5 Pediatric Trauma

- Pediatric Trauma

This chapter provides basic principles and algorithms for trauma management in children. Common diaphyseal fractures are not covered if there are no unique pediatric features. References are provided at the end of each section for further information.

- Basic Principles

Physeal Fractures

1. Classification

   a. There are several classification systems, including those of Aitken, Salter and Harris, and Peterson. Their goals are to (1) facilitate communication, (2) predict the risk of growth disturbance, and (3) determine treatment.

   b. The classifications provide information on
      1) Physeal alignment
      2) Articular alignment
      3) Stability and risk of displacement

   c. Physeal damage can occur from
      1) Step off at the level of the physis, with bar formation
      2) Damage to and death of physeal cells
      3) Ischemia of the physis if severe soft tissue damage occurs

   d. The classifications are usually predictive of the risk of growth disturbance. Salter 1 and 2 are typically at low risk of growth disturbance because the growth plate is not traversed by the fracture. However, there are some notable exceptions because damage may occur to the physis which is not visible on plain films. This is most common in the distal femur and the distal tibia, where there is a high risk of growth disturbance even in the “benign” fracture types such as Salter I and II. This may be due to complex physeal anatomy as well as compressive forces involved. By contrast, there is a low risk of growth plate damage in Salter 1 and 2 fractures of the distal radius and ulna and the proximal humerus.

   e. Salter–Harris classification: The most widely used (Fig. 5.1). Note that type V fractures are rarely, if ever, seen.

   f. Peterson classification: Recognizes a broader spectrum of injuries (Fig. 5.2)
Management of the Polytrauma Patient

1. Definition: A patient with more than one organ system injured or more than one component within one organ system.
   a. Laboratory studies: Complete blood cell count, type and cross, urinalysis, blood urea nitrogen, creatinine, amylase, electrolytes
   b. Indications for radiographic studies
      1) Cervical, thoracic, lumbar spine
         a) Tender
         b) Unconscious or heavily sedated
         c) Neurologically abnormal
      2) Pelvis
         a) Tender
         b) Unconscious
         c) Hematuria present
      3) Skull
         a) Head trauma and loss of consciousness for longer than 5 minutes, hematoma
         b) Skull depression
         c) Focal neurologic signs
         d) Cerebrospinal fluid from nose or middle ear
         e) Blood in middle ear
      4) Computed tomography (CT) of the head
         a) Glasgow Coma Scale less than 8
         b) Focal neurologic signs
         c) CT of the abdomen
         d) Shock
         e) Severe head injury
         f) Abnormal abdominal examination
Fig. 5.2 Peterson classification of physeal injuries. (From Peterson HA. Physeal fractures: Part 3. Classification. J Pediatr Orthop. 1994;14(4):443 (Fig. 8). Reprinted with permission.)
2. Initial evaluation

a. Physical examination
   1) Primary survey: To detect most urgent priorities (ABCDE)
      A Airway
      B Breathing (ventilation)
      C Circulation (hemorrhage)
      D Disability (neurologic status)
      E Exposure (temperature)
   2) Secondary survey
      a) Complete physical examination
      b) History of event
      c) Medical history
      d) Laboratory and radiographic results
      e) Reevaluation and stabilization

3) Normal vital signs for children (Table 5.1)

4) Glasgow Coma Scale (Table 5.2)

3. Adjuncts in management

a. Intracranial pressure measurement indications
   1) Glasgow Coma Scale less than 5 or less than 8 if shock is present
   2) CT scan showing mass or shift
   3) Progressive neurologic deterioration

b. Parenteral nutrition
   1) Indicated in polytrauma patient if enteral feeding not expected within 24 hours

c. Repeat physical examination

Table 5.1  Normal Vital Signs by Age

<table>
<thead>
<tr>
<th>Age</th>
<th>Pulse (beats/min)</th>
<th>Respirations (per min)</th>
<th>Blood Pressure (mm Hg, S/D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–6 mo</td>
<td>130 ± 45</td>
<td>30–40</td>
<td>80/46</td>
</tr>
<tr>
<td>6–12 mo</td>
<td>114 ± 40</td>
<td>24–30</td>
<td>95/65</td>
</tr>
<tr>
<td>1–2 yr</td>
<td>110 ± 40</td>
<td>20–30</td>
<td>99/65</td>
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<td>2–6 yr</td>
<td>105 ± 35</td>
<td>20–25</td>
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<tr>
<td>6–12 yr</td>
<td>95 ± 30</td>
<td>16–20</td>
<td>110/60</td>
</tr>
<tr>
<td>12 yr</td>
<td>80 ± 25</td>
<td>12–16</td>
<td>120/60</td>
</tr>
</tbody>
</table>
1) Should be performed at 24 and 48 hours because of the incidence of missed injuries
2) Bone scan is an alternative
d. Indications for deep venous thrombosis prophylaxis in polytrauma
   1) Oral contraceptive use
   2) Vascular injury
   3) Sickle cell anemia
   4) Prolonged immobility in older adolescent

**Pediatric Shoulder Injuries**

**Principles**

1. The proximal humeral physis is one of the most active in the skeleton, contributing 80% of the length of humerus; therefore it has tremendous remodeling potential.
2. Ossification
   a. Begins at 6 months in proximal humeral epiphysis, and growth ceases at 15 years in girls and 18 years in boys
   b. Ossific center for greater tuberosity appears at age 1; medial clavicle physis closes at around 23 years

Birth Fracture
1. Risk factors
   a. Difficult delivery
   b. Large size
   c. Breech presentation

2. Presentation
   a. “Pseudoparalysis” – limb moves little
   b. Rule out sepsis, brachial plexus injury

3. Diagnosis
   a. Plain radiographs or ultrasound

4. Treatment: Ace wrap or arm to chest for 2 weeks

Proximal Humeral Fractures
1. Background
   a. Age-based patterns: Preadolescent usually has fracture of metaphyseal region; adolescent, physeal fracture; Salter II or I
   b. Mechanism: Axial load or abduction; external rotation
   c. Muscle insertions with respect to physis: Internal and external rotators all on proximal fragment; deltoid and pectoralis, distal fragment displaces anteriorly and medially

2. Criteria for acceptable alignment
   a. Child under age 12 years: Virtually any alignment is acceptable.
   b. Child over age 12 year: Shortening or overlap less than 3 cm
   c. Angulation less than 45 degrees

3. Classification of displacement (pediatric)
   a. Neer and Horowitz
      ● I: Less than 5 mm translation
II: 5 mm to 33%
III: 33 to 66%
IV: Greater than 66% (most are grade IV)
Translation itself is not a problem. Note: Appearance on emergency department film is not the same as the appearance later. Angulation usually improves.

4. Treatment methods
   a. Sling
   b. Traction
   c. Shoulder spica
   d. Abduction brace
   e. Internal fixation

5. General recommendations
   a. Sling and swathe as long as any growth remains
   b. Closed or open reduction and internal reduction and internal fixation if
      1) Unacceptable angulation or shortening; older than 12 years
      2) Severe head injury with spasticity
      3) Polytrauma: To facilitate management
      4) Vascular injury
      5) Tenting skin: Risk of breakdown

6. Fracture through unicameral bone cyst (UBC)
   a. Common cause of proximal humerus fracture in child
   b. Differential diagnosis
      1) Eosinophilic granuloma
      2) ABC (aneurysmal bone cyst)
      3) Fibrous dysplasia
      4) Fibrous cortical defect
   c. Treatment of UBC
      1) Sling to heal fracture: 4 to 6 weeks
      2) Cyst regresses about 20% of time
      3) Assess and discuss the risk of refracture with family
         a) Depends mainly on cortical thickness
      4) Inject or bone graft if:
         a) Persistently thin cortex
         b) High desired activity level
         c) Family prefers active treatment
5) May need several injections

**Sternoclavicular Injuries**

1. Medial clavicle is last epiphysis to appear and to close (≤ 23 years old).
2. It provides 80% of clavicle growth.
3. Injury may be a dislocation or a fracture.
4. CT is most accurate if diagnosis is unclear.
5. Signs of **significant** displacement:
   a. Venous congestion
   b. Decreased pulse
   c. Difficulty breathing, swallowing
   d. Sensation of choking

6. Treatment
   a. Anterior displacement: usually no treatment
   b. Posterior displacement: treat if significant symptoms
   c. Closed reduction; may use towel clips
   d. Internal fixation: use sutures if unstable

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**Bibliography**


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**Pediatric Elbow Injuries**

**Lateral Condyle Fracture**

1. Background
   a. Vascular supply to the capitellum and lateral trochlea enters posteriorly
   b. Fracture may occur with varus or valgus force
   c. Distinguish this injury from a transphyseal separation by lack of swelling and tenderness medially and by alignment of the humerus with the forearm (**Fig. 5.3**); ultrasound may help.
   d. Internal oblique radiograph shows the fracture best.
2. Principles and significance

a. Lateral condyle fracture is one of the few pediatric fractures in which nonunion is not rare.

b. Cast is rarely able to maintain reduction of a displaced lateral condyle.

3. Treatment recommendations

a. Displacement less than 2 mm → splint in 90 to 100 degrees of flexion; pronation: recheck at 5 and 10 days (open reduction, internal fixation [ORIF] if further displacement)

Fig. 5.3 Differentiation of lateral condyle from distal humeral physeal fracture. In the latter, displacement of the entire forearm follows the metaphyseal fragment. In minimally displaced fractures, physical examination, ultrasound, arthrogram, or magnetic resonance imaging may be helpful. (A) Normal alignment of ulna and humerus. (B) Alignment maintained in lateral condyle fracture. (C) Alignment is lost in distal humeral Salter II physeal fractures.
b. Displacement greater than 2 mm or follow-up is unreliable: attempt closed reduction (optional)

<table>
<thead>
<tr>
<th>Reduced</th>
<th>Not Reduced</th>
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</table>

- internally fix ORIF

1) Avoid posterior dissection; visualize reduction anteriorly
2) Internal fixation: Two divergent pins preferred
3) May cross physis if needed
4) May use screw; remove later
5) Usually remove pins and splint at 6 to 8 weeks

c. Fiberglass allows best visualization of fracture

d. Late presentation (displaced and ununited longer than 6 weeks)
   1) Approach anteriorly with graft and rigid fixation if in good position (early). Operate only for lateral instability symptoms if after 3 weeks. Avoid excessive dissection.
   2) Valgus osteotomy if significant deformity exists
   3) Ulnar nerve anterior transposition if deformity is increasing

**Medial Epicondyle Fractures**

1. Background

a. Medial epicondyle begins to ossify at 4 to 6 years; fuses at around 15 years of age
b. Fracture most common in ages 9 to 12 years
c. Significance of this fracture
   1) Medial collateral ligament of ulna attaches to the base of the epicondyle.
   2) Entrapped medial epicondyle may be missed.
   3) Look for medial condylar extension.

2. Treatment

a. Principle: Displacement is well tolerated unless forceful loading is anticipated.
b. Indications for ORIF
   1) Epicondyle in joint despite attempt at manipulation
   2) High valgus stresses anticipated (dominant arm of throwing athlete, etc.) in patient with displaced epicondyle. “Stress test” in 15 degrees of flexion may be of interest, but most are unstable acutely; no specific guidelines for interpretation of this test exist.
c. Technique of ORIF
   1) Exposure is easier in prone position. May use screw or percutaneous pin. Ulnar nerve transposition is not recommended in most cases.

d. Indications for closed reduction: All cases not meeting the preceding criteria for ORIF, including the following special cases:
   1) Acute ulnar neuropathy: Likely to resolve with time; not a specific indication for ORIF or ulnar nerve transposition
   2) Displacement greater than 5 mm but not intra-articular
   3) Epicondyle fracture with elbow dislocation
   4) Technique of closed reduction: Extend elbow, wrist, and fingers simultaneously with slight valgus

Elbow Dislocations

1. Background
   a. More common in older children
   b. Before skeletal maturity, about 60% have associated fracture:
      1) Medial epicondyle
      2) Proximal radius
      3) Coronoid
      4) Olecranon
   c. Open dislocations have a high incidence of arterial injury.

2. Treatment
   a. Carefully examine for associated fractures, especially of radial head or lateral condyle.
   b. Closed reduction with sedation or anesthesia is successful in most cases.
   c. Admit or instruct parent in vascular examination
   d. Splint for 2 to 3 weeks
   e. Follow-up to rule out posterolateral instability
   f. If dislocation is missed for longer than 1 week, open reduction is needed.

Nursemaid’s Elbow (Annular Ligament Entrapment)

1. Caused by longitudinal traction in child 1 to 4 years old
2. Elbow held slightly flexed, pronated, guarded
3. Radiographs are normal.
4. Treatment: Flex and supinate (Fig. 5.4); immobilization usually is not needed.
Radial Head and Neck Fractures

1. Background

   a. Ossification develops in about 4 to 5 years
   b. Much of radial neck is intracapsular
   c. Wilkins classification
      1) Primary displacement of radial head
         a) Valgus fractures
         b) Salter I and II
         c) Salter IV
         d) Metaphyseal
         e) Fractures with elbow dislocation
         f) Reduction injuries
         g) Dislocation injuries
      2) Primary dislocation of radial neck (i.e., Monteggia variant)
2. Treatment guidelines
   a. More than 30 degrees of angulation: Accept, begin range of motion in 1 to 2 weeks
   b. 30 to 45 degrees of angulation: Manipulate but accept closed result
   c. More than 45 degrees (approximately) or translocated: Manipulate but require ORIF if unsuccessful

3. Manipulation techniques (with patient under anesthesia)
   a. Traction in extension
      1) Use fluoro to profile fracture.
      2) Press on displaced fragment.
      3) Apply varus stress to forearm.
   b. Flexion–pronation technique
      1) Flex elbow 90 degrees.
      2) Rotate forearm from full.
      3) Supination to pronation while applying pressure anteriorly to radial head
   c. Percutaneous K wire leverage:
      1) Elbow in extension
      2) Use fluoroscopy.
      3) Pin starts proximally in the "corner"of radial head, behind the posterior interosseous nerve.
   d. Metaizeau technique: 2 to 2.5 mm intramedullary rod from the distal radial metaphysis advanced retrograde into the epiphysis to obtain or maintain reduction

4. Maintaining reduction
   a. Flexion to 90 degrees if stable
   b. For unstable fractures, prefer oblique K wire from proximal to distal fragment. Protect with posterior splint.

Monteggia Fracture–Dislocation

1. Principle: Radial head dislocates in the direction in which a line through the distal ulnar fragment is pointing. Even a slight ulnar bend may be a sign of radial head subluxation (Fig. 5.5).
2. Bado classification (based on the direction of radial head dislocation)
   a. Anterior
   b. Posterior
   c. Lateral
   d. Anterior with fracture of proximal third of the radius
3. Treatment

   a. Reduction mechanism used to reduce the ulnar fracture, with supination added for anterior and lateral types of dislocation
   b. Failure to achieve or maintain radial head reduction: Intramedullary pinning or plating of ulna
   c. If this does not reduce the radial head, openly reduce it.

4. Late-presenting Monteggia fracture–dislocation can be operatively reduced up to several years after injury. Correct the ulnar bow and reconstruct the annular ligament (Bell Tawse procedure).

Supracondylar Humerus Fracture

1. Classification

   a. Direction of displacement
      1) Most are due to hyperextension; periosteal hinge is posterior.
      2) Few are due to flexion: Periosteal hinge is anterior.
   b. Degree of displacement
      1) Type I: Undisplaced
      2) Type II: Hinged/greenstick intact; posterior cortex
      3) Type III: Completely displaced
2. Principle: Type III fractures have an appreciable incidence of nerve and artery damage. They have little intrinsic stability. Best results in type III occur with pin fixation. Carefully document the status of all nerves and circulation before treatment. This involves (1) checking active palmar flexion (median nerve); (2) flexion of distal interphalangeal joints of index finger and thumb, anterior interosseous nerve; (3) dorsiflexion of the metacarpophalangeal joints, posterior interosseous nerve; (4) flexion of the fifth finger distal interphalangeal joint; or (5) crossing of the index and second fingers, ulnar nerve (Fig. 5.6).

3. Treatment

a. Type II: Correct hyperextension and any angulation. Flex > 90 degrees. Consider pin fixation.

b. Type III: Percutaneous pin fixation (Fig. 5.7)—one medial and lateral or two lateral pins. Both pins should start distal to the fracture site.

**Fig. 5.6** Documentation of the status of all nerves and circulation before treatment of supracondylar humerus fractures. This involves (A) checking active palmar flexion (median nerve); (B) flexion of distal interphalangeal joints of the index finger and thumb—anterior interosseous nerve; (C) dorsiflexion of the metacarpophalangeal joints—posterior interosseous nerve; (D) flexion of the fifth finger distal interphalangeal joint; or (E) crossing of index and second fingers—ulnar nerve.
Fig. 5.7  One technique of closed reduction and percutaneous pinning. Longitudinal traction is applied in slight flexion to correct angulation and yet allow visualization. Fluoroscopy receiver serves as platform.

Fig. 5.8  Desired pin placement for medial and lateral pin technique.
The lateral pin should engage a portion of the capitellum, and the medial pin should be slightly medial and anterior on the epicondyle to avoid the ulnar nerve (Fig. 5.8). Make a small incision to clear a tract. If two lateral pins are used, one should cross the lateral third of the fracture, and one should cross the central third of the fracture (Fig. 5.9).

c. If anatomic closed reduction is not possible, perform open reduction. Check alignment of the fracture using Baumann angle (Fig. 5.10A); normal is 72 ± 4 degrees. Also check the anterior humeral line (Fig. 5.10B), which should intersect the anterior one third to one half of the capitellum.

d. Aftercare: May begin protected range of motion at around 3 weeks with temporary splint removal. Remove pins at 6 weeks.

4. Nerve injury

a. Frequency: Radial > median > anterior interosseous > ulnar

b. Treatment: If deficit is present before reduction, it is probably a neuropraxia resulting from the injury; proceed with closed reduction. If no return by 5 months after injury, then obtain electromyelogram; explore and perform neurolysis if no recovery.
5. Arterial insufficiency

a. Reduce fracture; do not hyperflex.
   1) If perfusion returns, pin fracture.
   2) If perfusion does not return, perform an open exploration through an anterior Henry approach.
   3) If artery is entrapped, release and watch.
   4) If in spasm, use lidocaine.
   5) If an intimal tear occurs, repair.
   6) If transected, vein graft.

b. Measure compartment pressures after reperfusion and perform fasciotomy if needed.

Bibliography

♦ General

◆ **Lateral Condyle Fracture**


◆ **Medial Epicondyle Fracture**


◆ **Elbow Dislocation**


◆ **Radial Head/Neck Fractures**


◆ **Olecranon Fractures**


◆ **Supracondylar Fractures**

Pediatric Hand and Wrist Fractures

Hand Fractures

1. Distal phalanx fractures
   a. Pediatric mallet finger: Often an open injury
   b. Clean thoroughly
   c. Replace nail under fold
   d. Closed reduction or ORIF of the fracture as indicated
   e. Follow-up to rule out infection

2. Phalangeal neck (subcondylar) fractures
   a. Principles
      1) Most occur in proximal phalanx.
      2) Volar angulation is the most common.
      3) Minimal remodeling occurs in this region.
   b. Treatment of displaced fracture
      1) Closed reduction
      2) Transarticular percutaneous pinning for 3 weeks
      3) Buddy-tape for 1 week.
      4) Late presentation: May openly reconstruct up to 4 weeks post fracture
   c. Malunion: Loss of flexion may occur if malposition with bony impingement is allowed to persist.
   d. Treatment: Volar approach and removal of bony block to flexion

3. Phalangeal shaft fractures
   a. Less common in children than adults
   b. May accept 10 degrees dorsal/palmar angulation
   c. Immobilization: short arm cast/splint

4. Metacarpophalangeal joint injuries
   a. Collateral ligament does not protect physis of proximal phalanx or metacarpal head.
   b. “Extra octave” fracture of small finger
      1) Reduce using pencil in web space as a fulcrum.
      2) Reduction should be maintained when pressure is released.
      3) Hold with rolled cotton gauze between digits.
c. Intra-articular fractures
   1) If fragment is greater than 25% of the joint surface or involves any tendon insertion, it needs to be reduced to within 2 mm of anatomic alignment.
   2) Growth arrest is seen in less than 1% of patients.

d. Dislocation
   1) Often complex dorsal dislocation
      a) Volar plate entrapped
      b) Joint space wide, diaphyses parallel
      c) Sesamoids interposed
      d) Skin dimpled on volar surface
   2) Treatment
      a) One or two attempts at closed reduction
      b) Open reduction: Volar or dorsal approach
      c) Incise superficial transverse ligament lateral to volar plate

5. Pediatric thumb metacarpal fractures
   a. Metaphyseal or Salter I and II fractures: Attempt closed reduction and cast; pin if unacceptable
   b. Pediatric Bennett fractures: Closed reduction or ORIF if more than 1 mm displacement
   c. Gamekeeper's fracture
      1) Stener lesion, usually a Salter III type
      2) ORIF if displaced more than 1 mm or normal radiographs
      3) With positive stress test at 45 degrees of flexion

6. Scaphoid fractures
   a. Much less frequent in children than adults
   b. May occur with distal radius fracture
   c. If diagnosis is made within 0 to 3 months, it will usually heal with a short-arm thumb spica cast.
   d. Delayed union of more than 3 months $\rightarrow$ bone graft

**Distal Radial Physeal Fractures**

1. Salter I and II are most common.
2. One or two gentle reductions + with adequate analgesia or anesthesia
3. Immobilize in neutral position or pronation.
4. Growth arrest is rare.
5. Complications
   a. Compartment syndrome
   b. Median nerve injury

Bibliography


◆ Spine Fractures

Cervical Spine Fractures

1. General principles
   a. Child should be transported on a special backboard to accommodate large head: Recess under head or lift under shoulders
   b. Obtain radiographs if
      1) Unconscious patient
      2) Neck pain
      3) Head or facial bruising in motor vehicle accident
   c. Recommended films
      1) Lateral, anteroposterior, open mouth
      2) Obliques only if dislocation or subluxation is suspected
   d. Normal values
      1) See Chapter 1’s Fig. 1.13. Also refer to this section for normal ossification patterns
   e. Algorithms are shown for “clearing” (ruling out injury) in the trauma patient with normal radiographs but with tenderness or altered consciousness (Figs. 5.11, 5.12, 5.13, and 5.14).
Fig. 5.11  Evaluation of the asymptomatic blunt trauma patient. (From Anderson PA, Gugala Z, Lindsey RW, Schoenfeld AJ, Harris MB. Clearing the cervical spine in the blunt trauma patient. J Am Acad Orthop Surg. 2010;18(3):149–159 (Fig. 1). Reprinted with permission.)
Fig. 5.12  Evaluation of the temporarily unassessable trauma patient. (From Anderson PA, Gugala Z, Lindsey RW, Schoenfeld AJ, Harris MB. Clearing the cervical spine in the blunt trauma patient. J Am Acad Orthop Surg. 2010;18(3):149–159 (Fig. 2). Reprinted with permission.)
Fig. 5.13 Evaluation of the symptomatic trauma patient. (From Anderson PA, Gugala Z, Lindsey RW, Schoenfeld AJ, Harris MB. Clearing the cervical spine in the blunt trauma patient. J Am Acad Orthop Surg. 2010;18(3):149–159 (Fig. 3). Reprinted with permission.)
Altered mental status
Prolonged intubation
Psychiatric disturbance
Unable to cooperate

Imaging (required)

MDCT reformations

Negative
Option 1: Clear cervical spine
Discontinue collar and restrictions
Positive
Option 2: MRI

Spine consultation
Collar immobilization
Activity restrictions

MRI
(fat suppression or STIR)

Negative
Clear cervical spine
Discontinue collar and restrictions
Positive
Spine consultation
Collar immobilization
Activity restrictions

Fig. 5.14 Evaluation of the obtunded trauma patient. (From Anderson PA, Gugala Z, Lindsey RW, Schoenfeld AJ, Harris MB. Clearing the cervical spine in the blunt trauma patient. J Am Acad Orthop Surg. 2010;18(3):149–159 (Fig. 4). Reprinted with permission.)
2. Atlanto-occipital displacement (Fig. 5.15)
   
a. Usually skull is distracted and displaced forward. Suspect if dens-basion distance is greater than 12 mm or occipital condyles not resting in the superior facets of the atlas, or the Power ratio is greater than 1. Confirm with CT or magnetic resonance imaging. Document neurologic status.
   
b. Immobilize with recessed backboard and minimal or no traction.
   
c. Fusion of occiput to C1 or C2 is the most commonly accepted treatment.

3. Odontoid fracture
   
a. Reduce and hold in halo or Minerva for 8 weeks; then a Philadelphia collar for 4 weeks

4. Atlas (C1–Jefferson) fracture
   
a. Minimum (<7 mm) spread of lateral masses → Philadelphia collar
   
b. If significant spread of lateral masses (>7 mm) is seen, then traction for 4 weeks followed by collar

5. C1-C2 rotatory subluxation (Fig. 5.16)
   
a. CT scan is best study to confirm diagnosis
   
b. Symptom duration less than 1 week → collar, analgesics, bed rest, exercises to reduce
   
c. Symptom duration longer than 1 week → halter traction
\textbf{d.} Symptom duration longer than 1 month $\rightarrow$ halo traction, attempt reduction. Fuse in situ if not reducible

\textbf{6.} Transverse ligament insufficiency or os odontoideum (\textbf{Fig. 5.17})

\textbf{a.} Assess with flexion–extension views

\textbf{1)} 3 to 4 mm: Normal
2) 4 to 8 mm: Collar, restrict activities
3) More than 8 mm or any neurologic abnormalities → posterior fusion C1-C2

7. C2 pedicle fracture (Hangman’s)
   a. If C2-C3 disk is intact, immobilize in collar or halo.
   b. If C2-C3 disk disrupted, consider anterior spine fusion.

Thoracic and Lumbar Spine Fractures

1. Compression fracture
   a. If less than 20%, mobilize as tolerated.
   b. If greater than 20%, thoracolumbar spinal orthosis for comfort; mobilize as tolerated.

2. Burst fractures
   a. If neurologically normal, cast 6 to 8 weeks and then mobilize as tolerated.
   b. If neurologic deficit is present, decompress anteriorly or posteriorly and fuse.

3. Flexion–distraction (chance) (seatbelt) injuries (Fig. 5.18)
   a. Posterior elements distracted through facets, lamina, or pedicles. Minimal to no compression anteriorly
   b. Treatment: Attempt reduction in extension and immobilize for 6 to 8 weeks.
   c. If reduction is not obtained or is still unstable or if significant abdominal injury exists, then fuse.

◆ Femoral Shaft Fractures

Background Principles

1. Mechanism: Pedestrian struck by car; fall or sports; passenger in motor vehicle accident
2. Acceptable reduction: Varus/valgus of up to 10 degrees, anterior/posterior bow of 20 degrees
3. Overgrowth of about 1 cm occurs between ages 2 and 10 years.
4. Family factors are important in choosing treatment.
5. Consider child abuse if patient is younger than 2 years.
6. Hip spica cast is not a good way to maintain length.
Treatment

1. Age younger than 6 years: Resting overlap less than 2 cm or telescope test shows less than 3 cm of shortening:
   Yes → spica cast
   No → traction (in hospital or at home) or external fixator

2. Age 6 to 10 years
   a. If resting overlap is less than 2 cm or telescope test shows less than 3 cm of shortening, a spica cast is an option if the parents choose it.
   b. Preferred options:
      1) Flexible IM rods/plate/fixator
      2) Traction: in hospital or at home

3. Age older than 10 years
   a. IM rod with careful preparation of entry hole to avoid disrupting vessels at femoral neck (trochanteric entry)
   b. External fixator
   c. Plate

Fig. 5.18  Flexion-distraction (Chance) (seatbelt) injury.
Time to Union (Mean)

1. Infant: Less than 4 weeks.
2. Age 2 to 4 years: 4 to 6 weeks.
3. Age 4 to 6 years: 6 weeks.
4. Age 6 to 8 years: 6 to 8 weeks.
5. Times are longer for open or high-energy injuries.

Subtrochanteric Fractures

1. Overgrowth also occurs here: 1 cm on the average.
2. One can accept angulation of 25 degrees in any plane.
3. Fracture tends to develop anterior bow.
4. Fracture is harder to image in cast.
5. Treatment
   a. ORIF, plate
   b. External fixator
   c. Traction for 3 weeks in 90-degree flexion, then spica in 90–90 flexion

Physeal Injuries About the Knee

Normal Anatomy and Growth

1. Length of lower limbs doubles between 4 years and maturity.
2. Distal femoral physis
   a. Quadripodal shape
   b. Ligaments concentrate stress on this physis.
   c. Growth is 1 cm/year till age 13½ (girls), 15½ (boys).
   d. Blood supply to physis comes from epiphyseal vessels primarily, with some contribution from periosteal vessels.
3. Proximal tibial physis
   a. An anterior extension continues down to the tubercle.
   b. Ligaments, fibula, and semimembranosus insertion protect physis.
   c. Growth is 8 mm/year.

Distal Femoral Physeal Fracture

1. Most common physeal injury about the knee
2. Mechanism
a. Hyperextension, or  
b. Valgus

3. Findings

a. Hemarthrosis, especially in Salter III, IV  
b. May be missed in polytrauma patient.  
c. Ligamentous injury may coexist.

4. Radiographs

a. Obliques and tunnel views if needed  
b. Stress view if occult fracture suspected  
c. Plain tomograms or CT for complex Salter III and IV if fracture pattern or displacement is in question  
d. When to obtain arteriogram  
   1) If vascular examination is abnormal  
   2) Proximal tibia physeal fracture  
   3) Incidence of vascular injury ≤ 1%  
   4) In most cases, arteriogram is not necessary; especially in varus–valgus injuries. Instead, check circulation before and after reduction and instruct caregivers in monitoring it.

5. Treatment

a. Gentle closed reduction  
b. One may accept 5 degrees varus/valgus in Salter types I and II  
c. Open reduction if irreducible closed  
d. Pin if unstable  
e. ORIF all displaced type IV fractures  
f. Ensure physeal alignment by direct inspection as well as fluoro (at fracture and periphery).  
g. Immobilization  
   1) Long leg cast if limb is slender and fracture is stable  
   2) Spica cast otherwise  
h. Begin range of motion by 6 weeks  
   1) Follow-up at least 1 year to rule out growth plate injury

6. Results

a. 25 to 50% have length discrepancy greater than 1 cm.  
b. 25% have angular deformity >5 degrees.
7. Treatment of physeal bridge
   
   a. Imaging
      1) Growth lines visible on plain film should be present and parallel to physis if growth is normal.
      2) Tomograms (plain, not CT) if bridge is suspected
      3) MRI: Discuss with radiologist before study
   
   b. Indications for resection:
      1) Area of bar is less than 50% of physeal area.
      2) Growth remaining more than 2 years

**Proximal Tibial Physis Injury**

1. One quarter as common as distal femur physeal injury; 5% have popliteal, peroneal injuries.
2. Mechanism
   
   a. Hyperextension
   b. Valgus
   c. 50% occur in sports.
   
3. Treatment
   
   a. Closed versus open reduction; based on standard criteria
   b. Close vascular monitoring

**Tibial Tubercle Fractures**

1. Background
   
   a. Many have history of Osgood–Schlatter lesion.
   b. Frequency in males is greater than in females.
   c. Usual age range is 14 to 16 years.
   d. Almost always seen in jumping sports
   
2. Treatment
   
   a. Closed if minimally displaced and patient can activity actively extend knee
   b. ORIF
      1) Clear bed of interposed tissue.
      2) Use screw if fragment is large and the patient is near maturity.
      3) Otherwise, suture tendon and periosteum.
3. Complications: Rarely seen
   
a. Recurvatum: Only if patient is very young (i.e., younger than 11 years)
   
b. Lack of flexion

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Bibliography


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Physeal Injuries About the Ankle

Background

1. Normal growth
   
a. Distal tibial and fibular epiphyses appear at around the age of 2 years and close at age 15 to 16 years.
   
b. Anterolateral portion closes last.
   
c. Distal fibular physis is normally at the level of tibial plafond.

Fracture Classification (Dias)

1. SER (supination–external rotation)
2. PER (pronation–external rotation)
3. SPF (supination–plantar flexion)
4. SI (supination–inversion)
5. Axial loading
6. Tillaux
7. Triplane

Nonarticular Physeal Fractures

1. Closed versus open reduction: Standard criteria (5 degrees varus/valgus is acceptable)
2. Check rotation radiographically and clinically by thigh–foot angle.
3. Use long leg cast in most cases if displaced.

**Tillaux Fractures**
1. Anterior inferior tibiofibular ligament avulses unfused epiphyseal fragment.
2. Mechanism = SER
3. Treatment: Reduce with internal rotation gap greater than 2 mm → ORIF

**Triplane Fracture**
1. Mechanism usually SER
2. May be 2, 3, or 4-part
3. Concern is mainly articular congruity rather than growth remaining (most patients with this fracture are nearing maturity).
4. Treatment
   a. Attempt closed reduction.
   b. If it looks all right, get CT afterward to confirm.
   c. ORIF if more than 2-mm spread or any vertical displacement
   d. Anterolateral incision; Reduce posteromedial fragment first, then medial incision if needed.

**Salter IV**
1. Reduce and fix if there is any longitudinal displacement or more than 2-mm spread.

**Physeal Arrest**
1. Distal tibia is third most common site of growth arrest after fracture.
   a. Represents 25% of all physeal bars
   b. May occur with Salter II as well as III, IV, and V
2. Implications
   a. Counsel family of this risk at time of fracture
   b. Follow up for a year or longer after injury
3. Partial arrest
   a. Calculate potential angulation based on growth remaining
   b. Some guidelines
1) 8 mm = 10-degree deformity will occur if bar forms before age 13½ (boys) or 11½ (girls)
2) 1-cm growth remains after age 13 (boys), age 11 (girls)
3) Refer to growth remaining chart (Fig. 1.23).

4. Bar resection versus epiphysiodesis
   a. Latter simpler, more predictable
   b. Patient’s choice
   c. There is less need to do resection than in other areas of skeleton because length considerations are lessened.

Bibliography