What's New in Pediatric Orthopaedic Trauma: The Lower Extremity

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Background: Skeletal trauma is a primary tenet of pediatric orthopaedics. Many high-quality studies have been published over the last few years with substantial relevance to the clinical practice of pediatric orthopaedic trauma. Because of the volume of literature on the subject, this review excludes upper extremity trauma and focuses on the publications affecting the lower extremity.

Methods: An electronic search of the PubMed database was performed utilizing keywords for pediatric lower extremity trauma: pelvic injuries, femur fractures, tibial shaft fractures, femur fractures, ankle fractures, and foot fractures. All 835 papers related to the treatment of pediatric orthopaedic trauma of the lower extremity published from January 1, 2012 to July 31, 2017 were reviewed, yielding 25 papers that were believed to contribute significant findings to the profession.

Results: Of the 25 papers selected for presentation within this review, 8 related to tibial shaft injuries, 6 involved the pelvis, 5 involved femur fractures, 4 related to ankle injuries, 2 involved foot injuries, and 1 regarding trauma and venous thromoembolism. The level of evidence for these studies were either level III or IV.

Conclusions: Higher-grade pediatric pelvic fractures do not correlate with increased severity of splenic or hepatic injuries. Successful union of femur fractures in older children can be obtained by surgeon preferred method of surgical management. Pediatric tibia shaft fractures should be managed conservatively in most cases; however, fractures with $>20\%$ of displacement and associated fibula fractures have a 40% risk of requiring delayed surgical stabilization. Vigilance remains the sin qua non regarding identification and appropriate management of compartment syndrome and venous thromboemobolism in children. Many Salter-Harris I distal fibula fractures are now believed to be ligamentous injury and can be treated as such. Calcaneous fractures remain uncommon in pediatrics, but minimally invasive approaches of surgical reduction and fixation may reduce complications in management.

Level of Evidence: Level IV.

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Many high-quality studies have been published over the last few years with substantial relevance to the clinical practice of pediatric orthopaedic trauma. Because of the volume of publications on this topic, the presentation has been divided between upper and lower extremity injuries. The following is a publication of the most notable injuries of the lower extremity reviewed: pelvic injuries, femur fractures, tibial shaft fractures, femur fractures, ankle fractures, and foot fractures.

METHODS

We searched the PubMed database using the following terms: pediatric orthopedic trauma, tibia shaft fracture, femur fractures, ankle fractures, foot fractures, and pelvic fractures. We reviewed papers from January 1, 2012 to July 31, 2017, yielding 835 combined level 3 and 4 studies with references to pelvic injuries, femur fractures, tibial shaft fractures, femur fractures, ankle fractures, and foot fractures. Of these papers, 25 papers were identified as having contributed useful clinical data to the literature. Exclusion criteria included references outside of date range, meta-analysis, pathologic fracture, periprosthetic fracture, age above 18, papers not in English and poor quality data not applicable to clinical practice.

Pelvic Ring Fractures

Pediatric pelvic fractures (PPF) are rare injuries most frequently caused by high-energy blunt trauma primarily from pedestrian—car or motor vehicle accident.[1] The recent published data have attempted to use large cohorts to provide epidemiologic data, assess outcomes, modify the Torode PPF classification, and evaluate for safe sacral screw pathways. The incidence of PPF ranges from 0.8% to 1.6% in pediatric trauma,[1,2] whereas mortality ranges from 5% to 6.3%.[2,3] Zwingmann et al[3] reviewed a cohort of 208 children below 15 years of age with pelvic fractures compared with 13,317 adults in the German Trauma Registry. In total, 18.3% of fractures were treated operatively, commonly by external fixation (EF), and no child suffered from a thrombosis/embolism, acute respiratory distress syndrome, infectious multiorgan

failure, or neurological deficit.[3] In contrast to the adult population in which 1.5% suffered from a thrombosis/embolism, 1.3% acute respiratory distress syndrome, 1.1% multiorgan failure, or 2.0% neurological deficit.[3]

Swaid et al[1] assessed a cohort of 99,579 children (0 to 14) with blunt trauma and identified 812 (0.8%) with pelvic fractures with a median age of 8. Children without pelvic fracture involved in blunt trauma had a median age of 6; therefore this difference in age should guide clinic assessment and concern. Mortality was typically associated with severe traumatic brain injury and was found to be 5.2% for patients with a pelvic fracture versus 0.3% without.[1] The most common associated intra-abdominal injuries were liver (10.1%) and spleen (9.2%) with no correlation identified between severity of pelvic fracture and the presence of intra-abdominal injury in children, in contrast to the adult population.[1]

Kruppa et al[4] performed a retrospective analysis of 33 patients with a mean age of 12.6 years comparing unstable, operatively treated pelvic ring fractures (16) to stable, nonoperatively treated pelvic ring injuries (17). Outcomes measures in this study included radiographic deformity, leg-length discrepancy, low back, and sacroiliac joint pain. Children in both groups with 5 to 10 mm posterior sacral displacement had significantly more pain than children with 0 to 4 mm displacement ($P = 0.034$). Residual deformity did not remodel. Thirteen children (39%) had residual low back/sacroiliac joint pain; the rate was significantly higher in the operative group (3/17 vs. 10/16; $P = 0.008$).[4] These findings help guide discussion with families going through this trauma, but it does not change clinical practice.

Shore et al[2] proposed a modification to the Torode classification after review of 124 patients with PPF (Fig. 1). The modified Torode PPF classification divided type III injuries into A (simple, stable anterior ring fractures) and B ("stable" anterior and posterior ring fractures) due to the higher energy required to sustain an anterior and posterior ring fracture in children.[2] The majority (55%) of PPF occurred in skeletally mature patients with closed triradiate cartilage, 71% of patients had type III injuries and type III-B were >2.5 times more likely to require a blood transfusion than type III-A.[2] Nine patients (8%) required open reduction internal fixation (ORIF) of pubic rami fractures (2 patients) or EF for stabilization (7 patients) of which 8 were skeletally mature.[2] Burn et al[5] studied computed tomographic (CT) scans of 174 children with views of the sacrum to assess for safe radiographic sacral screw pathways. Radiographic pathways >7 mm in diameter are available in most children age 2 to 16 for placement of iliosacral screws at S1 (99%) and transsacral transiliac screws at S2 (89%). All pathway measurements, including pathway availability for transsacral transiliac at S1, increased with increasing age.[5]

Femur Fractures

Pediatric femur fracture management varies based on associated injuries, patient age, weight, and fracture characteristics. Indications for different techniques of surgical stabilization including submuscular plating, elastic stable intramedullary nail (ESIN), rigid intramedullary nailing, or EF have been a focus of the literature. A recent multicenter retrospective review of 215 patients aged 2 to 6 with femoral shaft fracture treated by immediate casting versus ESIN found the group treated with flexible nail to have a shorter time to weight-bearing and activities.[6] At final follow-up (spica 1.2 ± 1.5 y vs. ESIN 3.7 ± 2.7 y), the spica group was found to have a higher rate of leg-length discrepancies (predominately <2 cm) and residual deformity although these were not clinically significant and did not require treatment.

Outcomes of diaphyseal femur fractures treated by submuscular plating (mean age, 10.6), ESIN (mean age, 10.6), or rigid intramedullary nailing (mean age, 13.9) were compared in 196 patients by Sutphen et al.[7] They found submuscular plating had the fastest time to union and full weight-bearing (mean, 6.2 and 7.0 wk, respectively). Rigid intramedullary nailing had an increased incidence of radiographic heterotopic ossification and residual limp at

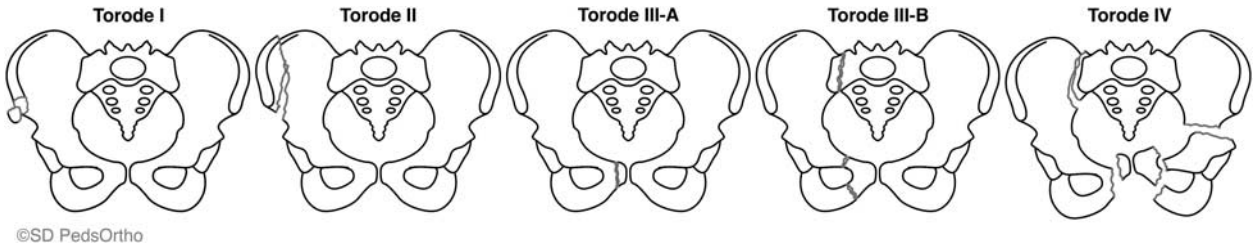

FIGURE 1. Modified Torode classification. Torode I (avulsion fractures): avulsion of the bony elements of the pelvis, a separation through or adjacent to the apophysis. Torode II (iliac wing fractures): resulting from a direct lateral force against the pelvis, causing a disruption of the iliac apophysis or an infolding fracture of the wing of the ilium. Torode III-A (simple anterior ring fractures): simple, stable anterior fractures involving the pubic rami or pubic symphysis. Torode III-B (stable anterior and posterior ring fractures): stable anterior and posterior ring fractures. Torode IV (unstable ring disruption fractures): unstable pelvic fractures, including ring disruptions, hip dislocations, and combined pelvic and acetabular fractures. Fracture stability was determined by clinical and radiographic examination, with "stable" (type III) fractures showing stability to pelvic compression and <2 mm of fracture displacement on computed tomographic imaging of the anterior and posterior ring fractures. "Unstable" (type IV) fractures showed gross clinical instability and/or >2 mm of displacement from both anterior and posterior pelvic ring fractures.[2]

12 weeks postoperatively (23.5%), whereas ESIN resulted in the highest rate of hardware irritation ($P = 0.02$), the longest time to full weight-bearing (12.1 wk; $P = 0.001$), and malunion (22.4%; $P < 0.0001$) ranging from 12-degree procurvatum to 10-degree recurvatum and from 15-degree valgus to 9-degree varus.[7]

Andreacchio et al[8] reviewed 38 children ages 4 to 8, comparing treatment of femoral fractures between EF and ESIN. EF (n = 15) and ESIN (n = 23) were both found to both be safe and effective methods of treatment. Patients treated with EF returned to weight-bearing slightly sooner and ESIN was used more commonly in the polytrauma patients.[8] Complications included 2 (13.3%) pin-site infections and 1 (6.7%) refracture with EF, whereas 1 (4.3%) event of hardware migration was recorded in the ESIN group, but no significant difference was observed ($P = 0.16$). These techniques are felt to produce no increase in periosteal damage and no disruption in the fracture hematoma or bone healing process.[8]

El-Alfy et al[9] assessed the combined use of EF with ESIN for comminuted long bone fractures. The average time to femoral union was 1.9 months and average time in EF was 1.4 months. No significant malunions or leg-length discrepancies were encountered while 18% of patients developed a pin tract infection. They concluded the combined fixation is an acceptable method for the treatment of comminuted long bone fractures in children and potentially decreases the complications associated with each method alone.[9] The use of limited open versus percutaneous K-wire joystick reduction for ESIN was evaluated in 63 pediatric femoral fractures by Liu et al.[10] The blood loss, operative time, duration of hospital stay, and postoperative pain at the incision site were considerably lower in joystick group than in limited open reduction group and 1 patient in the limited open group developed an infection.[10] Joystick reduction may be a useful tool for reduction when utilizing ESIN for pediatric femur fractures. Although the presented studies seem to support more rigid fixation in children (with earlier union and return to activity), the long-term outcomes of submuscular plating and rigid nails compared with ESIN have not been fully explored and require future study.

Tibia Shaft Fractures

Tibial shaft fractures are common in the pediatric and adolescent population. Mashru et al[11] in 2005, defined the acceptable alignment of pediatric (< 8 y old) tibial shaft fractures to be 10 degrees of coronal and sagittal angulation, 50% translation, and 10 mm of shortening as published guidelines. The angulation decreases to 5 degrees in the older pediatric and adult populations.[12] Because of the variety of treatment selections, recent literature has focused on management of these injuries.

Silva et al[13] performed a randomized controlled prospective study of 81 patients to evaluate the effectiveness of treatment of tibial shaft fractures in a non–weight-bearing long leg cast with 60 degrees of knee flexion (group A) versus long leg cast with 10 degrees of knee flexion and encouragement to weight bear as tolerated (group B). They found no significant difference in time to union or alignment between the 2 groups and no difference in activity scores by time to union.[13] Ho et al[14] reviewed cast treatment of 75 closed tibia fractures in adolescents, girls aged 10 to 18 years (average, 11.8 y) and boys aged 12 to 18 years (average, 13.8 y). They found 21% (16/75) of patients required a cast change or wedging in the clinic for loss of reduction and 3 of which required surgical fixation of their fractures. These 16 patients had increased initial radiographic deformities (anteroposterior angulation 5.1 degrees, lateral 4.5 degrees, 23.7% translation) and post-reduction radiographic deformities (anteroposterior angulation 3.7 degrees, lateral 3.2 degrees, 21.8% translation) and typically caused by high-energy trauma.[14] Immobilization for 3 months or longer was required for 59% of patients, more commonly with combined tibia-fibula fractures.[14] Canavese et al found no difference in final clinical outcomes between nonoperative treatment of displaced tibial shaft fractures with intact fibulas (56 patients) versus those treated with initial ESIN intramedullary nailing (ESIN, 26 patients) in pediatric patients aged 8 to 11. Although numeric radiographic differences were statistically significant the final degree of deformity in any plane was <3 degrees and not clinical relevant as all patients resumed previous daily and sport activities without difficulty or pain. Time of immobilization was clinically relevant with a mean of 6.6 ± 3.2 weeks following ESIN compared with a mean of 10.3 ± 1.7 weeks with conservative treatment.[15]

Kinney et al[16] retrospectively reviewed operative management versus conservative treatment of displaced tibial shaft fractures in 74 adolescents (ages 12 to 18, 57 treated closed and 17 with surgery). Of the 57 initially treated closed, 40% (23 patients) went on to surgery due to loss of reduction. The risk factors for closed treatment failure in these patients were initial displacement > 20% and presence of a fibula fracture.[16] Goodbody et al[17] investigated 95 patients to determine an upper weight (50 kg) or age limit (14 y) for the safe and effective use of titanium ESIN for tibial shaft fractures in the pediatric population. They did not find a significant difference in the rate of malunion or time to healing between younger and older (14 y and above) patients or between lighter and heavier ($\geq$ 50 kg) patients.[17]

Pennock et al[18] evaluated surgical treatment for pediatric tibia fractures following polytrauma (17%), open fracture (32%), compartment syndrome (7%), inability to obtain reduction (11%), or loss of reduction after closed treatment (32%). In total, 40 patients who underwent elastic nailing were compared with 26 patients who underwent ORIF with screws or a plate and screw construct. Patients who underwent ORIF had more anatomic reductions, lower rates of second surgeries including removal of implants (35% vs. 91%; $P < 0.001$) and decreased time to weight-bearing (6.6 ± 1.5 vs. 8.5 ± 3.0 wk; $P < 0.001$), but trended toward higher wound-related complications (23% vs. 9%; $P = 0.10$).[18] In all of these papers the threshold for surgical intervention was variable. This suggests that future studies may be warranted to better define what is considered acceptable for closed treatment.

Compartment Syndrome and Other Associated Complications

Compartment syndrome is a major concern following tibial shaft fractures. Ho[19] reported no occurrences of compartment syndrome in their patients treated with casting. Three patients (5.2%) developed compartment syndrome after closed reduction and casting by Kinney et al.[16] Kinney et al[16] and Pennock et al[18] found the incidence of compartment syndrome following ESIN to be 2% and 4.5%, respectively. The rate of compartment syndrome has been reported to be as high as 20% following ESIN by Pandya et al.[20] Age, weight, mechanism of injury, fracture pattern, and presence of neurological deficit were associated with increased rates of compartment syndrome following ESIN.[20] There were no reported cases of compartment syndrome following ORIF by Pennock et al.[18]

Venous thromboembolic events (VTE) are associated with traumatic injuries, infections, and central venous catheter in pediatric patients.[21] Analysis of the Pediatric Health Information System (PHIS) by Murphy et al,[21] the incidence of VTE events associated with pediatric orthopaedic lower extremity trauma to be 0.058%. VTE was more commonly associated with injuries of the femur/femoral neck, tibia/ankle, and pelvis in adolescent and polytrauma patients. Anticoagulation, mainly low–molecular-weight heparin (80/121, 66%), was provided for 72% (121/167) of patients found to have VTE.[21] There is no clear evidence to support the utilization of prophylactic anticoagulation in children or teenagers to prevent deep venous thrombosis or fatal pulmonary emboli.

Ankle Fractures

Pediatric ankle injuries are a common complaint leading to orthopaedic consultation. Ankle injuries with no radiographic evidence of a fracture and with tenderness overlying the physis of the distal fibula are often considered nondisplaced Salter-Harris type I physeal fractures of the distal fibula (SH1DF).[22] Boutis et al[22] conducted a prospective cohort study of 135 children to evaluate the frequency of SH1DF in radiographically negative ankle injuries using MRI. Four children (3%) had SH1DF, whereas 80% had ligamentous injuries and 22% had bone contusions. In total, 35% of those with ligamentous injury were found to have an associated occult fibular avulsion fracture.[22] Similarly, Kwak et al[23] found 26% of children with a diagnosed ankle sprain to have an associated fibular avulsion fracture using the anterior talofibular ligament view (Fig. 2) or 4-week follow-up x-rays. The study by Boutis et al[22] additionally evaluated outcomes at 1 month after management of all patients with a removable ankle brace and return to activities as tolerated and found no significant difference in scores between fractures or ligamentous injuries.

One pediatric radiologist, 1 musculoskeletal radiologist, and 3 fellowship-trained pediatric orthopaedic surgeons rated a spectrum of 25 triplane fractures with use of radiographs alone and then with CT scans on 2 separate occasions.[24] The Rapariz triplane fracture classification (Fig. 3) had poor interrater reliability (a κ of 0.17) and intrarater reliability (a κ of 0.31) with radiographs alone. The raters changed their definition of the fracture pattern in 46% of cases, degree of displacement in 39%, treatment plan in 27%, and either the number or orientation of screws in 41% of cases after reviewing the CT,[24] supporting the use of CT as an adjunct to radiographs for the treatment of pediatric triplane fractures.

Functional outcomes of 78 children with CT diagnosed triplane or tillaux fractures were assessed using Foot and Ankle Outcomes Score and the Marx Activity Scale.[25] In total, 60% of patients were treated with closed reduction percutaneous fixation, 33% with closed reduction and 5% with ORIF.[25] Residual articular displacement <2.5 mm, measured on follow-up x-rays or CT, did not diminish functional outcomes compared with an anatomic reduction.[25] No decline in function was found with longer-term follow-up (4 to 10 y) for residual displacement <2.5 mm.[25]

Os Calcis Fractures

Calcaneus fractures are rare in children and will often be nondisplaced or minimally displaced fractures that can be treated conservatively.[26] Operative treatment is recommended for those fractures that are significantly displaced or intra-articular.[26] This has typically been

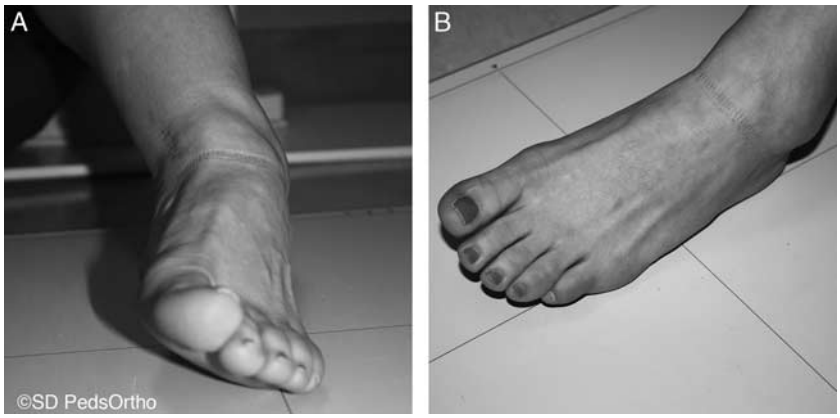

FIGURE 2. Anterior (A) and lateral (B) clinical photograph of the position during taking the anterior talofibular ligament view. Foot elevated 15 and 45-degree ankle plantar flexion with the beam directed vertically through the lateral malleolus to the cassette.[23]

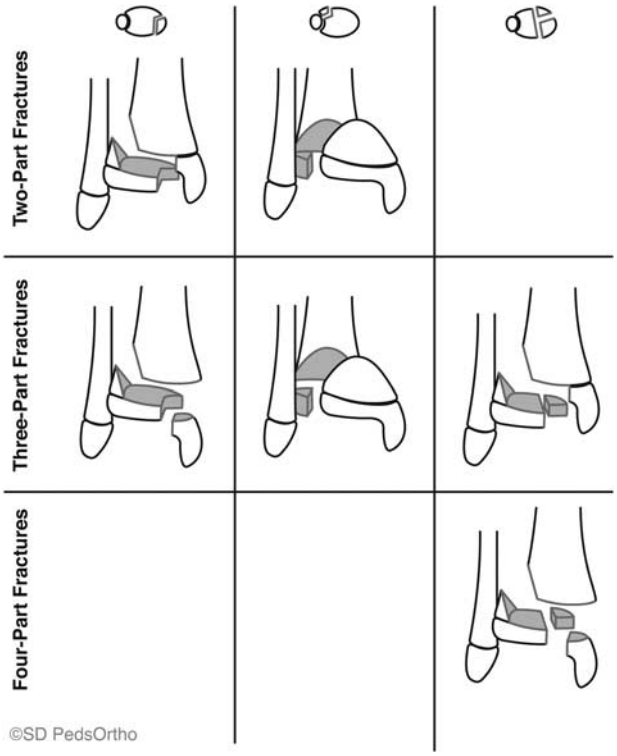

FIGURE 3. Proposed Rapariz triplane fracture classification system. Each fracture configuration is identified by the name of the lead author of the earliest known publication describing that fracture pattern.[24]

performed through an extended lateral approach.[27] Recently the outcomes of a minimally invasive sinus tarsi approach and closed reduction percutaneous fixation have been examined.[26,27] Both studies found patients to have good outcomes with few or no complications using these techniques.[26,27] The use of minimally invasive surgical approaches can be considered for displaced pediatric calcaneal fractures when surgery is indicated.

CONCLUSIONS

PPFs are uncommon. Residual radiographic deformity is a predictor of low back pain. The modified Torode PPF classification divided type III injuries into A and B due to the higher energy required to sustain an anterior and posterior ring fracture in children.

Pediatric femur fractures can be treated in a variety of ways, and the current literature suggests that the more rigid the fixation the shorten time to union and full weight-bearing. However, the long-term consequences (>2 y) of placing submuscular plates, rigid nails, etc. have not been fully explored in this young population and require further investigation.

Pediatric tibia shaft fractures are common injuries that should be managed conservatively with reduction and casting in the majority of cases. Low-energy injuries may be treated with long leg casting with 10 to 15 degrees of knee flexion and early weight-bearing. High-energy injuries are more likely to ultimately result in surgical management.

Compartment syndrome after tibia fractures remains a significant complication of the injury that requires vigilance in prompt recognition and treatment. Venous thromboembolism remains a rare complication, but one that does exist in children. No guidelines exist for prophylactic anticoagulation and it is not recommended in this age group.

Lateral injuries traditionally treated as physeal fractures, appear to be ligamentous injuries that can be managed with an ankle stirrup. Mid-term (4 to 10 y) follow-up suggests that slight incongruity at the tibiotalar surface is well tolerated with longer-term follow-up studies needed.

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