Biomechanical Evaluation of Tibial Eminence Fractures Using Suture Fixation

STEPHEN K. AOKI, MD; STUART H. CURTIS, BS

abstract

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This study evaluates the initial fixation strength of tibial eminence fracture repair using 1, 2, 3, and 4 sutures to determine the optimal number of sutures required to adequately secure the avulsed fragment to the tibia. Sixteen skeletally immature porcine knees were stripped of all soft tissues, isolating the femur–anterior cruciate ligament (ACL)–tibia complex. Type III tibial eminence fractures were simulated in the specimens, and each specimen was randomly assigned to a repair group using 1, 2, 3, or 4 #2 FiberWire sutures (Arthrex, Inc, Naples, Florida). Initial fixation strength of the repair was measured by single cycle pull to failure testing using a materials testing machine (Instron, Norwood, Massachusetts). The mean ultimate failure force during anterior tibial translation was 389±128, 627±66, 703±77, and 802±29 N for 1, 2, 3, and 4 sutures, respectively. The lower limit of the 95% confidence interval was >500 N (estimated force of native ACL during activities of daily living) for each group with 3 sutures. In this study, at least 2 high-strength sutures were needed for tibial eminence fracture repairs to withstand potential forces seen across the ACL in the postoperative period. Suture fixation of tibial eminence fractures is a reproducible method requiring a minimum of 2 high-strength polyester sutures to resist forces seen during early rehabilitation.

Dr Aoki and Mr Curtis are from the Department of Orthopaedics, University of Utah, Salt Lake City, Utah.

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Correspondence should be addressed to: Stephen K. Aoki, MD, Department of Orthopaedics, University of Utah, 590 Wakara Way, Salt Lake City, UT 84108 (stephen.aoki@hsc.utah.edu).

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Figure 1: AP view of the simulated tibial eminence fracture. MCL and LCL were cut prior to load testing in the materials testing machine.

Figure 2: Lateral view of a tibial eminence repair using 3 sutures. The eminence fracture was reduced and secured after the specimen was loaded into the materials testing machine.
Tibial eminence avulsion fractures result from injury mechanisms similar to anterior cruciate ligament (ACL) midsubstance injuries. Along with motor vehicle accidents, activities often associated with tibial eminence fractures include biking, skiing, and competitive sports.1-2 This type of fracture has an incidence of 3 per 100,000/year2 and occurs more often in children than adults.4,5 An increased incidence of tibial eminence fractures in the skeletally immature may be due to incomplete ossification of the tibia or increased elasticity of the ACL.4-9

Tibial eminence fractures are classified by the Myers and McKeever system.10,11 This system classifies the avulsed tibial fragment by amount of displacement. Fractures are classified as type I if nondisplaced, type II if displaced anteriorly with hinging of the posterior fragment, and type III if completely displaced. Zaricznyj12 added a type IV to indicate comminuted fractures.

Treatment of the injury consists of reduction, immobilization, and rehabilitation. For type III, type IV, and irreducible type II fractures, reduction is achieved through both open and arthroscopic techniques. Arthroscopic reduction has gained popularity due to its successful outcomes and improved recovery time.13-16 Internal fixation is currently performed using a variety of techniques and uses a wide range of devices such as sutures, screws, pins, and suture anchors.13-22 Arthroscopic suture fixation is advantageous because it is minimally invasive, allows fixation of type IV comminuted fractures, and does not require implant removal.14,17

Although suture-only fixation has been heavily used in repairing tibial eminence fractures, there is still no collective agreement on the technique. Included in this debate is the number of sutures needed to adequately reduce the avulsed fragment and maintain reduction throughout recovery and rehabilitation. Generally, the repair must resist forces up to 500 N during daily activity, as reported previously in the literature.23 The number of sutures used for internal fixation varies and is based largely on the judgment of the surgeon. To our knowledge, no study has evaluated the fixation strength of different numbers of sutures for tibial eminence fracture repair.

This study evaluates the initial fixation strength of tibial eminence fractures using 1, 2, 3, and 4 sutures to determine the optimal number required to adequately secure the tibial spine fragment. Optimization of suture repair will ensure that an adequate number of sutures are used to secure the avulsed fragment, allowing the patient a safe and effective recovery while avoiding a surplus of material and surgical time. We hypothesize that multiple high-strength sutures are required for tibial eminence fracture repairs to withstand forces encountered in the early postoperative period.

**MATERIALS AND METHODS**

In this study, 16 skeletally immature porcine knees (Innovative Medical Device Solutions, Logan, Utah) with an average age of 8 to 10 months were used to biomechanically evaluate suture fixation of displaced tibial eminence fractures. Skeletal immaturity in this model and age range has been reported in previous literature24 and has been used to simulate the pediatric skeleton because of its similarities in size, anatomy, structural content and organization, and mechanical strength of the physes.25-28 The specimens were stripped of all soft tissues except for the ACL, medial collateral ligament (MCL), and lateral collateral ligament (LCL), leaving the femur-ACL-tibia complex intact. The specimens were subsequently frozen at −20°C. Twenty-four hours prior to testing, the specimens were allowed to thaw at room temperature. A type III tibial eminence fracture was created using an oscillating saw (Stryker, Kalamazoo, Michigan) and osteotome, creating an eminence fragment measuring 1×2 cm. The undersurface cut was angled posteriorly to approximate a 5-mm posterior fragment (Figure 1).

The porcine knees were then randomly assigned to 1 of 4 fixation repair groups. Two tunnels were drilled using a standard 2.4-mm ACL guide pin. The tunnels were drilled using a standard ACL guide and were placed to flank the medial and lateral sides of the simulated tibial spine fracture. The tunnels were drilled on the proximal tibia, approximately 3 cm inferior to the joint line and spaced 1 cm apart. A #2 FiberWire (Arthrex, Inc, Naples, Florida) suture was then passed through the base of the ACL. Suture ends were pulled through their corresponding tibial tunnels using a suture retriever. All repairs were performed by the same surgeon (S.K.A.), with the only variance being number of sutures and suture placement in the ACL when multiple sutures were used.

The single-suture group was repaired using 1 suture placed just anterior to the midsubstance of the ACL. The 2-suture group was repaired by placing 1 suture in the anterior third and the other in the middle third of the ACL base. The 3-suture group was repaired by placing a suture in the anterior third, middle third, and posterior third of the ACL base. The 4-suture group was repaired by placing 4 sutures evenly spaced throughout the base of the ACL.

Sutures were left untied until the specimen was fastened into the materials testing machine (Model 1331; Instron, Norwood, Massachusetts) to prevent injury to the repair during setup (Figure 2). Each specimen was secured in the materials testing machine (Figure 1: AP view of the simulated tibial eminence fracture. The medial and lateral collateral ligaments were cut prior to load testing in the materials testing machine.)
machine with the proximal femur attached to a fixed position. The knee joint was positioned at 30° of flexion allowing the actuator arm to perform anterior tibial translation during loading. Once the specimen was fixed in the correct position, the sutures were individually tied into position to secure the avulsion fragment into the fracture bed. After repair of the eminence fracture, the MCL and LCL were cut, leaving only the repaired femur–ACL–tibia complex intact. Throughout preparation and testing, the specimens were kept moist using saline solution.

Tensile testing followed a similar biomechanical testing protocol as Bong et al17 (tibial eminence fracture repair) and Tomita et al29 (ACL reconstruction). The specimens were loaded until failure using a strain rate of 20 mm/minute with the knee positioned at 30° flexion. Force (N) and displacement (mm) were measured, and a load-deformation curve was generated. Ultimate failure load was calculated from the generated curves at the point of maximum force, and mean and standard deviation values were determined for each test group using MATLAB (MathWorks, Natick, Massachusetts). For each group, a 1-sample t test was performed comparing the mean ultimate failure load value against a constant 500 N force. All statistical results were obtained using Stata-11 (StataCorp, College Station, Texas). All P values are for a 2-sided comparison.

RESULTS

Four trials for each study group were performed, yielding a total of 16 trials. The mean ultimate failure force was 389 N for group 1, 627 N for group 2, 703 N for group 3, and 802 N for group 4. The mean ultimate failure loads for groups 2 through 4 were found to be statistically significant (P<.05) in withstanding forces >500 N. The results for the study can be found in the Table. Mode of failure for all specimens occurred by tibial side bone cutout. Figure 3 shows number of sutures against the mean ultimate failure load generated along with its corresponding confidence interval.

DISCUSSION

Tibial eminence fractures are successfully treated using several methods, and the outcome scores and return to preinjury level are generally good to excellent regardless of the fixation method chosen.30 In a clinical trial by Senekovic and Veselko,31 28 patients with an average age of 22 years were treated by arthroscopic reduction and internal fixation (ARIF) using cannulated screws. At an average follow-up of 3.1 years, the study population had a mean Lysholm score of 99, with a mean side-to-side difference in knee laxity of 1.04 mm. Side-to-side knee laxity differences >3 mm have been described as pathologic.15,32 Liljeros et al15 performed ARIF with bioresorbable nails in patients with a mean age of 10.6 years and showed successful outcomes. They treated 13 patients, and at a mean follow-up time of 3.4 years observed a mean Lysholm of 94, with a mean side-to-side laxity difference of 1.2 mm.

Another clinical trial performed by Huang et al14 had similar ARIF results using sutures. Their study consisted of 36 patients with an average age of 37 years. At a mean follow-up time of 2.8 years, they observed a mean Lysholm score of 98 with a mean side-to-side difference in knee laxity of 1 mm.

Although successful results were seen with other modes of fixation, suture fixation may have potential benefits including lower reoperation rates due to lack of retained hardware, the ability to fix commi-
nuted fragments, and potentially less physical seal disruption compared with traditional screw fixation.17,30

Most biomechanical studies in the literature aim to compare the fixation of different fixation devices, whereas few focus on variations within the same technique. In a biomechanical study performed by Eggers et al15 using porcine knees, 4 different fixation techniques were evaluated in the repair of tibial eminence fractures. They compared 2 screws, 1 screw, one 1-mm Ethibond suture (Ethicon, Somerville, New Jersey), and 1 #5 FiberWire suture. The FiberWire group had the highest yield and maximum failure load, followed by the 1-screw group, Ethibond suture group, and 2-screw group, respectively. Mahar et al18 also performed a study of 4 different fixation techniques consisting of 2 #2 Ethibond sutures, three 2.0-mm bioabsorbable nails, one 5.7-mm bioabsorbable screw, and one 3.5-mm metal screw. Failure load was greatest for the metal screw, followed by the absorbable screw, sutures, and bioabsorbable nails, respectively. A human cadaveric study by Bong et al17 evaluated screw vs suture fixation. The suture group consisted of 3 #2 FiberWire sutures, and the screw group consisted of a single 4×40-mm partially threaded cannulated screw. In a single tensile test, the suture group had a higher ultimate failure load than the cannulated screw. It can be seen from these studies that ultimate failure load depends on many variables, including type of fixation device, device material, and fixation technique.

The native ACL undergoes forces estimated from 450 to 500 N during activities of daily living.23,33,34 When extrapolating these numbers for our study, it appears that arthroscopic fixation with 2 sutures would be adequate to withstand activities of daily living and the potential stress that an ACL may see during the immediate postoperative period. Specimens with 1 suture did not consistently withstand a force of 500 N; only 1 of the specimens reached this threshold. However, every specimen with ≧2 sutures was able to withstand forces ≧500 N. Although 2 sutures appear to be the minimum needed to withstand potential stress across the ACL complex during the postoperative period, our study showed more reproducible curves as we added more sutures. With 4 sutures, we observed the highest mean ultimate failure force with the smallest standard deviation and 95% confidence interval.

The limitations of this study are consistent with limitations seen in other biomechanical studies evaluating tibial eminence fracture repairs. One of the primary limitations is the model used in the study. The ideal model for the study would be a human specimen. However, most tibial eminence fractures occur in children, and cadaveric specimens in this population are extremely difficult to obtain. Adult cadaveric specimens are more easily attainable but possess inherent differences in the mechanical properties of both bone and ACL.35-37 Porcine models have been used as an acceptable alternative to human models despite minor differences in anatomy, bone density, and composition.77,28,38

Limitations were also seen due to the method in which specimens were prepared and tested. Simulating type III tibial eminence avulsion fractures with a saw and osteotome results in consistent fragment dimensions that do not reflect the variance of injuries seen in practice. Strength of repair measured in the study may only pertain to this subset of type III eminence fractures and may not be applicable toward other patterns, such as comminuted fractures. We also used a nonabsorbable, high-strength suture for this study. The size and type of suture used varies greatly with surgeon preference and may affect overall strength of fixation. In addition, at the time of injury, the ACL midsubstance may be compromised along with a tibial eminence fracture, whereas simulated avulsion fractures maintain the integrity of the ACL. This may affect fixation strength in ways not yet understood.

The isolated testing of the femur–ACL–tibia repair complex is also a limitation because the intact knee has other tissues that provide some degree of stability and resistance. The force applied to the specimen was an anterior translation of the tibia relative to the femur with no degree of rotation. Rotational stress was not addressed in our study model. In our study design, we are also assuming that the repair needs to be strong enough to resist forces seen in the ACL during activities of daily living (approximately 500 N), as reported previously.23,33,34 This assumption may not adequately estimate forces seen in the postoperative period following a tibial eminence repair.

CONCLUSION

Arthroscopic suture fixation of tibial eminence fractures is a reproducible method of fixation. Our study supports that 2 sutures is the minimum needed to withstand the potential forces seen on the ACL complex during the immediate postoperative period. Our study also shows that using ≧2 sutures may provide more consistent fixation with less variation in ultimate failure and load-displacement curves.

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