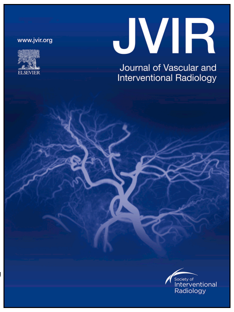

Society of Interventional Radiology Position Statement on Endovascular Trauma Intervention in the Pediatric Population

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Endorsed by: American Academy of Pediatrics, American College of Surgeons, American Pediatric Surgical Association, Pediatric Orthopaedic Society of North America, Pediatric Trauma Society, Society for Pediatric Interventional Radiology, Society for Pediatric Radiology

Introduction

Pediatric trauma care, including the role of endovascular management, varies considerably from that of adults. Pediatric solid organ injury is more frequently and effectively treated non-operatively. Protocols for non-operative management (NOM) in children were developed to maximize resource utilization and limit repeat imaging, and have been validated prospectively [1]. The use of endovascular interventions for trauma has yet to be defined for children. The purpose of this position statement is to evaluate the current literature and establish pediatric trauma guidelines for interventional radiologists. In this position statement, NOM is defined as no invasive treatment, whereas operative management is defined as surgical treatment, and endovascular management is defined as minimally-invasive interventions, such as arteriography and embolization. This differs from definitions frequently used in the surgical literature, which often group non-operative and endovascular management in the same category. This document follows the American Academy of Pediatrics age groups for children as 0-17 years old and pediatrics as 0-21 years old [2]. The authors recognize that there are physiologic differences between children (ages 2-12 years) and adolescents (ages 13-21 years) [2].

METHODS

Panel Formation

Under the direction of SIR, a multidisciplinary group of experts in pediatric trauma care, representing interventional radiology, emergency medicine, intensive care medicine, and surgery, was convened to review the current literature on the use of endovascular interventions for the management of trauma in children.

Literature Review

A comprehensive literature search was conducted in November 2020 in MEDLINE via PubMed using combinations of the following search terms: "pediatric," "children," "infant," "neonate," "adolescent," "trauma," "minimally invasive," "endovascular," "nonoperative," "wounds, penetrating," "wounds, nonpenetrating," "trauma centers," and "pediatric hospitals," in combination with body system terms including: "renal," "kidney," "abdominal," "spleen," "solid organ," "liver," "pelvic," "pelvic ring," "pelvis," "pelvic bones," "contrast blush," "computed tomography," "ultrasound," "fracture," "humerus," "closed fracture reduction," "open fracture reduction," "aortic injury," "aortic trauma," "aortic rupture," "vascular trauma," and "vascular system injuries." The search was limited to English-language publications after the year 2000 to focus on outcomes from the most recent evidence.

References within articles were also reviewed. Relevant studies were included in an evidence table (Appendix A) and quality of the evidence was assessed using the SIR evidence grading system (Appendix B).

Recommendation Development and Consensus

The literature for each subtopic was reviewed and is presented in order of level of evidence. Each topic and subtopic had different levels of supporting evidence. If a subtopic does not include a specific level of evidence, this indicates that the literature search returned no results for that evidence level. Where available, the existing societal guidelines for each subtopic are also summarized at the end of each section. Recommendations were drafted and graded with a level of evidence and strength of recommendation according to the updated SIR evidence grading system (Appendix C). A modified Delphi technique was used to achieve consensus agreement on the recommendation statements. Consensus is reached when 80% of the panelists agree with each statement (Table 1, 2).

RESULTS

Algorithmic Care of the Trauma Patient

The American Pediatric Surgical Association (APSA) first developed imaging-based guidelines for management of pediatric spleen and liver injuries in 2000 [3] with a more recent update in 2019 [4]. ATOMAC, (Arizona-Texas-Oklahoma-Memphis-Arkansas Consortium) is a pediatric trauma consortium that uses patient hemodynamic status and ongoing need for transfusion in addition to imaging findings to develop guidelines for management of pediatric blunt liver and splenic trauma.

In this position statement, hemodynamic stability is defined as stable blood pressure and circulation, with age-based parameters outlined in more detail in other publications [5-7]. They concluded that systolic blood pressure less than 50 mm Hg needs operative or angiographic evaluation [5]. A transfusion limit of 40cc/kg of packed red blood cells (PRBC) or >4 units PRBC indicates unsuccessful NOM [5]. Treating centers should follow evidence-based guidelines to ensure optimal care. See Figure 1.

Operator Training and Experience

The goal of this position statement is to educate all practitioners caring for injured children, realizing that pediatric expertise may not be available in all institutions or geographic areas. In pediatric trauma, experience with endovascular interventions in children is helpful. Familiarity with appropriately sized equipment, skill in performing endovascular procedures, knowledge of pediatric intraprocedural medication dosage, and an expertise in vascular anatomy by the operator is necessary to administer optimal care. Specific techniques, qualifications, and quality thresholds for endovascular interventions in pediatric patients have been described in detail in other publications [8-12].

The majority of pediatric patients will require general anesthesia for their procedure. Due to the need for sedation and cardiopulmonary support, anesthesiologists and nursing at the facility should have training and experience in the management of critically ill children. Team members should be comfortable with pediatric resuscitation and rapid transfusion of blood products. Post-procedure monitoring will require an intensive care unit (ICU) with an intensivist, nursing staff and respiratory therapists who have experience with pediatric trauma. The facility should have a full range of pediatric-sized equipment readily available for monitoring and interventions.

Distribution of Care

Despite the increasing number of designated pediatric trauma centers in the US over the past 20 years, the availability of specified pediatric expertise is still limited in many areas[13]. There is evidence that children benefit from care at a pediatric trauma center, but decisions regarding triage are not well defined [14]. Imaging of children should follow ALARA (as low as reasonably achievable) principles to reduce radiation dose. In adult trauma care, early angiography and embolization has been shown to improve outcomes in selected trauma scenarios. This has led to the recommendation by the American College of Surgeons Committee on Trauma that access to angiography and embolization should be available within 60 minutes for Level I and Level II trauma centers [15]. If this is not possible, transfer to another facility that can treat the patient immediately should be considered based on the patient condition, the injury and resources available.

A 2008 retrospective statewide database study found that pediatric patients treated at designated trauma centers had a higher injury severity score which resulted in differences in overall mortality rates between non-trauma centers, designated trauma centers, and pediatric designated trauma centers (1.71%, 4.23%, and 4.39%, respectively) [16]. Further analysis controlling for injury severity demonstrated that treatment of pediatric patients at designated trauma centers as compared to non-trauma centers reduced mortality by 3.15% ($p < 0.0001$) [16]. The same study additionally demonstrated that treatment in a pediatric designated trauma center as compared to a non-pediatric designated trauma center reduced mortality an additional 4.84% ($p < 0.001$) [16]. However, a 2017 retrospective statewide database study of 1,606 adolescent polytrauma patients ages 12-17 years old found no significant difference in mortality (adjusted odds ratio: 1.10, 95% CI 0.54–2.24; p = 0.794) between adult and pediatric designated trauma centers [17]. The study also found that adolescents treated at pediatric trauma centers had lower functional status at discharge (adjusted odds ratio: 0.38, 95% CI 0.15–0.97; p = 0.043) and higher total adverse events (adjusted odds ratio 1.78, 95% CI 0.98–3.32; p = 0.058) compared with adult trauma centers [17].

Several studies have examined the difference in management of pediatric solid organ injury inside and outside of the pediatric trauma center. A 2013 single state retrospective database study examined the rate of operative intervention and embolization for adolescent solid organ injury managed in adult and pediatric trauma centers [18]. Although the rates of both interventions were low overall, the rate of operative intervention in pediatric trauma centers was 0%, and the rate of embolization was only .6%, both considerably lower than in the adult centers, which had rates of operative intervention of 3.2% and embolization of 2.8% [18]. Another retrospective database study from 2006 found a higher rate of operative intervention in pediatric splenic injury in adult non-trauma centers as compared to adult trauma centers (18.47% vs. 9.23%, p < 0.0001) [19]. Although NOM is increasing across hospitals as the main treatment for children with solid organ injury, the available evidence supports that providers may consider transfer of stable patients with higher grade injuries or multisystem injury which includes solid organ injury to a pediatric trauma center, where successful NOM is standard.

There is some evidence to suggest that certain types of extremity injury in otherwise stable patients are more frequently transferred to pediatric centers for subspecialty care. A 2019 large retrospective cohort study examining the outcomes of pediatric patients with extremity vascular trauma found that limb salvage rate was significantly higher in American College of Surgeons (ACS)-verified pediatric trauma centers (97.9%) as compared to non-ACS verified pediatric centers (90.8%) ($p < 0.001$) [20].

With respect to central vascular injuries, there is evidence to suggest that optimal resources for care vary in free standing children's hospitals. Based on a 2018 survey study of 176 pediatric surgeons at ACS designated pediatric trauma centers, that the majority of vascular injuries at free standing children's hospitals were managed by vascular surgeons [21]. 36% of these institutions did not have a fellowship trained vascular surgeon on call and 27% did not have in house endovascular capabilities and 18% did not always have a radiology technologist always available [22]. The decision to transfer pediatric trauma patients must therefore account for the capabilities of the receiving institution.

SPECIFIC ORGAN SYSTEM MANAGEMENT

Multi-System Abdomen

Blunt abdominal trauma in children often involves multi-system injury, including liver, spleen, kidney, pancreatic, and bowel injuries. While most blunt abdominal injury is successfully managed non-operatively, embolization is a safe and effective tool in pediatric patients with ongoing hemodynamic instability [4, 5]. Possible adverse events related to arterial embolization include puncture site hematoma, rebleeding, infection, infarction, abscess, contrast induced nephropathy, nontarget organ embolization, posttraumatic hypertension, and allergy.

Published data on the management of blunt abdominal injuries are often reported together, rather than as individual organs. Individual organs are discussed in separate sections below, including specific imaging considerations relating to each organ.

Criteria for Imaging

Clinical criteria rather than mechanism of injury should be utilized to determine the need for computed tomography imaging (CT) in children to limit the use of CT and unnecessary radiation exposure. The Pediatric Emergency Care Applied Research Network (PECARN) derived a decision rule to determine which children warrant CT imaging after blunt trauma. In this prospective observational study of 12,044 children with blunt trauma, 761 (6.3%) had intra-abdominal injuries of which 203 (26.7%) required acute intervention (therapeutic laparotomy, angiographic embolization, blood transfusion for abdominal hemorrhage, or intravenous fluid for ≥2 nights for pancreatic/gastrointestinal injuries) [22]. The derived decision rule was 97% sensitive for intraabdominal injuries requiring acute intervention and included the following history and physical exam findings [22-24]:

- Glasgow Coma Scale of 3-13
- Evidence of abdominal wall trauma or seatbelt sign
- Complaint of abdominal pain
- Abdominal wall tenderness on exam
- Evidence of thoracic wall trauma
- Decreased breath sounds
- Vomiting

Use of laboratory markers may improve the diagnostic accuracy of the PECARN Abdominal Trauma clinical prediction rule and include [25]:

- Serum Aspartate Aminotransferase > 200u/L
- Serum Alanine Aminotransferase >125 u/L
- Hematocrit <30%
- Urinalysis with greater than 5 red blood cells per high-powered field

A 2018 analysis of 2,435 patients from the PECARN dataset, using a clinical prediction rule composed of five variables from the physical examination, laboratory markers, and chest x-ray, was 97.5% sensitive for identifying blunt intra-abdominal injuries, and 100% sensitive for those injuries requiring intervention [26].

Modalities for Imaging

Contrast-enhanced CT is the gold standard for imaging blunt abdominal trauma. Procedural considerations for performing CT In pediatric patients have been described in other publications [28]. Multiphase imaging may be performed in adults to better characterize the nature of abdominal hemorrhage. An unenhanced phase is often not necessary, although may aid in identifying hemorrhage in a patient with a history of multiple abdominal surgeries or pre-existing hyper-dense material. Findings on CT scans are highly predictive of successful conservative management. In a systematic review evaluating three prospective cohorts representing 2,596 patients, the rate of intrabdominal injury in patients with a negative abdominal CT was only 0.19% (95% confidence interval (CI) 0.08% to 44%) and the overall negative predictive value of abdominal CT was 99.8% (95% CI 99.6% to 99.9%) [28]. However, in a recent study by Rostad et al, multiphase CT in pediatric patients contributed to increased radiation dose and counteracts the gains made by promoting the ALARA principles for imaging [29]. The authors recognize that there are clinical scenarios where multiphase acquisitions are very useful for interpretation and clinical decision making for pediatric patients. CT angiography with arterial phase acquisition would be most useful for evaluating pediatric trauma while avoiding unenhanced and venous phase scans to limit radiation exposure [29-31]. As protocols and technology evolve, dual energy CT may be helpful to reduce these additional scans without increasing radiation dose [32]

Retrospective studies demonstrate that ultrasound should be used carefully when assessing solid organ injuries of the liver. Focused assessment with sonography in trauma (FAST) has been shown to be sensitive for detecting free fluid but does not predict subsequent need for therapy [33]. Contrast-enhanced ultrasound (CEUS) has been studied as an alternative method of assessing for solid organ injury in pediatric trauma patients [34, 35]. It is more sensitive than ultrasound and almost as sensitive as CT for parenchymal injury (CEUS sensitivity 91.4%, [36]). While CEUS offers very promising data, ultrasound relies on the skill of the sonographer and has not become standard practice in the United States. However, CEUS may prove to be very helpful for non-ionizing follow up assessment of trauma patients for resolution of injury or pseudoaneurysm formation [37, 38].

Follow-up Imaging

Several large systematic reviews have found a lack of evidence available to support the practice of routine follow up imaging in children with blunt abdominal injury, demonstrating that delayed adverse events are rare (0-5%) and do not increase mortality[4, 5]. As an exception, children with grade 4 or grade 5 liver injuries near the hilum may benefit from screening to assess for pseudoaneurysm formation [5].

Systematic reviews and meta-analyses

A 2010 systematic review and meta-analysis found a 28.2% (95% CI, 8.9%-61.3%) failure rate of NOM in patients with contrast extravasation, compared to the 6.5% rate in patients treated with arterial embolization, supporting the use of arterial embolization [39]. However, other studies found that while arterial embolization in children with blunt abdominal trauma may reduce the need for operative intervention, it is not required for most children with contrast extravasation [5]. A systematic review by the APSA supported the role of arterial embolization after intraabdominal injury, specifically to the spleen and liver. Several recommendations were made on the management of children with solid organ injury after trauma, including that length of hospitalization be based on clinical presentation as opposed to injury grade alone [4].

Registry-based studies

Large, multicenter retrospective studies have shown that the rate of angiography and embolization for abdominal injuries ranges from (1%-2%) [40, 41]. Compared to children managed at adult trauma centers, children at pediatric trauma centers demonstrated a higher rate of successful NOM and lower rate of arterial embolization (67.6% vs. 3.2%, $p < 0.001$) [41]; with generally similarly low mortality (5.5% IR intervention vs. 0.4% NOM, p = not significant) [41]. The adoption of NOM in hemodynamically stable pediatric trauma patients results in shorter hospital stays, less need for blood transfusion, and overall lower morbidity and mortality rates [42]. Mean time to endovascular intervention in patients with isolated solid organ injury was 3.6 hours, with only 7.9% occurring within an hour of arrival [41].

Retrospective observational studies

A retrospective study demonstrated that an algorithm for management of solid organ injuries in hemodynamically stable patients can safely decrease length of stay (111.08 hours vs. 83.28 hours, 95% CI, 75.77–90.78, p = 0.028) and cost ($11,965.38 vs. $8794.78, 95% CI, $8015.31–12,802.43, p = not significant) [43].

Liver

The liver is one of the most commonly injured solid organs in children [44]. Hemorrhage from blunt force or penetrating hepatic injury is one of the leading causes of morbidity and mortality. Management of children with blunt hepatic injury has vacillated between NOM and operative management. More recently, the high negative predictive value of CT in children with blunt abdominal trauma facilitated the transition to NOM [28].

Systematic reviews and meta-analyses

Systematic reviews have discussed the role of arterial embolization in pediatric patients. Arterial embolization is supported in pediatric patients with solid organ injury, arterial extravasation confirmed on CT imaging, and hemodynamic instability [4, 5, 39]. A systematic review by Gates et al. evaluated 4 studies that utilized embolization as an adjunct to NOM for pediatric liver injuries and found no evidence to support its use in hemodynamically stable patients with contrast extravasation [4]. In patients who fail NOM and present with persistent or recurrent hypotension, surgery, urgent embolization, or continued NOM should be considered based on the resources of the treating institution [5].

Registry-based studies

Registry-based studies found that compared to children managed at adult trauma centers, children at pediatric trauma centers have a higher rate of successful NOM and lower rate of arterial embolization (2% vs. 0%, p = 0.110 [17]; 1.51% vs. 0.84%, p = 0.1 [45]) with generally similar mortality [18, 46]. Another study highlighted NOM of penetrating abdominal trauma in children, identifying isolated liver injuries as one of the more successful scenarios [47]. Of the 28.5% of failed NOM cases with abdominal injuries, only 1.1% of those requiring laparotomy were for liver procedures [47].

Retrospective observational studies

Retrospective studies demonstrated that NOM as compared to surgical management in hemodynamically stable pediatric trauma patients results in shorter hospital stays (5.5 days vs. 11 days, p = 0.03), less need for blood transfusion (75% vs. 100%, p = 0.444), and overall lower mortality (0% vs. 14%) [45]. Those children that failed NOM of liver injury typically did so early (66.7% by 3 hours, 93.3% by 24 hours) [48]. The most common reason cited for failed NOM in children is hemorrhage (55%) [49].

Spleen

NOM of splenic injury is the standard of care in pediatric blunt abdominal trauma with success rates ranging from 90 to 98% after systematic NOM protocol implementation [50, 51]. Splenic artery embolization (SAE) is an important adjunct in the adult trauma population, however SAE use in children remains controversial based on the overall success of NOM. There is also wide variation across institutions regarding SAE use in pediatrics [4, 52].

Imaging

Isolated contrast extravasation on CT scan is not an indication for embolization in a hemodynamically stable patient. There is no role for prophylactic SAE in a hemodynamically stable pediatric patient with contrast extravasation on CT scan [53-57]. However, contrast extravasation should alert the treatment team that these patients do have a slightly higher rate of NOM failure 53]. There is no indication for serial imaging following SAE in trauma patients [58, 59].

Systematic reviews and meta-analyses

APSA's recent systematic review of 11 studies on the management of splenic injuries in pediatric patients concluded that SAE has comparable morbidity and mortality to splenectomy [4]. This data set is a useful adjunct in patients with a contrast extravasation on imaging and ongoing hemodynamic instability [4].

Registry-based studies

Recently, Swendiman et al. queried the National Trauma Databank to review all cases of pediatric patients with blunt abdominal trauma (n=7,542) who underwent SAE (n = 258, 3.5%) [41]. They found that splenic salvage rate was 3.5% in the NOM group vs. 4.8% in the SAE group (p = not statistically significant) [41]. Mortality rates were comparable between the embolization group and the non-embolization group (<0.1% for both groups, p = 0.744) [41]. Rialon et al. also used the National Trauma Databank and found that SAE and splenectomy had comparable mortality (10.0% vs. 13.4%, p = 0.31), length of stay (10.9 ± 11.1 vs. 9.9 ± 10.6, p = 0.37), and adverse events (no adverse events in 64.4% vs. 63.3%. p = 0.87) among those patients with high grade injuries and ongoing instability [6360].

Retrospective studies

Retrospective studies address the use of SAE in pediatric blunt trauma and are evenly divided between recommending the selective use of SAE in patient failing NOM [57, 61-65] and recommending against it [41, 53-56, 66, 67]. There is variation in utilization of SAE between centers that have combined adult and pediatric trauma, which have a higher utilization rate of SAE, and free-standing pediatric trauma centers, which rarely employ SAE.

Kidney

Renal injury is more common in children than adults due to children having less perinephric fat, musculature, and immature ossification of the rib cage [68]. Damage to the kidney can result in renal insufficiency or hypertension. The majority of renal injuries are low grade (I-III) and can be conservatively managed in the hemodynamically stable patient [68]. Higher grade injuries (IV-V) are more likely to require surgical or endovascular intervention [68, 69].

Imaging

In adults, radiographic risk factors associated with the need for intervention include a large perirenal hematoma (rim distance greater than 3.5 cm), active contrast extravasation, and medial renal laceration [70]. Radiographic predictors for the need to consider arterial embolization in children have not been delineated.

Retrospective studies

Published literature for the endovascular management of pediatric renal injury is limited to retrospective studies and report rates of transarterial embolization ranging from 11-22% [71-73]. Several studies support the use of transarterial embolization for renal injury in patients with active hemorrhage and pseudoaneurysm [71, 73]. One study of embolization versus NOM in children with persistent contrast extravasation reported no adverse events after transarterial embolization and no statistical difference between the groups in either frequency of blood transfusions (75% vs. 57%, $p = 0.151$) or hospital length of stay (11.0 ± 5.48 days vs. 9.9 ± 11.33, $p = 0.850$) [73]. Embolization also showed comparable rates of split renal function (27-30%) when compared to NOM (29%), and partial nephrectomy (32-37%) [73].

Current societal recommendations

Pediatric blunt renal trauma practice management guidelines from the Eastern Association for the Surgery of Trauma and the Pediatric Trauma Society strongly recommend arterial embolization versus surgical intervention for ongoing or delayed bleeding in hemodynamically stable children with high-grade (AAST grade III-V) renal injuries [74]. A 2004 consensus document from the World Health Organization and the Societe Internationale d'Urologie recommend angiography with possible embolization for Grade III and IV lacerations [75].

Pelvic

Pediatric pelvic fractures are rare, with a reported incidence ranging from 1-5% of pediatric trauma admissions [76-79]. This is likely related to the elasticity of the immature pelvis [77]. Avulsion injuries are more common in children due to the presence of non-fused apophysis, allowing single fractures with distraction rather than disruption of the pelvic ring. Substantial force is required for disruption of the pelvic ring and therefore, unstable pelvic fractures in children are considered a marker for severe trauma and increased risk for multi-system injuries [76, 80, 81]. Associated injuries are very common with severe pelvic fracture (incidence 68% - 86%) [76, 78-80,82¸]. Solid organ injuries are present in 13-26% of pediatric pelvic trauma cases –77, 80, 83]. An increased severity of fractures is noted with increased skeletal maturity [84-86]. Mortality in patients with pelvic fractures ranges from 0-16% [77, 79, 81, 87] with most deaths related to CNS injury. Mortality related to uncontrolled pelvic hemorrhage is very rare. Specific indications for angiography or embolization were not discussed in any of the reports.

Imaging

Extravasation on CT is seen in 5% of patient. When seen with unstable fracture pattern, sacroiliac joint widening and sacral fractures it is predictive of need for major operative intervention, including angiography [79]. This study noted that pelvic angiography and embolization occurred more frequently in patients with contrast extravasation than without (50% vs. 3%, $p < 0.05$) and with widening of the pubic symphysis (16% vs. 2%, $p < 0.05$) [79].

Retrospective studies

Angiography and embolization are rarely reported in children and there have been no dedicated studies to date which indicate the specific role for angiography and embolization. In a large, single center review of 163 children with pelvic fractures over a 20-year time span, pelvic angiography was performed in 7 (4%) with embolization in 4 (2%) [79]. Extravasation on CT scan as well as unstable fracture pattern, sacroiliac joint widening and sacral fractures were associated with operative intervention, including angiography. The use of angiography in this study increased over time from 1% to 9% in the most recent 5 years ($p = 0.02$) however, there was no reduction of overall mortality noted (11% versus 14%, $p = 0.55$) [79].

Aorta and Vascular

Over the past 20 years, the management of aortic injury in adults has evolved toward the use of endovascular techniques. Although no prospective randomized studies have compared endovascular and open repair, the trend towards endovascular management is supported by a series of studies which have demonstrated improved survival, decreased hospital length of stay, and fewer serious adverse events [88, 89].

The optimal management of aortic injuries in the pediatric population is less well defined. Injuries to the aorta are rare in children and children may have a different distribution pattern and improved survival when compared to their adult counterparts. A 2010 review of the National Trauma Databank registry of vascular injuries found that patients under the age of 16 had a rate of thoracic aortic injury of .03%, which was seven times lower than that seen in the adult population [90]. Abdominal aortic injures were found more frequently (24%) than thoracic aortic injuries (13%) [90]. Children demonstrated lower overall Injury Severity Scores (16.8 ± 14.9 vs. 26.3 ± 16.7, $p < 0.001$) and lower mortality (13.2% vs.23.2%, $p < 0.001$) when compared to adults [90].

Imaging

CT angiography is the current standard for non-invasive imaging of pediatric thoracic injury. It is fast, less expensive, and gives multiplanar visualization of the aorta and surrounding organs when compared to angiography [91]. As the overall incidence of pediatric thoracic injury is low, screening chest CTs are not indicated unless there is a high suspicion for vascular injury on chest radiographs [92].

Registry-based studies

A large database review of patients under the age of 18 with thoracic aortic injury demonstrated a doubling in the rate of endovascular repair between 2007 to 2015 (15.4% vs. 27.1%, p < 0.001), with decreased ICU stay (16.4 days vs. 21.4 days, p = 0.02) and hospital length of stay (10.1 days vs. 12.2 days, p = 0.01) in patients undergoing endovascular repair compared with open repair [93]. There was no difference in mortality between the groups (OR 1.20, CI: 0.29-5.01, p = 0.80) [93]. Another large National Trauma Databank study examined the epidemiology and outcomes of pediatric vascular injury, finding that only 10% of all vascular injuries occurred in children and adolescents, and of these 7% were managed by endovascular techniques (vs.63% open, 30% NOM) [94]. The most common endovascular interventions were aortic endografts, and showed difference in in-hospital mortality between the open and endovascular groups (3.0% vs.3.6%; OR 0.7; 95% CI, 0.1-6.1; p = 0.778) [94].

Retrospective studies

Retrospective studies demonstrated that not all aortic injuries require operative repair [95]. Evidence supports surgical or endovascular intervention for grade 3 and 4 lesions, including aortic pseudoaneurysm and rupture. NOM of lower grade lesions is safe in adults [96], and is practiced more frequently in children. For patients requiring operative intervention, endovascular repair may be limited by the availability of appropriate-sized stents and delivery systems. Patient growth over time is an additional consideration that does not exist for adults.

Retrospective studies report increased use of endovascular techniques, particularly in adolescents, with decreased recovery times and otherwise equivalent outcomes for survival and adverse events when compared to open techniques. Data shows a NOM rate for pediatric aortic injury ranging from 28-55% [97, 98]. A single institution, retrospective cohort study evaluated endovascular repair for blunt aortic injury in 17 patients under the age of 18 (n=7 endovascular, n= 10 open approach) and found equivalent survival (0% in-hospital mortality in both groups) and decreased hospital length of stay for the endovascular group (12 vs. 22 days, $p < 0.05$). [99].

Case series

Although standard endovascular repair equipment may have size limitations for use in children, case series have found that balloon expandable stents may be useful for the repair of aortic injuries in smaller patients. A recent case series demonstrated the successful use of covered stents in the management of aortic injury in 6 children, ages 11-13, with no deaths or severe adverse events over a 24 month follow up [100]. Similar success for the use of these stents was reported in another case series of 4 patients, with one death attributed to traumatic brain injury [101]. The authors of both studies suggested that more widespread availability of this technology should decrease the age and size limits for patients who are appropriate for endovascular repair.

Extremities

Vascular extremity injury in children is uncommon, ranging from 0.4-0.7% of all pediatric trauma admissions [20, 90, 102, 103]. Treatment strategies involve multiple specialties, but are primarily treated by orthopedic surgeons. Interventional radiologists are infrequently involved in treating these injuries, serving in a diagnostic capacity if imaging is required after reduction and fixation and a palpable pulse has still not returned. Endovascular treatment differs in pediatric patients due to smaller vessel size and potential future growth of the patient [20].

Extremity injuries in children are more commonly found in the upper extremities (60.9-65%) [20, 103-105] compared to lower extremities (30.4-35%) [104, 105]. Vascular injuries in the extremities are often found in the context of larger trauma and fractures. Supracondylar fracture of the humerus is a common upper extremity fracture in children, reported in up to one third of children younger than 7 years old [106]. Vascular injury in children with supracondylar fractures can result in long-term adverse events and neurovascular injury [92]. The brachial artery is the most common artery injured (10-30%) [20, 102-104, 106], followed by the femoral artery (10.1-15%) [20, 102-104].

In practice, open surgical repair is more common endovascular approaches [20]. A National Trauma Data Bank registry reported that endovascular repair was used in 4.0-8.8% of pediatric arterial injuries compared to operative repair in 32.6-49.1% of injuries [20]. This is consistent for venous extremity injuries, with endovascular repair in 0-1.8% of injuries compared to open repair in 8.0-20.2% of injuries [20]. Similarly, a California statewide registry reported that endovascular repair was used in 0-5.9% of arterial injuries, compared to NOM in 15.6-41.2% and open repair in 52.9-80.7% of injuries [102]. Although less common, endovascular approaches remain an important tool in the diagnosis and management of extremity trauma in children.

Imaging

Several studies have proposed algorithms for assessing "hard" and "soft" signs of injury in determining the necessity of CT angiography or duplex scanning to guide treatment decisions [103-10 48]. CT angiography and duplex scanning have been reported as having 100% correlation with operative findings, with no cases of unplanned operative intervention based on imaging findings [104]. However, the role and timing of angiography are still being clarified. A retrospective study in 24 children with supracondylar humeral fractures supported the use of angiography and vascular repair to improve treatment decisions in patients whose pulse had not returned after reduction of the fracture to identify potential arterial spasm and prevent unnecessary operative treatment of the brachial artery [107]. In contrast, a retrospective study of 66 children with supracondylar humeral fractures noted angiography may be insufficient to clearly distinguish arterial spasm from an intimal tear [108]. The authors suggested against CT angiography prior to operative repair due to the time required for the intervention, instead supporting non-invasive Doppler sonography prior to operation; MR angiography or color-flow duplex were suggested for evaluation after operative repair to evaluate patency of the brachial artery [108]. This is consistent with a retrospective study of 22 patients from 2015 that developed an assessment protocol eliminating vascular radiography prior to operative treatment of lower extremity vascular injuries [109].

Registry-based studies

A 2014 NTDB analysis of 119 pediatric patients with blunt brachial artery injury compared outcomes between NOM (n = 70) and arterial surgery (n = 49), and found no significant differences in the rate of amputations between the NOM group compared to the surgery group (2.9% vs. 0%, p = 0.22), or in the rate of fasciotomy between the NOM group compared to the surgery group (4.3% vs. 10.2%, p = 0.20) [106]. Mortality was 0% for both groups and, after adjustment for age, gender, race, injury severity score, Glasgow Coma Score, hospital region and affiliation, there were no significant differences in ICU length of stay (adjusted OR, 1.2; 95% CI, 0.85-1.59; p = 0.36) or total hospital length of stay (adjusted OR, 0.9; 95% CI, 0.63-1.36; p= 0.69) between the groups [106].

Retrospective observational studies

A single-institution retrospective study of 42 pediatric patients with peripheral vascular injuries reported that while nearly all (98%) pediatric patients with peripheral vascular injuries underwent surgical repair for one or more associated injuries, 33% of the peripheral vascular injuries were successfully managed without operative intervention to the vascular injury itself or with fracture reduction and fixation alone [103]. Vasospasm was identified as the reason for vascular insufficiency in 26% of patients and treated conservatively, with 82% of these cases occurring in younger children ages 1–10 years [103].

Retrospective studies have suggested a minimal role for endovascular approaches in pediatric extremity trauma, favoring use of Doppler ultrasound to guide decision-making. A 2013 single-institution retrospective study of 54 pediatric patients with Gartland type-3 supracondylar humeral fractures reported that 48% (n = 26) had pulse restored after closed reduction and percutaneous pinning, 35% (n = 19) had no palpable pulse but had a perfused hand and pulse signal on Doppler ultrasound and eventually regained palpable pulse, and 9% of patients (n = 5) lacked pulse on Doppler ultrasound and were sent for open vascular exploration [110]. The authors suggested that absence of a palpable pulse after closed reduction and percutaneous pinning is not an absolute indication for vascular exploration if the hand is well perfused, as identified by capillary refill and distal pulse identifiable on Doppler ultrasound [110]. Another 2013 single-institution retrospective study on 20 children with Gartland type-3 supracondylar humeral fractures who exhibited a pulseless, perfused hand reported that no patients were sent for open vascular exploration, 25% (n = 5) had pulse return directly after reduction and pinning, and all 100% (n = 20) had palpable pulse return (average 22.9 days; range: 0 to 223 days) by the end of the follow-up period [111]. Under Duplex ultrasound on follow-up, 70% (n = 14) had a patent brachial artery and 30% (n = 6) had either occlusion or stenosis of the brachial artery [97]. The authors recommended against routine open vascular exploration, instead supporting careful observation [111].

CONCLUSIONS

Pediatric trauma is managed differently than adult trauma and a multidisciplinary approach by a team with pediatric expertise is key to a successful outcome. Interventional radiology plays a limited yet important role that is continually expanding as new technology develops.

Table 1. RECOMMENDATIONS

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Table 2. Current Society Recommendations for Management of Pediatric Trauma

Abbreviations:

AAST: American Association for the Surgery of Trauma; APSA: American Pediatric Surgical Association; CT: computed tomography; LOS: length of stay; SOI: solid organ injury

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Appendix A: Search Strategy

Searches: Peds AND Trauma AND Body Site

Pediatric
(“pediatric”[All Fields] OR “children”[All Fields] OR “infant”[All Fields] OR “adolescent”[All Fields] OR “neonate”[All Fields]) OR (Infan* OR newborn* OR new-born* OR neonat* OR baby OR baby* OR babies OR toddler* OR minors OR minors* OR child OR child* OR children* OR adolescen* OR juvenil* OR youth* OR teen* OR under*age* OR pubescen* OR pediatrics[mh] OR pediatric* OR paediatric* OR peadiatric* OR prematur* OR preterm*)

AND

Trauma and Techniques
((“trauma”[All Fields] AND “minimally invasive”[All Fields] AND “endovascular”[All Fields] OR “Minimally Invasive Surgical Procedures”[MeSH Terms] OR “Endovascular Procedures”[MeSH Terms]) AND (“nonoperative”[All Fields] OR “non-operative”[All Fields] OR “blunt” [All Fields] OR “embolization”[All Fields]) OR “Multiple Trauma”[MeSH Terms] OR “Trauma Centers”[MeSH Terms] OR “Hospitals, Pediatric”[MeSH Terms] OR “Wounds, Nonpenetrating”[MeSH Terms] OR “Wounds, Penetrating”[MeSH Terms]))

AND

Kidney
((“renal”[All Fields] OR “kidney”[All Fields]) OR (“Kidney”[MeSH Terms] OR “Acute Kidney Injury”[MeSH Terms]))

Abdominal (Liver, Spleen, Other)
((“abdominal”[All Fields] OR “Abdominal Injuries”[MeSH Terms]) AND (“solid organ”[All Fields] OR “liver”[All Fields] OR “hepatic”[All Fields] OR “spleen”[All Fields] OR “Liver”[MeSH Terms] OR “Spleen”[MeSH Terms]))

Pelvic
((“pelvic”[All Fields] AND “fracture”[All Fields] OR “pelvic ring”[All Fields] OR “Pelvis”[MeSH Terms] OR “Pelvic Bones”[MeSH Terms]))

Imaging
((“contrast blush”[All Fields] AND “computed tomography”[All Fields] OR “contrast-enhanced ultrasound”[All Fields] OR “Ultrasonography”[MeSH Terms]))

Extremity
((“humerus fracture”[All Fields] OR “humeral fractures”[All Fields] OR “Humeral Fractures”[MeSH Terms]) OR (“Limb Salvage”[MeSH Terms] OR “Extremities”[MeSH Terms] AND “Vascular System Injuries”[MeSH Terms]))

Aortic/Vascular

((“aortic injuries”[All Fields] OR “aortic trauma”[All Fields] OR “vascular injuries”[All Fields] OR “vascular trauma”[All Fields]) OR (“Aorta”[MeSH Terms] OR “Aorta, Abdominal”[MeSH Terms] OR “Aorta, Thoracic”[MeSH Terms] OR “Aortic Rupture”[MeSH Terms] OR “Vascular System Injuries”[MeSH Terms]))

Appendix B: Level of Evidence and Recommendation Classification System [1-3]

LEVEL OF EVIDENCE

A HIGH QUALITY EVIDENCE

Types of Evidence	Characteristics of Evidence
Multiple RCTs Systematic reviews or meta-analyses of high-quality RCTs RCT data supported by high-quality registry studies	Homogeneity of RCT study population Intention-to-treat principle maintained Appropriate blinding Precision of data (narrow CIs) Appropriate follow-up (consider duration and patients lost to follow-up) Appropriate statistical design

B MODERATE QUALITY EVIDENCE—Randomized Study Design

Types of Evidence	Characteristics of Evidence
≥ 1 RCTs Systematic reviews or meta-analyses of moderate-quality RCTs	RCTs with limitations (eg, < 80% follow-up, heterogeneity of patient population, bias, etc) Imprecision of data (small sample size, wide CIs)

C MODERATE QUALITY EVIDENCE—Nonrandomized Study Design

Types of Evidence	Characteristics of Evidence
Nonrandomized trials Observational or registry studies Systematic reviews or meta-analyses of moderate quality studies	Nonrandomized controlled cohort study Observational study with dramatic effect Outcomes research Ecological study

D LIMITED QUALITY EVIDENCE

Types of Evidence	Characteristics of Evidence
Observational or registry studies with limited design and execution Systematic reviews or meta-analyses of studies limited by design and execution	Case series Case-control studies Historically controlled studies

E EXPERT OPINION

Types of Evidence	Characteristics of Evidence
Expert consensus based on clinical practice	Expert opinion without explicit critical appraisal or based on physiology, bench research, or "first principles"

STRENGTH OF RECOMMENDATION

Strong Recommendation	Moderate Recommendation	Weak Recommendation	No Recommendation
Supported by high quality evidence for or against recommendation	Supported by moderate quality evidence for or against recommendation; new research may be able to provide additional context	Supported by weak quality evidence for or against recommendation; new research likely to provide additional context	Insufficient evidence in the literature to support or refute recommendation

CI = confidence interval; RCT = randomized controlled trial.

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Society of Interventional Radiology Position Statement on Endovascular Trauma Intervention in the Pediatric Population

Reference	Ref. type	N	Objective	Results and Comments	Strength
Padia, S.A., C.R. Ingraham, J.M. Moriarty, et al., Society of Interventional Radiology Position Statement on Endovascular Intervention for Trauma. J Vasc Interv Radiol, 2020. 31(3): p. 363-369 e2 doi: 10.1016/j.jvir.2019.11.012	Societal guideline	N/A	To provide the society's position on parameters to consider for endovascular intervention in various organ systems.	Provides recommendations for algorithmic care of the trauma patient and specific organ system management: aorta, pelvis, liver, spleen, kidney, and extremities. Supports the role of endovascular interventions for traumatic injury by improving survival, reducing morbidity, and decreasing operative blood loss.	N/A
Stylianos, S., Compliance with evidence-based guidelines in children with isolated spleen or liver injury: a prospective study. J Pediatr Surg, 2002. 37(3): p. 453-6 doi: 10.1053/jpsu.2002.30860	Prospective study	312	To disseminate and apply 5 previously defined, evidence-based guidelines in children with isolated spleen or liver injuries to standardize treatment, promote consensus, and utilize resources in a safe and efficient manner.	Specific guideline compliance was 81% for ICU stay, 82% for hospital stay, 87% for follow-up imaging, and 78% for interval of activity restriction. Compliance significantly reduced ICU stay, hospital stay, follow-up imaging, and physical activity restriction.	C
Rotondo, M.F., C. Cribari, and R.S. Smith. Resources for Optimal Care of the Injured Patient. American College of Surgeons 2014; Available from: https://www.facs.org/-/media/files/quality-programs/trauma/vrc-resources/resources-for-optimal-care.ashx.	Societal guideline	N/A	To define the resources required to provide optimal care of injured patients within an appropriately designed and funded system of care.	Provides recommendations for verified trauma center resources and environment, including trauma systems, prehospital care, transfer, clinical functions (general surgery, emergency medicine, neurosurgery, orthopaedic surgery), pediatric, collaboration, rehabilitation, rural considerations, burn patients, registry use, performance improvement, education, prevention, training, and verification.	N/A
Stylianos, S., Evidence-based guidelines for resource utilization in children with isolated spleen or liver injury. The APSA Trauma Committee. J Pediatr Surg, 2000.	Societal guideline	832	To provide consensus on the management of isolated spleen and liver issues in children	There is variation in management and resource utilization in this population. Routine follow-u pimaging is not recommended, but imaging should be	N/A

35(2): p. 164-7; discussion 167-9 doi: 10.1016/s0022-3468(00)90003-4			to maximize patient safety, efficiency, and cost-effectiveness.	based on clinical symptoms. Prospective studies and evidence-based guideline compliance should be encouraged to reduce variation and maximize patient safety.	
Gates, R.L., M. Price, D.B. Cameron, et al., Non-operative management of solid organ injuries in children: An American Pediatric Surgical Association Outcomes and Evidence Based Practice Committee systematic review. J Pediatr Surg, 2019. 54(8): p. 1519-1526 doi: 10.1016/j.jpedsurg.2019.01.012	Systematic review	36 articles on liver, 31 articles on spleen, 42 articles on kidney	Evaluate the published evidence regarding treatment of solid organ injuries in children	Hospital length of stay based on physiology. Shorter activity restrictions may be safe. Minimize post-injury imaging for lower injury grades and embolization only in patients with evidence of ongoing hemorrhage. Routine follow-up imaging for asymptomatic, uncomplicated, low-grade injured children with abdominal blunt trauma is not warranted.	C
Notrica, D.M., J.W. Eubanks, 3rd, D.W. Tuggle, et al., Nonoperative management of blunt liver and spleen injury in children: Evaluation of the ATOMAC guideline using GRADE. J Trauma Acute Care Surg, 2015. 79(4): p. 683-93 doi: 10.1097/ta.0000000000000808	Systematic review	142 articles, 69,182 patients	Evaluate the ATOMAC guideline	In rare cases, endoscopic retrograde cholangiopancreatograpy (ERCP) should be used for blunt liver and spleen injury. APSA guidelines do not recommend routine follow-up imaging. Management should be based on hemodynamic status rather than grade of injury. Management should account for local resources and concurrent injuries in children failing to stabilize.	C
Pracht, E.E., J.J. Tepas, 3rd, B. Langland-Orban, et al., Do pediatric patients with trauma in Florida have reduced mortality rates when treated in designated trauma centers? J Pediatr Surg, 2008. 43(1): p. 212-21 doi: 10.1016/j.jpedsurg.2007.09.047	Registry study (statewide)	27,313	Compare the survival associated with treatment of seriously injured patients with pediatric trauma in Florida at designated trauma centers with nontrauma centers and to evaluate differences in mortality between designated pediatric and nonpediatric trauma centers.	Mortality is reduced by 3.15% at designated trauma centers. In children, there was a 4.84% reduction in mortality at a pediatric designated trauma centers vs. nonpediatric designated trauma centers.	C

			Database review of mortality and outcomes for pediatric trauma patients treated at TC s vs non TCs, one states database		
Matsushima, K., A.N. Kulaylat, E.J. Won, et al., Variation in the management of adolescent patients with blunt abdominal solid organ injury between adult versus pediatric trauma centers: an analysis of a statewide trauma database. J Surg Res, 2013. 183(2): p. 808-13 doi: 10.1016/j.jss.2013.02.050	Registry study (statewide)	1,532 (spleen 946, liver 505, kidney 424)	Identify management differences in adolescents with blunt solid organ injury treated at adult trauma centers versus pediatric trauma centers	Adolescents at adult centers had higher ISS and lower GCS. Procedures for spleen and liver injury are more common at adult trauma centers than pediatric centers. Transarterial embolization for spleen injuries is more common at adult centers. Rate of procedures was higher in adult centers than pediatric centers (Spleen 16.1% vs 3.2%, liver 5.9% vs. 0%). Rate of splenic embolization was higher at adult centers than pediatric centers (2.88% vs. 0.6%).	C
Stylianos, S., N. Egorova, K.S. Guice, et al., Variation in treatment of pediatric spleen injury at trauma centers versus nontrauma centers: a call for dissemination of American Pediatric Surgical Association benchmarks and guidelines. J Am Coll Surg, 2006. 202(2): p. 247-51 doi: 10.1016/j.jamcollsurg.2005.10.012	Retrospective Cohort	3,232	To identify the frequency and compare the treatment of children with spleen injury in hospitals with and without recognized trauma expertise.	Adolescents (15-18 years), those with increased severity, and multiple injuries were more likely to have splenectomy. Splenectomy rates higher at nontrauma centers. Patients treated at nontrauma centers had a significantly higher rate of operation than did those treated at trauma centers. Neither group achieved the APSA benchmark for non operative management.	D
Prieto, J.M., J.M. Van Gent, R.Y. Calvo, et al., Pediatric extremity vascular trauma: It matters where it is treated. J Trauma Acute Care Surg, 2020. 88(4): p. 469-476 doi: 10.1097/TA.0000000000002595	Registry study (NTDB)	702	To investigate variations in the management and outcomes of pediatric patients with peripheral vascular trauma based on hospital type.	31% were treated at nontrauma centers, 40% at pediatric trauma centers, and 29% at adult trauma centers. Patients treated at pediatric centers were more likely to receive patients as a transfer from another institution, possibly increasing preoperative ischemia time with certain injury patterns. The incidence of pediatric extremity vascular injury is low. Hospitals with	C

				ACS trauma center verification have greater pediatric limb salvage rates than those without verification.	
Bonasso, P.C., L.A. Gurien, S.D. Smith, et al., Pediatric vascular trauma practice patterns and resource availability: A survey of American College of Surgeon-designated pediatric trauma centers. J Trauma Acute Care Surg, 2018. 84(5): p. 758-761 doi: 10.1097/TA.0000000000001799	Survey	176	To determine practice patterns for vascular trauma management at ACS verified pediatric trauma centers and evaluate the resources available for management of vascular trauma at both freestanding children's hospitals and pediatric hospitals within general adult hospitals.	Vascular surgeons are more likely to operatively manage vascular trauma compared to pediatric surgeons in all hospital settings. Freestanding hospitals have fewer resources to provide optimal care: 36% lack fellowship-trained vascular surgeon, 27% lack endovascular capabilities, and 18%d lack a radiology technologist.	E
Hom, J., The risk of intra-abdominal injuries in pediatric patients with stable blunt abdominal trauma and negative abdominal computed tomography. Acad Emerg Med, 2010. 17(5): p. 469-75 doi: 10.1111/j.1553-2712.2010.00737.x	Systematic review/meta-analysis	2,596 (3 studies)	Prevalence of intra-abdominal injuries and negative predictive value of an abdominal CT in children who present with blunt abdominal trauma.	Overall rate of intra-abdominal injury with negative CT was low: 0.19%. Overall Negative Predictive Value was 99.8%. 5 patients required additional intervention despite negative CTs. It may be safe to discharge stable children after negative abdominal CT.	C
van der Vlies, C.H., T.P. Saltzherr, J.C. Wilde, et al., The failure rate of nonoperative management in children with splenic or liver injury with contrast blush on computed tomography: a systematic review. J Pediatr Surg, 2010. 45(5): p. 1044-9 doi: 10.1016/j.jpedsurg.2010.01.002	Systematic review	117 (9 studies)	Assess the failure rate of NOM in children with blunt liver and/or splenic injury when a contrast blush is present on a CT scan.	Pooled failure rate of NOM was 21% in hemodynamically stable patients with CT contrast blush. Management of splenic and hepatic injury in children should not only be based on the physiologic response but should include consideration of the presence of a contrast blush. NOM with angioembolization had a 6.5% failure rate.	C
Rostad, B.S., K.E. Applegate, T. Kim, et al., Multiphase acquisitions in pediatric abdominal-pelvic CT are a common practice and contribute to unnecessary radiation dose. Pediatr Radiol, 2018.	Retrospective study	754 external, 939 internal	To determine the frequency of multiphase acquisitions and radiation dose indices in contrast enhanced	53% of outside institutions had multiphase imaging, compared to 12%a at the pediatric institution. Outside imaging facilities had CT dose index-volumes 2.7 times higher the pediatric institution. Imaging facilities	D

48(12): p. 1714-1723 doi: 10.1007/s00247-018-4192-y			CTs of the abdomen and pelvis.	with high multiphase rates should eliminate multiple phases from routine contrast-enhanced CT of the abdomen and pelvis exams in children.	
Frush, D.P., Pediatric abdominal CT angiography. Pediatr Radiol, 2008. 38 Suppl 2: p. S259-66 doi: 10.1007/s00247-008-0795-z	Review article	N/A	To review the technique of pediatric abdominal CT angiography and applications.	Reviews benefits of CT angiography, CT angiography technique, contrast media administration, image review, and applications.	N/A
Parra, D.A., G.B. Chavhan, A. Shammas, et al., Computed tomography angiography in acute gastrointestinal and intra-abdominal bleeding in children: preliminary experience. Can Assoc Radiol J, 2013. 64(4): p. 345-50 doi: 10.1016/j.carj.2012.12.002	Case report	4	To describe the use of CT angiography for the diagnosis and management of patients with acute bleeding.	Reviews 4 patients: 1 with traumatic iatrogenic vascular injury, 1 with ruptured liver tumor, and 2 with GI bleeds. CTA is useful in clarifying etiology and deciding on appropriate treatment options and endovascular interventions. Conventional angiography should be the initial diagnostic approach in hemodynamically unstable patients.	E
Frush, D.P., 'Here's looking at you, kid' ... again? Revisiting multiphase CT in children. Pediatr Radiol, 2018. 48(12): p. 1711-1713 doi: 10.1007/s00247-018-4248-z	Commentary	N/A	To discuss multiphase CT in children.	Reviews studies discussing reducing unnecessary multiphase CT in children.	N/A
Quan, G.E., J.L. Kendall, M.C. Bogseth, et al., Predictors of False-Negative Focused Assessment With Sonography for Trauma Examination in Pediatric Blunt Abdominal Trauma. Pediatr Emerg Care, 2020. 36(5): p. e274-e279 doi: 10.1097/PEC.0000000000002094	Retrospective cohort	141	To investigate injury characteristics and FAST in children with blunt abdominal trauma.	High rate of false negative FAST in study (63%). No specific patient or injury characteristics were associated with a false negative FAST. FAST had no impact on mortality or hospital stay. Clinicians need to be cautious applying a single initial FAST to patients with minor abdominal trauma or suspected injuries to organs other than the spleen or bladder.	D
Miele, V., C.L. Piccolo, M. Trinci, et al., Diagnostic imaging of blunt abdominal trauma in pediatric patients. Radiol Med, 2016. 121(5): p. 409-30 doi: 10.1007/s11547-016-0637-2	Review article	N/A	To present imaging findings of blunt abdominal trauma in children.	Reviews imaging in high- and low-energy trauma, imaging techniques, types of abdominal traumatic injuries (liver, spleen, urinary system, pancreas, bowel, and adrenal glands).	N/A

Piccolo, C.L., M. Trinci, A. Pinto, et al., Role of contrast-enhanced ultrasound (CEUS) in the diagnosis and management of traumatic splenic injuries. J Ultrasound, 2018. 21(4): p. 315-327 doi: 10.1007/s40477-018-0327-0	Review article	N/A	To review the typical appearance of traumatic splenic injuries, and the use of CEUS.	Reviews imaging techniques (US-CEUS, CE-MDCT) and management of splenic injuries (grading, classification).	N/A
Valentino, M., C. Serra, G. Zironi, et al., Blunt abdominal trauma: emergency contrast-enhanced sonography for detection of solid organ injuries. AJR Am J Roentgenol, 2006. 186(5): p. 1361-7 doi: 10.2214/AJR.05.0027	Prospective study	69, 35 with abdominal injuries	To compare the diagnostic value of sonography and contrast-enhanced sonography with CT to detect solid organ injuries in blunt abdominal trauma patients.	The sensitivity and specificity of sonography were 45.7% and 91.8%, respectively, and the positive and negative predictive values were 84.2% and 64.1%, respectively. Contrast-enhanced sonography had a sensitivity of 91.4%, a specificity of 100%, and positive and negative predictive values of 100% and 92.5%, respectively. Contrast-enhanced sonography was more sensitive than sonography and almost as sensitive as CT.	C
Durkin, N., A. Deganello, M.E. Sellars, et al., Post-traumatic liver and splenic pseudoaneurysms in children: Diagnosis, management, and follow-up screening using contrast enhanced ultrasound (CEUS). J Pediatr Surg, 2016. 51(2): p. 289-92 doi: 10.1016/j.jpedsurg.2015.10.074	Retrospective study	101	To examine the use of CEUS as an alternative to contrast enhanced CT for identifying pseudoaneurysm formation following abdominal trauma.	17% (n=17) developed pseudoaneurysm. 35% (n=6) became symptomatic and five required embolization. These were detected by Contrast enhanced CT (n=4) and CEUS (n=2). Eleven children remained asymptomatic, detected by contrast enhanced CT (n=8) and CEUS (n=3). CEUS had a detection sensitivity of pseudoaneurysm of 83% and specificity of 92% (PPV=71%, NPV=96%). CEUS is highly sensitive and specific for diagnosis and follow-up imaging.	D
Trinci, M., C.L. Piccolo, R. Ferrari, et al., Contrast-enhanced ultrasound (CEUS) in pediatric blunt abdominal trauma. J Ultrasound, 2019. 22(1): p. 27-40 doi: 10.1007/s40477-018-0346-x	Review article	N/A	To review CEUS in pediatric blunt abdominal trauma.	Reviews CEUS technique, traumatic lesions of the liver, spleen, kidneys, and pancreas)	N/A
Fenton, S.J., K.N. Sandoval, A.M. Stevens, et al., The use of angiography in pediatric blunt abdominal trauma patients.	Registry study (Pediatric Emergency Care	12,044, 973 with abdominopelvic	To determine the incidence of angiography in the	2% underwent angiography by IR. 11 patients had splenic embolization. 50% required subsequent surgery, 35%	C

J Trauma Acute Care Surg, 2016. 81(2): p. 261-5 doi: 10.1097/TA.0000000000001097	Applied Research Network)	injuries evaluated for angiography	treatment of blunt abdominal trauma among injured children.	required transfusion, and 42% were admitted to ICU. Mortality rate was 19%. Emergent use of angiography with embolization is uncommon in pediatric patients with blunt abdominal injuries.	
Swendiman, R.A., M.A. Goldshore, S.J. Fenton, et al., Defining the role of angioembolization in pediatric isolated blunt solid organ injury. J Pediatr Surg, 2020. 55(4): p. 688-692 doi: 10.1016/j.jpedsurg.2019.04.036	Registry study (NTDB)	Spleen 7,542, Liver 4,549, Kidney 2,640	Determine the incidence and outcomes of angiography in pediatric patients with blunt solid organ injury (SOI)	258 IR interventions were performed. Odds of angiography were higher at adult trauma centers than pediatric trauma centers, especially for isolated splenic trauma. Splenic salvage was 3.5% in patients without angioembolization and 4.8% in patients with angioembolization.	C
Feigin, E., L. Aharonson-Daniel, B. Savitsky, et al., Conservative approach to the treatment of injured liver and spleen in children: association with reduced mortality. Pediatr Surg Int, 2009. 25(7): p. 583-6 doi: 10.1007/s00383-009-2398-7	Registry study (Israel Trauma Registry)	598 (321 spleen, 249 liver, 28 both spleen and liver)	To examine changes in the rate of surgery and their impact on outcome within the same medical centers over time.	Over a 7 year period, the rate of operations reduced from 19% to 9.5%. In-hospital mortality rate reduced from 4.5% to 1.76%. Increased use of diagnostic imaging able to identify candidates for conservative treatment. Avoiding surgery as long as possible is recommended for children with blunt spleen and liver injury.	C
Holmes, J.F., K. Lillis, D. Monroe, et al., Identifying children at very low risk of clinically important blunt abdominal injuries. Ann Emerg Med, 2013. 62(2): p. 107-116 e2 doi: 10.1016/j.annemergmed.2012.11.009	Prospective study	12,044	To determine a prediction rule to identify children at very low risk for intra-abdominal injuries who can avoid CT imaging.	6.3% of children had intra-abdominal injuries, and 26.7% of these children required acute interventions. The predictive rule had a negative predictive value of 99.9% (95% CI 99.7-100%), sensitivity of 97% (95% CI 94-99%), and specificity of 42.5% (95% CI 41.6-43.4%).	C
Sigal, A.P., T. Deaner, S. Woods, et al., External validation of a pediatric decision rule for blunt abdominal trauma. J Am Coll Emerg Physicians Open, 2022. 3(1): p. e12623 doi: 10.1002/emp2.12623	Retrospective study	794	To validate the PECARN abdominal decision rule in pediatric patients with blunt abdominal trauma.	23 of 794 patients required an acute intervention. The decision rule had a sensitivity of 91.3% and a negative predictive value of 99.5.	D
Springer, E., S.B. Frazier, D.H. Arnold, et al., External validation of a clinical prediction rule for very low risk pediatric	Retrospective study	133	To determine the sensitivity of the PECARN prediction	One patient our of 133 met the criteria for low risk. Sensitivity was 99% (95% CI 96-100%).	D

blunt abdominal trauma. Am J Emerg Med, 2019. 37(9): p. 1643-1648 doi: 10.1016/j.ajem.2018.11.031			rule for identifying patients with very low risk for intra-abdominal injuries and reducing CT use.		
Holmes, J.F., P.E. Sokolove, W.E. Brant, et al., Identification of children with intra-abdominal injuries after blunt trauma. Ann Emerg Med, 2002. 39(5): p. 500-9 doi: 10.1067/mem.2002.122900	Prospective observational	1,095 enrolled, 107 with intra-abdominal injuries.	To determine the utility of lab testing after adjusting for physical examination findings in the identification of children with intra-abdominal injuries after blunt trauma.	6 factors are associated with intra-abdominal injury: low systolic blood pressure, abdominal tenderness, femur fracture, serum aspartate aminotransferase concentration >200 U/L or serum alanine aminotransferase concentration >125 U/L, urinalysis with > 5 RBCs per high-powered field and an initial hematocrit of <30%. Lab testing contributes significantly to the identification of children with intra-abdominal injuries after blunt trauma.	C
Cunningham, A.J., K.M. Lofberg, S. Krishnaswami, et al., Minimizing variance in Care of Pediatric Blunt Solid Organ Injury through Utilization of a hemodynamic-driven protocol: a multi-institution study. J Pediatr Surg, 2017. 52(12): p. 2026-2030 doi: 10.1016/j.jpedsurg.2017.08.035	Retrospective cohort	106 (55 control, 51 protocol)	To demonstrate the feasibility of a hemodynamic-driven solid organ injury protocol implemented across different institutions and models of clinical practice.	Protocol adherence led to decreased length of stay, time spent in ICU, and total lab draws. Direct hospital cost also decreased.. Provides a protocol for patient assessment.	D
Cywes, S., D.H. Bass, H. Rode, et al., Blunt liver trauma in children. Injury, 1991. 22(4): p. 310-4 doi: 10.1016/0020-1383(91)90013-5	Prospective study	228	To evaluate children under 13 years of age with liver injury following blunt abdominal trauma.	The liver was an isolated intra-abdominal injury in 119. There were 69 associated splenic, 33 renal, 21 pancreatic, and 3 bowel injuries. NOM was used in 215 patients (successful in 214). Blood transfusion was required in 40%. There were 10 complications and two deaths (0.88%). Eight underwent laparotomy because of instability.	C
Ameh, E.A., L.B. Chirdan, and P.T. Nmadu, Blunt abdominal trauma in children: epidemiology, management, and management problems in a developing	Retrospective study	57	Review the epidemiology, management, and unnecessary	Of 34 splenic injuries, 33 treated with operations (13 splenectomies), 20 with splenic preservation, and 1 non-operative. Imaging was not available	D

country. Pediatr Surg Int, 2000. 16(7): p. 505-9 doi: 10.1007/s003830000406			laparotomies for pediatric BAT in a developing country.	for many. Highlights need for resources in underdeveloped countries	
Arslan, S., M. Guzel, C. Turan, et al., Management and treatment of liver injury in children. Ulus Travma Acil Cerrahi Derg, 2014. 20(1): p. 45-50 doi: 10.5505/tjtes.2014.58295	Retrospective study	52 (45 managed conservatively; 7 managed with surgery)	To assess the causes of trauma that result in liver injury and additional solid organ injuries, management types and results of management in children referred for liver injuries.	87% were managed conservatively and 13% underwent surgical management. Those that were surgically managed had increased mortality rate, duration of ICU stay, required blood transfusions, and blood pressure management.	D
Deluca, J.A., D.R. Maxwell, S.K. Flaherty, et al., Injuries associated with pediatric liver trauma. Am Surg, 2007. 73(1): p. 37-41	Retrospective study	105	Establish current patterns of injury, management and outcomes in ped liver injury	Perihospital mortality was 8.6%, with 67% of mortality being attributed to head injury. 81% managed nonoperatively. Surgical management was associated with higher injury severity score, mortality, and associated injuries. Blunt abdominal trauma patients are at risk of significant morbidity and mortality; however, these risks stem more likely from associated injuries than injury to the liver itself.	D
Safavi, A., E.D. Skarsgard, P. Rhee, et al., Trauma center variation in the management of pediatric patients with blunt abdominal solid organ injury: a national trauma data bank analysis. J Pediatr Surg, 2016. 51(3): p. 499-502 doi: 10.1016/j.jpedsurg.2015.08.012	Registry study (NTDB)	6,799 Spleen: 2,375 Liver: 2,867 Kidney: 1,557	Identify differences in management of children with SOI treated at adult trauma centers vs. pediatric trauma centers	TAE performed in 17 patients with splenic, 34 with liver and 14 with kidney trauma. Risk of splenic surgery higher in adults vs. pediatric trauma centers. No practice variation between adult and pediatric trauma centers regarding kidney and liver operations.	C
Sakamoto, R., K. Matsushima, A. de Roulet, et al., Nonoperative management of penetrating abdominal solid organ injuries in children. J Surg Res, 2018. 228: p. 188-193 doi: 10.1016/j.jss.2018.03.034	Registry study (NTDB)	3,005 (2,121 kidney, 1,210 liver, and 159 splenic)	To characterize the epidemiology, injury patterns, and factors associated with trial and failure of NOM.	For liver, 24.6% managed nonoperatively with 80.5% success. For kidney, 17.0% managed nonoperatively with 65.9% success. For spleen, 22.0% managed nonoperatively with 48.7% success. Pediatric trauma centers more likely to use NOM than adult trauma centers.	C

				High injury grade was associated with NOM failure.	
Holmes, J.H.t., D.J. Wiebe, M. Tataria, et al., The failure of nonoperative management in pediatric solid organ injury: a multi-institutional experience. J Trauma, 2005. 59(6): p. 1309-13 doi: 10.1097/01.ta.0000197366.38404.79	Retrospective study	1,818, 1,729 treated with NOM	Evaluate predictors of, and the time course to, failure in the subset of children suffering solid organ injury who required operative intervention.	5% overall failure rate of NOM. Rates differed by organ: 4% failure rate in splenic trauma, 3% in kidney and liver. Isolated pancreatic injury, and >1 organ injured were significantly associated with NOM failure. 76% of NOM failures occurred by 12 hours (median 3 hours).	D
Tataria, M., M.L. Nance, J.H.t. Holmes, et al., Pediatric blunt abdominal injury: age is irrelevant and delayed operation is not detrimental. J Trauma, 2007. 63(3): p. 608-14 doi: 10.1097/TA.0b013e318142d2c2	Retrospective cohorts from seven Level I pediatric trauma centers	2,944 (140 requiring operation)	Characterize children requiring operative intervention.	4.8% required operation. Of those requiring operation, 58% had laparotomy <3 hours after arrival and 42% failed NOM and were sent to laparotomy >3 hours after affival. There were no differences in age between the groups. The immediate operative group had worse hemodynamics, Injury Severity Score, Glasgow Coma score, and more liver injuries compared to the NOM group. Immediate operation and failed nonoperative management are rare events and independent of age	D
Bairdain, S., H.J. Litman, M. Troy, et al., Twenty-years of splenic preservation at a level 1 pediatric trauma center. J Pediatr Surg, 2015. 50(5): p. 864-8 doi: 10.1016/j.jpedsurg.2014.08.022	Retrospective study	630 (502 isolated splenic injuries.	Outcomes study of all blunt splenic trauma at single Level 1 pediatric trauma center managed without splenectomy.	3% of all trauma admissions had splenic injury. No in-hospital mortality or splenectomies were reported. 2 operations for splenorrhaphy and 11 splenic arterial embolizations. Implementation of protocols from clinical practice guidelines reduced length of stay.	D
Booth, B.J., S.M. Bowman, M.A. Escobar, Jr., et al., Long-term sustainability of Washington State's quality improvement initiative for the management of pediatric spleen injuries. J Pediatr Surg, 2018. 53(11): p. 2209-2213 doi: 10.1016/j.jpedsurg.2018.05.002	Registry study (statewide)	570	To review NOM based on era pre and post intervention from the trauma registry.	Rate of splenectomy was 10.3%. Among spleen-conserving management, 94.5% managed nonoperatively, 3.9% received splenorrhaphy, and 1.6% partial splenectomy. Splenectomy patinets had higher in-hospital mortality than spleen-conserving management.	C

				Splenectomy rate decreased from 14% to 7% after implementation of a quality improvement initiative. Patients treated at pediatric trauma hospitals 70% less likely to receive a splenectomy than those treated at general trauma hospitals.	
Bansal, S., F.M. Karrer, K. Hansen, et al., Contrast blush in pediatric blunt splenic trauma does not warrant the routine use of angiography and embolization. Am J Surg, 2015. 210(2): p. 345-50 doi: 10.1016/j.amjsurg.2014.09.028	Retrospective study	740 blunt abdominal trauma, 549 solid organ injury, 270 splenic injury	To determine if the presence of contrast blush on CT impacted patient outcomes.	All patients managed with NOM. Contrast blush visible on CT in 17.4%. There were no differences in blood transfusion, length of stay, or splenectomy in children with or without contrast blush. No deaths secondary to splenic trauma. Pediatric trauma patients with blunt splenic injuries can be safely managed without splenic artery embolization. Physiologic response and hemodynamic stability should be the primary determinants of appropriate management.	D
Ben-Ishay, O., I.M. Gutierrez, E.C. Pennington, et al., Transarterial embolization in children with blunt splenic injury results in postembolization syndrome: a matched case-control study. J Trauma Acute Care Surg, 2012. 73(6): p. 1558-63 doi: 10.1097/TA.0b013e31826c6ab7	Matched case-control	448	To report the incidence of postembolization syndrome in children undergoing transarterial embolization.	2.5% of children underwent transarterial embolization. The embolization group had longer ICU and hospital stays compared to those without embolization. Postembolization occurred in 90.1%. The embolization had a 27.3% rate of late complications compared to none in the non-embolized group. Post-embolization syndrome had no effect on operative rate or mortality.	D
Cloutier, D.R., T.B. Baird, P. Gormley, et al., Pediatric splenic injuries with a contrast blush: successful nonoperative management without angiography and embolization. J Pediatr Surg, 2004. 39(6): p. 969-71 doi: 10.1016/j.jpedsurg.2004.02.030	Retrospective study	107	To evaluate the outcome of children with blunt splenic trauma and contrast extravasation.	12.3% rate of operative intervention.. Arterial blush identified in 9.7%. One of these patients underwent splenectomy for hemodynamic instability, while the others were treated non-operatively. No instances of delayed splenic rupture, delayed failed non-operative management, or	D

				spleen-related deaths. Splenic embolization is often unnecessary in the pediatric population despite presence of contrast blush.	
Lutz, N., S. Mahboubi, M.L. Nance, et al., The significance of contrast blush on computed tomography in children with splenic injuries. J Pediatr Surg, 2004. 39(3): p. 491-4 doi: 10.1016/j.jpedsurg.2003.11.042	Retrospective study	133	Review contrast blush as predictor for intervention at single institution	6 patients showed contrast blush on CT, of whom 5 were treated with NOM. Contrast blush was associated with higher injury grades, but did not require embolization or surgery in most cases. Contrast blush sign alone should not prompt intervention.	D
Vo, N.J., M. Althoen, D.S. Hippe, et al., Pediatric abdominal and pelvic trauma: safety and efficacy of arterial embolization. J Vasc Interv Radiol, 2014. 25(2): p. 215-20 doi: 10.1016/j.jvir.2013.09.014	Retrospective study	97	Assesses the safety and efficacy of arterial embolization for blunt abdominal and pelvic trauma in the pediatric population.	Rate of embolization 56% (including pelvis, liver, kidney, spleen, and retroperitoneum). 87% hemorrhage control rate. 7% complication rate, including 3 major complications. 2 required subsequent splenectomy. Angiography and embolization safe and potentially effective in abdominal and pelvic trauma in children.	D
Notrica, D.M., B.L. Sussman, N.M. Garcia, et al., Reimaging in pediatric blunt spleen and liver injury. J Pediatr Surg, 2019. 54(2): p. 340-344 doi: 10.1016/j.jpedsurg.2018.08.060	Prospective observational study	534	Assess safety of selective imaging in pediatric blunt trauma pts based on symptoms following initial discharge.	Re-imaging performed in 6% of patients due to symptoms and 3 required additional intervention. Routine re-imaging is unnecessary, while selective re-imaging is safe if based on symptoms.	C
Skattum, J., R.J. Loekke, T.L. Titze, et al., Preserved function after angioembolisation of splenic injury in children and adolescents: a case control study. Injury, 2014. 45(1): p. 156-9 doi: 10.1016/j.injury.2012.10.036	Case control study	11	To evaluate long-term plenic function after splenic artery embolization in the pediatric population.	Follow-up 4.6 years (range 1-8 years). No significant differences between patient with and without splenic artery embolization. Embolized patients had normal sized and well perfused spleens.	D
Rialon, K.L., B.R. Englum, B.C. Gulack, et al., Comparative effectiveness of treatment strategies for severe splenic trauma in the pediatric population. Am J Surg, 2016. 212(4): p. 786-793 doi: 10.1016/j.amjsurg.2015.06.009	Registry study (NTDB)	11,694	To assess outcomes related to splenectomy vs. splenic artery embolization.	90% treated nonoperatively. 265 underwent splenectomy, 199 underwent embolization. No significant differences between Injury Severity Score, number of transfusions, or complications. Mortality was 13.4%	C

				for splenectomy and 10.0% for embolization.	
Gross, J.L., N.L. Woll, C.A. Hanson, et al., Embolization for pediatric blunt splenic injury is an alternative to splenectomy when observation fails. J Trauma Acute Care Surg, 2013. 75(3): p. 421-5 doi: 10.1097/TA.0b013e3182995c70	Retrospective comparative study	259	To evaluate the use of splenic artery embolization as an alternative to splenectomy to preserve the spleen in children with blunt splenic trauma.	Initial management: 15 embolized, 17 splenectomy. 4% failed initial NOM, 8 embolized and 1 splenectomy. Significant differences in blood transfusion between NOM (17%), embolization (40%), and splenectomy (88%). 3 deaths in NOM group, 4 deaths in splenectomy group, 0 deaths in embolization group.	D
Kiankhooy, A., K.H. Sartorelli, D.W. Vane, et al., Angiographic embolization is safe and effective therapy for blunt abdominal solid organ injury in children. J Trauma, 2010. 68(3): p. 526-31 doi: 10.1097/TA.0b013e3181d3e5b7	Retrospective study	127	Use of angiographic embolization to control bleeding pediatric blunt abdominal injuries for efficacy and safety.	120 (97%) successfully treated with NOM. 7 patients underwent embolization due to ongoing hemorrhage (2 liver, 3 renal, 2 spleen). All had hemorrhage control with no procedure-related complications. 4 minor complications and no major complications.	D
Kirkegard, J., T.H. Avlund, N. Amanavicius, et al., Non-operative management of blunt splenic injuries in a paediatric population: a 12-year experience. Dan Med J, 2015. 62(2)	Retrospective study	34	To report one institution's experience treating children with blunt splenic injuries with NOM.	Initial NOM for all patients with 88% success rate. 5.9% of patients required splenic artery embolization, and 5.9% required surgical intervention. Success rate NOM with embolization of 94%. No difference in injury grade between initial CT and follow-up evaluation.	D
Mayglothling, J.A., J.M. Haan, and T.M. Scalea, Blunt splenic injuries in the adolescent trauma population: the role of angiography and embolization. J Emerg Med, 2011. 41(1): p. 21-8 doi: 10.1016/j.jemermed.2008.10.012	Retrospective study	97	To evaluate if angiography and embolization is a safe and effective adjunct to NOM in adolescents.	79 initially treated with NOM while 18 had immediate surgery. In the NOM group, 56% underwent angiography and 53% of that group required embolization. Splenic salvage rates 100% in NOM, 100 with negative angiography, 87% embolization group. Embolization group had higher injury grade.	D
Skattum, J., C. Gaarder, and P.A. Naess, Splenic artery embolisation in children and adolescents--an 8 year experience. Injury, 2014. 45(1): p. 160-3 doi: 10.1016/j.injury.2012.10.015	Retrospective study	72	To review indications for splenic artery embolization and clinical outcome of splenic injury	92% treated with NOM with a 98% success rate and 90% splenic preservation rate. 22 embolizations performed in NOM patients. Most common indications were delayed	D

			management in children.	bleeding and high injury grade. Two complications were reported: 1 hepatic infarct, 1 allergic reaction. Two needed splenic cystectomies, one died of OPSI due to pneumonia.	
Ingram, M.C., R.V. Siddharthan, A.D. Morris, et al., Hepatic and splenic blush on computed tomography in children following blunt abdominal trauma: Is intervention necessary? J Trauma Acute Care Surg, 2016. 81(2): p. 266-70 doi: 10.1097/TA.0000000000001114	Retrospective study	318	To report one institution's management of pediatric hepatic and splenic blush.	Blush in 30 patients (9%): 18 hepatic and 16 spleen. Blush not correlated with demographics, but was associated with higher injury grade and higher Injury Severity Score. No correlation between blush and overall survival. 83% of blush patients were successfully managed nonoperatively with no significant difference in need for blood products or in overall mortality. Blush patients had increased ICU stay and transfusion Data suggests that a blush can be managed nonoperatively and that treatment should be dictated by change in physiology.	D
Nwomeh, B.C., E.P. Nadler, M.P. Meza, et al., Contrast extravasation predicts the need for operative intervention in children with blunt splenic trauma. J Trauma, 2004. 56(3): p. 537-41 doi: 10.1097/01.ta.0000112328.81051.fc	Retrospective study	216	To determine whether the finding of contrast blush on CT scan could predict failure of nonoperative therapy in children with blunt splenic injury.	27 presented contrast blush on CT scan. 80% of those with contrast blush were successfully managed non-operatively. Contrast blush was associated with significantly lower hematocrit and required operative intervention more frequently (22% vs. 4%. Contrast blush is a specific marker of active bleeding that may predict the need for early splenic intervention in a specific subset of patients at presentation..	D
Arthurs, Z.M., B.W. Starnes, V.Y. Sohn, et al., Functional and survival outcomes in traumatic blunt thoracic aortic injuries: An analysis of the National Trauma Databank. J Vasc Surg, 2009. 49(4): p. 988-94 doi: 10.1016/j.jvs.2008.11.052	Registry study (NTDB)	3,114	To determine the incidence of blunt abdominal injury and analyze functional and survival outcomes compared with matched controls.	68% no repair, 28% open aortic repair, 4% endovascular repair. Mortality rates for each group: 65%, 19%, 18%, respectively. Blunt abdominal injury had higher mortality compared to matched controls.	C

Lee, W.A., J.S. Matsumura, R.S. Mitchell, et al., Endovascular repair of traumatic thoracic aortic injury: clinical practice guidelines of the Society for Vascular Surgery. J Vasc Surg, 2011. 53(1): p. 187-92 doi: 10.1016/j.jvs.2010.08.027	Societal guideline	N/A	To provide the society's clinical practice guidelines for the management of traumatic thoracic aortic injuries with thoracic endovascular aortic repair.	Provides recommendations for timing of TEVAR, injury management, pediatric considerations, thoracic endografts, revascularization, systemic heparinization, spinal drainage, anesthesia, femoral access technique, and follow-up strategy. Mortality is lower in those treated with endovascular repair as compared to open repair and NOM.	N/A
Barmparas, G., K. Inaba, P. Talving, et al., Pediatric vs adult vascular trauma: a National Trauma Databank review. J Pediatr Surg, 2010. 45(7): p. 1404-12 doi: 10.1016/j.jpedsurg.2009.09.017	Registry study (NTDB)	1,138	To examine nationwide data on vascular injuries in children and to compare pediatric and adult patients with respect to the incidence, injury mechanisms, and outcomes.	0.6% of patients had vascular injuries. Locations of injuries were upper extremity 35.7%, lower extremity 18.6%, abdomen 24.2%, chest 13.2%, and neck 9.9%. Overall incidence of thoracic aorta injuries 0.03%, 7 times lower than adults. Mortality lower in pediatric patients than adult patients.	C
Pabon-Ramos, W.M., D.M. Williams, and P.J. Strouse, Radiologic evaluation of blunt thoracic aortic injury in pediatric patients. AJR Am J Roentgenol, 2010. 194(5): p. 1197-203 doi: 10.2214/AJR.09.2544	Retrospective study	17	To assess mechanism of injury, associated injuries, and radiographic findings of pediatric patients with blunt thoracic aortic injury at a single institution from 1986-2007.	The most common concurrent injury was solid abdominal organ injury (53%). Chest CT increased over time (44% to 100%). Thoracic aortography decreased over time (89% to 38%).	D
Arbuthnot, M., C. Onwubiko, M. Osborne, et al., Does the incidence of thoracic aortic injury warrant the routine use of chest computed tomography in children? J Trauma Acute Care Surg, 2019. 86(1): p. 97-100 doi: 10.1097/TA.0000000000002082	Registry study (Pediatric Health Information System)	46	To determine the incidence of aortic injuries in pediatric patients and consider the risk of CT imaging.	Thoracic aortic injuries in children are rare with the US, with 41.9% of hospitals having no patients with a thoracic aortic injury in the 10-year period. The mortality rate was 11% (n = 5). 47.8% (n = 22) underwent a chest CT. The positive rate for aortic injury on chest CT for all trauma patients (n = 124,909) was 1.8/10,000.	C
Hasjim, B.J., A. Grigorian, C. Barrios, Jr., et al., National Trends of Thoracic	Registry study (NTDB)	650	Review the incidence and outcome TEVAR	78% underwent TEVAR and 22% underwent open repair. Use of	C

Endovascular Aortic Repair versus Open Thoracic Aortic Repair in Pediatric Blunt Thoracic Aortic Injury. Ann Vasc Surg, 2019. 59: p. 150-157 doi: 10.1016/j.avsg.2018.12.094			vs. open repair in children with blunt thoracic aortic injury.	TEVAR over time increased to 27%. TEVAR patients had decreased ICU length of stay, but increased rate of traumatic brain injury. No difference in mortality risk between the two groups.	
Branco, B.C., B. Naik-Mathuria, M. Montero-Baker, et al., Increasing use of endovascular therapy in pediatric arterial trauma. J Vasc Surg, 2017. 66(4): p. 1175-1183 e1 doi: 10.1016/j.jvs.2017.04.072	Registry study (NTDB)	35,771, 3,637 pediatric	Determine epidemiology and outcomes of endovascular intervention in pediatric trauma.	7% underwent endovascular intervention, 62% open procedures, and 30% NOM. The endovascular group were likely to be older, admitted to level 1 trauma centers, less hypotensive, higher Injury Severity Score, and more associated injuries. Increase in use of endovascular procedures to 7.9%. Angioembolization of internal iliac injury and thoracic aortic endograft were the most common endovascular procedures. There were no significant differences in outcomes or in-hospital mortality between the groups.	C
Azizzadeh, A., K. Keyhani, C.C. Miller, 3rd, et al., Blunt traumatic aortic injury: initial experience with endovascular repair. J Vasc Surg, 2009. 49(6): p. 1403-8 doi: 10.1016/j.jvs.2009.02.234	Retrospective study	71	To report one institution's experience with endovascular repair using thoracic devices.	21% underwent open repair and 38% underwent TEVAR. Patients undergoing TEVAR were older than those with open repair. There was no difference in ICU or hospital length of stay between the two groups. Mortality was correlated to Injury Severity Score.	D
Paul, J.S., T. Neideen, S. Tutton, et al., Minimal aortic injury after blunt trauma: selective nonoperative management is safe. J Trauma, 2011. 71(6): p. 1519-23 doi: 10.1097/TA.0b013e31823b9811	Retrospective study	47	To examine the experience with a policy of nonoperative management of patients with minimal aortic injuries.	15 patients (32%) of blunt aortic injuries were identified as minimal. 19 repaired operatively, 13 endovascular stent graft repair, 15 NOM. No difference between groups for Injury Severity Score, overall length of stay, or ICU stay. The NOM group had shorter length of ventilator than other groups. No deaths in the NOM group. Patients with minimal aortic injuries can be considered for NOM.	D

Anderson, S.A., M. Day, M.K. Chen, et al., Traumatic aortic injuries in the pediatric population. J Pediatr Surg, 2008. 43(6): p. 1077-81 doi: 10.1016/j.jpedsurg.2008.02.030	Retrospective study	11	To investigate the demographics, treatment, and outcomes of children with blunt aortic injuries over a 10-year period.	7 thoracic and 4 abdominal injuries. 6 managed NOM, 4 operative repair of thoracic injures, 1 abdominal operative repair. No endovascular techniques in this cohort. Complications occurred in all 4 in the thoracic operative group, none in the NOM or aortic group.	D
Malgor, R.D., T.V. Bilfinger, J. McCormack, et al., Outcomes of blunt thoracic aortic injury in adolescents. Ann Vasc Surg, 2015. 29(3): p. 502-10 doi: 10.1016/j.avsg.2014.10.012	Retrospective study	18	To assess the clinical presentation and treatment outcomes of blunt traumatic aortic injury in adolescents.	10 underwent operative repair, 3 endovascular treatment, and 2 NOM. In-hospital and overall mortality 21% and 39% respectively. Incidence is low, but high rate of mortality, Injury Severity Score, and aortic wall disruption.	D
Brinkman, A.S., A.P. Rogers, C.W. Acher, et al., Evolution in management of adolescent blunt aortic injuries--a single institution 22-y experience. J Surg Res, 2015. 193(2): p. 523-7 doi: 10.1016/j.jss.2014.08.058	Retrospective cohort	17	To evaluate a single level 1 pediatric trauma center's experience with traumatic aortic injuries over 22 years.	An endovascular approach was used in 7 (41%). Differences in length of hospitalization between endovascular group (12 days) and open approach (22.5 days). No operative deaths or paraplegia were reported.	D
Hiremath, G., G. Morgan, D. Kenny, et al., Balloon expandable covered stents as primary therapy for hemodynamically stable traumatic aortic injuries in children. Catheter Cardiovasc Interv, 2020. 95(3): p. 477-483 doi: 10.1002/ccd.28575	Case series	5	To expand the literature of the use of balloon expandable covered stents to treat traumatic aortic injuries in the pediatric population.	6 stents were placed in 5 patients. 100% procedural success and no post-procedural complications reported. Balloon expandable covered stent treatment is feasible as an alternative to open surgical repair, and fewer size limitations compared to endovascular grafts.	E
Goldstein, B.H., R. Hirsch, M.E. Zussman, et al., Percutaneous balloon-expandable covered stent implantation for treatment of traumatic aortic injury in children and adolescents. Am J Cardiol, 2012. 110(10): p. 1541-5 doi: 10.1016/j.amjcard.2012.06.063	Case series	4	To describe the use of balloon-expandable covered endovascular stents for the treatment of traumatic aortic injury after blunt chest trauma in children and adolescents.	6 stents were placed in 4 patients. 100% technical success rate and complete exclusion of aortic wall injury in all cases. No access site complications. One patients required additional stent implantation after 24 months follow-up. Method is generally safe and effective in pediatric patients.	E
Prieto, J.M., J.M. Van Gent, R.Y. Calvo, et al., Evaluating surgical outcomes in	Registry study (California Office	775	To evaluate the management of	Management was predominantly by open surgical repair (53-81%).	C

pediatric extremity vascular trauma. J Pediatr Surg, 2020. 55(2): p. 319-323 doi: 10.1016/j.jpedsurg.2019.10.014	of Statewide Health Planning and Development)		pediatric vascular extremity trauma and assess factors that contribute to poor outcomes.	Amputation rate was <7%. There was no difference in amputation or mortality rates for pediatric trauma centers vs. adult trauma centers.	
Shah, S.R., P.D. Wearden, and B.A. Gaines, Pediatric peripheral vascular injuries: a review of our experience. J Surg Res, 2009. 153(1): p. 162-6 doi: 10.1016/j.jss.2008.03.006	Retrospective study	42	To evaluate peripheral vascular injuries in pediatric trauma to identify diagnostic and therapeutic modalities used, and to understand the role of pediatric surgical subspecialists.	17 diagnostic angiograms were performed. Almost all (98%) of patients had operative treatment for one or more injuries. 67% underwent operative management specifically for vascular injury. Vasospasm occurred in 26% and all were managed conservatively. 23% were managed by pediatric surgeons, 43% by extremity specialists (orthopedic or plastic surgeons), and 29% by adult vascular surgeons.	D
Jaipuria, J., S. Sagar, M. Singhal, et al., Paediatric extremity vascular injuries - experience from a large urban trauma centre in India. Injury, 2014. 45(1): p. 176-82 doi: 10.1016/j.injury.2013.08.002	Retrospective study	82	To describe a single center's experience with pediatric peripheral vascular trauma from 2007-2012.	An algorithm for CT angiography and duplex scan based diagnostic algorithm identified missed injuries and aided complex operative treatment. The brachial and femoral vessels were most commonly injured. Lower extremity vascular injury was associated with higher ISS and requirement for fasciotomy. Upper extremity vascular injury was associated with higher odds of neural injury.	D
Wang, S.K., N.A. Drucker, J.L. Raymond, et al., Long-term outcomes after pediatric peripheral revascularization secondary to trauma at an urban level I center. J Vasc Surg, 2019. 69(3): p. 857-862 doi: 10.1016/j.jvs.2018.07.029	Retrospective study	1,339	To describe a single center's experience with revascularization and outcomes of pediatric blunt and penetrating trauma from 2010-2017.	Vascular injury suspected in 2.6% (n=36) of cases. All but one patient underwent open surgical treatment. Injuries were to the upper extremity in 60.9%, lower extremity in 30.4%, and neck in 8.7%. One patient treated with endovascular approach and open surgery in all others. No reported mortality, infections, or amputations in 30-day follow-up.	D
Tan, T.W., D. Rybin, G. Doros, et al., Observation and surgery are associated	Registry study (NTDB)	119	To compare surgical and non-surgical	41.2% had arterial surgery and 58.8% were observed. Two amputations	C

with low risk of amputation for blunt brachial artery injury in pediatric patients. J Vasc Surg, 2014. 60(2): p. 443-7 doi: 10.1016/j.jvs.2014.02.054			outcomes of blunt brachial artery injury in pediatric patients.	occurred in the observation cohort (vs arterial surgery; P = 0.22). 5 fasciotomies occurred in the arterial surgery group compared to 3 in the observation group (10.2% vs 4.3%; P = 0.20). No significant differences in ICU LOS (adjusted OR, 1.2; 95% CI, 0.85-1.59; P = 0.36) and total hospital LOS (adjusted OR, 0.9; 95% CI 0.63-1.36; P = 0.69) between the groups.	
Luria, S., A. Sucar, S. Eylon, et al., Vascular complications of supracondylar humeral fractures in children. J Pediatr Orthop B, 2007. 16(2): p. 133-43 doi: 10.1097/01.bpb.0000236236.49646.03	Retrospective study	24	To analyze the vascular complications of children with supracondylar humeral fractures and propose a management plan.	Angiography was performed in 6 of the 24 cases and improved management in comparison with cases in which no angiography was performed. Intra-operative angiography and vascular repair are indicated in cases where pulse does not resume after fracture reduction.	D
Korompilias, A.V., M.G. Lykissas, G.I. Mitsionis, et al., Treatment of pink pulseless hand following supracondylar fractures of the humerus in children. Int Orthop, 2009. 33(1): p. 237-41 doi: 10.1007/s00264-007-0509-4	Retrospective study	66	To describe a single center's experience bweteen 1994-2006 with children with supracondylar humeral fracture and a pulseless hand in which radial pulse does not return after fracture reduction.	9% had neurovascular complications (n=6) and 7.6% (n=5) had an absent radial pulse in a perfused hand. Vascular exploration done in patients who did not have pulse return after closed reduction of fracture (n=4). The initial reduction was adequate in 5 patients (83.3%) and satisfactory in one patient (16.7%). Angiography may be insufficient to clearly distinguish arterial spasm from an intimal tear	D
Gans, I., K.D. Baldwin, L.S. Levin, et al., A Lower Extremity Musculoskeletal and Vascular Trauma Protocol in a Children's Hospital May Improve Treatment Response Times and Appropriate Microvascular Coverage. J Orthop Trauma, 2015. 29(5): p. 239-44 doi: 10.1097/BOT.0000000000000246	Retrospective study	22	To assess if time to revascularization in lower extremity vascular trauma was impacted by a lower-extremity vascular trauma protocol.	Mean time to treatment dropped from 6.4 hours preprotocol to 4.6 hours postprotocol. After protocol initiation, injuries were treated by lower extremity microvascular repair-capable surgeons increased from 38% to 100%, and preoperative radiographic vascular study dropped from 37.5% to 0%.	D

Armstrong, L.B. and D.P. Mooney, Pediatric renal injury: which injury grades warrant close follow-up. Pediatr Surg Int, 2018. 34(11): p. 1183-1187 doi: 10.1007/s00383-018-4355-9	Retrospective study	171	To determine what grades of injury from renal trauma in children are concerning for complications and warrant close follow-up.	Grade 2 and 3 did not receive any intervention or suffer long-term sequelae. Grades 4 and 5 required intervention: 5 stenting, 4 surgery, 2 embolization, and 1 drain. 2 required late interventions and 6 patients grades 4 and 5 were newly hypertensive. Grades 2 and 3 had low risk of complication and did not require repeat imaging. Grades 4 and 5 carried meaningful risk of adverse outcome.	D
Barsness, K.A., D.D. Bensard, D. Partrick, et al., Renovascular injury: an argument for renal preservation. J Trauma, 2004. 57(2): p. 310-5 doi: 10.1097/01.ta.0000141329.74804.e2	Retrospective	34	To determine if preservation of severely injured kidney can be achieved without complications.	No difference in renal function, hypertension or need for dialysis between NOM and nephrectomy cohort. Renal preservation should be attempted for children with grade 4 or 5 injury.	D
Hagedorn, J.C., N. Fox, J.S. Ellison, et al., Pediatric blunt renal trauma practice management guidelines: Collaboration between the Eastern Association for the Surgery of Trauma and the Pediatric Trauma Society. J Trauma Acute Care Surg, 2019. 86(5): p. 916-925 doi: 10.1097/TA.0000000000002209	Societal guideline	N/A	To guide clinicians on appropriate methods for managing pediatric renal trauma.	Reviewed 51 articles and meta-analysis to inform panel recommendations. Recommendations support NOM over operative management, angioembolization versus surgery for ongoing or delayed bleeding, and support routine blood pressure checks.	N/A
Dugi, D.D., 3rd, A.F. Morey, A. Gupta, et al., American Association for the Surgery of Trauma grade 4 renal injury substratification into grades 4a (low risk) and 4b (high risk). J Urol, 2010. 183(2): p. 592-7 doi: 10.1016/j.juro.2009.10.015	Retrospective study	102	To update and refine the American Association for the Surgery of Trauma Organ Injury Scale for renal trauma.	Radiologic risk factors associated with intervention for bleeding were: increased perirenal hematoma size, intravascular contrast extravasion, medial renal laceration site. Patients with a 0-1 risk factor had 7.1% risk of intervention compared to 2-3 risk factor with 66.7% risk of intervention.	D
Eassa, W., M.A. El-Ghar, R. Jednak, et al., Nonoperative management of grade 5 renal injury in children: does it have a place? Eur Urol, 2010. 57(1): p. 154-61 doi: 10.1016/j.eururo.2009.02.001	Retrospective study	18	To assess the feasibility and outcome of initial NOM in grade 5 blunt renal trauma in children.	50% managed NOM successfully. 22% required nephrectomy.11% managed with embolization. 17% had progressive urinoma drained percutaneously. Kidney salvage rate 78%. Major vascular injuries required	D

				prompt intervention, but NOM is feasible for grade 5 renal trauma. Superselective embolization important for patients with continuing hemorrhage and pseudoaneurysms.	
Lee, J.N., J.K. Lim, M.J. Woo, et al., Predictive factors for conservative treatment failure in grade IV pediatric blunt renal trauma. J Pediatr Urol, 2016. 12(2): p. 93 e1-7 doi: 10.1016/j.jpurol.2015.06.014	Retrospective study	26	To identify clinical factors and radiological features associated with the need for intervention in children with blunt renal trauma initially treated conservatively.	Factors associated with higher urological intervention included: need for transfusion, main laceration location in the antero-medial portion of kidney, intravascular contrast extravasation, and a large perinephric hematoma. Follow-up imaging recommended inf children with predictive factors.	D
Lin, W.C. and C.H. Lin, The role of interventional radiology for pediatric blunt renal trauma. Ital J Pediatr, 2015. 41: p. 76 doi: 10.1186/s13052-015-0181-z	Retrospective study	18	To determine the role of interventional radiology in children with blunt renal trauma.	6 underwent angiography for contrast extravasation in the kidney found on CT. 4 of these underwent transarterial catheter embolization. One non-embolized patient required nephrectomy. Both groups had good outcomes and normal renal function at follow-up.	D
Henderson, C.G., S. Sedberry-Ross, R. Pickard, et al., Management of high grade renal trauma: 20-year experience at a pediatric level I trauma center. J Urol, 2007. 178(1): p. 246-50; discussion 250 doi: 10.1016/j.juro.2007.03.048	Retrospective study	126	To evaluate one institution's experience with NOM of high grade blunt renal trauma in children over 20 years.	8.7% of patients required surgical or endoscopic intervention. 6.3% received surgical intervention. 3.2% required nephrectomy. Initial NOM is effective; if persistent symptomatic urinary extravasation, minimally invasive techniques should be first choice over open operation.	D
Santucci, R.A., H. Wessells, G. Bartsch, et al., Evaluation and management of renal injuries: consensus statement of the renal trauma subcommittee. BJU Int, 2004. 93(7): p. 937-54 doi: 10.1111/j.1464-4096.2004.04820.x	Societal guideline	N/A	To determine the optimal evaluation and management of renal injuries.	Provides an overview of the epidemiology, pathophysiology, classification of renal injury, initial patient evaluation, initial imaging, management of injuries, operative management, and complication management. Hemodynamically stable patients with Grade 3 and 4 lacerations are candidates for angiography and embolization. No follow-up imaging is	N/A

				recommended in Grade 1-3 in hemodynamically stable patients. All patients with Grade 4 or 5 renal injuries should be evaluated regardless of the method of treatment.	
Chia, J.P., A.J. Holland, D. Little, et al., Pelvic fractures and associated injuries in children. J Trauma, 2004. 56(1): p. 83-8 doi: 10.1097/01.TA.0000084518.09928.CA	Retrospective study	120	To document the clinical presentation, work-up, management, complications, and long-term outcomes of pelvic fractures in children.	Associated injuries were present in most patients (78%,), including head injury at 44%. 27% required surgery for associated injuries. Unstable fractures pattern was present in only 12%. Angiography was performed in 2 children. Overall mortality rate of 4% with no deaths directly related to pelvic injuries. NOM of pelvic fracture in 94%. One third of patients had long-term sequalae at 36 months.	D
Demetriades, D., M. Karaiskakis, G.C. Velmahos, et al., Pelvic fractures in pediatric and adult trauma patients: are they different injuries? J Trauma, 2003. 54(6): p. 1146-51; discussion 1151 doi: 10.1097/01.TA.0000044352.00377.8F	Retrospective study	268 adults, 51 children	To compare pelvic fracture injuries between adults and pediatric patients in a single level 1 trauma center.	Pelvic fracture rate of 10% in adult admissions compared to 4.6% in children. Severe pelvic fractures equal between adults (8.8%) and pediatrics (9.5%). Injury Severity Scores were similar. Associated abdominal injuries were common in both adults (16.7%) and children (13.7%). Adults were treated with open reduction and internal fixation significantly more often than children. Bleeding leading to death in 2.9% of adults and 0% of children. No difference in mortality between groups (6% vs. 8%).	D
Grisoni, N., S. Connor, E. Marsh, et al., Pelvic fractures in a pediatric level I trauma center. J Orthop Trauma, 2002. 16(7): p. 458-63 doi: 10.1097/00005131-200208000-00003	Retrospective study	57 patients	Assess the risk factors for complications and mortality due to pelvic fractures in children.	Overall, 2% of trauma patients presenting to a single large Level I trauma center had pelvic fractures. CT found posterior ring fractures in 7 that were not found on radiographs. Almost all (54) patients were treated nonoperatively. Associated injuries were present in 58% with additional fractures most common followed by neurologic, abdominal, thoracic and	D

				genitourinary injuries. Blood transfusion was required in 21%, primarily related to other injuries. Hemorrhage directly related to pelvic fracture only occurred in 2%. Three patients did not survive with cause of death attributable to CNS injury.	
Mulder, M.B., M.J. Maggart, W.J. Yang, et al., Outcomes of Pediatric Pelvic Fractures: A Level I Trauma Center's 20-Year Experience. J Surg Res, 2019. 243: p. 515-523 doi: 10.1016/j.jss.2019.07.011	Retrospective study	163	To evaluate if fracture severity correlates with additional injuries and to determine if more modern imaging, resuscitation and use of angiography improves outcomes in pediatric pelvic fracture patients.	The overall incidence of pelvic fractures was 1.9%. Rate of arterial extravasation on CT was 5%. Isolated pelvic fractures were rare with associated injuries found in 86%, especially solid organ, chest, and brain (25%). Major operative intervention was associated with unstable pelvic fractures, contrast extravasation on CT, SI joint widening and sacral fractures. Pelvic angiography was performed in 7 patients with embolization in 4. Need for angiography was strongly associated with contrast extravasation on CT and widening of the pubic symphysis. Use of angiography increased over time with decreasing pelvic operations. No change in mortality over time with overall mortality of 13%. There were no deaths in isolated pelvic fractures.	D
Bajaj, M., G. Stefanutti, H. Crawford, et al., Paediatric pelvic fractures: Starship Hospital experience. N Z Med J, 2018. 131(1471): p. 13-20	Retrospective study	179	Review the experience with pelvic fractures at a single large center demonstrating the role of pelvic fracture as a marker of severe trauma.	Associated injuries were found in 68%, other fractures in 42%, thoracic injuries in 33%; head injuries in 31%, and abdominal injuries in 26%. Overall mortality was 6.1%, all with significant associated injuries. No deaths directly attributable to pelvic fractures. 7% required operative intervention for pelvic fractures and 38% required operation for other conditions. 2 patients underwent successful embolization.	D

Leonard, M., M. Ibrahim, P. McKenna, et al., Paediatric pelvic ring fractures and associated injuries. Injury, 2011. 42(10): p. 1027-30 doi: 10.1016/j.injury.2010.08.005	Retrospective study	39	Highlights unique features of pelvic fractures in children as a marker for severe trauma.	The most common type of fracture was a simple ring fracture. Associated injuries were very common (82%), including head (25%) and other orthopedic (33%). Most pelvic fractures were treated with NOM. There were no mortalities associated with pelvic injury with only one death due to traumatic brain injury. Long term sequelae were found in 20% including leg length discrepancy, behavioral difficulties, continence difficulties, low back and hip pain.	D
Haasz, M., L.A. Simone, P.W. Wales, et al., Which pediatric blunt trauma patients do not require pelvic imaging? J Trauma Acute Care Surg, 2015. 79(5): p. 828-32 doi: 10.1097/TA.0000000000000848	Retrospective study	87	To determine which pediatric blunt trauma patients are at low risk of pelvic fracture and can safely avoid pelvic imaging.	The strongest significant independent predictors of pelvic fracture included pelvic or hip pain, or abnormal exam of pelvis and hip, and either micro or macroscopic hematuria. Other independent predictors included femoral deformity, hemodynamic instability, and Glascow Coma Score $\leq$ 13. Plain radiograph sensitivity for pelvic fracture was 83%. Operative repair of pelvic fracture was performed in 5.7% with no patients requiring angiography or embolization for hemorrhage.	D
Kruppa, C.G., J.D. Khoriaty, D.L. Sietsema, et al., Does skeletal maturity affect pediatric pelvic injury patterns, associated injuries and treatment intervention? Injury, 2018. 49(8): p. 1562-1567 doi: 10.1016/j.injury.2018.06.015	Retrospective study	90	Analyze the effect of skeletal maturity on the pattern of pelvic injuries as well as other associated injuries and their treatment.	Skeletal maturity was judged by closure of the triradiate cartilage on plain AP pelvic radiographs. Associated injuries were common and similar in both groups. Injuries in the mature pelvis were more complex, with a significantly higher Injury Severity Score, transfusion requirement, and more genitourinary injuries. Unstable B3 or C2 fractures were more likely in the mature group. Operative intervention was more common in the mature group for	D

				abdominal trauma as well as orthopedic repair, angiography, and embolization.	
Shore, B.J., C.S. Palmer, C. Bevin, et al., Pediatric pelvic fracture: a modification of a preexisting classification. J Pediatr Orthop, 2012. 32(2): p. 162-8 doi: 10.1097/BPO.0b013e3182408be6	Retrospective study	124	To propose a modification of Torode and Zieg pediatric pelvic fracture classification with addition of IIIB disruption of anterior and posterior ring. IIIB is a stable fracture pattern but higher associated injuries, blood loss, severity of injury. The study was designed to assess the significance of this change in treatment over time.	Most of the pelvic fractures were type III, with equal distribution of A and B. Patients with IIIB fractures had significantly longer lengths of stay, were more likely to require ICU admission, and were more likely to receive blood products. More severe fractures were noted in skeletally mature patients. The most common additional injury was head injury, followed by lower limb and chest. Type IIIB injuries are stable, however, they represent a higher level of trauma and should require more attention and resuscitation.	D
Banerjee, S., M.J. Barry, and J.M. Paterson, Paediatric pelvic fractures: 10 years experience in a trauma centre. Injury, 2009. 40(4): p. 410-3 doi: 10.1016/j.injury.2008.10.019	Retrospective study	44	Address the uncertainties of treatment and outcomes in pediatric pelvic fractures among patients admitted to a large urban Level 1 trauma center.	Most pelvic fractures associated with low Glascow Coma Score, and high Injury Severity Score. Only 1 unstable pelvic fracture in fatal injuries group. Most pelvic fractures were stable ring type. Common associated injuries included long bone fracture (13%) and head injury (12%). Injury Severity Score was significantly higher in those that died. Imaging with pelvic radiographs satisfactory in only 47%. All pelvic fractures treated conservatively. 1 patient underwent angiography and embolization. The mean hospital stay was 22 days, with mean ICU stay of 6 days. Late outcomes were reported in 30 patients with mean follow up of 26 months.	D

Momiy, J.P., J.L. Clayton, H. Villalba, et al., Pelvic fractures in children. Am Surg, 2006. 72(10): p. 962-5	Retrospective study	74	To describe the single center experience of management of pelvic fractures in children.	Early hemodynamic instability was present in 14% with a mortality in these patients of 40%. Overall mortality was 5%, all with Injury Severity Score of >25. 2 of the 4 deaths were attributable to pelvic and retroperitoneal bleeding. Operative intervention was needed in 50% of the unstable patients, including angiography in 2 patients (3%). Associated injuries were found in most patients (82%), especially additional fractures and central nervous system injuries.	D
Eisa, A., O. Farouk, D.G. Mahran, et al., Predictors of mortality after pelvic fractures: a retrospective cohort study from a level one trauma centre in Upper Egypt. Int Orthop, 2019. 43(10): p. 2405-2413 doi: 10.1007/s00264-018-4230-2	Retrospective study	951 adults; 237 children	To determine predictors of mortality in pelvic trauma patients with secondary endpoint to identify differences in adult and pediatric	No statistical difference between adults and children in stable compared to unstable. FAST exam was positive in 11% (children 19.4% vs adult 8.9%); Associated injuries were common. The overall mortality rate was 8.7%. Notable overall predictors of mortality included increasing age, pelvic fractures with soft tissue injury, head injury, positive FAST exam, and admission to the intensive care unit. In children, the presence of soft tissue injury, a positive FAST, and admission to an ICU were significant predictors of mortality.	D
Committee On Pediatric Emergency Medicine Council On Injury Violence Poison Prevention, Section On Critical Care, Section On Orthopaedics, et al., Management of Pediatric Trauma. Pediatrics, 2016. 138(2) doi: 10.1542/peds.2016-1569	Societal policy statement	N/A	To provide the society's position on the management of pediatric trauma.	Provides recommendations for prehospital care, trauma centers, rehabilitation, performance improvement, injury prevention, and disaster preparedness. Supports centers having appropriate resources and evidence-based protocols for evaluating and managing children, including transfer coordination.	N/A

Table 2. Current Society Recommendations for Management of Pediatric Trauma

American Academy of Pediatrics [114]	1. The unique needs of injured children need to be integrated specifically into trauma systems and disaster planning at the local, state, regional, and national levels. 2. Every state should identify appropriate facilities with the resources to care for injured children and establish continuous monitoring processes for care delivered to injured children. These facilities are especially important for the youngest and most severely injured children. 3. Evaluation and management of the injured child should begin with the providers at the bedside who have basic competency in pediatric trauma care. 4. Prehospital and hospital providers should make every effort to stay current in the emergency management of injured children. In addition, providers should actively participate in and cultivate an injury-prevention program within their service area to ultimately reduce the rate of children injured. 5. Pediatric providers should be familiar with the pediatric trauma services in their region and how to integrate the available services into their practice. Hospital-based providers who are not at regional pediatric centers should be able to evaluate, stabilize, and transfer acutely injured children. 6. Pediatric injury management should include an integrated public health approach from prevention through prehospital care, to emergency and acute hospital care, to rehabilitation and long-term follow–up, as indicated, for stress reactions associated with the injury. 7. Qualified pediatric critical care transport teams should be used when available in the interfacility transport of critically injured children. 8. Interfacility transfer agreements should be in place to facilitate rapid acceptance and transport of critically injured children to a facility with the appropriate level of care. 9. National organizations with a special interest in pediatric trauma, such as the AAP, the ACS, the American College of Emergency Physicians, the American Academy of Emergency Medicine, the Emergency Nurses Association, the Pediatric Trauma Society, the American Pediatric Surgery Association, the Pediatric Orthopaedic Society of North America, the American Pediatric Surgical Nurses Association, and the Society of Trauma Nurses, should collaborate to advocate for a higher quality of care across the nation.

	10. Evidence-based protocols for the management of the injured child can be developed for essential aspects of care, including prehospital, acute resuscitation, and postdischarge through rehabilitation. 11. Research including data collection for best practices in isolated trauma and mass casualty events specifically addressing the needs of children should be supported. 12. State and federal financial support for research, advocacy, education, and trauma system development and maintenance must be provided. 13. Steps should be taken to increase the number of trainees in specialties that care for injured children to address key subspecialty service shortages in pediatric trauma care. Strategies should include increased funding for graduate medical education and appropriate reimbursement for pediatric trauma specialists. 14. Direct, constructive feedback to field providers and referring hospitals should occur from the pediatric trauma center to allow for continued education and improved pediatric care. 15. All health care providers should be aware that injured children and their families should be evaluated and referred for stress reactions related to injury. 16. All health care providers should be alert to signs of potential abuse when evaluating injured children and should report concerns to the appropriate authorities.
American Pediatric Surgical Association [6]	2.1 LOS for children with isolated SOI should be based upon clinical presentation; there is insufficient evidence to support the use of injury grade alone to determine LOS. The total LOS required may be less than previously indicated by the APSA guidelines. (Level III–IV evidence, grade C recommendation) 2.2 Restricting activity to grade of injury plus 2weeks is safe. Shorter periods of activity restriction have not been studied in a prospective fashion. Radiographic healing may not correlate with organ integrity. (Level 3–4 evidence, grade C recommendation) 2.3 Arterial embolization is a useful tool in the non-operative management of solid organ injuries in patients with an arterial blush on imaging AND hemodynamic compromise from ongoing bleeding. Prophylactic embolization in hemodynamically stable patients, even if an arterial blush is noted on imaging is not indicated. (Level 3–4 evidence, Grade D recommendation) 2.4 Routine follow-up imaging for asymptomatic, uncomplicated, low grade injuries in children with solid organ injuries is not indicated. The risk of complications in high grade spleen, liver or kidney injuries is low but may

	require interventions. Limited data are available to support the need for follow-up imaging for high grade injuries. Imaging should be reserved for symptomatic patients at follow up. (Level IV evidence, Grade C recommendation)
Eastern Association for the Surgery of Trauma and the Pediatric Trauma Society [71]	1. In pediatric patients with blunt renal trauma of all grades, we strongly recommend nonoperative management versus operative management in hemodynamically stable patients. 2. In hemodynamically stable pediatric patients with high-grade (AAST grade III-V) renal injuries from blunt trauma, we strongly recommend angioembolization versus surgical intervention for ongoing or delayed bleeding. 3. In pediatric patients with blunt renal trauma, we strongly recommend routine blood pressure checks on follow up to diagnose hypertension.

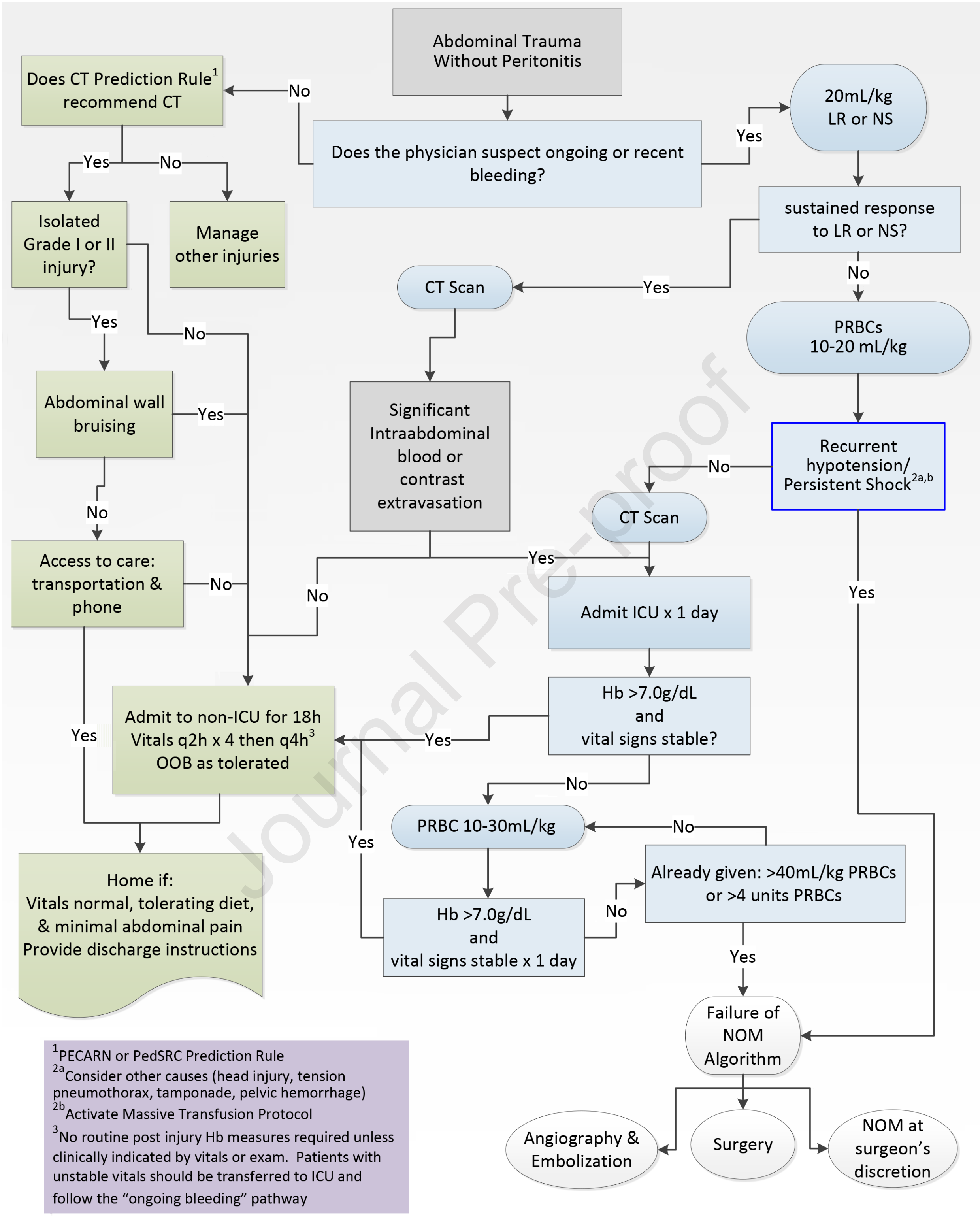
Table 1.

Recommendation
1. The development and adherence to evidence-based treatment algorithms for each trauma scenario is necessary to ensure streamlined and consistent care to optimize patient outcomes. (Level of Evidence: E; Strength of Recommendation: Strong)
2. Operator endovascular expertise is essential to treat pediatric patients in the trauma setting. Familiarity with a range of age appropriate vital signs and pediatric size equipment is necessary (Level of Evidence: E; Strength of Recommendation: Strong)
3. **Providers should consider transfer, if possible, to a center with pediatric expertise for those children with multisystem injury, isolated but high-grade solid organ injury, injury requiring pediatric subspecialty care and/or injury requiring critical care management. (Level of Evidence: C; Strength of Recommendation: Moderate)**
4. **Nonoperative management should be the first line treatment in *hemodynamically stable* pediatric patients with blunt abdominal trauma with or without contrast extravasation. (Level of Evidence: C, Strength of Recommendation: Strong)**
5. **Implementation of a treatment algorithm in *hemodynamically stable* patients can safely reduce cost of care in pediatric solid organ trauma patients. (Level of Evidence: D, Strength of Recommendation: Moderate)**
6. **In children with liver injury, with or without contrast extravasation on CT imaging and *fluctuations in hemodynamic stability*, arterial embolization is an effective means of treatment. (Level of Evidence: C, Strength of Recommendation: Moderate)***
7. **SAE may be a useful adjunct in patients with high grade splenic injuries and fluctuations in hemodynamic stability after a trial of NOM. (Level of Evidence: C; Strength of Recommendation: Moderate)**
8. In patients with high grade splenic injuries and contrast extravasation in the setting of hemodynamic stability, prophylactic SAE is rarely indicated. (Level of Evidence: C; Strength of Recommendation: Strong)
9. Selective arterial embolization for blunt renal injury in pediatrics may be considered for hemodynamically stable patients with ongoing bleeding to improve renal salvage. (Level of Evidence: D; Strength of Recommendation: Weak)
10. In adolescent patients with anatomically favorable high-grade (i.e. grade 3 or 4) aortic injuries, emergent endovascular repair may be indicated. (Level of Evidence: D; Strength of recommendation: Moderate)
11. Non-operative management is recommended for lower grade (i.e. grade 1 or 2) aortic injuries. (Level of Evidence: D; Strength of recommendation: Moderate)
12. Insufficient evidence exists to recommend the routine use of balloon expandable stents for the treatment of aortic injuries in younger pediatric patients. (Level of Evidence: E; Strength of recommendation: No Recommendation)
13. Angiographic imaging of extremity vascular injury should be performed in pediatric patients without return of normal pulses after fracture reduction to evaluate vessel patency and guide treatment decisions. (Level of Evidence: D; Strength of Recommendation: Moderate)**

14. Angiography and embolization may be considered for the treatment of bleeding complications associated with pediatric pelvic trauma. (Level of Evidence: D; Strength of Recommendation: Weak)	
15. Future research in the form of comparative studies (either through well-conducted cohort studies or registry studies) is recommended to strengthen the evidence base for the role of endovascular approaches in pediatric trauma patients. (Level of Evidence: E; Strength of Recommendation: Moderate)	

* *Comment: Although the published evidence comes from patients with contrast extravasation, the clinical care of pediatric patients without contrast extravasation will not differ in real world practice. Therefore, the recommendation applies to all suitable pediatric patients with liver injury and fluctuations in hemodynamic stability, regardless of contrast extravasation.*

***Comment: A recommendation of moderate strength normally requires prospective studies but is provided here due to the potential for negative outcomes if imaging is not performed in the absence of normal pulses after fracture reduction. The moderate strength reflects a concern for patient safety, as imaging can identify the reasons for vascular insufficiency and guide treatment decisions that can reduce unnecessary operative treatment in patients whose injury may otherwise be successfully managed nonoperatively.*



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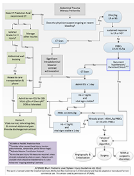
Abdominal Trauma Without Peritonitis
CT Scan
Admit ICU x 1 day
Angiography & Embolization
Surgery
Yes