Effect of Skeletal Maturity on Fixation Techniques for Tibial Eminence Fractures

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Background: Several fixation methods have been reported for the operative treatment of tibial eminence fractures. Previous biomechanical studies have demonstrated that suture fixation may be a stronger construct; however, the maturity status of these specimens was not scrutinized.

Purpose: To examine if suture fixation remains a biomechanically superior fixation method to screw fixation in both skeletally mature and immature specimens.

Study Design: Controlled laboratory study.

Methods: Sixteen total matched porcine (Yorkshire) knees (8 skeletally immature knees and 8 skeletally mature knees) were procured, and a standardized tibial eminence fracture was created. In each age-matched group of knees, 4 knees underwent randomization to fixation with 2 screws while 4 knees were randomized to fixation using a dual-suture technique. Once fixation was complete, the specimens underwent cyclic loading (200 cycles) in the anteroposterior plane of the tibia and load-to-failure testing, both with the knee positioned at 30° of flexion. Relevant measurements were recorded, and data were analyzed.

Results: Among mature specimens, load to failure was 1.9 times higher in the suture fixation group compared with the screw fixation group (1318.84 ± 305.55 vs 711.66 ± 279.95 N, respectively; $P = .03$). The load to failure was not significantly different between the groups in immature specimens (suture: 470.00 ± 161.91 N vs screw: 348.79 ± 102.46; $P = .08$).

Conclusion: These findings suggest that suture fixation may represent a better construct choice for fixation of tibial eminence fractures in the skeletally mature population. However, in the skeletally immature population, fixation with screws or suture may be equivalent. Displacement after cyclic loading did not appear to differ by fixation method, nor did stiffness.

Clinical Relevance: A stronger fixation construct may be beneficial and allow for earlier range of motion to help potentially decrease postoperative stiffness. Clinical studies are warranted to see if these results may be replicated in humans.

Keywords: biomechanics; knee; pediatric sports medicine; tibial eminence fracture

Tibial eminence fractures are relatively uncommon and occur most frequently in the skeletally immature population. With an incidence estimated at 3 per 100,000 persons, they account for 2% to 5% of all knee injuries with knee effusion.[2,14] These injuries most commonly occur in patients between the ages of 8 and 14 years, before complete skeletal maturation, and are usually a result of a valgus load delivered to a hyperextended knee, similar to an anterior cruciate ligament (ACL) tear.[2,13] Nonetheless, tibial eminence fractures can occur in both skeletally immature and mature individuals.

There are several key differences to note between skeletally immature and mature patients. In adults, the injury is typically a result of high-energy trauma and is more frequently associated with other concomitant injuries, such as a meniscal tear or collateral ligament injury, than in the pediatric population.[2,19] Pediatric patients who are skeletally immature have an open physis that may be violated or damaged during fixation attempts; however, it is unclear what role the open physis may play in the ultimate failure strength of surgical fixation constructs used for tibial eminence fractures.

Typically, surgical fixation methods vary by surgeon preference and fracture pattern. Fixation strategies often use an open or arthroscopic approach in combination with various implant types, including screws, sutures, suture anchors, wires, and even hybrid fixation combining multiple types of implants.[18] There are data to suggest that there is no difference in fracture healing rates in arthroscopic versus open reduction and fixation.[8] The effect of different implant types in the fixation of tibial eminence fractures has been previously studied with varied results.[10,25]

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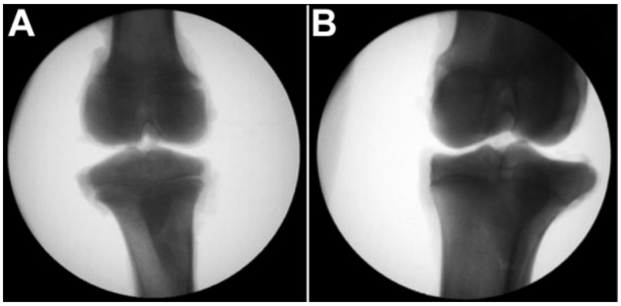

Figure 1. Fluoroscopic images demonstrating anteroposterior views of (A) the knee of an immature specimen with an open physis and (B) the knee of a mature specimen with a closed physis before fracture creation and fixation.

Although there is literature comparing fixation methods, there is no current literature comparing screw versus suture methods in either mature or immature specimens. Although the majority of patients with tibial eminence fractures are skeletally immature, there is an increasing rate of tibial eminence fractures in skeletally mature patients, and optimal resistance to failure may help guide both fixation strategies and postoperative rehabilitation.

This study investigated screw versus suture fixation technique in both an immature and mature porcine model. We hypothesized that suture fixation would provide improved structural properties (ie, cyclic displacement, cyclic stiffness, and ultimate failure load) compared with screw fixation in both the immature and mature specimens.

METHODS

Sixteen fresh-frozen Yorkshire porcine knees were obtained from a local medical laboratory. These comprised 8 (4 matched pairs) mature knees with a mean age of 34 months (range, 32-36 months) and 8 (4 matched pairs) immature knees with an age range of 5 to 6 months. The specimens were fresh-frozen at –20°C and thawed for 24 hours before testing. All muscle and soft tissues were removed with the exception of the ACL and posterior cruciate ligament (PCL) before testing. Anteroposterior (AP) and lateral fluoroscopic images were taken to confirm a closed proximal tibial physis in the mature specimens and an open proximal tibial physis in the immature specimens (Figure 1). The specimens were potted in polyvinyl chloride tubes and mounted for mechanical testing. Next, a standardized simulated fracture using previously described dimensions (20 mm [length] × 20 mm [width] × 10 mm [depth]) was created with an oscillating saw.[4,6,20] The matched specimens were randomized using a random number generator to undergo fixation with either a screw or suture technique.

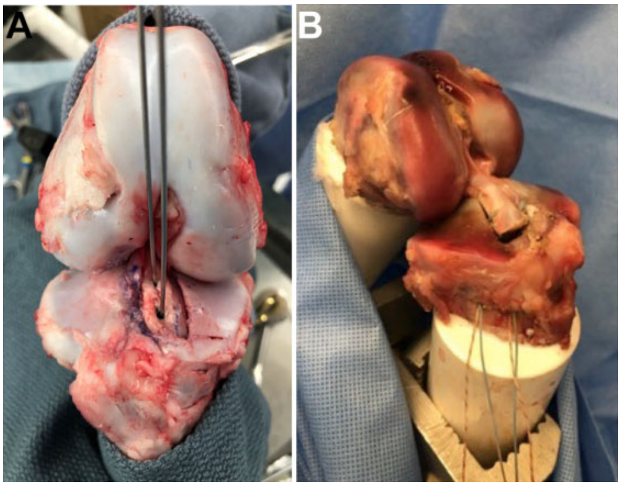

Figure 2. Specimen fixation techniques. (A) Provisional fixation in immature specimen with K-wires in planned trajectories before screw insertion. (B) Suture fixation in mature specimen before knot tying.

Fixation Techniques

In the screw fixation group, the fracture was reduced and held in place with two 1.25-mm K-wires (DePuy/Synthes), which were placed in divergent screw trajectories (Figure 2A). The first wire was positioned anterior to the ACL insertion site, and the second was placed just posterior to the first wire, within the ACL insertion site in a divergent manner. Next, the K-wires were overdrilled using a 2.7-mm drill to the distal end of the fracture site. Two standardized 35 mm–length, 3.5 mm–diameter, partially threaded cannulated screws (DePuy/Synthes) were then placed over the K-wires and tightened to adequate

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Ethical approval was not sought for the present study.

TABLE 1
Comparing Load to Failure, Cyclic Displacement, and Stiffness by Fixation Method[a]

	Load to Failure, N		Cyclic Displacement, mm		Stiffness, N/mm	
Fixation Method	Mean (95% CI)	*P*	Mean (95% CI)	*P*	Mean (95% CI)	*P*
Mature specimens		**.03**		.70		.83
Suture	1318.84 (1031.77-1685.78)		1.37 (0.86-2.18)		47.61 (33.80-67.04)	
Screw	711.66 (469.09-1079.66)		1.06 (0.57 -1.96)		55.12 (35.54-85.48)	
Immature specimens		.08		.70		.80
Suture	470.00 (326.28-677.04)		2.12 (1.27-3.56)		41.50 (33.50-51.42)	
Screw	348.79 (255.50-476.14)		3.01 (1.34-6.76)		49.01 (33.59-71.49)	

[a]Bolded *P* value indicates statistically significant difference between fixation methods ($P < .05$).

purchase. AP and lateral fluoroscopic images were obtained to ensure that all threads traveled past the fracture site.

In the suture fixation group, a tibial ACL guide (Arthrex) was used to drill 2 medial entry bony tunnels (1 cm apart) into the base of the fracture site on both the medial and lateral aspects of the fracture bed. Two No. 2 high-tensile-strength sutures (FiberWire; Arthrex) were passed through the base of the ACL, one anterior and one posterior. Two sutures were used because of previous studies demonstrating the need for at least 2 high-strength sutures to withstand the forces on the ACL in early rehabilitation.[4] A suture passer was used to retrieve the suture ends through the bony tunnels. Next, the fracture was reduced, and the sutures were secured with 5 alternating surgical knots over a bony bridge (>1 cm) (Figure 2B). Adequate fracture reduction was assessed clinically as well as with AP and lateral fluoroscopic images.

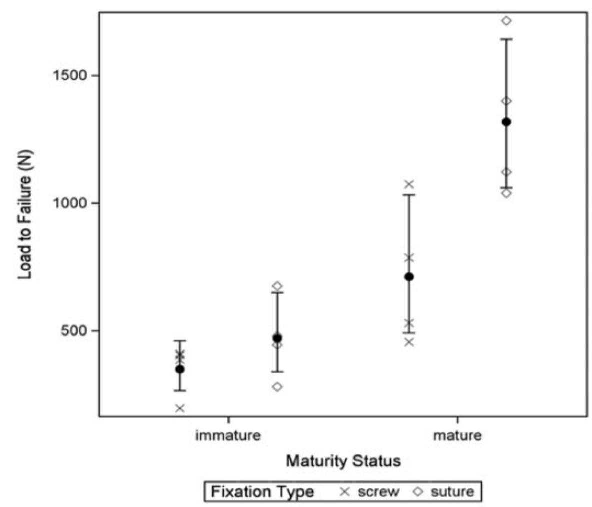

Figure 3. Mean ultimate loads to failure for screw fixation and suture fixation for mature and immature specimens. Error bars indicate 95% confidence interval.

Testing

The potted specimens were secured on a servohydraulic load frame (MTS 810; MTS) at a knee flexion angle of 30°, as previously described.[9,15,20] After applying a preload of 5 N, cyclic loading between the load limits of 5 and 150 N was applied for 200 cycles at a test frequency of 1 Hz. After cyclic loading, a load-to-failure test was performed at a loading rate of 0.5 mm/s. During the cyclic phase of testing, the primary variable was displacement (mm) over 200 cycles, which was defined as the difference in displacement between the maximum displacement observed at the 5th cycle and the maximum displacement observed at the 200th cycle. Cyclic stiffness (N/m) was a secondary variable and was calculated using the slope of the load/displacement curve during the 5th cycle. Ultimate load to failure (N) was the primary outcome variable for the load-to-failure testing. The mode of failure was also recorded.

Statistical Analysis

Generalized estimating equations were used to model the load to failure (N), displacement (mm), and cyclic stiffness (N/mm) as functions of age (immature vs mature) and procedure type (suture vs screw). A separate model was performed for each outcome. To satisfy the model assumption of normality, load to failure, cyclic displacement, and cyclic stiffness were logarithmically transformed. The model included a main effect for maturity status (mature, immature), a main effect for procedure type (screw, suture), and the 2-way interaction between maturity status and procedure type. The maximum likelihood estimators of the models were adjusted for any model misspecification using classical sandwich estimation. Pairwise comparisons between groups were conducted via orthogonal contrasts. The Holm test was used to calculate adjusted *P* values. All modeling was performed using PROC GLIMMIX (SAS Institute, Inc), and all orthogonal contrast was done using the lsmeans statement. Statistical significance was established at the $P < .05$ level, and all interval estimates were calculated for 95% confidence. Data were imported into SAS Version 9.4 (SAS Institute, Inc) for statistical analysis.

RESULTS

Load to failure was 1.9 times higher in the suture fixation group compared with the screw fixation group in mature specimens (suture: 1318.84 ± 305.55 N vs screw: 711.66 ± 279.95 N; $P = .03$). The load to failure was not significantly different between the screw fixation group and the suture fixation group in immature specimens (suture: 470.00 ± 161.91 N vs screw: 348.79 ± 102.46 N; $P = .08$) (Table 1 and Figure 3).

Cyclic displacement was not significantly different between the screw fixation group and the suture fixation group in the mature specimens (suture: 1.37 ± 0.59 mm vs screw: 1.06 ± 0.62 mm; $P = .70$) or in the immature specimens (suture: 2.12 ± 1.03 mm vs screw: 3.01 ± 2.29 mm; $P = .70$) (Table 1).

Cyclic stiffness was not significantly different between the screw group and the suture group among mature specimens (suture: 47.61 ± 15.3 N/mm vs screw: 55.12 ± 22.83 N/mm; $P = .83$) or among immature specimens (suture: 41.50 ± 8.39 N/mm vs screw: 49.01 ± 17.47 N/mm; $P = .80$) (Table 1).

All specimens that underwent screw fixation failed with screw cutout. In the suture fixation group, the majority failed by means of fracture around the suture; however, in one immature specimen, the suture cut through the bony bridge.

DISCUSSION

Tibial eminence fractures, although more common in the pediatric population, can occur in both skeletally immature and mature patients. In this porcine model, suture fixation demonstrated a higher load to failure in mature specimens. This result was similar to those reported by Bong et al,[6] wherein a mature human cadaveric model using a high-strength suture fixation method yielded high ultimate initial strength.

A systematic review of 16 studies with mostly mature patients investigated screw versus suture fixation and found that patient-reported instability was equivalent; however, objectively measured instability was higher with screw fixation compared with suture fixation.[5] A retrospective review of 48 skeletally mature patients examining screw versus suture fixation did find that the screw fixation group had better patient-reported outcomes and a nonstatistically significant trend toward a lower rate of perceived instability compared with the suture group.[17] Biomechanical cadaveric mature human models have shown that suture fixation with a high-strength braided suture (Fiber-Wire; Arthrex) demonstrated higher load-to-failure strength compared with cannulated screw fixation and suture fixation with another high-strength braided suture (Ethibond; Ethicon).[6,9] Using a mature human cadaveric model, another group found that suture fixation, with high-strength braided suture, had a higher maximum failure load and higher stiffness than screw fixation. This group also noted that there was no difference in load to failure between use of 1 or 2 screws for fixation.[9] Aoki and Curtis[4] looked at immature porcine models and determined that at least 2 high-strength polyester sutures were needed to withstand forces that would normally be seen in the early postoperative rehabilitation period (>500 N). Using an immature porcine model, Sawyer et al[20] determined that suture anchor (Arthrex) suture-bridge fixation was potentially stronger than both screw and suture fixation. To our knowledge, no previous study has included both mature and immature specimens.

Interestingly, we found that the mean load to failure for both the screw and suture fixation methods was higher in the mature porcine model compared with the immature specimens. Our fixation methods crossed the physis in the immature specimens, and this may have led to some weakness of the overall fixation construct in both the screw and suture compared with the mature specimen group. Previous biomechanical studies have used both physeal-sparing and transphyseal fixation techniques.[3,4] Physeal-sparing techniques may help potentially avoid growth disturbance complications; however, some fracture patterns may necessitate transphyseal fixation.[3,24]

Given the risk of laxity after surgical repair, displacement during cyclic loading is an important area of study in the fixation of tibial eminence fractures. In addition, one of the most common complications after tibial eminence fracture fixation is arthrofibrosis, which can lead to poor outcomes and delayed return to sport.[7,11,18,21,22] Aggressive and early postoperative physical therapy may help prevent the risk of arthrofibrosis. Our study did not find a significant difference between fixation constructs in either skeletally mature or immature groups. Similarly, Mahar et al[15] found no significant difference in the total deformation with cyclic loading in an immature bovine model. A strong fixation method, which allows less initial displacement postoperatively, may potentially allow surgeons to pursue a more aggressive postoperative rehabilitation course, which may subsequently help decrease the risk of arthrofibrosis. Both the adult and pediatric populations are at risk for postoperative stiffness; however, adults historically develop arthrofibrosis after knee surgery at a higher rate than do children.[1]

Cyclic stiffness of the repair constructs was also similar between groups in this study. Multiple studies have found no difference in stiffness between fixation methods in both the immature and mature models.[6,12,20] In biomechanical testing of human knees, the femur-ACL-tibia complex has been found to decrease in stiffness with advancing age.[26] Stiffness, while important to take into account, does not appear to play a significant role in fixation of tibial eminence fractures.

There are some limitations with this biomechanical study. Although porcine models have been used extensively in the orthopaedic literature for ACL testing, there are inherent differences between pigs and humans in vivo.[4,13,16,20,23] The cadaveric porcine models were fully dissected and implants were placed in an open fashion, which does not exactly replicate the true arthroscopic environment in which these procedures are typically performed. We also used only Meyers and McKeever type 3 fractures, similar to previous cadaveric studies, to create a replicable, standardized model.[4,6] This may not completely represent clinically encountered fracture types, necessitating a specific fixation method (ie, suture or suture anchor fixation with comminuted type 4 fractures). In addition, cadaveric studies do not account for healing after fracture fixation or other factors that occur in vivo.

CONCLUSION

In this study, suture fixation resulted in a higher load-to-failure construct in the treatment of tibial eminence fractures in mature porcine specimens. Further testing in mature and immature human specimens may be indicated to further delineate the role the physis may play in surgical fixation strength in the treatment of tibial eminence fractures.

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