Management of Fractures in Adolescents

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Adolescence is defined as a transition phase between childhood and adult- hood. It encompasses puberty (a period of rapid growth and hormonal changes), which includes an acceleration phase of growth (for about two years), a peak (peak height velocity), and a deceleration phase (for one to two years). The mean age at the time of the peak height velocity is twelve years (typical range, ten to fourteen years) for girls and fourteen years (typical range, twelve to sixteen years) for boys. Typically, girls who are more than fourteen years of age and boys who are more than sixteen years of age are considered skeletally mature and can undergo treatment similar to that for their adult counterparts. For the sake of this article, girls from eight to fourteen years old and boys from ten to sixteen years old will be considered adolescents.

The gold standard for fracture treatment in adults is often not applicable to an adolescent. Similarly, what is considered appropriate for a child is not considered acceptable for an adolescent; for example, the use of a hip spica cast is considered appropriate for a femoral shaft fracture in a child but not for one in an adolescent.

A primary difference between adults and skeletally immature patients is the quality of the bone. Because the bones of an adolescent are less mineralized, more vascular, more porous, and more elastic than the bones of an adult, the bones of an adolescent absorb more energy before they fracture, heal more quickly, and produce greater callus. The immature skeleton dissipates energy better than does the adult skeleton, and this decreases the severity of the comminution of fractures. Physes are present in adolescents, and they are the weakest link in the bone. Physeal fractures occur in adolescents, while dislocations and ligamentous injuries would occur in adults. The pattern of physeal closure in adolescents determines the physeal fracture pattern, which explains the Tillaux fracture of the distal part of the tibia and tibial tuberosity avulsion in the proximal part of the tibia. It is essential to consider the presence of an open physis during the treatment of nonphyseal fractures in adolescents to avoid iatrogenic physeal injury and possible growth disturbances. Other issues, including compliance, emotional outbursts, peer pressure, aesthetics, and other psychosocial and behavioral elements, should be considered when treating an adolescent.

Specific implants and instruments are now available to treat certain fractures in adolescents. However, this is not true for all fractures in adolescents, and it is not uncommon for fractures in adolescents to be fixed with the use of implants and instruments from an orthopaedic set meant for adults. Tibial nails have been used to treat femoral shaft fractures in adolescents, and the feasibility of using humeral nails for femoral and tibial shaft fractures has been explored.

Estimation of Maturity
Chronological age does not necessarily correlate with skeletal maturity or allow sufficient prediction of remaining growth. Determination of skeletal age is the preferred method for the estimation of the years of growth remaining. Greulich's and Pyle's atlas (hand/wrist radiographs), Pyle's and Hoerr's atlas (knee radiographs), the Sauvegrain method (elbow radiographs), the Risser sign (iliac apophyseal ossification), the Oxford score (hip and pelvic radiographs), and the Tanner-Whitehouse-III RUS score (radiographs of the radius, ulna, and small bones of the hand) are all used to estimate skeletal age. We find it simple to use the method described by Sanders et al., which is based on a simplified Tanner-Whitehouse-III RUS maturity assessment. According to this method, if the physis of the distal phalanges of the hand are wide open, the patient is skeletally immature; if these physes are partially closed, the patient is...

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approaching peak height velocity; and once these physes are closed, the patient has reached peak height velocity. Biologic age estimation with use of the traditional Tanner staging method or based on secondary sexual characteristics or menarche is important but less commonly used.2,15

**Classification of Physeal Fractures**

Although each anatomic region has a separate fracture classification, all injuries around the physis can be classified with the commonly used Salter-Harris system (Fig. 1). Salter-Harris Types I and II are extra-articular fractures, Salter-Harris Types III and IV are intra-articular fractures, and Salter-Harris Type V is a retrospective diagnosis. Rang et al.17 described a Type-VI fracture, which involves injury to the perichondral ring of LaCroix. The other two commonly seen physeal fracture patterns not described by the Salter-Harris classification are the Peterson Type-I fracture (a fracture of the metaphysis extending into the physis) and the Peterson Type-VI fracture (a fracture with a portion of the physis missing). A Peterson Type-VI fracture is similar to a Rang Type-VI fracture. These classification systems help to predict the extent and prognosis of physeal injury, aid in decision-making for its management, and allow better communication for clinical and research purposes.

**Imaging**

General principles of fracture imaging and the inclusion of joints above and below the fractures should be followed. Comparison views of the contralateral extremity may be useful for the evaluation of physeal fractures or minimally displaced or nondisplaced fractures, or to delineate ossification patterns. Stress radiographs are not recommended because of the pain involved and the risk of

![Salter-Harris classification system for physeal fractures. Type I is a fracture through the hypertrophic zone of the physis with no involvement of the surrounding bone. Type II is similar to Type I but has a metaphyseal fragment on the compression side of the fracture (the Thurston-Holland sign). Type III involves physeal separation with fracture through the epiphysis into the joint. Type IV is a fracture through the metaphysis, physis, and epiphysis. Type V is a compression or crushing injury to the physis.](image-url)
iatrogenic physeal injury. A computerized tomography (CT) scan is recommended for the evaluation of certain intra-articular fractures in the knee or ankle region to better define the fracture pattern and aid in management. Magnetic resonance imaging (MRI) is used for the evaluation of suspected ligamentous injuries, chondral injuries, and osteochondral injuries or to determine the “health” of physes.

Principles of Treatment of Physeal Fractures in Adolescents

1. Reduce displaced physeal fractures with traction and very gentle manipulation. Open reduction is better than multiple attempts at closed reduction to avoid iatrogenic physeal injury.
2. Do not attempt to reduce a physeal fracture later than seven to ten days after injury, unless there is an intra-articular step-off of >2 mm.
3. Pins or screws used for internal fixation should be parallel to the physis. Use smooth pins if they must cross the physis. Pins crossing the physis are removed as soon as early signs of fracture-healing appear.
4. Arthroscopic examination during internal fixation of intra-articular fractures can improve the accuracy of a reduction.
5. Resecting a small portion of periosteum on either side of the physis during an open fracture reduction requiring elevation of the periosteum near the physis reduces the risk of osseous bar formation across the physis.
6. For an exposed or crushed physeal injury, an acute Langenskiöld procedure (use of free fat interpositional graft) can be performed to help prevent growth arrest.
7. Most physeal fractures heal in three weeks.
8. Once a physeal fracture has healed, monitor the patient for growth disturbances for at least six months or until the patient is skeletally mature.
9. Growth arrest lines (Park-Harris lines) are transverse lines seen in the metaphysis. Their orientation and relationship to the physis are used to assess growth.
10. The sequelae and complications of physeal fracture and their management is described in Figure 2. This algorithm is applicable when the patient has at least two years of growth remaining.

Principles of Treatment of Nonphyseal Fractures in Adolescents

1. Following a fracture, the bone in adolescents does not remodel as it does in young children. The acceptable fracture reduction parameters in adolescents are similar to those used for adults.
2. Besides age, the weight of the patient and the fracture characteristics help to determine the optimal fracture fixation method and postoperative management.

**Fig. 2**
Algorithm for management of physeal injuries and their complications.
3. For most displaced diaphyseal fractures of long bones, elastic stable intramedullary nails are the implants of choice.

4. Locking plates are usually not needed.

5. For most displaced metaphyseal fractures, percutaneous pin fixation is adequate. These pins can be cut and left outside the skin for later removal in the physician’s office.

6. Fracture fixation is usually supplemented by use of a splint, cast, or brace.

7. Implant removal is optional, although it is recommended that elastic stable intramedullary nails be removed after the fracture heals.

Clavicle Shaft

The clavicle is the first bone to start the ossification process and the last to finish it\(^5\). The treatment of incomplete and minimally displaced fractures of the clavicle shaft is nonoperative. The healing and remodeling capacities of the clavicle are excellent, and this is a major reason for nonoperative care of nearly all clavicle fractures. However, it has been shown that the vast majority of clavicle growth has been completed by adolescence, with 80% of longitudinal growth completed by nine years of age in girls and by twelve years of age in boys; thus, the remodeling potential beyond these ages may be limited\(^5\). The discussion between the family and the pediatric orthopaedic surgeon regarding an adolescent with a completely displaced clavicle shaft fracture has changed substantially in the last several years. Recent published evidence regarding the treatment of adults with clavicle fractures\(^4\) has expanded the discussion of the treatment of completely displaced clavicle shaft fractures to include the possibility of open reduction and internal fixation\(^2,3\). Two centimeters or more of fracture fragment displacement has been suggested as an important threshold in adults. However, in the Level-I comparative study performed by the Canadian Orthopaedic Trauma Society that demonstrated superiority of treatment with open reduction and internal fixation with a plate and screws, the authors simply used “completely displaced” as a criterion for study entry\(^24\).

Currently, the most common procedure for surgical treatment of a displaced clavicle shaft fracture in an adolescent is open reduction and internal fixation with a plate and screws. A transverse incision is placed near or slightly below the anticipated lower border of the reconstructed clavicle shaft. The surgical approach involves progressive exposure of the fracture fragments through subcutaneous tissue, platysma, and the clavipectoral fascia and periosteal layers, with protection of crossing branches of the supraclavicular nerve\(^5,27\). Standard fixation principles, including selective use of interfragmentary lag screws as indicated, are applied. Careful drilling and a depth gauge technique are advised for all portions of the procedure, but, more medially, the subclavian neurovascular bundle is only about 10 mm away from the clavicle\(^5\). Open reduction and plate fixation allows adolescents to return to full activities about four weeks sooner than would be possible with nonoperative treatment (i.e., at twelve weeks rather than sixteen weeks)\(^5\).

Radial and Ulnar Shafts

Forearm shaft fractures are the third most common fracture in children. The literature reflects a strong and positive precedent for nonoperative care, but the outcomes of many of the studies may be biased by the inclusion of very young patients and of distal metaphyseal radial fractures under the heading of “forearm fracture.” Analysis of the outcomes of forearm shaft fractures in adolescents has shown that these fractures are more difficult to manage with nonoperative methods than has been generally believed\(^54,60\).

The shaft of the radius is that portion extending from the proximal base of the tubercle of Lister to the proximal base of the bicipital tuberosity, with the ulnar shaft defined in a similar manner. A practical classification of shaft fractures of the forearm in the pediatric population recognizes the existence of two bones, three levels (the proximal, middle, and distal thirds), and four fracture patterns (plastic deformation, greenstick, complete, and comminuted)\(^5\). Good-quality radiographs should be obtained in two orthogonal planes. If there is angulation in both planes, the true angulation will be greater than either single view reveals. The proximal and distal radioulnar joints should be carefully inspected in a patient who has what appears to be a single-bone shaft fracture.

Greenstick fractures have continuity of at least one cortex and may be reduced by derotating the forearm. A complete shaft fracture of both forearm bones in a child who is less than ten years of age can usually be successfully managed with closed methods. Angulation of more than 20° in the distal third, 15° in the middle third, or 10° in the proximal third is not acceptable even in patients younger than ten years of age\(^62,63\). Bayonet apposition is acceptable in these young patients provided that satisfactory angular, rotational, and interosseous space alignment is maintained. In children older than ten years of age, angulation of >10° is usually unacceptable. The most common indications for operative fixation are an open fracture and an inadequately reduced fracture involving both the radial and the ulnar shaft in an adolescent. Intramedullary flexible nails (elastic stable intramedullary nails) are the fixation implants of choice. A closed reduction and elastic nail fixation should be tried initially, but if this cannot be achieved within the first ten minutes, it should be converted to a minimally open reduction and elastic nail fixation. Elastic stable intramedullary nails (1.5 to 2.0 mm) are adequate, and, if needed, smaller smooth Steinmann pins are used. The radial nail is contoured to reestablish the radial bow, while the ulnar nail is minimally contoured. The narrowest portion of the intramedullary canal of the radius is central, near the isthmus, while the narrowest portion of the ulna is near its distal third. Internal fixation of the radius should be performed first. The radial entry point is the floor of the first dorsal compartment or the bare area just
proximal to the Lister tubercle between the second and third dorsal compartments. Appropriate rotation of the contoured radial implant is necessary to properly restore the radial bow. The ulnar entry point is the “anconeus starting point” along the lateral edge of the proximal part of the ulna, just distal to the growth plate. The intramedullary fixation devices should not violate either of the physes, and the extensor tendons should be protected from the sharp edges of the distal aspect of the radial elastic nails. The intramedullary nails are removed after six or more months. The potential complications of elastic stable intramedullary nailing include nail migration, delayed union or non-union, loss of reduction, loss of motion, infection, nerve injury, muscle entrapment, extensor tendon injury, a reoperation, physeal injury, and compartment syndrome (Fig. 3).

**Femoral Shaft**

The goals of treatment of femoral shaft fractures are timely union, no rotational deformity, <2 cm of shortening, and angular alignment within the acceptable parameters of 10° to 20° in the sagittal plane and 5° to 10° in the frontal plane. Valgus and procurvatum are tolerated better than varus and recurvatum deformity. Numerous treatment options are available, and the surgeon must base his or her decision on a combination of patient factors, such as age and size, fracture morphology, and type and extent of other injuries and morbidities; surgeon factors, such as familiarity with and preference for a particular technique and availability of equipment; and social factors, such as the psychological impact on the patient, disruption to the family, loss of time from school, and cost.

For adolescents, surgical treatment of femoral shaft fractures is favored over nonsurgical treatment. The benefits of surgery are lower rates of malunion, shorter hospitalization, earlier mobilization, and better social acceptance and cost-effectiveness. The potential disadvantages are the risks of surgery, scars, infection, bleeding, the need for implant removal, and the risk of damage to the physis. The various surgical treatment options include external fixation, plating, the use of elastic stable intramedullary nails, and the use of rigid intramedullary nails. We are not aware of any prospective randomized trials comparing operative treatments, but the many retrospective studies of the various options all have demonstrated acceptable results. Recently, the American Academy of Orthopaedic Surgeons (AAOS) published clinical practice guidelines for pediatric femoral fractures. Use of elastic stable intramedullary nails is a treatment option for patients eleven years of age or less, whereas surgical treatment with elastic stable intramedullary nails, trochanteric antegrade nails, or plating are options for those eleven years of age or older.

External fixation is simple and quick to apply, it can be applied at the
bedside if necessary, and the technique is familiar to most orthopaedic surgeons. It is used primarily in patients with soft-tissue injury, multiple traumatic injuries, or severe shortening. Compared with some other treatment options, it is not as well accepted by patients and families, and the cosmetic appearance of the pin site scars can be an issue. Pin site irritation and infection are common, and a relatively high refracture rate and loss of knee range of motion and quadriceps strength have been reported.

Plate and screw fixation is useful for very proximal or distal fractures, and when the medullary canal is too small for a nail. The plate is inserted through a straight lateral approach. Alternatively, a minimally invasive technique with submuscular plating through small, transverse incisions may be utilized. Locking screws may be used for very proximal or distal fractures, to convert the construct to a fixed-angle construct. In a growing child, the plate generally must be removed before it is overgrown with bone. It is unclear whether or not the plate or screw holes act as a stress riser leading to an increased refracture rate in these patients.

Elastic stable intramedullary nails have become the treatment of choice for adolescent femoral fractures because they are simple and quick to insert, the incisions are small, and family acceptance is high. The original indications for elastic stable intramedullary nails were Winquist Type-0 or 1, mid-diaphyseal fractures, but good results can be achieved when the devices are used for proximal, distal, and comminuted fractures. However, complications and loss of reduction are more likely in children who are eleven years of age or older, children heavier than 108 lb (49 kg), those with a distal or (especially) proximal fracture, and those with a comminuted or “length unstable” fracture. Adjunctive immobilization or alternate treatment options should be considered in those cases. When flexible nails are chosen, the surgeon should always use two nails of the same diameter. Failure to do so will lead to angulation. The width of each nail should be 40% of the diameter of the diaphysis at its narrowest point. The canal should never be >80% filled. The nails are bent before insertion, such that the apex of the bend is at the fracture site. For mid-diaphyseal fractures being treated with retrograde insertion, the nails should be contoured into two “c” shapes. For proximal fractures being treated with antegrade insertion, the medial nail should be contoured into a “c” and the lateral nail, into an “s.” The nails should be removed six months to one year after insertion. Overgrowth at the fracture site has not been a substantial problem with the use of elastic stable intramedullary nails. Complications include irritation at the insertion sites, the tendency for the fracture to fall into varus, and the potential for intra-articular nail penetration.

Trochanteric antegrade nails can be used in older, heavier children, and for unstable fracture patterns. The technique is generally familiar to orthopaedists who treat adults, although there are some variations among available systems. These variations include cannulated versus non-cannulated nails, universal versus right and left nails, and nails that are prebent versus those requiring custom bending. The differences are not critical, but the surgeon should know the details of the system being used. Trochanteric antegrade nails generally do not require reaming; however, the nails are typically wider proximally than distally, and the proximal part of the canal may need to be reamed to accommodate this. Complications include potential harm to the hip abductors, potential osteonecrosis of the greater trochanter, and “explosion” of the proximal part of the femur during insertion. The piriformis entry point is reserved for patients with closed physes, as cases of osteonecrosis of the femoral head have been reported in children with open physes.

**Distal Part of Femur**

Distal femoral fractures in adolescents are due either to high-energy trauma or a sports-related injury. A careful neurovascular examination of the injured extremity is necessary. Fractures of the distal part of the femur are either metaphyseal or physeal.

Metaphyseal fractures are classified by the direction of the apex of angulation. The gastrocnemius muscles pull the distal fragment posteriorly, producing an apex-posterior angulation. In patients who are less than ten years of age, closed reduction, percutaneous cross-pin fixation, and a long leg cast are satisfactory treatment. Loss of reduction is a risk, and the patient should be evaluated every week for at least the first three weeks. In patients ten years of age or older or those with a comminuted and/or unstable fracture, submuscular plating or external fixation is recommended. For distal fractures, locking screws may be used with the submuscular plate to achieve a fixed-angle device. For open fractures, patients with multiple injuries, or a floating knee, external fixation should be used.

Physeal fractures of the distal part of the femur are classified with the Salter-Harris system. For intra-articular fractures, a CT scan may help to identify fracture lines and aid in preoperative planning. Vascular and nerve injuries are not infrequent. CT angiography is recommended if a vascular injury is suspected. Reduction of the fracture into anatomic alignment and maintenance of reduction are the goals of treatment for displaced fractures. For nondisplaced Salter-Harris Type-I and II physeal fractures, a long leg cast is usually adequate. If a cast alone is inadequate, stabilization with percutaneously placed, crossed, transphyseal, smooth pins is recommended; this is similar to the treatment for displaced Salter-Harris Type-I or II fractures with a small metaphyseal fragment after closed reduction. A long leg cast and close follow-up is recommended. The pins are removed at approximately four weeks. A Salter-Harris Type-II fracture with a large metaphyseal fragment can be stabilized with cannulated screws through the metaphyseal fragment into the metaphyseal bone and application of a long leg cast, avoiding transphyseal fixation. Displaced Salter-Harris Type-III and IV fractures should be anatomically reduced and internally fixed with...
cannulated compression screws placed across the fracture and parallel to the physis. All patients with a fracture of the distal femoral physis should remain non-weight-bearing until the fracture has healed. About 50% of all distal femoral physeal fractures lead to a growth disturbance, and patients with a Salter-Harris Type-II injury have the greatest risk of limb-length inequality or angular deformity. Other potential complications include nonunion, which is treated with bone graft and rigid fixation, and arthrofibrosis, which is treated with knee manipulation and aggressive physical therapy after the fracture heals.

**Proximal Part of Tibia**

In adolescents, tibial spine fractures occur with hyperextension of the knee, typically during bicycling. The pull of the anterior cruciate ligament (ACL) leads to an avulsion fracture of the tibial spine, which may extend into the medial or lateral tibial plateau. Pain, swelling due to hemarthrosis, and a positive Lachman test are present. The avulsed tibial spine fracture is best seen on the lateral radiograph. An MRI may be necessary for a patient younger than ten years of age, as much of the eminence is still cartilaginous. Tibial eminence fractures were classified by Meyers and McKeever into three types. Type I is minimally displaced, Type II is displacement of the anterior part of the tibial spine with an intact posterior hinge, and Type III is complete separation of the avulsed fragment from the proximal tibial epiphysis. Zaricznyj described a Type-IV fracture, which is a comminuted tibial spine fracture fragment (Fig. 5). Type I is managed with a long leg cast with the limb flexed approximately 10° to 15° to avoid excessive tension on the ACL and further displacement of the tibial spine. If anatomic reduction of a Type-II fracture can be achieved by aspiration of the hemarthrosis and extension of the leg, then, like Type-I fractures, the Type-II fracture can be treated with a long leg cast, with weekly radiographs to ensure maintenance of reduction. For irreducible Type-II and Type-III fractures, arthroscopic or open reduction is recommended. An entrapped meniscus may be seen during arthroscopic surgery. We prefer arthroscopic epiphyseal or transphyseal screw fixation for Type-II and Type-III fractures with a large fracture fragment, and we recommend suture fixation woven through the base of the ACL and tied over the metaphyseal bridge on the proximal part of the tibia for treatment of a Type-IV or small fracture fragment. A transphyseal screw, if used, should be removed after three months to prevent growth disturbances. The ACL may be stretched during this injury, but symptomatic instability is uncommon. Other potential complications include nonunion, malunion with resultant notch impingement, and arthrofibrosis.

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**Fig. 4**

Salter-Harris Type-II fracture of the distal part of the femur (A), treated with open reduction and percutaneous pinning (B and C). An attempt at closed reduction showed a persistent gap over the medial part of the distal femoral physis due to interposed periosteum, which was removed during open reduction. Although the fracture healed, the patient had a physeal bar. The CT scan (D) shows the area of the physis and the area of physeal arrest. The physeal arrest is a central type.
Proximal tibial physeal fractures are categorized with the Salter-Harris classification. In adolescents, these fractures occur during sports activities or motor-vehicle accidents, with a valgus or a hyperextension force on a fixed knee. A CT scan is recommended for complex, high-energy injuries such as Salter-Harris Type-III and IV fractures involving the tibial plateau. Neurovascular injuries and compartment syndromes are not uncommon, and the possibility that they are present should be considered for every patient. The principles of treatment for proximal tibial physeal fractures are similar to those for distal femoral physeal fractures. Potential complications include neurovascular injuries, compartment syndrome, and growth disturbances.

Metaphyseal fractures of the proximal part of the tibia are usually treated with closed reduction and a long leg cast. With low-energy fractures in patients less than ten years old, so-called Cozen fractures 97, the most common complication is genu valgum in the first six to twelve months after the fracture due to medial proximal tibial overgrowth. No treatment is needed for this deformity, as it usually corrects spontaneously. For high-energy fractures in patients ten years of age or older, closed or open reduction and internal fixation with buttress plates and/or interfragmentary compression screws is used if the reduction cannot be held with a cast or if the patient cannot be treated with a long leg cast. Neurovascular injuries, compartment syndrome, and malunion are potential complications.

Tibial tubercle fractures occur most commonly in teenaged males who participate in repetitive jumping sports, and these injuries usually cause pain, swelling, and an inability to extend the knee against gravity. The fractures are classified according to the Watson-Jones classification, as modified by Ogden et al. 99 (Fig. 6). Nondisplaced Type-I fractures without an extensor lag can be treated in a cylinder cast with the knee in extension for four to six weeks, followed by rehabilitation. All displaced fractures (Types II, III, and IV) require open anatomic reduction and internal fixation with 4.5 or 6-mm screws. For Type-III fractures, arthroscopic or open joint visualization should be performed to ensure adequate joint-surface reduction. Type-IV fractures are similar to Salter-Harris Type-I or II fractures of the proximal part of the tibia, with a potential for neurovascular injuries. For Type-V fractures, the periosteal sleeve should be reattached with use of sutures or suture anchors. Prophylactic anterior compartment fasciotomy should be performed. Postoperatively, the knee should be immobilized until the bone heals. Potential complications include prominent implants requiring removal, compartment syndrome, and genu recurvatum due to premature closure of the tibial apophysis.

Ankle

Physeal injuries to the ankle account for 15% to 38% of all physeal injuries 99-102. The distal tibial physis appears by one year of age and closes by twelve to fourteen years of age in girls and by fifteen to eighteen years of age in boys. The distal fibular physis appears by two years of age and closes somewhat later than the distal tibial physis—i.e., by the age of nineteen to twenty. The medial malleolus projection appears by the age of seven and is fully formed by the age of ten. Ankle physeal injury patterns are partly due to the physeal anatomy as it relates to the patient’s age. The distal tibial physis closes in a circular pattern that proceeds from the center to medial to lateral, and the fracture patterns reflect the areas of the physis that are still open. A CT scan is recommended for intra-articular fractures to evaluate for articular displacement, physeal congruity, and surgical planning 103,104. A CT scan is also recommended after initial reduction if there are concerns about persistent or recurrent displacement. The ankle fracture classifications commonly used for adults, such as the Weber 100,101 and Lauge-Hansen 107-110 systems, are not useful for adolescents. The Dias-Tachdjian 111 classification incorporates the Salter-Harris classification.
tion; the first word in each descriptor indicates the position of the foot, and the second indicates the direction of the force. The Valvanen-Aalto classification stratifies physeal ankle fractures into two groups: group I comprises low-risk avulsion fractures and epiphyseal separations and group II, high-risk transphyseal fractures.

Patients with a nondisplaced Salter-Harris Type-I or II fracture should be treated with a below-the-knee walking cast for three to four weeks. Patients with a displaced Salter-Harris Type-I or II fracture should have a closed reduction under appropriate sedation followed by application of a well-molded above-the-knee cast, which can be switched to a below-the-knee cast after three weeks. If there is a physeal gap or translation of >2 mm after a closed reduction, an open reduction and fixation is indicated. A periosteal flap often prevents an anatomic reduction and, if it is not removed, there is a 60% incidence of premature physeal closure. In children less than ten years of age, the acceptable reduction parameters are <10° of flexion or extension and <20° of varus or valgus angulation. In children ten years or older, no more than 5° of angulation in any direction should be accepted. Most Salter-Harris Type-III and IV fractures require open reduction and internal fixation to obtain and maintain an anatomic reduction and joint congruity. An accurate reduction helps prevent premature growth arrest. Pins or screws can be used for fixation. Transphyseal fixation should be avoided if possible, but, if transphyseal fixation is necessary, smooth pins should be used and should be removed at three to four weeks. Use of a short leg cast or splint for four to six weeks is recommended. Once the cast is removed, motion and proprioception exercises should be performed before the patient returns to full activity. Radiographs should be obtained at three-month intervals for at least a year to check for growth arrest.

The Tillaux fracture is a Salter-Harris Type-III fracture of the anterolateral portion of the distal tibial epiphysis, which is the final tibial physeal area to close. It appears on the anteroposterior radiograph as a vertical line through the epiphysis. The appropriate closed reduction maneuver is internal rotation of the foot; however, these fractures may require open reduction to restore the joint surface and prevent articular degeneration. One or two pins or screws placed through the epiphysis are usually sufficient. Tillaux fractures occur toward the conclusion of physeal closure, and symptomatic growth arrest is rare.

A triplane fracture is a multiplanar Salter-Harris Type-IV fracture, which appears as a Salter-Harris Type-II fracture on the lateral radiograph and a Salter-Harris Type-III fracture on the anteroposterior radiograph. Patients with such a fracture are usually younger than those who have a Tillaux fracture and more of the physis is open, but a growth arrest is clinically unimportant.
These fractures are usually described as being in two or three parts, but they may also be in four parts. Because these patterns are so complicated, a CT scan helps one assess the fracture pattern, and it is suggested that CT be performed before surgery.

The closed reduction maneuver for a typical triplane fracture is flexion of the knee to 90°, and plantar flexion and internal rotation of the foot, with the patient under adequate sedation or general anesthesia. Multiple or forceful reduction attempts should be avoided. If the reduction is acceptable, the limb is immobilized in a long leg cast for three weeks, after which a short leg cast is worn for three weeks. If there is a concern about redisplacement, percutaneous screw fixation in a mediolateral plane in the epiphysis and in the anterior-posterior plane in the metaphysis should be performed at the time of the initial reduction. If closed reduction is unacceptable, open reduction should be performed with use of an anterolateral or anteromedial incision and a posterolateral or posteromedial incision. The goal of open reduction is to obtain a congruous joint surface.

**Overview**

The challenges in the management of fractures in adolescents are unique and should be recognized. These fractures should not be grouped with pediatric fractures, for which nonoperative treatment often suffices. The presence of physes and unique bone characteristics should differentiate the fracture management in adolescents from that of their adult counterparts.

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