Review. *Pediatrics*. May 1 2022;149(5)doi:10.1542/peds.2021-055523

39. Leonard JC, Harding M, Cook LJ, et al. PECARN prediction rule for cervical spine imaging of children presenting to the emergency department with blunt trauma: a multicentre prospective observational study. *Lancet Child Adolesc Health*. Jul 2024;8(7):482-490. doi:10.1016/S2352-4642(24)00104-4

40. Expert Panel on Pediatric I, Kadom N, Palasis S, et al. ACR Appropriateness Criteria((R)) Suspected Spine Trauma-Child. *J Am Coll Radiol*. May 2019;16(5S):S286-S299. doi:10.1016/j.jacr.2019.02.003

41. Lee RP, Zhou NJ, Hidalgo J, et al. Weighing the Risk Profile of Cervical Spine MRI in Evaluating Pediatric Cervical Spine Injuries. *Pediatr Neurosurg*. 2022;57(5):314-322. doi:10.1159/000525863

42. Holscher CM, Faulk LW, Moore EE, et al. Chest computed tomography imaging for blunt pediatric trauma: not worth the radiation risk. *J Surg Res*. Sep 2013;184(1):352-7. doi:10.1016/j.jss.2013.04.044

43. Stephens CQ, Boulos MC, Connelly CR, Gee A, Jafri M, Krishnaswami S. Limiting thoracic CT: a rule for use during initial pediatric trauma evaluation. *J Pediatr Surg*. Dec 2017;52(12):2031-2037. doi:10.1016/j.jpedsurg.2017.08.039

44. Lynch P, Samoilov L, Brahm G. Thoracic Imaging in Pediatric Trauma: Are CTs Necessary? *Pediatr Emerg Care*. Feb 1 2023;39(2):98-101. doi:10.1097/PEC.0000000000002896

45. Pearce MS, Salotti JA, Little MP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. *Lancet*. Aug 4 2012;380(9840):499-505. doi:10.1016/S0140-6736(12)60815-0

46. Holl EM, Marek AP, Nygaard RM, Richardson CJ, Hess DJ. Use of Chest Computed Tomography for Blunt Pediatric Chest Trauma: Does It Change Clinical Course? *Pediatr Emerg Care*. Feb 2020;36(2):81-86. doi:10.1097/PEC.0000000000002040

47. Orscheln E, Sandhu P, Shet N. Imaging in pediatric blunt thoracic trauma. *Pediatr Radiol*. Aug 9 2025;doi:10.1007/s00247-025-06356-6

48. Polycarpou A, Kim BD. Pediatric surgical rib fixation: A collected case series of a rare entity. *J Trauma Acute Care Surg*. Dec 1 2021;91(6):947-950. doi:10.1097/TA.0000000000003376

49. Herbert JP, Venkataraman SS, Turkmani AH, et al. Pediatric blunt cerebrovascular injury: the McGovern screening score. *J Neurosurg Pediatr*. Jun 2018;21(6):639-649. doi:10.3171/2017.12.PEDS17498

50. Venkataraman SS, Herbert JP, Ravindra VM, et al. Multi-Center Validation of the McGovern Pediatric Blunt Cerebrovascular Injury Screening Score. *J Neurotrauma*. Jul 2023;40(13-14):1451-1458. doi:10.1089/neu.2022.0336

51. Ravindra VM, Bollo RJ, Sivakumar W, et al. Predicting Blunt Cerebrovascular Injury in Pediatric Trauma: Validation of the "Utah Score". *J Neurotrauma*. Jan 15 2017;34(2):391-399. doi:10.1089/neu.2016.4415

52. Ravindra VM, Riva-Cambrin J, Sivakumar W, Metzger RR, Bollo RJ. Risk factors for traumatic blunt cerebrovascular injury diagnosed by computed tomography angiography in the pediatric population: a retrospective cohort study. *J Neurosurg Pediatr*. Jun 2015;15(6):599-606. doi:10.3171/2014.11.PEDS14397

53. Ravindra VM, Bollo RJ, Dewan MC, et al. Comparison of anticoagulation and antiplatelet therapy for treatment of blunt cerebrovascular injury in children <10 years of age: a multicenter retrospective cohort study. *Childs Nerv Syst*. Jan 2021;37(1):47-54. doi:10.1007/s00381-020-04672-w

54. Holmes JF, Lillis K, Monroe D, et al. Identifying children at very low risk of clinically important blunt abdominal injuries. *Ann Emerg Med*. Aug 2013;62(2):107-116 e2. doi:10.1016/j.annemergmed.2012.11.009

55. Holmes JF, Mao A, Awasthi S, McGahan JP, Wisner DH, Kuppermann N. Validation of a prediction rule for the identification of children with intra-abdominal injuries after blunt torso trauma. *Ann Emerg Med*. Oct 2009;54(4):528-33. doi:10.1016/j.annemergmed.2009.01.019

56. Sola JE, Cheung MC, Yang R, et al. Pediatric FAST and elevated liver transaminases: An effective screening tool in blunt abdominal trauma. *J Surg Res*. Nov 2009;157(1):103-7. doi:10.1016/j.jss.2009.03.058

57. Williams RF, Grewal H, Jamshidi R, et al. Updated APSA Guidelines for the Management of Blunt Liver and Spleen Injuries. *J Pediatr Surg*. Aug 2023;58(8):1411-1418. doi:10.1016/j.jpedsurg.2023.03.012

58. Brown J, Warnock B, Turk E, Hobson MJ, Friedman ML, Gray BW. Open abdomen during extracorporeal membrane oxygenation is a safe and effective treatment for abdominal compartment syndrome. *J Pediatr Surg*. Sep 2022;57(9):216-222. doi:10.1016/j.jpedsurg.2021.11.020

59. Demetriades D, Murray JA, Chan L, et al. Penetrating colon injuries requiring resection: diversion or primary anastomosis? An AAST prospective multicenter study. *J Trauma*. May 2001;50(5):765-75. doi:10.1097/00005373-200105000-00001

60. Dokucu A, Ozturk H, Yagmur Y, et al. Colon injuries in children. *J Pediatr Surg*. Dec 2000;35(12):1799-804. doi:10.1053/jpsu.2000.19262

61. Fouda E, Emile S, Elfeki H, et al. Indications for and outcome of primary repair compared with faecal diversion in the management of traumatic colon injury. *Colorectal Dis*. Aug 2016;18(8):O283-91. doi:10.1111/codi.13421

62. Haut ER, Nance ML, Keller MS, et al. Management of penetrating colon and rectal injuries in the pediatric patient. *Dis Colon Rectum*. Sep 2004;47(9):1526-32. doi:10.1007/s10350-004-0605-0

63. Spencer BL, Lotakis DM, Carducci J, et al. Outcomes of Prolonged Open Abdomen in Children. *J Surg Res*. Jun 2024;298:1-6. doi:10.1016/j.jss.2024.02.010

64. Guidelines for the Management of Pediatric Severe Traumatic Brain Injury, Third Edition: Update of the Brain Trauma Foundation Guidelines: Erratum. *Pediatr Crit Care Med*. Apr 2019;20(4):404. doi:10.1097/PCC.0000000000001945

65. Kochanek PM, Tasker RC, Carney N, et al. Guidelines for the Management of Pediatric Severe Traumatic Brain Injury, Third Edition: Update of the Brain Trauma Foundation Guidelines, Executive Summary. *Pediatr Crit Care Med*. Mar 2019;20(3):280-289. doi:10.1097/PCC.0000000000001736

66. Newgard CD, Lin A, Goldhaber-Fiebert JD, et al. Association of Emergency Department Pediatric Readiness With Mortality

to 1 Year Among Injured Children Treated at Trauma Centers. *JAMA Surg*. Apr 1 2022;157(4):e217419. doi:10.1001/jamasurg.2021.7419

67. Newgard CD, Lin A, Olson LM, et al. Evaluation of Emergency Department Pediatric Readiness and Outcomes Among US Trauma Centers. *JAMA Pediatr*. Sep 1 2021;175(9):947-956. doi:10.1001/jamapediatrics.2021.1319

68. Newgard CD, Rakshe S, Salvi A, et al. Changes in Emergency Department Pediatric Readiness and Mortality. *JAMA Netw Open*. Jul 1 2024;7(7):e2422107. doi:10.1001/jamanetworkopen.2024.22107

69. Newgard CD, Fischer PE, Gestring M, et al. National guideline for the field triage of injured patients: Recommendations of the National Expert Panel on Field Triage, 2021. *J Trauma Acute Care Surg*. Aug 1 2022;93(2):e49-e60. doi:10.1097/TA.0000000000003627

70. Glass NE, Salvi A, Wei R, et al. Association of Transport Time, Proximity, and Emergency Department Pediatric Readiness With Pediatric Survival at US Trauma Centers. *JAMA Surg*. Oct 1 2023;158(10):1078-1087. doi:10.1001/jamasurg.2023.3344

71. Amado V, Couto MT, Filipe M, Moller J, Wallis L, Laflamme L. Assessment of critical resource gaps in pediatric injury care in Mozambique's four largest Hospitals. *PLoS One*. 2023;18(6):e0286288. doi:10.1371/journal.pone.0286288

72. Ankomah J, Stewart BT, Oppong-Nketia V, et al. Strategic assessment of the availability of pediatric trauma care equipment, technology and supplies in Ghana. *J Pediatr Surg*. Nov 2015;50(11):1922-7. doi:10.1016/j.jpedsurg.2015.03.047

73. Rivas JA, Bartoletti J, Benett S, Strong Y, Novotny TE, Schultz ML. Paediatric trauma education in low- and middle-income countries: A systematic literature review. *J Glob Health*. Dec 29 2022;12:04078. doi:10.7189/jogh.12.04078

74. Whitaker J, O'Donohoe N, Denning M, et al. Assessing trauma care systems in low-income and middle-income countries: a systematic review and evidence synthesis mapping the Three Delays framework to injury health system assessments. *BMJ Glob Health*. May 2021;6(5)doi:10.1136/bmjgh-2020-004324

75. Gajewski J, Pittalis C, Borgstein E, et al. Critical shortage of capacity to deliver safe paediatric surgery in sub-Saharan Africa: evidence from 67 hospitals in Malawi, Zambia, and Tanzania. *Front Pediatr*. 2023;11:1189676. doi:10.3389/fped.2023.1189676

76. Abdur-Rahman LO, van As AB, Rode H. Pediatric trauma care in Africa: the evolution and challenges. *Semin Pediatr Surg*. May 2012;21(2):111-5. doi:10.1053/j.sempedsurg.2012.01.003

77. Bhattarai HK, Bhusal S, Barone-Adesi F, Hubloue I. Prehospital Emergency Care in Low- and Middle-Income Countries: A Systematic Review. *Prehosp Disaster Med*. Aug 2023;38(4):495-512. doi:10.1017/S1049023X23006088

78. Delaney M, Telke S, Zou S, et al. The BLOODSAFE program: Building the future of access to safe blood in Sub-Saharan Africa. *Transfusion*. Nov 2022;62(11):2282-2290. doi:10.1111/trf.17091

79. Albertyn R, Rode H, Millar AJ, Thomas J. Challenges associated with paediatric pain management in Sub Saharan Africa. *Int J Surg*. Apr 2009;7(2):91-3. doi:10.1016/j.ijsu.2009.01.005