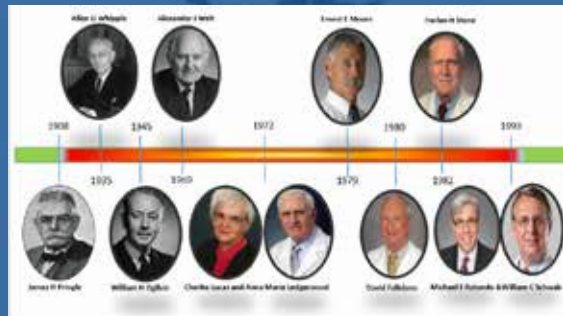




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TRAUMA AND CRITICAL CARE SURGERY UPDATE: EXPANDING THE EVIDENCE — PART II



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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-impliments 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 management¹. 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 phase³⁻⁵. 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 cohort¹. In one study, earlier blood transfusion was associated with decreased length of stay and hospital related morbidity but not mortality⁸. 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 transfusion¹²⁻¹⁴. 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 systems¹. 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 protocols¹⁶⁻¹⁸. 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 cycle²¹. 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 cohorts²⁴. 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 products²⁷. 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 subgroups²⁸. 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 shock²⁸.

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 access¹. First-attempt PIV placement has been observed to be as low as 53% among non-injured and injured children³¹. 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 permit³⁴. 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

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)

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 pain³⁴. 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 success³⁸.

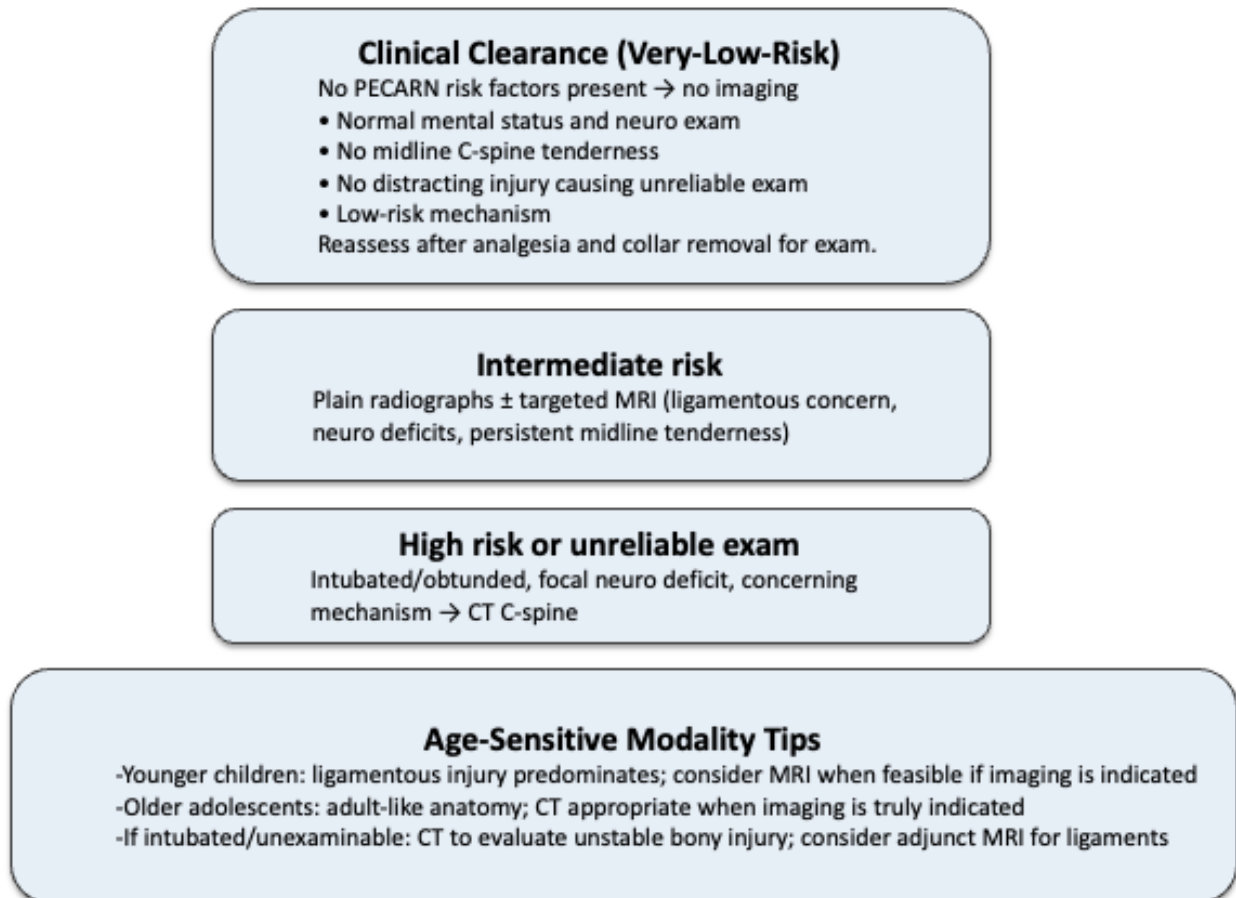
Minimizing Radiation: C-Spine and Chest Imaging

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 ($\sim 8\%$) ^{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 ($\sim 71\%$) 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 $\geq 25\%$ 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 control⁵⁴⁻⁵⁶. 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}.

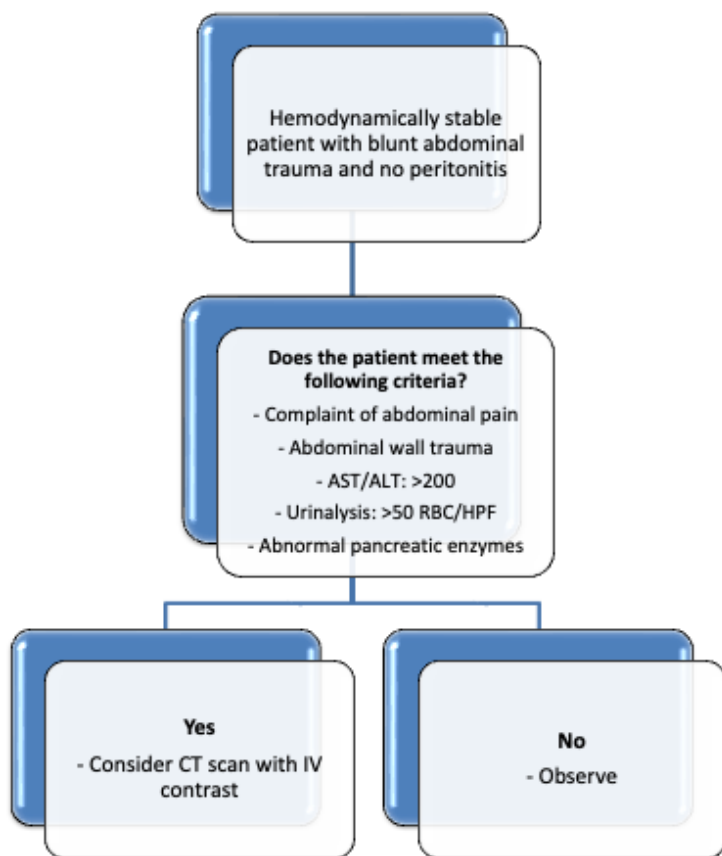
In solid organ injury, American Pediatric Surgical Association (APSA) guidance emphasizes a physiology-first approach. Admission decisions are based on hemodynamic status rather than CT grade. Mandatory bed rest is minimized or omitted, early mobilization is encouraged, and discharge is considered once hemoglobin and vital signs are stable. Routine follow up imaging is not required⁵⁷. 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 recur⁵⁷.

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 contamination⁵⁸⁻⁶³. 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}.

Figure 4: Blunt Abdominal Trauma Evaluation



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 mid-line 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	Hypnatremia, 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-disposition⁶⁶⁻⁶⁸. 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 benefit⁶⁶.

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-occur⁶⁹. 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 systems⁶⁹.

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 care⁷¹⁻⁷³. Broader systems work highlights governance problems and the need for nationally coordinated trauma systems⁷⁴, 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 centers⁷⁵. 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



mortality⁷⁶. 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 children⁷⁷. Safe blood supply is consistently limited, and failures across recruitment, storage, and distribution translate into delayed or inadequate hemorrhage control⁷⁸.

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 limitations⁷⁹. 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 pre-hospital 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.

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