Orthopedic Injuries in Pediatric Trauma

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Abstract: Background: Trauma remains the leading cause of death in children, of which the majority of patients have orthopedic injuries. The range of injured bones is various, each requiring knowledge and expertise to appropriately manage in a timely fashion.

Objectives: The importance of a systematic approach to the pediatric polytrauma patient is paramount. This chapter will highlight orthopedic issues important to the pediatric polytrauma patient including the unique anatomy and properties of pediatric bone. A systematic approach to the pediatric polytrauma patient will also be discussed.

Methods: A review of the literature was undertaken to identify current practices in pediatric orthopedic trauma care.

Result and Conclusion: Orthopedic injuries in polytrauma are a common and important entity in children. Special attention to the unique anatomy and injury patterns in children should be undertaken as they are important for their management.

Keywords: Orthopedic, pediatric, fracture, trauma, injuries, polytrauma patients.

1. INTRODUCTION

1.1. Orthopedic Injuries in Pediatric Trauma

Trauma remains the leading cause of death in children [1]. Among pediatric polytrauma patients, approximately 63% have associated orthopedic injuries [2]. In a recent review of data from the Kids’ Inpatient Database, an American database including over 80 000 pediatric trauma admissions, femur fractures were the most common orthopedic injury (21.7%) followed by tibia/fibula fractures (21.5%), humerus fractures (17%) and radius/ulna fractures (14.7%) [1]. Vertebral and pelvic fractures, despite representing only 5.2% and 4% of pediatric trauma admissions, respectively, were associated with the highest rates of mortality (0.82% and 0.55%) and concomitant injury [1]. This highlights the importance of a systematic approach to the pediatric polytrauma patient in order to ensure that all injuries are diagnosed and addressed in a timely manner.

This chapter will highlight orthopedic issues important to the pediatric polytrauma patient including the unique anatomy and properties of pediatric bone, a systematic approach to the pediatric polytrauma patient, spinal injuries, pelvic fractures, characteristic pediatric fracture patterns and complications such as open fractures and compartment syndrome.

2. BACKGROUND

2.1. Anatomy and Unique Properties of Pediatric Bone

The immature skeleton has several unique properties. Understanding these properties is important as they influence the diagnosis, management and prognosis of fractures in children.

Adult long bones differ from those of children whose bones are maturing and growing. As seen in Fig. (1), the bone is divided into four distinct and constantly evolving anatomic areas: the epiphysis, the physis (also known as the growth plate or epiphyseal plate where growth occurs), the metaphysis and the diaphysis. An apophysis is a cartilaginous area that forms the site of tendon attachments in the immature skeleton. This represents a weak point in the muscle-tendon attachment [3]. The structure of the pediatric skeleton results in features unique to pediatric fractures. Some of these are listed in Table 1.

2.2. Orthopedic Assessment in Pediatric Trauma

The principles of the Advanced Trauma Life Support (ATLS) Course have been widely adopted in North America...
since its introduction in the 1970’s, providing a standardized approach to the polytrauma patient. Several studies have shown that adherence to ATLS principles in trauma care results in improved patient management and outcomes [4, 5].

The ATLS approach includes a primary survey comprised of assessment and stabilization of the airway, breathing and circulation, and neurological assessment of the trauma patient. During the primary survey, cervical spine protection and immobilization must be ensured with a cervical collar. Cervical spine injury should be assumed in children with a history of significant trauma or those with altered level of consciousness who cannot be adequately clinically evaluated. Cervical spine immobilization with appropriate sized cervical collars should be undertaken in these children until injury can be ruled out. Infants and young children (less than 8 years old) have a disproportionately large head as compared to their torso. As a result, when placed on a hard spinal board, their neck is held in a position of relative flexion. Thus, modification of the spinal backboard is needed to maintain the young child's neck in neutral position (Fig. 2). This can be accomplished by creating a recess for the child's head or by placing a mattress pad beneath the body to allow the head to rest on the board with the neck in neutral position [6].

During the primary survey, musculoskeletal injuries affecting hemodynamic status - such as significant pelvic fractures or multiple long bone fractures - are addressed with immobilization to minimize blood loss [7]. The pelvis should be palpated and immobilized if instability is detected, and fractured femurs should be placed in traction.

The primary survey is then followed by a secondary survey in which a more detailed assessment and documentation of injuries is performed. Assessment of musculoskeletal injury during the secondary survey should include patient exposure allowing examination for obvious deformity and bruising. The colour of the exposed extremities should be assessed. Pallor may be indicative of vascular injury and requires urgent intervention to prevent limb ischemia. Observation of spontaneous movement may provide clues to musculoskeletal injuries. A child who refuses to move an extremity must be assessed to rule out a fracture, and urinary catheter drainage should be assessed for blood. The urethral meatus should also be checked for blood prior to placement of a urinary catheter. Presence of blood at the meatus suggests urethral disruption secondary to pelvic fracture. In such cases, a catheter should not be placed until the full extent of the injury is assessed.

Palpation of the spine for tenderness or step deformity while maintaining cervical spine immobilization should be undertaken once patient exposure is complete. Pulses in all

![Fig. (1). Bone characteristics of adults and children. (Figure Credit: E Lim).](image)

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<thead>
<tr>
<th>Table 1. Unique features of pediatric bones.</th>
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<tr>
<td>• More porous, less dense bones therefore less energy required to cause fracture</td>
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<td>• More vascular periosteum therefore larger callous formation and more rapid fracture healing</td>
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<td>• Fractures can result in abnormal growth (e.g. overgrowth or bowing of bone)</td>
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<td>• Bone capable of plastic deformation leading to unique pediatric fracture patterns</td>
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<td>• Increased remodeling ability compared to adult bone</td>
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<td>• Decreased incidence of comminuted fractures</td>
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<td>• Differing appearance on X-Ray makes diagnosis of fracture more difficult</td>
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![Bone characteristics of adults and children.](image)

![Table 1. Unique features of pediatric bones.](image)
extremities should be assessed. Absent pulses in the presence of a fracture is an orthopedic/vascular emergency. Fracture reduction and orthopedic consultation under such circumstances must occur emergently to prevent limb ischemia. Compartments of the extremities should be palpated. Hard, tender or firm compartments may indicate the presence of compartment syndrome, another orthopedic emergency. Finally, a neurologic assessment of the extremities should be undertaken to check sensation and strength. Splinting of extremity fractures is sufficient in the initial management of most polytrauma patients. Musculoskeletal injuries resulting in neurovascular compromise must be reduced immediately to prevent limb ischemia [7].

Specialized equipment geared towards the unique anatomy of the child at different stages of development is essential in the safe and proper management of the pediatric polytrauma patient. This includes appropriately sized cervical collars, spine boards to accommodate the relatively large pediatric head, intraosseous needles, smaller gauge intravenous needles and small endotracheal tubes. This equipment must be made available to first responders as well as the emergency department staff who care for pediatric patients.

After head injuries, musculoskeletal injuries are the second leading cause of long-term morbidity in pediatric polytrauma patients [8]. Despite this, fractures are rarely life threatening in the setting of polytrauma with the exception of significant pelvic fractures and multiple long bone fractures. However, spine immobilization is essential in the initial assessment of the pediatric polytrauma patient who should be assumed to have a spinal injury until proven otherwise. Serial examinations are also important as orthopedic injuries may initially be missed in the polytrauma patient with an altered level of consciousness.

2.3. Spinal Injuries in Pediatric Trauma

Spinal injuries account for 1-10% of traumatic injuries in children [9]. Of these, cervical spine injuries are the most common followed by lumbar then thoracic spine injuries [9-11]. In this section, we will discuss the approach to spinal injury, spinal injuries unique to children such as spinal cord injury without evidence of radiographic abnormality (SCIWORA), high-energy injuries such as atlanto-occipital dislocations and the use of clinical decision rules in cervical spine assessment.

2.4. Injuries to the Cervical Spine

In a large multi-centre American study using the National Pediatric Trauma Registry (comprising over 75,000 children with traumatic injuries), cervical spine injuries were found to account for 1.5% of pediatric trauma admissions [12]. Most cervical spine injuries were caused by Motor Vehicle Collisions (MVC) followed by falls. Upper cervical spine injuries were more common in younger children (less than 8 years of age) than lower cervical spine injuries and had an almost 6 fold increase in mortality as compared to lower cervical spine injuries. A third of children with cervical spine injuries had associated spinal cord injury and among those, half of them had Spinal Cord Injury Without Radiographic Abnormality (SCIWORA) underlining the importance of maintaining a high index of suspicion when clearing the cervical spine of children with normal imaging following significant trauma. Multi-level injuries were found in 29-34% of children, 7-25% of which are non-contiguous, highlighting the importance of imaging the complete spine in children with an identified spinal injury or a dangerous mechanism of injury [9, 11].

Spinal Cord Injury Without Evidence of Radiographic Abnormality (SCIWORA) is a term coined by Pang and Wilberger, in 1982, to describe acute traumatic spinal cord injury in the setting of normal plain films and CT scans of the spine [13]. The incidence varies in the literature with some reporting as high as 67% [14]. More than half of the children with traumatic spinal cord injury showed a delay in the onset of paralysis of up to four days following injury [13]. SCIWORA had a higher incidence in children less than 8 years old who typically had more severe neurologic injuries than older children [15]. This data highlights the importance of spinal immobilization following trauma - even in the setting of normal spinal imaging - until a complete neurologic exam can be performed.

Atlanto-occipital Dislocation (AOD) is defined as disruption of the atlanto-occipital junction. This entity is now known to be more common than once thought and is found in 8% of polytrauma fatalities on postmortem examination [16]. AOD is more frequent in children less than 8 years old due to their relatively small occipital condyles and large heads, greater ligamentous laxity and flat articulation between the occiput and atlas. Improved survival in patients with AOD is thought to be due to improved on-scene resuscitation and spinal immobilization, improved imaging tech-
nologies and increased awareness among health care personnel [16]. Patients with AOD can be presented in a variety of ways. Cardio-pulmonary instability is common and thought to be due to associated mediullary injury. Quadriplegia or quadripareisis may be present secondary to spinal cord injury. Cranial nerve palsies, in particular palsies of cranial nerves VI and IX through XII, are common. Occasionally, patients may present with no neurologic symptoms underlying the need to maintain a high index of suspicion in patients with high risk mechanisms of injury including motor vehicle collisions and pedestrian versus motor vehicle injuries [16]. Diagnosis of AOD can be made on cervical spine radiographs where findings include widening of the distance between the tip of the dens and the basion as well as the upper cervical soft tissue swelling. Although CT Scan is sensitive for detection of bony injury, Magnetic Resonance Imaging (MRI) is useful in assessing ligamentous injury. Management includes cardiopulmonary stabilization, cervical spine immobilization and emergency neurosurgical consultation [16].

2.5. Cervical Spine Decision Rules

Several decision rules exist for the use of imaging in suspected cervical spine injuries in adults. However, no decision rule has been validated for use in children. As a result, physicians treating pediatric trauma patients often rely on modified adult rules for cervical spine clearance. Of these, the American National Emergency X-Ray Utilization Study (NEXUS) criteria and the Canadian C-Spine Rule are the most commonly used by physicians in Canada [17]. The NEXUS criteria assess for the presence of low risk factors in patients including the absence of: midline cervical spinal tenderness, intoxication, focal neurologic deficit and painful distracting injury in an alert patient. In the setting of these findings, the patient is deemed to be at low risk of cervical spinal injury and the patient's cervical spine can safely be cleared clinically without the need for radiographic examination. The Canadian C-Spine Rule takes into account both the high risk factors (age > 65 years, dangerous mechanism of injury and numbness or tingling in the extremities) as well as low risk factors (low speed MVC, ambulatory at the scene, absence of neck pain at the scene and absence of midline neck pain on evaluation in the emergency department). In the absence of all high-risk criteria and the presence of low risk criteria, a decision can be made to clinically clear the cervical spine by examining active range of motion of the neck. The Trauma Association of Canada (TAC) Pediatric Subcommittee has produced consensus guidelines on pediatric cervical spine evaluation in trauma that incorporate both the Canadian C-Spine Rules as well as the NEXUS criteria to create pathways for the evaluation of pediatric patients with C-spine injuries [18]. The TAC Guidelines define two separate pathways - one for the evaluation of the pediatric patient with a reliable exam and the second for the evaluation of the pediatric patient with an unreliable exam. These guidelines provide a good resource for use in clearance of the C-Spine in the pediatric trauma patient [18]. Despite the utility of current guidelines in pediatric C-spine clearance, care must be exercised when attempting C-Spine clearance in a very young child (less than 8 years old) as studies have shown a poorer sensitivity and specificity of the existing guidelines in this age group [19, 20].

Evaluation of the pediatric cervical spine radiograph can be fraught with challenges. Incomplete ossification of the cervical vertebrae, as well as normal variants unique to children such as pseudosubluxation make cervical spine radiograph interpretation difficult. A complete review of the many normal variants of the pediatric spine is beyond the scope of this article.

2.6. Injuries to the Thoracolumbar Spine

Thoracolumbar injuries occur more commonly in adolescents than younger children [11]. The most common cause is Motor Vehicle Collisions (MVC) with the majority of children being unrestrained passengers [9, 11]. As mentioned above, the diagnosis of spinal fracture or injury at one level should prompt evaluation of the entire spine due to the increased risk of multi-level injuries in children with an identified spinal injury or a dangerous mechanism of injury [9, 11].

Most spinal injuries in children are managed conservatively [9, 11]. Nonsurgical management includes bed-rest and the use of spinal orthosis for immobilization. Surgical interventions, including decompression with or without fusion and instrumentation of the spine, were performed in only 18-26% of patients [9, 11]. Mortality rates in patients with spinal injury were low overall although mortality was the highest among children with high cervical spine injuries [9-11]. Most children with spinal injury recover partially or completely after neurological injury with few long-term complications following spinal surgery such as scoliosis or growth disturbance [9, 11].

The need for surgical intervention in children with spinal injury depends on the type, level and severity of the injury. Indications for surgical management are discussed in Table 2 [11].

3. PELVIC FRACTURES IN PEDIATRIC TRAUMA

3.1. Epidemiology

Pelvic fractures account for 2.4% [21] to 7.5% [22] of injuries in all children requiring admission following blunt trauma. Pelvic fractures occur in the setting of high-energy trauma and are often associated with other injuries. Most pelvic fractures occur as a result of motor vehicle collisions or pedestrian versus vehicle collisions. Due to the increased plasticity of pediatric pelvic bones, the increased elasticity of the pubic symphysis and sacroiliac joints, single bone fractures are more common in children with pelvic fractures. As a result, there is a decreased incidence of vascular disruption and hemorrhage as well as a lower mortality rate compared with adults [23]. In two case series at nine American pediatric level I trauma centres, mortality rates in children with pelvic fractures ranged from 3.6% [24] to 5% [25]. In all cases, death was due to associated injuries, with injuries to the head representing the most common cause of mortality in these children [24, 25]. Non-operative treatment was the most common management of children with pelvic fractures ranging from 91% [25] to 97% [24].
3.2. Classification and Management of Pediatric Pelvic Fracture

Pelvic fracture patterns vary based on skeletal maturity. The immature pelvis has an open tri-radiate cartilage, more elastic pelvic ligaments and weaker iliac wings. As a result, fractures of the iliac wings and pubic rami are more likely. Once the tri-radiate cartilage has closed (around the age of 14 years in males and 12 years in females), the pelvic bones become stronger than the pelvic ligaments leading to an increased likelihood of acetabular fractures, fractures of the pubic symphysis and diastasis or separation of the sacroiliac (SI) joints [23]. Children with pelvic injuries have a high rate of associated injuries and require careful evaluation for other potentially life-threatening injuries [24, 25]. In the setting of hemodynamic instability, a search must be made for other sources of blood loss including intra-abdominal injury. Most pediatric pelvic fractures heal without complication and operative intervention is rarely required [23, 25].

Several systems of classification exist for pediatric pelvic fractures. The Torode-Zieg system of classification was developed based on pediatric data and is currently among the most commonly used classification systems for pediatric pelvic fractures dividing them into four types [26]. Type I pelvic fractures involve apophyseal avulsion fractures. Type II fractures are fractures of the iliac wing. Type III fractures are simple pelvic ring fractures such as pubic rami and pubic symphysis fractures. Type IV fractures are unstable fractures involving pelvic ring disruptions.

Type I and II fractures are quite stable and can be managed symptomatically with analgesia and protected weight bearing for 2 to 4 weeks followed by physiotherapy for strengthening. Type III fractures can be treated with weight bearing as tolerated (based on pain) in the compliant patient and bed rest for the non-compliant or very young patient until they can ambulate without pain. Non-displaced fractures extending into the acetabulum can be treated with no weight bearing with a slow increase to weight bearing as pain decreases. Type IV fractures are unstable and require patient stabilization as well as pelvic immobilization with a sling and possible external fixation if associated with hemodynamic instability [23].

3.3. Pediatric Fracture Patterns

Physeal fractures are relatively common, constituting 18-30% [27] of all fractures in children. These fractures are more common in adolescents with the peak incidence at 11-12 years of age [27]. Though several systems exist for the classification of physeal fractures, the most commonly used is the Salter-Harris classification system [28] (Fig. 3).

The Salter Harris Classification system has been shown to correlate with prognosis in physeal fractures [29, 30]. Salter Harris I and II fractures tend to have good prognosis, though there is an increased risk of compartment syndrome with Salter Harris I fractures involving the proximal tibia. Salter Harris III-V fractures more commonly lead to growth disruption and surgical intervention due to joint involvement.

Torus (Buckle) Fractures are caused by a compressive load and occur in the metaphyseal region and metaphyseal-diaphyseal junction of growing bone. Prognosis for these

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<td>• Spinal cord compression with progressive neurological symptoms</td>
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<td>• Significant vertebral body compression (&gt;40% loss of spinal canal height)</td>
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<tr>
<td>• Spinal kyphotic deformity ≥20 degrees</td>
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<tr>
<td>• Vertebral dislocation</td>
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<tr>
<td>• Extradural hematoma, herniated disc</td>
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<td>• Injuries that cannot be stabilized externally</td>
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Fig. (3). Salter harris classification of growth plate injuries.
fractures is excellent and recent studies have shown that splinting patients with torus fractures of the distal radius is at least as effective at reducing pain and allowing return to function as use of circumferential casting [31, 32]. Follow-up with an orthopedic surgeon in outpatient clinic is only necessary if the diagnosis is in question [31].

**Greenstick Fractures** are incomplete fractures involving the diaphyseal-metaphyseal junction or diaphysis. The cortex remains intact on one side and as such, at times results in the need to complete the fracture in order to achieve an anatomic reduction. Unlike torus fractures these fractures are inherently unstable and require close orthopaedic follow up.

**Plastic Deformation (Bowing) fractures** are fractures of immature bone in which the force causing the fracture fails to create a discontinuity in the cortex but instead results inbowing of the bone. Such fractures can lead to cosmetic as well as functional deficiencies and should be referred to an orthopedic surgeon for reduction and follow-up.

**Avulsion fractures** are fractures that occur through the apophyseal plate at the point of muscular attachment to secondary centres of ossification. These fractures most commonly occur in the pelvis but are also commonly seen in the tibial tubercle and the phalanges. Most avulsion fractures heal well with conservative management including restriction of activity and pain control. Avulsion fractures of the tibial tubercle however may propagate into the joint requiring surgical management.

### 4. IMPORTANT ORTHOPEDIC COMPLICATIONS

#### 4.1. Open Fractures

Open fractures are defined as fractures associated with a disruption of overlying skin or tissue, leading to a communication between the fracture and the external environment [27].

The goals of therapy in children with open fractures include prevention of infection, and fracture stabilization to allow healing and restoration of function in affected limbs [33]. A recent Cochrane review showed that antibiotic use reduced the incidence of early infection in open fractures [34]. As such, systemic antibiotic use is the standard of care in children with open fractures. Commonly, first generation cephalosporins are used in patients with minimal wound contamination while those with substantial contamination receive both first generation cephalosporins and an aminoglycoside [33]. Surgical debridement of open fractures has also been shown to reduce the risk of infection although some controversy exists as to the timing of debridement. While some studies have shown that debridement within 6 hours of injury leads to lower rates of infection [35, 36], other studies have shown no difference between patients debrided within 6 hours and those in whom delayed surgical debridement was performed [37, 38].

**Tetanus** prophylaxis is indicated depending on patient immunization status. In patients who have never received tetanus immunization, tetanus immune globulin must also be given.

**Neurovascular injury** is perhaps the most concerning acute fracture complication. A complete exam of sensation and pulses distal to the fracture site should be conducted on assessment of any child with a fracture. Discovery of neurovascular injury should precipitate an emergent orthopedic consult and immediate fracture reduction.

**Compartment syndrome** is an acute fracture complication resulting from excessive swelling and increased pressure in a fascial compartment. This leads to compression of nerves and vessels within the compartment. Diagnosis of compartment syndrome in children is more difficult due to their inability to reliably communicate symptoms. The classic findings of compartment syndrome in adults (painlessness, paraesthesia, paralysis, pallor and pain with passive stretch) are late findings in children. Instead, pediatric patients often present with the three A's: Anxiety, Agitation and Analgesics (increased requirement for analgesia). Serial examinations and a high index of suspicion are important to ensure timely diagnosis of compartment syndrome. Treatment of compartment syndrome is urgent fasciotomy or, in situations in which a tight cast is the cause of compartment syndrome, immediate removal of the cast.

### CONCLUSION

Orthopedic injuries in polytrauma are a common and important entity in children. Special attention to the unique anatomy and injury patterns in children should be undertaken as they are important for their management. Despite representing only 5.2% and 4% of pediatric trauma admissions, vertebral and pelvic fractures deserve more attention, as they are associated with the highest rates of mortality. The importance of an organized and systematic approach to the pediatric polytrauma patient is paramount in order to ensure that all injuries are diagnosed and addressed in a timely manner.

### LIST OF ABBREVIATIONS

- AOD = Atlanto-occipital Dislocation
- ATLS = Advanced Trauma Life Support
- MRI = Magnetic Resonance Imaging
- MVC = Motor Vehicle Collision
- NEXUS = American National Emergency X-Radiography Utilization Study
- SCIWORA = Spinal Cord Injury without Evidence of Radiographic Abnormality
- SI = Sacroiliac
- TAC = Trauma Association of Canada

### CONSENT FOR PUBLICATION

Not applicable.

### CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

### ACKNOWLEDGEMENTS

Declared none.
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