Comparison of Two Fixation Methods in Treating Displaced Pediatric Tibial Eminence Fractures at Boston Childrens Hospital

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Abstract:

Introduction: Tibial eminence fractures (TEF) occur most often in children, and disrupt the bony attachment of the anterior cruciate ligament (ACL) to the tibia. Displaced TEF are managed surgically with reduction and fixation of the displaced fragment. This study compares the two most common methods of surgical fixation, suture and screw fixation.

Methods: A retrospective case-study review of 78 patients treated at Boston Childrens Hospital for tibial eminence fractures comparing surgical results following suture or screw fixation.

Results: Seventy-eight tibial spine injuries were analyzed with an average age at surgery of 11. Thirty-six knees were treated with sutures versus 35 with screws. Sport related injuries were found to be the most common cause of TEF. Mild activity-related pain was reported in 23% of patients. It was noticed that concurrent meniscal pathology leads to statistically significantly higher rates of loss of flexion. The total complication rate of the cohort was found to be 33%.

Conclusions: We concluded that no major outcome differences were seen with suture vs. screw fixation. Numerous observations can be made from this study regarding percentage of complications and residual symptoms. Future work will aim to follow patients prospectively for assessment of knee function.

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Glossary

ACL: Anterior Cruciate Ligament

CHB: Children's Hospital Boston

CT: Computer Tomography

DynaSplint: Dynamic Splinting

LCL: Lateral Collateral Ligament

MCL: Medial Collateral Ligament

MRI: Magnetic Resonance Imaging

PCL: Posterior Cruciate Ligament

Pedi-IKDC: Pediatric International Knee Documentation Committee

Introduction[1]:

Tibial eminence fractures occur most often in children and adolescents between the ages of 8 and 14, particularly in the setting of bicycle and sport-related accidents.(1) These fractures are analogous to anterior cruciate ligament (ACL) ruptures in adults. However, in the actively growing pediatric population, the ligamentous ACL is stronger than its bony insertion and therefore this injury often results in an avulsion of the bony ACL insertion on the tibia rather than a mid-substance rupture of the ACL. This bony weakness is due to an incomplete ossified tibial eminence secondary to skeletal immaturity.(2)(3) Moreover, greater ligament elasticity of younger patients has also been suggested as potential cause for tibial eminence fracture rather than ACL disruption.(4) The tibial eminence, site of attachment of the ACL bundles, is not considered an articulating component; hence, these fractures are considered functional fractures that destabilize the ACL rather than articular fractures that may result in arthritis. In order to restore the integrity of the ACL following this injury, the bony fragment must be reduced back to its native tibial insertion site.[2]

Younger patients can also sustain midsubstance ACL injuries although this is much less common. Recent studies at our institution have shown that age- and sex- matched patients with tibial eminence fractures have a wider "notch index" (ratio of width of intercondylar notch to total width of the distal femur) when compared to similar aged patients with midsubstance ACL injuries which suggests that the notch-width index may play a role in whether or not a skeletally immature patient sustains a tibial eminence fracture or a midsubstance ACL injury. (5)

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[1] Parts of this work were previously reported as part of the scholarly project proposal submitted to Scholars in Medicine Office (Anciano Granadillo V., Kramer D. [2012] Scholarly Project Proposal.
[2] Part of this work is currently part of the manuscript in preparation by Kramer Et al. as part of a book chapter for the upcoming "Master Techniques in Orthopaedic Surgery: Pediatrics"

Tibial eminence fractures are categorized according to the Meyers and McKeever classification system (Figure 1). Type I fractures are non-displaced and do not interfere with knee extension. In Type II fractures, the anterior portion of the fracture is elevated, but not completely displaced. Type III and Type IV fractures involve complete displacement of the intercondylar eminence from the tibia (Figure 2). Many Type II fractures and nearly all Type III – IV fractures require surgical intervention.(6) Displaced tibial eminence fractures are managed surgically with reduction and fixation of the displaced fragment. Surgery can be done arthroscopically or through an open approach. Lubowitz et al. (4) suggests numerous advantages of arthroscopic reduction and internal fixation (ARIF) versus open reduction and internal fixation (ORIF) of tibial eminence fractures, specifically minimal surgical morbidity and decreased length of hospital stay (most are performed on an outpatient basis).

Displaced tibial eminence fractures tend to result in knee instability, primarily through the loss of the ACL's biomechanical function. In addition, tibial eminence fracture fragments that heal with significant bony elevation may block full knee extension. Moreover, tibial eminence fractures can present with associated injuries to collateral ligaments, menisci, capsule and cartilage. During surgery, it is common to find entrapment of the anterior intermeniscal ligament, anterior horn of the medial meniscus or anterior horn of the lateral meniscus in the fracture site. Kocher et al. (7) described, at our institution, the prevalence of meniscal entrapment in a patient pool of 80 to be 26% of patients with type 2 tibial eminence fractures and 65% of patients with type 3 tibial eminence fractures. He also reported 3.8% of patients with associated meniscal tears. Kocher et al. recommended arthroscopic or open reduction consideration for type 2 fractures that do not reduce in extension to allow for removal of incarcerated meniscus giving way for anatomic reduction. Without surgery, it is unknown how the meniscus would function if the incarcerated meniscal fragment permanently healed into the fracture site (a non-native position).

Determining the frequency of tibial eminence fractures is difficult. The occurrence of these fractures was once believed to be rare; however, the incidence seems to be rising, possibly because of greater awareness of the injury among physicians, greater utilization of advanced imaging such as MRI or an increase in sports participation in early adolescence. Increased sports participation with a subsequent increase in sports-related injuries has been partially attributed to the passage of Title IX.(8)

Many different types of fixation methods for tibial eminence fractures have been described including screw, suture, anchor, and suture-button fixation. Currently, there is no fixation method that has been shown to be superior. At our institution the two most popular techniques employed are suture and screw fixation. Each of these methods employs a slightly different technique. In both cases, the bony fracture fragment is reduced to its native site. Suture fixation involves passing a suture through the base of the ACL and retrieving each end of the suture through bone tunnels in the tibia. Sutures are then tied over a tibial bone bridge to achieve stable fixation. Screw fixation involved direct fixation of the fracture fragment itself through compression with a small screw or screws. For a more detailed description of the operative techniques, refer to the Methods Section. There are advantages and disadvantages associated with each procedure, outlined in Table 1. The most significant advantages for suture fixation is that it allows for fixation of smaller bony fragments, and can therefore can be used in all fracture patterns. Suture fixation is not dependent on size of the bony fragment since the suture is passing through the base of the ACL and not the bone itself. The bony fracture is indirectly reduced through tension on the base of the ACL. Potential disadvantages of suture fixation include the potential that the suture could cause tethering of proximal tibial physis, that a second incision over bone cortex of tibia is necessary to tie the sutures, and at times removal of painful or prominent non-absorbable suture may be necessary. (9)(10) In contrast, advantages of screw fixation of tibial eminence fractures include direct compressive fixation across the

tibial eminence fracture itself, and avoidance of suture through the ACL substance. Disadvantages of screw fixation involve increased difficulty with smaller fragment sizes (as placement of the screw can fragment a small bony fracture), potential need for a second surgery for hardware removal and potential growth disturbance due to a damaged growth physis (if the screw is placed too long it can enter the proximal tibial physis).(9)(11)

Currently, there is a lack of literature comparing clinical and radiographic outcomes of these two fixation methods in children and adolescents. There is no consensus among surgeons as to what is the optimal fixation method. We set out to achieve several goals with this study. We intended to compare clinical and radiographic outcomes in patients who had arthroscopic suture or screw fixation of a displaced tibial eminence fracture at Boston Children's Hospital, a major referral center for pediatric orthopedic injuries. The specific outcomes of interest determined retrospectively at follow-up included comparison of time to radiographic healing, return to sports (if applicable) and time to return to sports, postoperative loss of knee motion (extension vs. flexion), stability of knee on exam, residual symptoms, need for hardware removal, complications, reoperation, and re-injury to knee. These outcomes have proven to be of interest for surgeons in operative planning and for patients prior to surgery in terms of informed consent. (9)(12)

Furthermore, we are interested in the evaluation of long-term outcomes of each fixation technique. Consistent with other literature available, the standardized Pediatric International Knee Documentation Committee (pedi-IKDC) has proven to be a good measure for prospective studies that takes into account four areas (subjective assessment, symptoms, range of movement and ligament examination). In contrast to other outcome measurements, the pedi-IKDC offers a language appropriate assessment in addition to a qualitative range rather than a numerical one.(13)(14)

Thus, the ultimate goals of obtaining comparative outcomes measures will be to establish a treatment guideline for tibial eminence fractures in terms of fixation technique and post-operative management. The latest review on pediatric tibial eminence fractures by LaFrance et al. notes a lack of available literature comparing suture fixation vs. screw fixation, in addition to contradictory results.(9) Some physicians agree that both methods are equally effective for treating both young and adult patients. (12)(15) Most comparative studies are biomechanical or clinical studies with a mixed age range of patients. Biomechanical studies have tested fixation strength. Eggers et al.(16) demonstrated that under cyclic loading conditions suture fixation is stronger than screw fixation. However, other biomechanical studies have not been able to show a clear biomechanical advantage of one fixation technique versus another.(17)(18). It is also important to note that most literature comparing screw fixation to suture fixation have studied a heterogeneous patient population, with widely varying ages, and has been limited in their sample size.

With such limited literature comparing outcomes of these two methods in a pediatric population, physicians lack clear criteria for deciding when to perform suture fixation vs. screw fixation. It is difficult for physicians to assess what method of surgery will yield the best results for their young patients. This study aims to address tibial eminence fractures outcomes in a relatively large pediatric population.

Moreover, a dedicated study of fracture fixation outcomes in pediatric patients is still missing from the literature. More importantly, most available studies involve small sample sizes and short-term assessments. Our approach is innovative in that we are looking at a larger sample of pediatric patients and retrospectively assessing their outcome evolution from the time of their surgery to the present day. Having the potential to collect data from a relatively larger patient pool in Boston's Children's Hospital offers an opportunity to study more in depth,

the two available most common techniques for fixation of tibial eminence fractures. Surgery on some patients dates over 10 years, allowing us to include long-term outcomes of suture vs. screw fixation that may be found in patient follow-up. This study hopes to provide physicians a more informed choice of fixation methods, considering short- and long-term clinical outcomes in patients with tibial eminence fractures.

This scholarly project was a joint contribution by Victor J. Anciano Granadillo, first author of this scholarly report, Patricia Miller, biostatistician, Elizabeth Conroy, and Brett Fluttie, research assistants, and research mentor Dr. Dennis Kramer. Research assistants performed the initial query for patients. Victor J. Anciano Granadillo was directly responsible for review and coding of patient's history into a patient database; the student coordinated patient contact through postal mail and phone calls. The student was responsible for tables and figures in the report. The patient database was analyzed with the help of Patricia Miller, biostatistician at the Department of Orthopedics in Boston Childrens Hospital, who contributed with comparison tables. The results were reviewed and included in this report by the student. The mentor, Dr. Dennis Kramer, was available for advice and guidance at all steps of the project, and carefully reviewed the database, data analysis and writing of the scholarly project.

Methods

With the assistance of a mentor and a research assistant, a preliminary set of parameters was established that would allow us to obtain a proper comparison between suture and screw fixation of pediatric tibial eminence fractures. These parameters represented inclusion and exclusion criteria to build a database of patients for retrospective study. The inclusion criterion was simple in that ALL patients must have had their tibial eminence fracture treated surgically at Boston Childrens Hospital. To identify these patients, the Boston Childrens Hospital electronic medical record database, PowerChart, was queried from January 2000 until December 2012.

The initial query of the medical record database yielded 156 records of patients who had a tibial eminence fracture related injury. It was decided against setting an upper age limit and including all patients who met the criteria above. However, an exclusion criterion was applied to the patients found in the initial query. Those patients who had less than 6 months post-op follow up would be excluded from the study. After carefully going through every medical record that the initial query provided and applying inclusion and exclusion criteria, the study remained with a total pool of 78 patients. In doing so, a retrospective study was started, which looked at pediatric patients who had experienced a tibial eminence fracture and had fixation through suture or screw at our institution. No patients were identified who had surgical fixation using a different technique.

The first step of data gathering involved retrieving information from the patient's history. Initial data was divided in the following categories: Demographic data, pre-operative (pre-op) planning, operative details, post-operative (post-op) protocols, and post-op recovery. The patient's medical record was coded into the database for each of the categories mentioned above. This task involved reading over 700 clinical notes, operative reports, physical therapy reports, emergency

reports, and telephone communications. The demographic, pre-op planning, operative details, post-op recovery data searched for is listed below.

- Demographic Features: medical record number, birthdate, current age of patient, gender, affected knee, mechanism of Injury (Twist, contusion or fall), sport involved (football, soccer, dance, ski, biking or skating, horse back riding, baseball, kickball, and other), history of prior knee surgery, patient height (in meters), patient weight (in Kg), and patient's Body Mass Index (BMI) at time of presentation.

- Pre-operative planning data: McKeever Classification (taken from clinic notes), McKeever classification, coronal size of fragment (coronal measurement in millimeters [mm] taken from the CT scan or MRI scan when available, if not available then taken from radiographs), sagittal size of fragment (Sagittal measurement in mm), size of fragment (calculated surface area of fragment), imagining modality used for calculation of fragment size (CT, MRI or plain radiographs), status of physis (open or closed, based on the injury radiographs), and provider (primary surgeon performing the surgery). Refer to Figure 3 for CT scan measurements examples.

- Operative details: Injury date, date of initial presentation to clinic, time from injury to surgery (in days), patient's age at time of surgery, reduction technique (arthroscopic or open), type of fixation (screw, suture or both), number of sutures, number of screws, number of absorbable implants (in the case of absorbable screws), type of suture (absorbable or non-absorbable), type of screw (3.5-4.5mm cannulated screws, Smartnails or 3.0mm Herbert screws), notation of whether the screw crossed the proximal tibial physis, post-op immobilization (cast, brace or both), casting time (in weeks), length of time in restricted motion in knee brace (in weeks), entrapped meniscus noted intraoperatively (gleaned from operative note), need for meniscal repair, need for menisectomy, need for chondroplasty, need for micro-fracture, need for loose body removal, need for plicaectomy, total tourniquet time, and other procedures performed during surgery.

- Post-op recovery data: date of last appointment, date of last contact with patient, length of follow-up after surgery (in months), loss of flexion (graded as: less than 5 degrees, 5-10 degrees, more than 10 degrees), loss of extension (less than 5 degrees, 5-10 degrees, more than 10 degrees), ability to return to sports, date of return to sports, time to return to sports, date of radiographic healing, time to radiographic healing, assessment of knee stability, elevation of anterior aspect of tubercle fragment relative to adjacent plateau (in mm), residual symptoms (mild activity-related pain or constant pain, gleaned from clinic notes) stiffness, instability, physeal growth disturbances, complications (arthrofibrosis or flexion contracture requiring surgery, arthrofibrosis + flexion contracture requiring dynamic bracing, or other), need for hardware removal, need for reoperation (planned hardware removal, unplanned hardware removal, lysis of arthrofibrosis, likely removal at outside hospital), time on dynamic splinting (DynaSplint) if used, and re-injury to the knee.

Of note, many of these parameters were used in combination with formulas to calculate point of data showed in our results. For example, injury date, time of initial presentation, date of service and date of last appointment, all helped in calculating time of follow up presented in the results. For other parameters, where no result is presented (i.e. time to return to sports, or time in restricted motion in Bledsoe brace), it should be assumed that there is no significant statistical difference found between the comparable groups of screw and suture fixation. Lastly, for a few parameters, enough data was not available in the clinical notes that would allow for statistical comparison; thus it is not included in the results section.

Regarding Post-op recovery data, this study is unique in that it will provide not only reoperation rates, but will classify indications for reoperations. This is important since prior studies have reported higher reoperation rates with screw fixation. One study reported that a 44% rate of reoperation is associated with screw fixation

versus a 13% rate of reoperation of suture fixation.(15) These increased rates of reoperation in the screw fixation subgroups are associated with hardware removal. In our study, it was distinguished between planned hardware removals and unplanned hardware removals. The difference aims to distinguish between the latter, which is more of a complication of screw fixation, versus the former, which is sometimes included in surgical protocols.

With the aid of the Boston Childrens Hospital Department of Orthopedics biostatistician, comparison tables and figures were created between patients subjected to screw or suture fixation. Patient and injury characteristics were compared across treatment groups (suture versus screws). Continuous characteristics were compared with Student's t-test, categorical characteristics were compared with a chi-squared test, and binary characteristics were compared using Fisher's exact test. Patient outcomes including loss of motion, return to sports, radiographic healing, residual symptoms, complications, reoperations, and re-injury to the knee were compared across treatment groups. Univariable and multivariable analysis were used to control for any potential confounding in outcomes. Categorical outcomes were analyzed using the Cochran-Armitage test for trend or ordinal logistic regression, as necessary. Binary outcomes were analyzed using logistic regression analysis. Continuous outcomes were analyzed using general linear modeling. For time to radiographic healing, the data was analyzed using a long-transformation of the time data in order to meet the assumptions of the model.

Of note, one of the study's initial aims attempted to follow prospectively some of the patients in the database. Patient contact was attempted according to our IRB protocol, which stated for sequential contact limited to mail, email, and phone calls. Prospective studies were initially planned with Lysholm Scores and Tegner Activity Scales. The Lysholm Score has been previously used in other tibial eminence fracture studies for assessment of outcome.(19) The Lysholm Score and Tegner Activity Scale have been found to be acceptable psychometric parameters as a

patient-administered survey.(20) They involve a point-based system according to the amount of activity that the patient is able to perform, in addition to assessing discomfort and use of the joint in several routine tasks. It was decided against the Lysholm Score and Tegner Activity Scale as the pedi-IKDC offers a language appropriate version that can be answered by children and adolescents with validity and consistency. (21) However, such data will not be presented in this report, due to low initial patient responses to survey mailings and contacts. Where survey responses were received, the information was included in the postoperative patient assessment. Please refer to the discussion section regarding limitations and future plans of this project.

In order to obtain the appropriate information from operative reports, the two fixation techniques (screw and suture fixation) must be well understood. Kramer et al. described suture fixation and screw fixation, as performed by most surgeons in Boston Childrens Hospital. Suture fixation begins with initial identification and reduction of the tibial spine fragment. Fragment fixation is then achieved by passing one or two sutures through the base of the ACL (therefore fracture fixation is not dependent on size of the bony fragment). The two suture ends are then retrieved by drilling parallel bone tunnels through the proximal tibia and into the fracture site using the ACL tibial guide. These tunnels serve as conducts for suture retrievers. These sutures are retrieved and tension applied for optimal reduction of the avulsed fragment. See Figure 4 for pre-operative and post-operative plain radiographs. Applying flexion to the knee to 30 degrees, the sutures are tied and reduction is achieved. (22)(23)

Screw fixation involves initial reduction of the tibial eminence fracture into its fracture bed before temporarily fixing the fragment to the proximal tibia with the aid of a Kirchner wire (K-wire). Then, a guide pin is driven through the fracture fragment at a 30-45 degree sagittal angle to the tibia up to but not across the tibial physis. At this point, at the discretion of the surgeon, a second guide pin may be

placed if a second screw is to be used. This depends on a fragment size – larger fragment may accommodate two screws. The next step involves drilling over the guide wire before passing the selected screw over the guide pin and through the bony fragment into the proximal tibia. The screw must not cross the proximal tibial physis. Once the screw(s) is placed, the reduction is assessed for sufficient compression using fluoroscopy. (22) See Figure 5 for pre-operative and post-operative plain radiographs in a patient who underwent screw fixation.

All the work in this project was based at the Department of Orthopaedics of Boston Childrens Hospital. Most patients were seen in location or at one of the satellite hospitals of Boston Childrens Hospital. This project was supervised by Dr. Dennis Kramer. Dr. Kramer is an instructor of Orthopaedic Surgery at Boston Childrens Hospital and Harvard Medical School. He specializes in Sports Medicine in Pediatric Orthopaedics, with a dedicated interest in ACL and Knee injuries.

Results:

After the initial query for patients in the Childrens Hospital Boston medical records, an initial number of 156 patient records were pulled from the system. Of the 156 patients, 21% of patients (n=33) were excluded from the study due to lack of minimum 6 months follow up post-operatively. Nineteen percent of patients (n=31) were found to be repeated medical records provided by the search engine. A few patients (n=4, 3%) did not receive their tibial eminence fracture surgery at Children's Hospital, but were seen for follow up. Five patients (n=5, 3%) received non-operative management for either type 1 or reducible type 2 fractures, and 4 patients actually suffered from ACL substance rupture rather than tibial eminence fracture. Lastly, 78 patients (51%) were found to match inclusion and exclusion criteria and were accepted into the study.

Seventy-eight tibial spine injuries were analyzed including 53 male and 25 female knees with an average age at surgery of 11.4 (range 6.7 to 17.6 years). Thirty-six (46%) knees were treated with sutures, 35 knees (45%) were treated with screws, and 7 (9%) were treated with a combination of sutures and screws. Summary demographics for all three treatment groups are detailed in Table 2. A total of 53 male patients (68%) were included in the study compared to 25 female patients (32%). The gender distribution among the comparable groups (suture versus screw) was similar in both groups, with 69% male patients and 31% female patients in each group.

Our study included 38 right knees (49%) and 40 left knees (51%). Of note, one patient was included who had bilateral tibial eminence fractures. This patient was analyzed in terms of each of his knees, hence contributing to n=1 for each surgery performed. Mechanism of injury was also recorded for patients showing an equal distribution between twisting and falling mechanism: thirty-three reports of twisting injuries (42%) versus thirty-three reports of falling injuries (42%). A lesser common mechanism of injury was a contusion mechanism, which added to 11 tibial

eminence fractures (14%). Lastly, patients also reported the sport involved in the injury, if applicable. Most patients (61 cases, 78%), incurred the tibial eminence fracture as a consequence of a sports-related injury. The most common sport involved in tibial eminence fractures was found to be skiing, with a total number of 37 patients (47%) in the study. The second most common sport involved in tibial eminence fractures in our study was biking/skating with a total of 15 patients (19%). Other sporting activities recorded at the time of injury were: football, soccer, dancing, horseback riding, softball, and kick ball. All seventy-eight patients in the study reported no previous history of surgery on the affected knee.

In terms of fracture characteristics, the McKeever classification was noted for each surgical group. The suture fixation group reported types II and III/IV of the McKeever classification, 8 (27%), and 22 (73%), respectively. The screw fixation group had a similar spread with 11 (36%) type II fractures and 20 (65%) type III fractures. The screw fixation did not have any type IV fractures. Most patients in the study had open physes at the time of the injury: 34 (94%) patients in the suture group versus 31 (97%) patients in the screw group. Regarding associated injuries, 5 patients were included in the study who presented with concomitant proximal tibial fractures. Three of these patients were treated with tibia plateau fixation with screw in addition to their tibial eminence fracture fixation. All three patients were included in the screw fixation group; they did not contribute any complications or reoperations to the group.

As a cohort, there was loss of motion in flexion in 17/78 patients (22%), and loss of motion in extension in 33/78 patients (42%). Sixty six patients reported on ability to return to sports; 63/66 (96%) acknowledged returning to their sport. The mean time to radiographic healing was 19 weeks (±14.1). Mild activity-related pain was reported in 23% of patients. Significant pain was noticed in 3% of patients, while subjective instability was reported in 14%. The total complication rate of the cohort was found to be 33%.

For the primary analysis, knees that were treated only with sutures were compared with knees that were treated only with screws. Patient characteristics between suture and screw treatment groups were comparable (see Table 3). With respect to treatment, tourniquet time was significantly higher in the suture group (90.3 ⌢± 25.1 minutes compared to 67.4 ⌢± 29.8 minutes, respectively; p=0.002). Knees in the suture group were primarily immobilized in a brace (92%), whereas knees in the suture group were casted (29%), braced (49%), or both casted and braced (23%).

Outcomes by treatment group are detailed in Table 4. There were no differences in outcomes between treatment groups and no confounding effects on outcome were identified. Statistically, both fixation groups had similar healing rates, ability to return to sports, and complications. Initial results showed a significant difference regarding total hardware removal. The total number of patients receiving a reoperation for hardware removals was 24 (31%). Of the 24 cases of hardware removal, 4 cases were part of the suture group, while twenty cases were reported in the screw group. After distinguishing between planned and unplanned hardware removals, the difference between the groups was no longer significant: 4 cases in the suture group (11%) were unplanned hardware removals versus 10 cases of the screw fixation group (29%) (p=.26). Despite having a larger percentage of complications in the screw fixation group; there was no statistically significant differences regarding arthrofibrosis that required reoperation (3/36 patients in suture group versus 5/35 patients in screw group – p=.32), arthrofibrosis which required dynamic splinting (7 patients in suture group versus 8 in screw group – p=.29), or re-injury to knee (3 patients in suture group versus 5 patients in screw group – p=.43). The screw fixation group had a higher frequency of having at least one complication (arthrofibrosis, arthrofibrosis requiring dynamic splinting, or unplanned hardware removal), 17/35 (49%) patients, compared to 14/36 (39%) patients in the suture group; however, this was not a significant difference (p=.74).

Fragment size prior to surgical reduction and fixation was measured in 54 patients. Anterior elevation of the bony fragment post reduction was measured in 70 patients. The fragment size was not related to surgical outcome nor was anterior elevation of the tibial fragment. This is important to note as anterior elevation > 2mm was seen in 34/70 cases but not related to final outcome. There was also no correlation on complication rate given elevation of the TS with (p=0.91) our without controlling for treatment type (p=0.36).

Loss of motion (flexion or extension) was also analyzed in the overall patient population. There was an association between loss of flexion and meniscal injury (p=.002). Eight out of the 15 subjects who incurred a meniscal injury experienced some loss in flexion, 4 of which lost more than 10 degrees. There were 7 patients who lost flexion without meniscal injury; however, only one of those seven patients experienced loss of more than 10 degrees of flexion. There was no statistical difference between suture and screw groups in terms of loss of motion in flexion. The suture group had 2/36 (6%) who lost 0-5 degrees of motion, and 5/36 (14%) patients who lost 5-10 degrees of motion. This is compared to patients in the screw group that reported 1/35 (3%) with loss of 0-5 degrees, 3/35 (3%) with loss of 5-10 degrees, and 5/35 (14%) with loss of more than 10 degrees (p=0.12). When comparing loss of extension, there was no statistical difference between suture and screw groups either. The suture group had 7/36 (19%) that lost 0-5 degrees of motion, and 5/36 (14%) patients who lost 5-10 degrees, and 3/36 (14%) with loss of more than 10 degrees. This is, again, contrasted to patients in the screw group that reported 4/35 (11%) with loss of 0-5 degrees, 7/35 (20%) with loss of 5-10 degrees, and 3/35 (9%) with loss of more than 10 degrees (p=0.47).

Re-injury of the knee involved different injuries to the ACL. The most common recorded re-injuries were ACL tears or strains, 3/36 in the suture group vs. 2/35 in the screw group. There were no repeat avulsions of the reduced bony fragments in any of the patients in the study. Of note, there were a few findings in

the long-term outcomes of some patients that were not included in the analysis, as they were believed to be unrelated to the initial injury and surgery. These included 3 patients who returned to the clinic 3-5 years later for treatment of ipsilateral patella-femoral syndrome (a very common form of knee pain in this age group). Two patients experienced knee effusion of unknown etiology. One patient developed an ipsilateral 5th metatarsal stress fracture during rehabilitation while wearing a Bledsoe brace. Lastly, one patient suffered from lateral subluxation of the patella of the affected knee several years after surgery.

Discussion:

For this study, we were interested in finding evidence that would support the use of either suture or screw fixation in the operative treatment of tibial eminence fractures. We decided to tackle a question that has been unanswered for many years: is one method better than the other in terms of short- and long-term outcomes? We encountered multiple challenges along the way, but we are able to present interesting and initial data that puts the field closer to establishing set guidelines for treatment of tibial eminence fractures.

As previously mentioned, most of the current literature does not include a large patient pool. Even more importantly, current literature lacks pediatric studies. (9) Our study is unique to the literature in that we include one of the largest retrospective patient studies, seventy-eight patients, with a mean age at time of surgery of 11.4 years (SD= ±2.66). This allows for our study to be extrapolated to future pediatric studies involving tibial eminence fractures. However, we should be cautious with any generalizations, as this was a retrospective case-study review, and as such, it is subject to biases of studies of its kind. Moreover, it is important to note that even though our study is one of the largest of its kind, we still require a greater sample size in order to make a study with sufficient power across all categories of variables.

We noted a few interesting observations in our initial demographic analysis. Most adult studies describe tibial eminence fractures as a result of road-traffic accidents. (24). Also, pediatric eminence fractures were mostly associated with cycling accidents, and in current literature noted to be more related to sports injuries.(25) Our patient population was mostly injured during sports-related accidents. The most common sport involved in tibial eminence fractures was skiing, with 47% of overall patients. Following this, biking/skating-related accidents were involved with 19% of patients. Such findings have been noted in smaller studies regarding tibial eminence fractures. (26) In support of previous literature,

mechanisms of injury are similar to those reported in injury of the ACL. (4)(9)(24) All patients described a twisting, falling or contusion mechanism involved in his or her tibial eminence fracture.

Our study was not able to determine if one fixation is better than the other. Our outcomes involving reoperation, arthrofibrosis, DynaSplint, and re-injury were not significantly different across the groups. Edmonds et al. (27) recently commented on differences regarding closed versus open versus arthroscopic management of tibial eminence fractures. Arthroscopic and open management were found to be better treatments in terms of reduction ability, with the downside that they increased risk of arthrofibrosis. Our study showed no difference in terms of risks associated with arthrofibrosis for either group. However, there is an apparent association between meniscal injury (requiring meniscal repair or menisectomy) and loss of some degree of flexion. Once we controlled for hardware removal, we did not find that either suture or screw fixation led to a higher risk of reoperation. One suggestion that we feel is important in terms of reoperations is that patients should know in advance of the initial surgery whether a planned hardware removal will take place. This should aid patients and surgeons in operative planning as a 2nd surgery will sometimes deter from using screw fixation.

Some of our surgeons at Boston Childrens Hospital have used absorbable implants rather than metallic screws. Our initial observational data showed that 25% of patients treated with the absorbable implants required reoperation for lysis of adhesions. Even if absorbable implants reduce the need of planned hardware removal, they may still be subject to arthrofibrosis as is the case with suture and metallic screw fixation. This data is not shown in our tables as a separate category since absorbable implants were considered part of the screw or suture/screw (both) fixation groups. Most absorbable implants (6 cases out of 8) were part of the suture/screw fixation group. As mentioned, the data for this group was limited in numbers and hence was not included in our comparable results.

During the making of this project we encountered numerous challenges. Our initial attempt to add a prospective section to the study was not possible due to difficulty of contact with patients. Initial contact was made through the mailing of pedi-IKDCs. Our return rate was extremely low. We proceeded with direct patient contact, which was not successful in obtaining higher responses. Our study was thus limited to a retrospective analysis of tibial eminence fractures only. Considering future aims, the prospective section of this project could possibly be finished with more time and manpower. This will provide subjective data regarding current knee performance. In addition, it may increase the size of our patient pool by lengthening follow-up time in those patients who did not meet inclusion criteria (>6 months follow-up). Another possible solution for this problem would entail longer clinic follow-up with patients. This is difficult in the pediatric population however as many patients heal completely in 6 months and do not want to come back to clinic for unnecessary visits. Other studies have included pedi-IKDC data obtained in the final clinic notes, which allowed for subjective data regarding knee function to be obtained despite low rates of mail return.(28) During my data-gathering of clinical encounters, I found few patients who received pedi-IKDC's at their appointment. Making this a common practice at a defined period of time postoperatively could provide insightful data into patients' subjective assessment of their surgeries.

Another challenge encountered was gathering data from clinical notes. As expected, clinical notes written across 10 years vary in format, style and content. Most notes contained the information required for our study; however, there were patients whose information was not included in the calculations due to lack of reporting in the clinical notes. Initially, we set out to investigate outcomes such as radiographic healing time and time to return to sports. These parameters were reported inconsistently across clinical notes. For radiographic healing time, clinical encounters tended to obtain radiographs at set points post-operatively, and at times did not comment on the healing process. If a patient did not receive radiographs at

their 3-month post-op clinical encounter (or missed appointment), then healing of the fracture was not mentioned until their next appointment (most likely 6 months post-operatively). This reporting was similar when considering time to return to sports. The data collected from the clinical encounters was inconsistent. In addition, there were many patients who had no reporting of their time to return to sports until later post-op clinical encounters. Rather than using these values, we decided simply to look for ability to return to sports when applicable.

Limitations of this study include our limited patient pool and factors that affect generalization to the rest of the pediatric population. Despite having a relatively large number of patients, seventy-eight cases are not enough to obtain significant differences in a retrospective study. Furthermore, this study is limited to patients from Boston Childrens Hospital. A more generalizable study would include patients across different institutions resulting in a higher number of patient and providers. Our study's cases included procedures performed by twelve different surgeons. All surgeons are (were) affiliated with Boston Childrens Hospital. A study that includes numerous surgeons across institutions might result in very different outcomes. Lastly, one should consider when generalizing this project that BCH is a primary center of referral for many institutions in Boston and New England. Surgeons at BCH see a larger number tibial eminence fractures than smaller orthopedic centers.

Overall, our study was successful in creating a large database for tibial eminence fractures treated at BCH. We were able to compare suture versus screw fixation among our patients. We discovered that our study did not find significant differences in terms of our studied outcomes in suture versus screw fixation. A larger prospective study may be helpful in setting further guidelines in treatment of tibial eminence fractures.

The major conclusions of our study included that more patients are males, and almost all patients are skeletally immature. It was noted that the most common

mechanism of injury is sports, specifically skiing. Tibial spine fractures treated surgically have high rates of return to sports and few patients with significant residual pain. Arthrofibrosis is a common complication happening in 32% of the reviewed cases; sometimes responding to dynamic splinting, and others needing surgery. Subjective instability is a relatively common postoperative complain (14%). Concurrent Meniscal pathology leads to statistically significantly higher rates of loss of flexion. Reoperation rates in the cohort as a whole is high (30%) but lower if you exclude planned hardware removals (17%). Tourniquet time is significantly longer in suture fixation group. The anterior elevation of the fragment on postoperative films does not affect outcome and is not affected by procedure. Finally, no major outcome differences were seen with suture vs. screw fixation, and re-injury can occur, although rarely (6%).

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Table 1: Summary of advantages, disadvantages and considerations to take into account for repair of tibial eminence fractures

	Advantages	*Disadvantages*	*Considerations*
Suture Fixation	• Allows for fixation of fractures with small fragments of bone. • Can be used for all fracture patterns • Does not rely on bone fragment for fixation	• Permanent suture might cause tethering of growth physis • Prominent suture might need second surgery for removal • Involves second incision over bone cortex of tibia to tie sutures	• Suture through ACL substance or bony fracture has unclear long term affects • Absorbable suture vs. permanent suture has risks and benefits to both
Screw Fixation	• Provides direct compressive fixation across fracture • Avoids placing suture through ACL	• Fracture fragment may be too small to accommodate screw • Second surgery might be needed for removal of hardware • Growth disturbance due to damaged growth physis if screw is too long	• Cannulated vs. non-cannulated screw • One screw vs. two screw fixation (one screw is more acceptable in more recent literature)

Table 2. Patient Demographics

	Overall (n=78)		Suture (n=36)		Screw (n=35)		Both (n=7)	
	Freq.	(%)	Freq.	(%)	Freq.	(%)	Freq.	(%)
Age (y *years; mean ⌢ SD)*	11.4	± 2.66	11.7	± 2.61	11.3	± 2.77	11.1	±2 .48
Gender								
Male	53	68%	25	69%	24	69%	4	57%
Female	25	32%	11	31%	11	31%	3	43%
Affected Knee								
Right	38	49%	19	53%	15	43%	4	57%
Left	40	51%	16	44%	20	57%	3	43%
Mechanism of Injury *								
Twist	33	42%	16	46%	14	40%	3	43%
Fall	33	42%	16	46%	13	37%	4	57%
Contusion	11	14%	3	9%	8	23%	0	0%
Sport Involved**								
Football	4	5%	1	3%	3	9%	0	0%
Soccer	3	4%	3	9%	0	0%	0	0%
Ski	37	47%	19	54%	13	38%	4	57%
Biking Skating	15	19%	4	11%	9	26%	2	29%
Other	18	23%	8	23%	9	26%	1	14%
Hx of Sx**	78	100%	36	100%	35	100%	7	100%

* Suture Group n=35
** Suture Group n=35, Screw Group n=34
*** History of prior knee surgery (Hx of Sx) on affected knee

Table 3. Patient and injury characteristics by treatment type.

|	Suture (n=36)		Screw (n=35)			Both (n=7)	
	freq.	(%)	freq.	(%)	P*	freq.	(%)
Age (*years; mean ~ SD*)	11.7	± 2.61	11.3	± 2.77	0.52	11.1	± 2.48
Sex (*% male*)	25	(69%)	24	(69%)	1.00	4	(57%)
BMI							
< 25	31	(91%)	23	(96%)	1.00	5	(83%)
25 to < 30	1	(3%)	0	(0%)		1	(17%)
> 30	2	(6%)	1	(4%)		0	(0%)
Open physis	34	(94%)	31	(97%)	1.00	7	(100%)
McKeever classification							
2	8	(27%)	11	(36%)	0.37	1	(20%)
3	20	(67%)	20	(65%)		4	(80%)
4	2	(7%)	0	(0%)		0	(0%)
Fragment area (*mm²*)	265.4	± 213.84	314	± 144.83	0.36	268.4	± 102.21
Meniscus injury	5	(14%)	10	(29%)	0.16	1	(14%)
Acute surgery (≤ 42 days)	34	(94%)	31	(91%)	0.67	7	(100%)
Arthroscope	31	(86%)	32	(91%)	0.71	7	(100%)
Tourniquet time	90.3	± 25.14	67.4	± 29.79	0.002	49.6	± 9.84
Entrapped meniscus	15	(42%)	19	(54%)	0.35	4	(57%)
Immobilizer							
Cast	3	(8%)	10	(29%)	<0.001	2	(29%)
Brace	33	(92%)	17	(49%)		1	(14%)
Both	0	(0%)	8	(23%)		4	(57%)
Elevation of TS fragment							
< 2*mm*	20	(57%)	15	(52%)	0.61	3	(50%)
2-4*mm*	15	(43%)	13	(45%)		3	(50%)
≥ 5*mm*	0	(0%)	1	(3%)		0	(0%)

*P-values are for comparisons between suture only and screw only treatment groups.

Table 4. Outcomes by treatment group.

Outcome	Suture (n=36) freq.	(%)	Screw (n=35) freq.	(%)	P
Loss of motion in flexion					
None	29	(81%)	26	(74%)	0.12
0-5 degrees	2	(6%)	1	(3%)	
5-10 degrees	5	(14%)	3	(9%)	
> 10	0	(0%)	5	(14%)	
Loss of motion in extension					
None	21	(58%)	21	(60%)	0.47
0-5 degrees	7	(19%)	4	(11%)	
5-10 degrees	5	(14%)	7	(20%)	
> 10	3	(8%)	3	(9%)	
RTS	31	(100%)	28	(93%)	0.21
Time to heal (*mean ⁓ SD*)	19	± 12.90	19.7	± 16.58	0.76
Residual symptoms					
None	21	(58%)	18	(51%)	0.51
Mild pain improved from preop	10	(28%)	9	(26%)	
significant pain	0	(0%)	2	(6%)	
Instability	5	(14%)	5	(14%)	
Stiffness	0	(0%)	1	(3%)	
Complications					
At least one complication	14	(39%)	17	(49%)	0.74
Arthrofibrosis or flexion contracture	3	(8%)	5	(14%)	0.32
Arthrofibrosis+DynaSplint	7	(19%)	8	(23%)	0.29
Unplanned Hardware Removal	8	(22%)	12	(34%)	0.26
Re-injury to knee	3	(8%)	5	(14%)	0.43

Figure 1: Classification of tibial eminence fractures according to Meyers and McKeever, and Zaricznyyj.

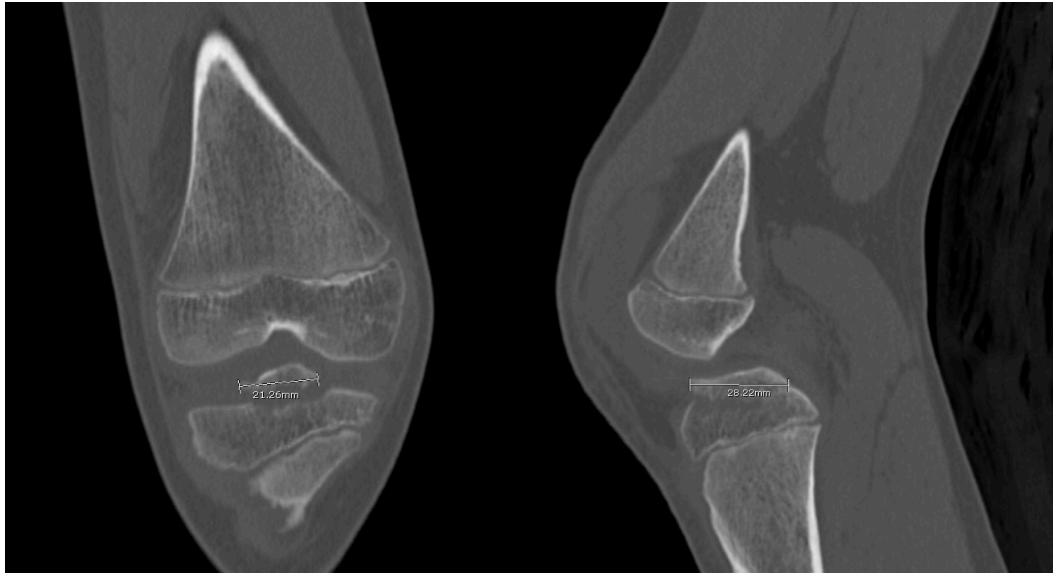Type I   Type II   Type III   Type IV
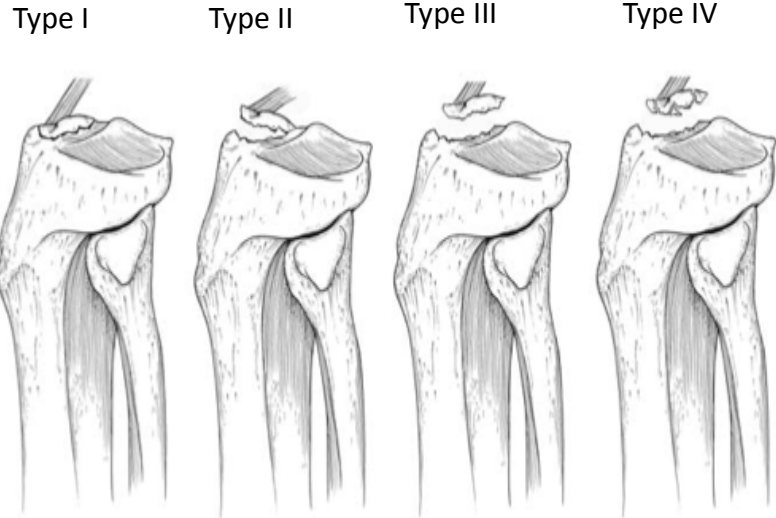
Figure 2: 3D Reconstruction of a type III tibial eminence fracture

3-D reconstruction from computer tomography scan of a type III tibial eminence fracture. Bony fragment is elevated from its fracture bed.

**Figure 3: Computer tomography scan measurement of bony fragment of a type III avulsion fracture**

Left: Coronal CT-Scan showing a type III tibial eminence fracture; ruler measuring coronal segment of bony fragment. Right: Sagittal CT-Scan showing same type III tibial eminence fracture; ruler measuring sagittal segment of bony fragment.

Figure 4:

Left: Lateral plain radiograph of a left knee showing a type III tibial eminence fracture at time of presentation. Radiograph also shows significant joint effusion. Right: Lateral plain radiograph of same left knee status-post arthroscopic reduction and internal fixation with suture.

Figure 5:
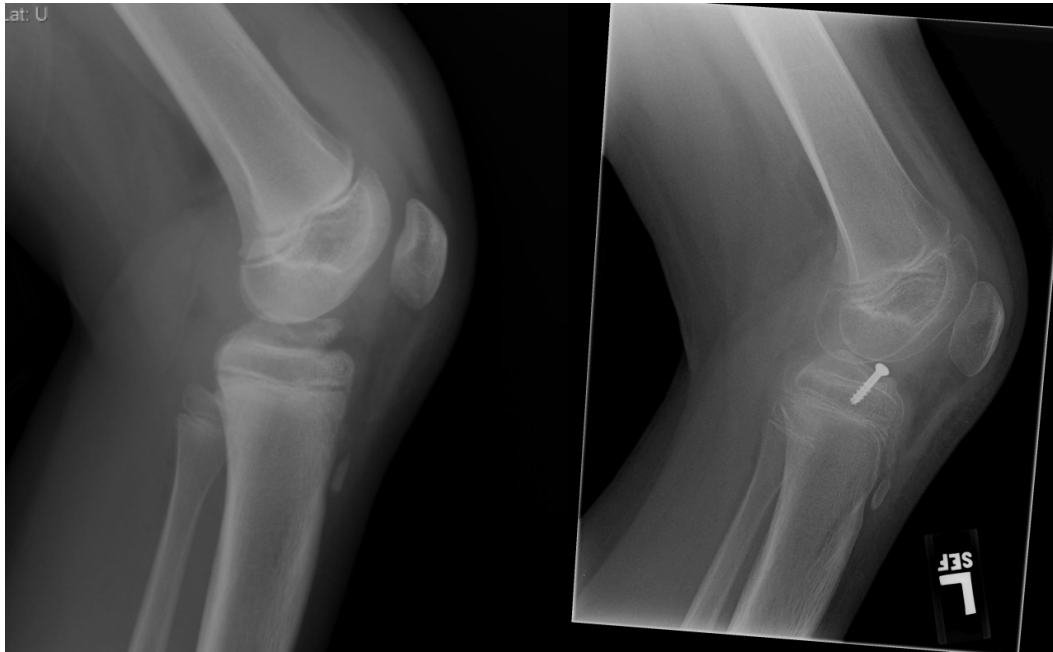
Left: Lateral plain radiograph of a left knee showing a type II tibial eminence fracture at time of presentation. Also noticeable is a joint effusion. Right: Lateral plain radiograph of same left knee status-post arthroscopic reduction and internal fixation with cannulated screw.

Acknowledgments: