Tibial Eminence Fractures

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KEYWORDS

• Tibial spine • Tibial eminence • ACL avulsion • Pediatric

Tibial eminence fracture, a bony avulsion of the anterior cruciate ligament (ACL) from its insertion on the intercondylar eminence,[1] was first described by Poncet in 1875.[2] Also known as tibial spine fractures, these injuries occur most commonly in skeletally immature patients between the ages of 8 and 14 years.[3] They account for 2% to 5% of knee injuries in the pediatric population[4,5] and 14% of ACL injuries,[6] and have an incidence of 3 per 100,000 children per year.[7] Although tibial eminence fractures are relatively rare, pediatric knee injuries, in general, are increasing in frequency secondary to increased competitive sports participation,[8,9] and present a public health problem because of the detrimental effects they can have on the health and well-being of young athletes.[10] Given these concerns, appropriate treatment of tibial eminence fractures is paramount to the restoration of knee function, return-to-sports participation, and overall quality of life.

ANATOMY

The tibial intercondylar eminence is an elevated region of bone between the medial and lateral tibial condyles. It is anatomically divided into 4 distinct regions—a medial and lateral intercondylar spine and an anterior and posterior recess[11,12]—and serves as an insertion point for the cruciate ligaments and menisci.[12,13] The ACL is oriented obliquely, originating from the posteromedial side of the lateral femoral condyle, and inserting into a broad oval- or triangular-shaped region in the medial portion of the anterior recess.[12–15] The anterior fibers of the ACL flatten out anteriorly and blend with the insertional fibers of the anterior horn of the medial meniscus, whereas the posterior ACL fibers insert into the base of the medial spine and blend with anterior insertion of the anterior horn of the lateral meniscus.[13,14,16]

MECHANISM

In the pediatric population, tibial eminence fractures are most likely to occur while children are participating in various sports, eg, falling from a bike and skiing.[17–19] The

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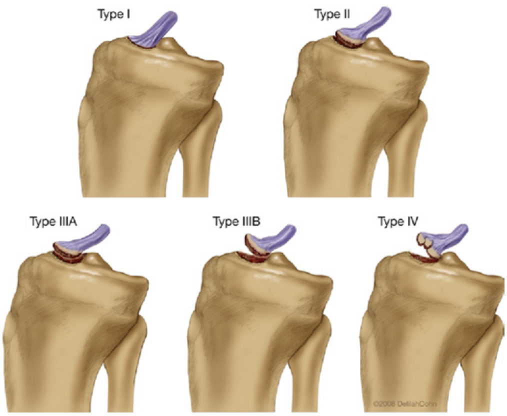

Fig. 1. Classification system of tibial eminence fractures. Type I, nondisplaced or minimally displaced anterior margin; type II, the anterior 1/3 to 1/2 of the fragment is displaced; type IIIA, complete displacement of the fragment; type IIIB, complete displacement and cephalad rotation of the fragment; type IV, comminution of the fragment. (*Courtesy of* Delilah Cohn, MFA, CMI, Nashville, TN.)

mechanism of injury is similar to intrasubstance ACL tears—hyperextension of the knee with a valgus or rotational force.[3,20–23] In a biomechanical study on primates, Noyes and colleagues[1] found that eminence fractures are more likely to occur at slower loading rates compared with intrasubstance ACL tears. In children, the weakness of their incompletely ossified tibial plateau relative to the ACL results in an avulsion fracture as tensile load is applied.[3,23] Before bone failure, an in situ stretch injury of the ACL may occur[1] and may result in clinical laxity despite adequate reduction of the fracture fragment.[24–26]

CLASSIFICATION

ACL avulsion fractures may vary considerably in the size of fragment, depth of the fracture into the tibial plateau, degree of displacement, and amount of comminution.[27] These injuries may also result in complete or incomplete ACL avulsions, with the majority of incomplete avulsions involving the anteromedial bundle.[27] The most commonly used classification system is based on 4 fracture patterns that vary in degrees of displacement and comminution (**Fig. 1**). Meyers and McKeever[28] defined types I to III. A type I fracture is the least severe, with a nondisplaced or minimally displaced anterior margin and excellent bony apposition. In a type II fracture, the anterior 1/3 to 1/2 of the fragment is displaced, with an intact posterior hinge. Type III fractures are classified in 2 subcategories. Type IIIA avulsion fractures have complete separation of the fragment from the bony bed without apposition, and type IIIB fractures are completely displaced and rotated cephalad. Zaricznyi[29] described type IV fractures, which represent comminution of the fragment.

DIAGNOSIS

A patient with a tibial eminence fracture typically presents with a painful knee hemarthrosis, decreased range of motion, and difficulty bearing weight.[24] Physical examination should include a complete neurologic and vascular examination of the lower extremity, as well as a thorough musculoskeletal examination of the knee.

Several studies have shown an association between eminence fractures and injury to the collateral ligaments, menisci, and articular cartilage.[30–32] Surgeons should be cognizant of these associated injures and treat them appropriately when encountered.

Radiographic evaluation should include anteroposterior (AP) and lateral radiographs of the knee, the latter of which is particularly useful in determining the degree of displacement of the fracture fragment. Although radiographs are used to make the diagnosis, in skeletally immature patients the fracture fragments may be considerably larger than how they appear on radiograph, because a significant part of the fragment may be cartilaginous.[23] Computed tomographic scanning allows improved visualization of the fracture fragment compared with radiographs and provides a more precise assessment of the fracture and presence of comminution.[27] Magnetic resonance imaging (MRI) can be helpful in preoperative planning by identifying concomitant injuries of the knee and the position of the fragment relative to the soft tissue structures that may impede reduction.[19,33,34] MRI is also useful in determining if interstitial injury of the ACL is present.[19]

TREATMENT

Tibial eminence fractures vary significantly in regards to fracture type, associated intraarticular injury, entrapment of soft tissue within the fracture site, and extension of fracture into the tibial plateau.[18,23,27,35] Treatment is based on these characteristics and tailored to each fracture pattern. Displaced tibial eminence fractures disrupt the continuity of the femur-ACL-tibial viscoelastic chain and can cause mechanical block to knee extension. The goals of treatment, therefore, are to restore continuity of the ACL and its stabilizing function, eliminate the mechanical block caused by the fragments, and restore congruity of the tibial plateau.[27,35–37]

TYPE I FRACTURE

The general consensus among researchers is that type I fractures can be treated nonoperatively with long-leg cast immobilization.[6,22,23,26,28,38–44] Aspiration of the knee hemarthrosis may be performed before casting to decrease swelling and pain. Although there is agreement on treatment with immobilization among researchers, opinions on knee position during treatment vary. McLennan[45] demonstrated in cadavers and in vivo that greatest tension of the ACL occurred at 0° and 45° of flexion, whereas the least tension was noted at 30° of flexion. Some researchers immobilize the knees in “slight flexion,”[23, 41] whereas others recommend immobilization at specific knee flexion angles. Meyers and McKeever[46] and Willis and colleagues[38] recommended placing the knee in 20° of flexion, Beaty and Kumar[43] recommended 10° to 15° of flexion, and Fyfe and Jackson[42] immobilized knees at 30° to 50° of flexion.

Although most investigators treat type I fractures with immobilization in flexion, others place the knee in full extension[22,41] or hyperextension.[26] However, placing the knee in hyperextension may cause discomfort for the patient[23] and can theoretically increase the risk of compartment syndrome because of excessive tension on the popliteal artery.[3] Even so, Wilfinger and coworkers[19] treated 14 skeletally immature patients with type I fractures with aspiration and closed reduction in hyperextension for 3 weeks, followed by conversion to a cast with 10° to 15° of knee flexion. In this series, no compartment syndromes or complaints of discomfort were reported.

Healing occurs rapidly in skeletally immature patients, and most researchers have treated type I fractures with 4 to 6 weeks of immobilization.[6,19,22,38] Radiographs should be obtained immediately after casting to ensure maintenance of fracture reduction and weekly or bimonthly thereafter. The duration of immobilization depends on the patient's age, signs of radiographic union, and the patient's compliance and motivation. To prevent the stiffness associated with immobilization of tibial spine fractures, the shortest period of immobilization possible is recommended.[23,35,40]

TYPE II FRACTURE

The treatment of type II fractures is more controversial than that of type I fractures; both operative and nonoperative treatments have been recommended. Nonoperative treatment typically involves cast immobilization for 4 to 6 weeks, with or without aspiration, and closed reduction of the knee in extension.[19,41] Wiley and Baxter[23] showed that the fracture line can extend into the tibial plateau, which supports the use of closed reduction to allow the femoral condyles to hold the fragment reduced. However, in a cadaveric study, McLennan[45] showed that the footprint of the femoral condyle was not congruous with the fracture line at any point of flexion. Even so, some investigators have hypothesized that extension causes the fat pad to act as a space-occupying cushion that holds the fracture reduced regardless of its size.[47] Meyers and McKeever,[46] in contrast, warned that closed reduction may convert a type II fracture to a type III fracture. If closed reduction is attempted, fluoroscopy should be used to confirm adequate position of the fragment, and the patient should be followed up closely to confirm maintenance of reduction in the cast. Kocher and colleagues[18] were only successful in closed reduction in 26 of 49 patients with type II fractures. Of those fractures that were irreducible, 26% were found to have soft tissue entrapment within the fracture preventing reduction.[18] Senekovic and Veselko[48] found intermeniscal ligament entrapment in 5 of 8 type II fractures. If an acceptable fracture reduction cannot be achieved by closed manipulation or if concurrent intraarticular injuries are present, operative treatment is indicated.

TYPE III/IV FRACTURES

Closed reduction and immobilization can be attempted in type III or IV tibial spine fractures (**Fig. 2**A). This technique is less successful in maintaining fracture reduction because the fragment is completely displaced.[39,41,45,49] The lower likelihood of success with closed reduction may be due, in part, to the higher incidence of soft tissue entrapment observed in this fracture pattern.[18,48] Kocher and coworkers[18] found 65% and Senekovic and Veselko[48] found 100% of type III fractures had intermeniscal ligament, anterior horn of medial meniscus, or anterior horn of the lateral meniscus incarcerated within the fracture. However, Lowe and colleagues[49] found no tissue interposition in 12 type III fractures, but they observed that extension of the knee caused displacement of the fracture fragment by pulling the anterior horn of the lateral meniscus that inserted on the osteochondral fragment. Given the difficulties associated with nonoperative management, most authors have recommended operative fixation for type III or IV fractures. Operative treatment regimens have included open reduction with casting,[39,41] open reduction with internal fixation (ORIF),[6,23,38,39] arthroscopic reduction with casting,[38,46] and arthroscopic reduction and internal fixation (ARIF) with sutures,[20,32,36,50–65] metal screws,[22,25,31,48,66–68] bioabsorbable nails,[69] Kirschner wires,[23,30,38,39] and, more recently, suture anchors.[70–73]

The best ARIF technique has not yet been determined because of the paucity of comparative studies in the literature. In a cohort study, Seon and coworkers[37] compared suture with screw fixation in type II and type III fractures and found no difference in functional outcomes. Biomechanical studies to determine the fixation

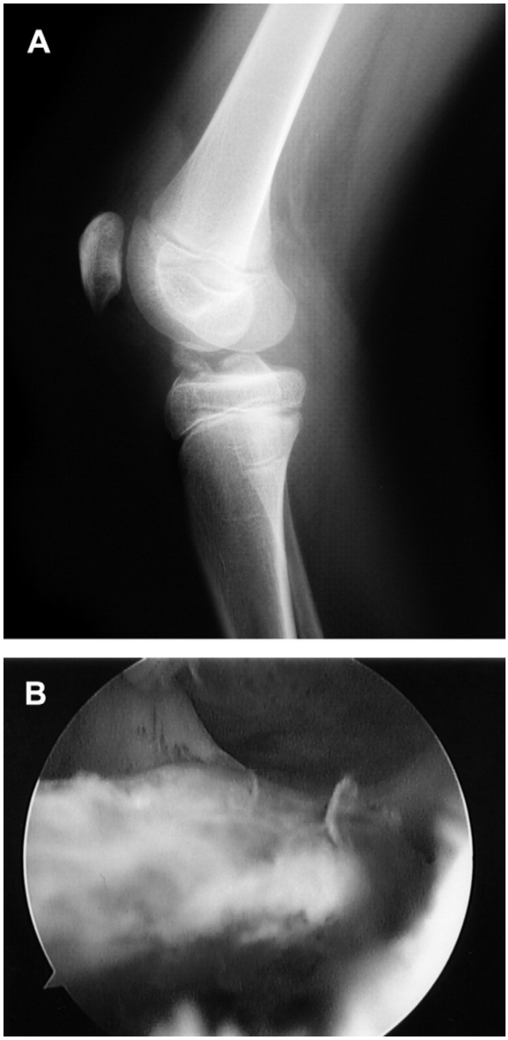

Fig. 2. (*A*) This lateral radiograph demonstrates a type IIIB tibial spine fracture in a 12-year-old male. (*B*) This arthroscopic view shows the type IIIB tibial spine fracture after the entrapped intermeniscal ligament was retracted with a 2-0 Prolene suture.

strength of various techniques have had mixed results.[74–77] In a porcine model, Eggers and colleagues[75] demonstrated that FiberWire sutures (Arthrex, Naples, FL, USA) were superior to Ethibond sutures (Ethicon, Norderstedt, Germany) and 1 or 2 antegrade cannulated screws in both cyclic and single-cycle loading protocols. They found that the use of 2 cannulated screws weakens the bone fragment, resulting in earlier failure.[75] Bong and coworkers[77] also found that FiberWire sutures were significantly stronger than 1 cannulated screw in a single-cycle failure test. In a bovine model, Mahar and colleagues[74] found no difference between Ethibond suture, bioabsorbable nails, a single bioabsorbable screw, or a single metal screw in an ultimate failure test. In a cyclical loading test, Tsukada and coworkers[76] found a statistically significant difference in displacement favoring an antegrade cannulated screw over Ethibond sutures.

Comminuted fractures should be treated with suture fixation, because screws are unlikely to provide adequate fixation.[6,60] With screw fixation, the fracture fragment should be at least 3 times the size of the screw diameter[60] to prevent disruption of the fragment. However, a second surgery may be needed for hardware removal if the screw head is prominent.[78]

SURGICAL TECHNIQUE

In the recent literature, ARIF, rather than open surgery, has become the standard of care. A mini-arthrotomy for ORIF may still be necessary in fractures that are irreducible by arthroscopic means.[37] In skeletally immature patients, physeal sparing techniques should be used to prevent growth disturbance.[79] The following techniques are based on our previous work.[80]

Setup

The operative extremity is placed in a circumferential leg holder with the hip flexed to 20° to allow lateral fluoroscopic imaging of the knee. A tourniquet is used to reduce bleeding and improve visualization. The C-arm is placed on the opposite side of the injured leg, and the tibial physis is visualized in the AP and lateral planes before the limb is prepped and draped.

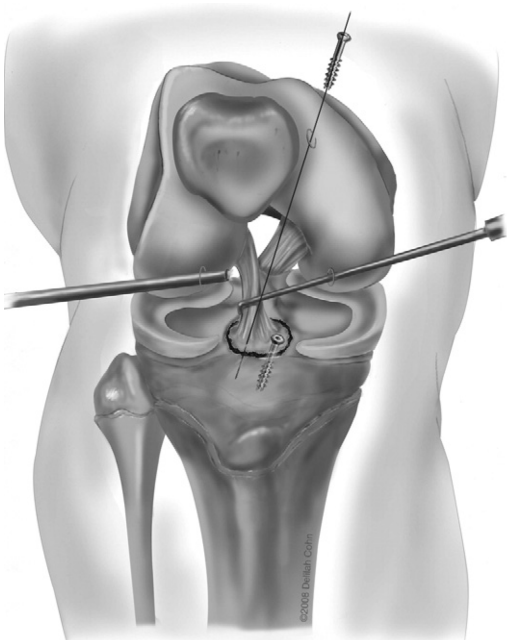

Fig. 3. With the knee flexed, a superomedial portal is established by first inserting an 18-gauge spinal needle at the level of the mid to upper patella at an angle that is as perpendicular as possible to the tibial plateau. A portal is established at this location. After the fracture fragment is reduced, a 1.25-mm threaded A-0 guide wire is inserted into the fragment, the hole is drilled with C-arm visualization, and the appropriate 3.5-mm self-tapping cannulated cancellous screw is inserted.

Screw Fixation

Standard anterolateral and anteromedial portals are created and the knee is lavaged to remove the hemarthrosis. A systematic examination is performed and any meniscal pathology should be treated at this time. A shaver is then used to resect the ligamentum mucosum and enough of the infrapatellar fat pad to allow adequate visualization. The fracture fragment is elevated, and residual blood clot and debris are removed with a shaver or small curette (**Fig. 2**B). With the knee in 60° of flexion, a superomedial portal is established at the level of the mid to upper patella by first inserting an 18-gauge spinal needle as perpendicular as possible relative to the tibial plateau. Soft tissue incarcerated in the fracture crater can be retracted with a probe through this portal. If the tissue cannot be retracted with the probe, a suture may be placed through the anteromedial portal into the soft tissue and used to extract the soft tissue from the fracture. A probe or Freer elevator is used through the anteromedial

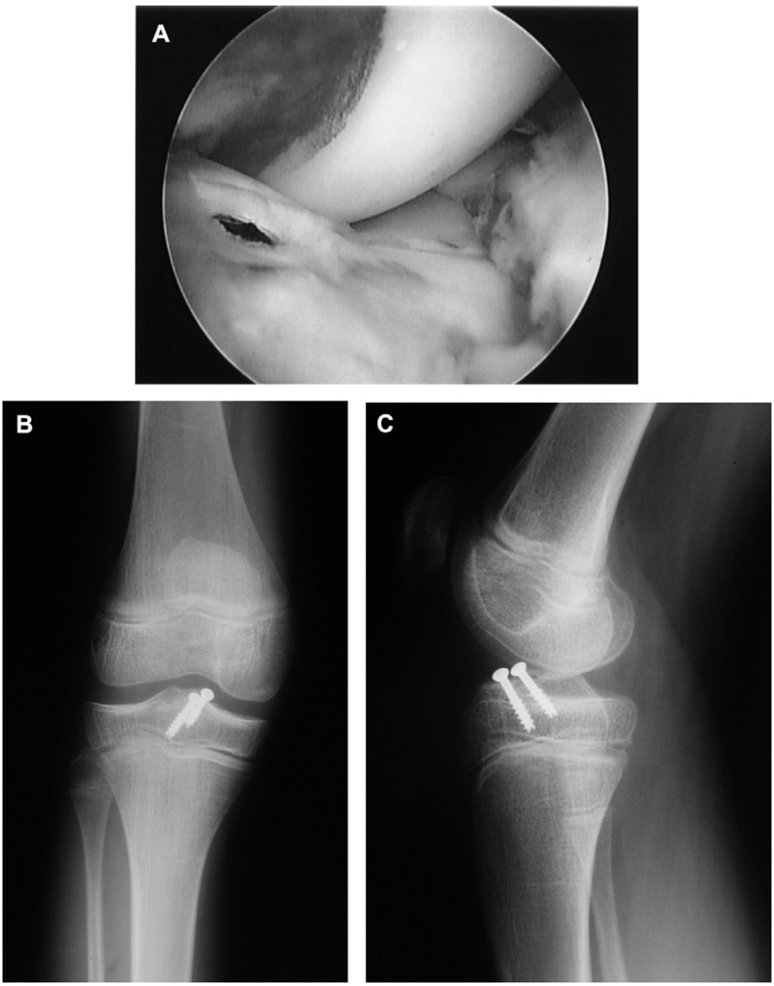

Fig. 4. (*A*) This arthroscopic view shows the fracture after fixation with 2 cannulated screws. (*B, C*) The corresponding radiograph demonstrates reduction of the fragment.

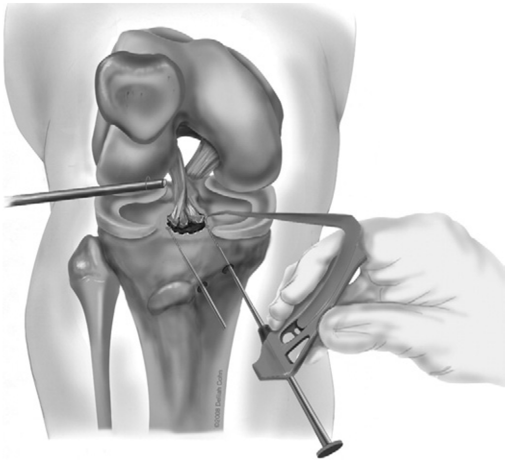

Fig. 5. An ACL drill guide, inserted through the anteromedial portal, is used to insert two 2.4-mm drill-tip guide pins that enter the joint at the lateral and medial edges of the fracture crater.

portal to reduce the fragment. A 1.25-mm thread-tip guide wire is inserted through the superomedial portal under real-time fluoroscopy into the anterior medial half of the fragment. The guide wire should be stopped before entering the tibial physis. Carefully insert the guide wire as perpendicular to the fracture as possible. A second

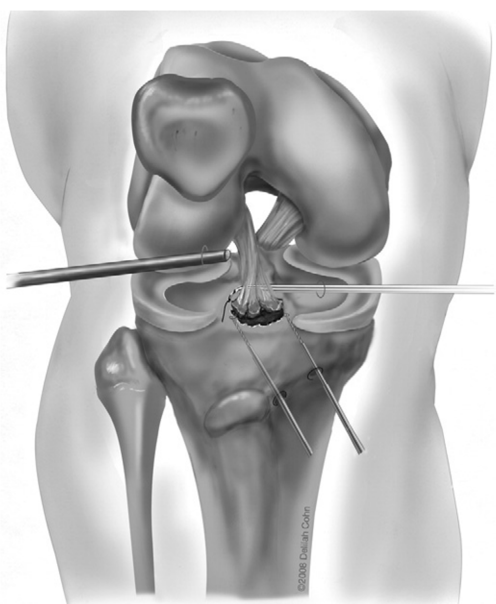

Fig. 6. A Spectrum suture passer is used to pass a 2-0 Prolene suture or shuttle relay through the posterior fibers of the ACL.

guide wire can be placed into the anterolateral half of the fragment to serve as provisional fixation while the screw is being inserted. A cannulated measuring device is placed over the guide wire, and a partially threaded, cannulated screw of appropriate length is selected. The wire is then overdrilled with a 2.7-mm cannulated drill bit under fluoroscopy, again avoiding the physis. The self-tapping 3.5-mm screw is then inserted. A second screw can be placed over the provisional guide wire if the fragment is large enough (**Fig. 3**). The knee is extended to determine if the screw head impinges on the femur (**Fig. 4**A, B, C). A small notchplasty may be performed if necessary to prevent impingement.

Suture Fixation

The initial preparation for arthroscopic suture fixation is similar to that for screw fixation. The fracture is reduced, and a thread-tip, 1.25-mm guide wire is inserted into the anterior central portion of the fragment for provisional fixation. For Tanner stage I, II, or III patients, the physis may be avoided by using a transepiphyseal rather than a transphyseal technique. Using C-arm visualization, an ACL drill guide is introduced through the anteromedial portal. Determine the entrance site of the pins on the anteromedial aspect of the tibia epiphysis by advancing the drill sleeve to the skin. A 2-cm to 3-cm incision is made in this location and the periosteum is elevated. The ACL drill guide and a 2.4-mm drill-tip guide wire are used to make 2 parallel tunnels 1 cm apart that enter at the medial and lateral edges of the fracture crater on either side of the ACL insertion (**Fig. 5**). The drill guide is removed, and a Spectrum suture passer (Conmed Linvatec, Largo, FL, USA) with a 90° tip is used to pass a 2-0 Prolene suture through the posterior fibers of the ACL as close to the bony fragment as possible (**Fig. 6**). Both ends of the suture are then retrieved with a grasper through a 5-mm cannula in the anteromedial portal. The suture is used to shuttle a #2 FiberWire (Arthrex) through the ACL (**Fig. 7**).

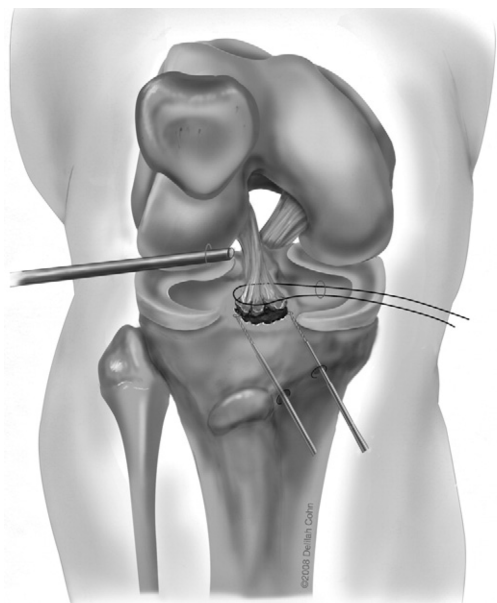

Fig. 7. A #2 FiberWire is shuttled through the ACL and pulled out the medial portal.

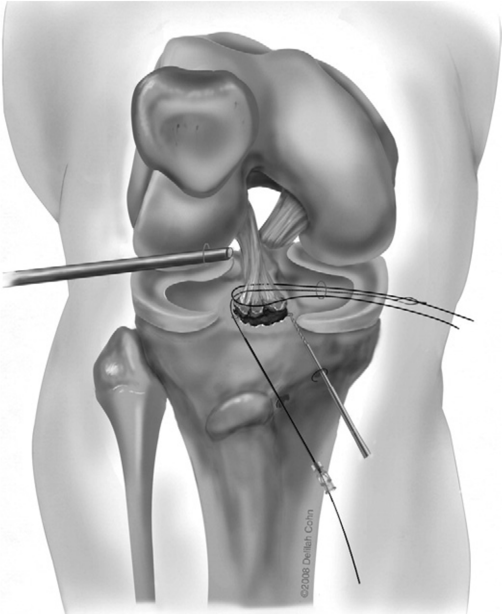

Fig. 8. The lateral guide pin is removed first and an 18-gauge spinal needle is placed in the drill hole. A CHIA suture passer is inserted through the spinal needle and is pulled out through the medial portal. The FiberWire suture limb on the medial side of the ACL is then loaded on the CHIA suture passer and pulled out through the lateral tibial drill hole.

The lateral pin is removed first and replaced with an 18-gauge spinal needle. A CHIA suture passer (Depuy Mitek, Raynham, MA, USA) is inserted through the spinal needle into the knee and retrieved through the cannula in the medial portal. The medial limb of the FiberWire suture is loaded on the CHIA passer and pulled through the lateral drill hole (**Fig. 8**). The lateral limb of the FiberWire suture is passed through the medial drill hole in a similar manner, creating a loop around the anterior portion of the ACL (**Fig. 9**). A second #2 FiberWire is passed through the base of the ACL more anterior than the first. The limbs are passed in the same manner as before, and the sutures are tied independently over the 1-cm bone bridge on the anteromedial tibial epiphysis (**Fig. 10**).

Postoperative Regimen

Place the patient in a long-leg, hinged-knee brace that is locked in extension. Encourage the patient to do quadriceps muscle contractions and straight leg raises. The day after the surgery, initiate range-of-motion exercises (ROM) and hamstring stretching in the prone position. Toe-touch weight-bearing with crutches is allowed. Progression to full weight-bearing can begin 6 weeks after surgery. Active ROM exercises, including terminal extension, and patella mobilization can also begin 6 weeks after surgery. Exercises are introduced in levels of increasing difficulty. Patients can resume participating in sports within 4 to 6 months of surgery.

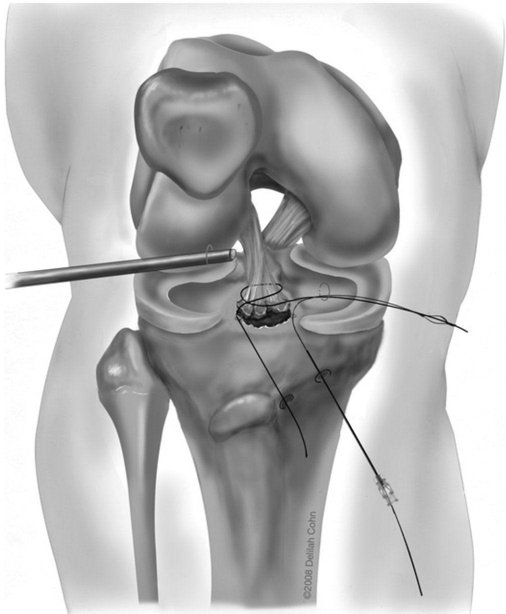

Fig. 9. The medial drill-tip guide pin is then removed and, using the same technique, the lateral FiberWire suture limb is passed out through the medial hole creating a loop around the ACL and the fracture fragments.

DISCUSSION

Despite generally good results, complications of both operative and nonoperative treatments may occur in children with tibial spine fractures, including residual laxity, loss of motion, nonunion, and growth deformity.

Residual laxity is one of the most common complications and has been reported with both operative[24,25] and nonoperative[19,39,40] treatment of all fracture patterns. Anterior laxity may be due, in part, to interstitial elongation of the ACL at the time of injury[1] and/or soft tissue interposition that impedes fracture reduction.[18] Despite the presence of objective residual laxity, many researchers found that most patients have no complaints of instability.[23,24,38,40] Residual laxity may be asymptomatic because preservation of proprioceptive feedback allows normal neuromuscular control of the knee.[22] However, other studies report that increased laxity associated with interstitial elongation results in worse outcomes.[26,45] McLennan[45] reviewed a series of type III fractures treated with closed reduction and immobilization (CRI), arthroscopic reduction and immobilization (ARI), and ARIF. He reported that International Knee Documentation Committee (IKDC), Lysholm, and Tegner scores were highest in those undergoing ARIF and lowest in the CRI group.[45] Anterior laxity was lowest in ARIF and highest in CRI. Second-look arthroscopy revealed fracture displacement in CRI and ARI groups, and 6 of 7 patients treated with immobilization had retropatellar chondromalacia.[45] Although most authors recommend an anatomic reduction,[17,18,24,48] others recommend countersinking the fragment to account for interstitial injury and minimize residual laxity.[25,72]

Loss of motion, a common problem after treatment of tibial spine fractures, may be caused by arthrofibrosis or malunion of the fracture. Arthrofibrosis has been attributed

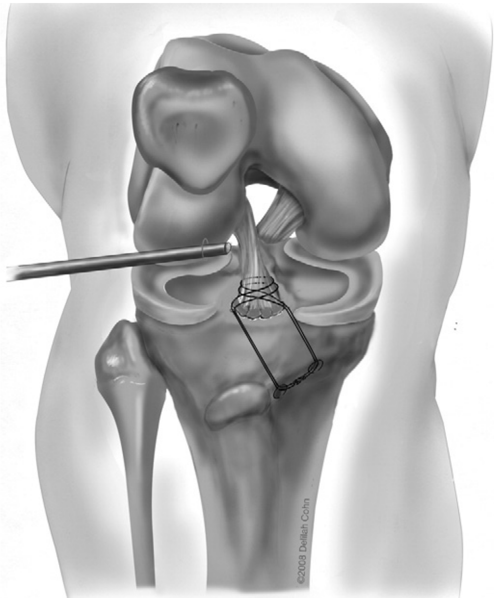

Fig. 10. A second suture is then passed through the ACL fibers more anterior than the first and the limbs are passed through the same tibial drill holes as described.

to prolonged postoperative immobilization.[23,35,40,81] The use of rigid internal fixation may allow more aggressive rehabilitation in an attempt to minimize stiffness.[81] Fracture malunion may occur as a result of incomplete reduction during nonoperative treatment[45] or malreduction during operative treatment of displaced fractures.[68] Femoral notchplasty has been used to regain extension in cases of malunion.[82,83]

Nonunion, although uncommon, has been associated with nonoperative treatment of displaced fractures.[55,56] Zhao and Huangfu[55] presented a series of nonunions of type II and III fractures that were treated with removal of the fibrous tissue and ARIF using sutures. This treatment restored normal laxity in 10 of 11 patients. The IKDC scores in these patients improved from abnormal or severely abnormal to normal or nearly normal.[55]

Iatrogenic growth disturbance, an uncommon complication after fixation of tibial spine fractures, may cause significant impairment. Mylle and colleagues[79] presented a case report of an 11-year-old girl treated with a transphyseal screw for a displaced tibial eminence fracture. Hardware was left in place for 2 years postoperatively. The patient had premature closure of the anterior half of the growth plate, resulting in 25° hyperextension, 30° loss of flexion, and instability during sports.[78] Ahn and Yoo[56] reported a series of displaced fractures treated with absorbable suture fixation through the tibial physis, with 2 cases of growth deformity. Given the potential severity of iatrogenic growth disturbance, physeal sparing techniques are recommended to fix tibial eminence fractures in skeletally immature patients.[56,63,79]

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