Do Tibial Eminence Fractures and Anterior Cruciate Ligament Tears Have Similar Outcomes?

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Background: Avulsion fractures involving the tibial eminence are considered equivalent in terms of the cause to anterior cruciate ligament (ACL) tears; however, there are limited data comparing the outcomes of adolescent patients undergoing surgical fixation of a tibial eminence fracture (TEF) with those undergoing ACL reconstruction.

Purpose: To compare the clinical outcomes, subsequent ACL injury rates, and activity levels between adolescent patients who underwent TEF fixation with patients with midsubstance ACL tears who required acute reconstruction.

Study Design: Cohort study; Level of evidence, 3.

Methods: This study included a group of patients with TEFs treated with surgical fixation matched to a group of similar patients with ACL tears treated with reconstruction between the years 2001 and 2015. Data regarding the initial injury, surgical intervention, ACL/ACL graft injury rates, and physical examination findings were recorded. Clinical and functional outcomes were obtained using a physical examination, the International Knee Documentation Committee (IKDC) subjective score, the Lysholm score, and the Tegner activity score.

Results: Sixty patients with a mean follow-up of 57.7 months (range, 24-206 months) were included; 20 patients (11 male, 9 female; mean age, 11.9 years [range, 7-15 years]) who underwent surgical fixation for a TEF were matched to a group of 40 patients (23 male, 17 female; mean age, 12.5 years [range, 8-15 years]) who underwent reconstruction for ACL tears. The TEF group demonstrated significantly lower postoperative IKDC scores (TEF group, 94.0; ACL group, 97.2; \( P = .04 \)) and Lysholm scores (TEF group, 92.4; ACL group, 96.9; \( P = .02 \)). The TEF group returned to sport 119 days sooner (\( P < .01 \)), but there was no difference in postoperative Tegner scores (TEF group, 7.3; ACL group, 7.6; \( P = .16 \)). The TEF group demonstrated increased postoperative anterior laxity (\( P = .02 \)) and a higher rate of postoperative arthrofibrosis (\( P = .04 \)). There was no difference in subsequent ACL injuries (\( P = .41 \)).

Conclusion: Both groups demonstrated quality outcomes at a minimum 2-year follow-up. Patients with TEFs demonstrated lower mean clinical outcome scores compared with patients with ACL tears, but the differences were less than reported minimal clinically important difference values. Additionally, the TEF group experienced more postoperative anterior laxity and had a higher rate of postoperative arthrofibrosis. There was no difference in the rate of subsequent ACL injuries. The TEF group returned to sport sooner than the ACL group, but the postoperative activity levels were similar.

Keywords: tibial eminence fracture; ACL tear; ACL avulsion; pediatric ACL; ACL reconstruction

Avulsion fractures involving the tibial eminence of the knee are considered equivalent, in terms of the cause, to anterior cruciate ligament (ACL) tears.12 Although these fractures have been described in adults,20 they are more common in the pediatric population.6 Pediatric tibial eminence fractures (TEFs), as opposed to ACL ruptures, result from incomplete ossification of the tibial eminence with failure through the cancellous subchondral bone interface.50

A classification system for TEFs was first published in 1959 by Meyers and McKeever59 and was later modified by Zaricznyj.52 Type 1 represents nondisplaced fractures, which are generally treated without surgery.12,44,47 Some controversy exists regarding the proper treatment of type 2 fractures, which occur when the anterior one-third to one-half of the tibial eminence is lifted up or displaced. Most studies support nonoperative treatment for type 2 injuries with possible attempted closed reduction.6,12,14 Type 3A and 3B fractures represent completely displaced fragments, and type 3B fractures are distinguished by additional cephalad rotation of the fragment. Type 4 fractures are displaced and comminuted. Various surgical options...
have been described for type 3 and 4 fractures, but the general consensus is that operative treatment is necessary. Gans et al conducted a systematic review and concluded that no consensus exists regarding the ideal surgical technique for the treatment of displaced TEFs. This stems from the wide array of described techniques and lack of literature directly comparing the options. A high rate of arthrofibrosis after both open and arthroscopic surgical fixation of TEFs has been widely reported in the literature.

Comparative outcomes after various ACL reconstruction techniques have also been studied exhaustively. Some authors have reported postoperative complications that are unique to the pediatric population. For example, there is a known risk of injuries to the growth plate, causing possible growth arrest, with transphyseal ACL reconstruction. Additionally, the risk of subsequent ACL injuries is higher in pediatric patients compared with adults. In the pediatric population, TEFs and ACL tears have often been considered analogous injuries, but a direct comparison of their outcomes is lacking in the current literature.

The purpose of this matched-cohort study was to compare the clinical outcomes, subsequent ACL injury rates, and activity levels between pediatric patients undergoing surgical treatment of TEFs and patients requiring surgery for midsubstance ACL ruptures at a minimum 2-year follow-up. Both groups were treated surgically and were matched based on age, sex, physeal maturity, and preinjury activity level. We hypothesized that the TEF group would show an improvement in knee function after surgery, a lower rate of subsequent ACL injuries, and higher activity levels than the ACL group at a minimum 2-year follow-up.

**METHODS**

Approval from an institutional review board was granted before commencement of the study. Electronic medical records were searched for all patients who underwent surgical fixation for a TEF between January 1, 2001, and December 31, 2015. Patients were included if they (1) underwent fixation of a confirmed eminence fracture, (2) were younger than 15 years old at the time of surgery, and (3) had a minimum of 2-year follow-up. Exclusion criteria were as follows: (1) concomitant tibial plateau fracture, (2) multiligament knee injury, (3) nonoperative management of an eminence fracture, or (4) less than 2 years of follow-up (Figure 1).

The diagnosis of a TEF (Figure 2) was confirmed by imaging. Fractures were graded based on the modified classification system of Meyers and McKeever. All data regarding the initial injury, surgical intervention, physis status, age, body mass index, sex, Tegner activity score, and physical examination findings were recorded preoperatively. All operative procedures were performed by 1 of 5 fellowship-trained orthopaedic surgeons at a single tertiary-care medical center. Concurrent injuries were recorded along with concomitant procedures, as documented in the operative report. If a subsequent procedure on the injured or contralateral knee was needed, the procedure date and time to injury were analyzed.

The primary postoperative clinical outcome measures were the International Knee Documentation Committee (IKDC) subjective score and Lysholm score. The postoperative ACL status was determined based on Lachman testing at final follow-up, as performed by the attending orthopaedic surgeon. Examination results were reported preoperatively. All operative procedures were performed by 1 of 5 fellowship-trained orthopaedic surgeons at a single tertiary-care medical center. Concurrent injuries were recorded along with concomitant procedures, as documented in the operative report. If a subsequent procedure on the injured or contralateral knee was needed, the procedure date and time to injury were analyzed.

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with the contralateral knee, grading was as follows: 0, normal (–1 to 2 mm); 1+, nearly normal (3 to 5 mm); 2+, abnormal (6 to 10 mm); and 3+, severely abnormal (>10 mm). The subsequent ACL injury rate as well as knee range of motion (ROM) on physical examination were also investigated. The postoperative activity level was reported based on the Tegner activity score and return-to-sport rate. Postoperatively, TEF healing was determined by radiographic analysis.

Matched Cohort

A designated database of 120 pediatric (<16 years old) ACL reconstructions performed within our institution between January 1, 2001, and December 31, 2015, was deidentified and blinded. From this pool, patients were matched to our study group only on the basis of sex, age, physis status, and preinjury activity level. A matching ratio of 2:1 resulted in 40 patients who underwent ACL reconstruction, with a mean age of 12.5 ± 1.7 years. The 2:1 matching ratio was employed to increase the power and precision of results and to control for confounding variables when the sample size is small.17,29,38 All reconstructions were performed by 1 of 5 fellowship-trained orthopaedic surgeons at a single tertiary-care medical center.

Surgical Technique

All patients in the TEF group underwent surgical treatment for their fracture. An open technique42,50 was used in 8 patients, and in the remaining 12 patients, an arthroscopic technique35,49 was used. Suture fixation35,42 was used in 7 patients, and screw fixation was utilized in 13 patients.25,44 Gans et al14 conducted a systematic review evaluating these different surgical and fixation techniques. They ultimately concluded that no consensus on the ideal technique could be established and that all were reasonable options.

Postoperatively, patients were limited to touch weight-bearing, and the knees were kept in full extension with a knee immobilizer for 3 weeks.25 After 3 weeks, ROM exercises consisting of active flexion and passive extension were begun. At 6 weeks, patients returned for nonstanding anteroposterior and lateral knee radiographs, and the hinged knee brace was removed. After this, full active knee ROM and weightbearing as tolerated were allowed. Patients typically engaged in an ACL rehabilitation and prevention program. Patients were allowed to return to sport as early as 3 months postoperatively, and by 6 months postoperatively, the majority of patients had returned to activities as tolerated based on strength and functional criteria.

Various techniques were used for ACL reconstruction in the ACL group because of the evolving standard of care over the years of this study. All 40 patients received a hamstring graft. An autograft was used in 37 patients, a hybrid allograft/autograft in 2 patients, and an allograft in 1 patient. During the early years of this study, a transtibial femoral drilling technique45 was used in 18 patients. A transportal/anatomic drilling technique45 was utilized in 19 patients. In the remaining 3 patients, an outside-in technique10,45 was used. A transphyseal technique was used in 36 patients, and a physeal-sparing technique was used in 4 patients.43

Postoperatively, patients in the ACL group were allowed to bear weight as tolerated with crutches for the first 2 weeks. Patients were allowed to discontinue crutches and a knee brace as tolerated. The patients began an ACL rehabilitation/prevention program. Patients began straight-line jogging at 3 to 4 months, and they were cleared for return to sport at 6 to 12 months postoperatively based on strength and functional criteria.

Statistical Analysis

An a priori analysis was used to determine the TEF group size needed to demonstrate postoperative outcome efficacy. Based on the IKDC validation and responsiveness data published by Irrgang et al,19 an alpha of 0.05, and power of 0.80, it was determined that 14 patients would be needed to demonstrate significant postoperative improvements. Descriptive statistics including means, standard deviations, and ranges were applied as appropriate to assess the available demographic, surgical, physical examination, and patient-reported outcome data. Statistical hypothesis testing was performed using the Fisher exact test and Wilcoxon rank-sum test. Analysis was performed with 95% CIs, and P values <.05 were considered statistically significant. All statistical analyses were performed using JMP software (version 12.0.1; SAS Institute) and G*Power 3.1.9.2 (G*Power Team).

RESULTS

The final patient cohort consisted of 60 patients. The TEF group consisted of 20 patients who had undergone surgical fixation of a TEF, and the matched group consisted of 40 patients who had undergone ACL reconstruction. All patients had a minimum 2-year follow-up. The mean time to final follow-up in the TEF group was 67.7 ± 30.2 months compared with 52.7 ± 49.3 months in the ACL group. Demographics were similar between the 2 groups, but the TEF group
underwent surgery much sooner after an injury compared with the ACL group (Table 1). The ACL group had a higher rate of comorbid injuries (Table 2). Additionally, the ACL group had a higher rate of concomitant procedures, which consisted of meniscal repair in the majority of cases (Table 3).

Clinical Outcomes

The mean postoperative patient-reported outcomes including the IKDC and Lysholm scores were significantly lower in the TEF group (Table 4).

Physical Examination Findings

Failures were excluded from the analysis of postoperative physical examination results. The TEF group had significantly greater anterior laxity at postoperative follow-up. Lachman testing results are shown in Table 5.

In the TEF group, the mean preoperative ROM was $11.7^\circ \pm 4.0^\circ$ of extension to $65.8^\circ \pm 34.1^\circ$ of flexion; postoperatively it was $2.1^\circ \pm 2.7^\circ$ of extension to $129.4^\circ \pm 15.8^\circ$ of flexion. The ROM are significantly increased after surgery (from $54.1^\circ$ to $127.3^\circ$; $P < .01$).

In the ACL group, the mean preoperative ROM was $-1.0^\circ \pm 9.3^\circ$ of hyperextension to $119.2^\circ \pm 24.6^\circ$ of flexion; postoperatively it was $-0.5^\circ \pm 5.9^\circ$ of hyperextension to $134.2^\circ \pm 14.6^\circ$ of flexion. The ROM are significantly increased after surgery (from $120.2^\circ$ to $134.6^\circ$; $P = .01$). The final ROM arc was not significantly different between groups.

Subsequent ACL Injuries

In the TEF group, 1 patient (5%) sustained an ACL rupture 41 weeks after TEF fixation during a sport-related injury.
and required ACL reconstruction; his graft reruptured 2 years later, and he required revision ACL reconstruction.

In the ACL group, 6 patients (15\%) sustained an ACL rerupture at a mean of 43.4 ± 41.2 months, 5 of which occurred during sport-related activities and 1 with activities of daily living. All required revision ACL reconstruction and remained free of further reruptures at latest available follow-up. The failure rate did not significantly differ between the TEF and ACL groups (\(P = .41\)).

Tegner Activity Score

No significant difference between groups was seen in the postoperative activity level, according to the Tegner activity score at follow-up (Table 4). The mean Tegner activity score decreased in both the TEF group (from 8.1 to 7.3; \(P = .05\)) and ACL group (from 8.0 to 7.6; \(P = .40\)) when compared with preinjury levels; however, these findings were not statistically significant.

Return to Sport

The mean time to return to sport was 161 ± 87.6 days in the TEF group versus 280 ± 91.1 days in the ACL group (\(P < .01\)). Two patients in each group never returned to sport.

TEF Healing

Radiographic evidence of healing was seen in all 20 patients in the TEF group at a mean of 70 days after surgery.

Complications

The arthrofibrosis rate was higher in the TEF group (\(P = .04\)). Surgical complications in the TEF group included 4 cases of arthrofibrosis (20\%), for which 3 patients required arthroscopic intervention; 1 case of hemorrhatis (5\%) requiring aspiration; and 1 case of superficial wound dehiscence managed nonoperatively. For the cases of arthrofibrosis, 2 of the index surgeries were performed with open arthrotomy, with 1 being fixed with sutures and the other with screws. The additional 2 cases were treated with arthroscopic screw fixation.

In the ACL group, there were 2 cases of hemorrhatis (5\%) requiring arthrocentesis, 2 cases requiring tibial screw and washer removal (5\%), 1 case of arthrofibrosis (2.5\%) requiring arthroscopic intervention, and 1 case of a growth plate injury requiring epiphysiodysis for a leg-length discrepancy more than 5 years after the index ACL reconstruction.

DISCUSSION

The mechanisms of injury for TEFs and ACL tears are similar, but the results of surgical treatment have not been directly compared. In the present study, the TEF group demonstrated decreased clinical outcome scores and an increased rate of postoperative arthrofibrosis and anterior laxity compared with the ACL group. There was no difference in the rate of subsequent ACL injuries or postoperative activity level between groups, although the TEF group returned to sport sooner.

Both groups demonstrated very good outcome scores at a minimum 2-year follow-up, but the TEF group had lower IKDC and Lysholm scores compared with the ACL group. The mean IKDC score of 97.2 and mean Lysholm score of 96.9 in the ACL group are comparable with those published in previous studies with a similar follow-up time.\(^{48}\) The mean Lysholm and IKDC scores in the TEF group are also comparable with the scores in previously published cohorts.\(^{14}\) This supports the validity of the mean clinical outcome scores of both groups in the present study.

The difference in IKDC and Lysholm scores between groups was statistically significant. This suggests that patients with TEFs may have lower functionality compared with patients with ACL tears; however, the differences were less than the established minimal clinically important difference (MCID) (Lysholm, 10.1; IKDC, 11.5).\(^{9,19}\) It should be noted that these MCID values were based on a group of patients with a mean age of 40.5 years and may not directly apply to the young patients in the present study.\(^{18}\) There is a need to establish MCID values specific to the adolescent population.

The TEF group demonstrated increased anterior laxity compared with the ACL group on Lachman testing at midterm follow-up. Persistent anterior laxity after a TEF is consistent with previously published studies.\(^{7,14,25,44}\) In the present study, 26\% of patients in the TEF group demonstrated grade ≥1+ on Lachman testing at follow-up. The relevance of this finding is unknown. It has been hypothesized that the increased laxity is the result of a mild injury to the ACL at the time of an eminence fracture.\(^{1,3,25,50}\) This relatively high rate of persistent anterior laxity has caused some to question whether it would lead to future ligament, chondral, or meniscal injuries.\(^{25,26}\) This has not yet been demonstrated in the current literature, and it did not appear to be a factor in the current study.

The increased anterior laxity did not correlate with an increase in the rate of subsequent ACL injuries when compared with the ACL group. In the TEF group, 1 patient (5\%) sustained a subsequent ACL rupture 41 weeks after TEF fixation. Aderinto et al\(^1\) reported a 10\% rate of symptomatic anterior laxity after TEF fixation. It is unclear how many patients went on to require revision or ACL reconstruction. Aderinto et al\(^3\) did report that the risk of symptomatic anterior laxity is much more common when these fractures are treated nonoperatively. In the ACL group of the current study, 6 (15\%) patients sustained a rerupture at a mean of 43.4 months postoperatively. The rate of reruptures in the ACL group is slightly higher than in some previously reported studies.\(^{22,28}\) This is likely related to the relatively young mean age of the ACL group in this study.\(^{1,4}\)

Both groups demonstrated a decrease in the Tegner score at midterm follow-up. This finding is likely more related to the high level of competitive athletic involvement in the younger population, which commonly decreases with age.\(^{27}\) The Tegner scores in the present study are very comparable with those in other published studies for both the TEF\(^{25}\) and the ACL\(^{48}\) groups. The TEF group returned to sport
sooner than the ACL group, but no difference was seen in the rate of return to sport, as the majority returned in both groups. Patients tend to be cleared earlier for return to sport after TEF treatment compared with those after ACL reconstruction because fracture healing occurs faster than ligamentization of the ACL graft.11

There were no major intraoperative complications in either group. The TEF group had a higher rate of postoperative arthrofibrosis than the ACL group (20% vs 2.5%, respectively). Other studies have reported similar rates of arthrofibrosis after fracture fixation and report it as the most common postoperative complication.1 Rehabilitation protocols did differ between the 2 groups, and notably, patients in the TEF group required 3 weeks of knee immobilization in full extension to protect the fracture fixation site. This prolonged period of immobilization may have contributed to the increased rate of arthrofibrosis in the TEF group. It is also possible that the shorter time from injury to surgery in the TEF group may have contributed to the higher arthrofibrosis rate. In the ACL group, 1 patient developed a leg-length discrepancy and required epiphyseodesis. The growth plate does seem to be at an increased risk of injuries with ACL reconstruction compared with TEF fixation, depending on the method of ACL socket and tunnel drilling.

Given the constellation of these findings, one could certainly question whether the ACL should be reconstructed at the time of the TEF rather than fixed. This is not our current practice, as there is likely some benefit to preserving the native anatomy and proprioceptive fibers of the native ACL. More research is certainly needed on this topic.

There are several limitations to this work that merit discussion, as the inherent drawbacks of any retrospective study are well established. Unfortunately, the cohort was too small to perform subgroup analysis of the different TEF fixation techniques and approaches. Examiners were not blinded, and the pivot-shift test was not consistently performed. Additionally, functional testing was not compared between groups. Although injuries with major prognostic implications such as multiligament injuries were excluded, we were unable to match the groups based on any additional concomitant injuries. There were more meniscal tears in the ACL group and more medial collateral ligament injuries in the TEF group. However, we do not feel that this greatly affected the results of the study, as the majority of the meniscal tears were repaired and the medial collateral ligament injuries did not require operative intervention. This allowed the native anatomy to be preserved in both groups. It is possible that the increased rate of meniscal tears may have major implications regarding the long-term prognosis of the knees in the ACL group. The TEF group had a greater mean follow-up time, but all patients in both groups achieved a minimum 2-year follow-up. No instrumented measuring device was used for the physical examination, which limited interexaminer reliability. Despite these limitations, to our knowledge, this is the first study directly comparing the outcomes of patients with TEFs with patients with ACL tears after surgical treatment.

CONCLUSION

Both study groups demonstrated good outcomes at a minimum 2-year follow-up. Patients with TEFs demonstrated lower mean clinical outcome scores compared with patients with ACL tears, but the differences were less than reported MCID values. Additionally, the TEF group experienced more postoperative anterior laxity and had a higher rate of postoperative arthrofibrosis. There was no difference in the rate of subsequent ACL injuries. The TEF group returned to sport sooner than the ACL group, but the postoperative activity levels were similar. These results can be useful for clinical decision making and discussion with patients and their families who are affected by these injuries.

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