What is the Utilization and Impact of Advanced Imaging for Tibial Tubercle Fractures? An Analysis of 598 Patients From the Tibial Tubercle Study (TITUS) Group

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Background: Given the rare nature of tibial tubercle fractures, previous studies are mostly limited to small, single-center series. This results in practice variation. Previous research has shown poor surgeon agreement on utilization of advanced imaging, but improved evidence-based indications may help balance clinical utility with resource utilization. The purpose of this study is to quantify diagnostic practices for tibial tubercle fractures in a large, multicenter cohort, with attention to the usage and impact of advanced imaging.

Methods: This is a retrospective series of pediatric tibial tubercle fractures from 7 centers between 2007 and 2022. Exclusion criteria were age above 18 years, missing demographic and pretreatment data, closed proximal tibial physis and tubercle apophysis, or a proximal tibia fracture not involving the tubercle. Demographic and injury data were collected. Fracture classifications were derived from radiographic evaluation. The utilization of advanced imaging was recorded as well as the presence of findings not identified on radiographs. Standard descriptive statistics were reported, and χ^2 tests were performed (means reported ± SD).

Results: A total of 598 patients satisfied the inclusion criteria, of which 88.6% (530/598) were male with a mean age of 13.8 ± 1.9 years. Internal oblique x-rays were obtained in 267 patients (44.6%), computed tomography (CT) in 158 (26.4%), and magnetic resonance imaging (MRI) in 64 (10.7%). There were significant differences in the frequency at which CT (7.2% to 79.4%, $P < 0.001$) and MRI were obtained (1.5% to 54.8%, $P < 0.001$). CT was obtained most frequently for Ogden type IV fractures (50/99, 50.5%), and resulted in novel findings that were not visualized on radiographs in a total of 37/158 patients (23.4%). The most common finding on CT was intra-articular fracture extension (25/37). MRI was obtained most frequently for Ogden type V fractures (13/35, 37.1%), and resulted in novel findings in a total of 31/64 patients (48.4%). The most common finding was patellar tendon injury (11/64), but only 3 of these patients required tendon repair.

Conclusions: Substantial variation exists in the diagnostic evaluation of tibial tubercle fractures. CT was most helpful in clarifying intra-articular involvement, while MRI can identify patellar tendon injury, periosteal sleeve avulsion, or a nondisplaced fracture. This study quantifies variation in diagnostic practices for tibial tubercle fractures, highlighting the need for evidence-based indications for advanced imaging.

Level of Evidence: Level III.

Key Words: tibial tubercle fracture, computed tomography, magnetic resonance

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The tibial tubercle generally ossifies between the ages of 10 to 15 years in girls and 11 to 17 years in boys.[1] Due to the timing and pattern of physeal closure in the proximal tibia, adolescents are most susceptible to avulsion fractures of the tibial tubercle.[1,2] The typical mechanism of injury involves abrupt, eccentric contraction of the quadriceps (ie, during landing) or a concentric contraction during jumping.[1,3–5] Tibial tubercle avulsion fractures are a relatively uncommon injury, representing fewer than 1% of all physeal injuries[1–4,6,7] and 0.4% to 2.7% of all pediatric fractures.[1,2,8] They are estimated to have an incidence of 0.25 to 2.7 cases per year.[9] Given this relatively low frequency, the available literature is mostly limited to small, retrospective series from single centers.[2,5,10–16] The limitations inherent to such data may contribute to a lack of evidence-based indications and variation in diagnostic and treatment practices.[8]

Previous studies have reported wide variability in the utilization and impact of advanced imaging in the evaluation of tibial tubercle fractures. A survey of pediatric orthopaedic surgeons found only slight or poor agreement on indications for ordering oblique x-rays, contralateral knee x-rays, or advanced imaging.[8] Furthermore, the frequency at which advanced imaging yields novel findings that impact treatment is unclear.[17–19] These rates vary widely in the existing literature for computed tomography (CT).[17–19] Magnetic resonance imaging (MRI) seems to be used infrequently but may identify concurrent soft tissue injury.[6,20] However, existing data on imaging practices are based on small, retrospective series or systematic reviews of such studies. Quantifying variation in diagnostic practices is the first step in identifying areas of future research, developing evidence-based indications, and balancing clinical benefit with resource utilization. In this context, the purpose of this study is to investigate diagnostic practices for tibial tubercle fractures in a large, multicenter cohort, with attention to the usage and impact of advanced imaging.

METHODS

This study is a retrospective series of tibial tubercle avulsion fractures treated at 7 centers across the United States. Institutional review board approval was granted at all sites. Patients were included in the study if they sustained a fracture of the tibial tubercle between 2007 and 2022, were younger than 18 years, and had full demographic and pretreatment data. Exclusion criteria were age 18 years or older, missing demographic or pretreatment data, a fully fused proximal tibial physis, tubercle apophysis, or a proximal tibia fracture not involving the tubercle. Patients were initially queried broadly by searching for International Classification of Diseases (ICD)-9 codes (822.0, 822.1, 823.00, 823.02, 823.12, 823.10, 823.80) and ICD-10 codes (all codes under S82.0, S82.15, S82.10, S82.19, and S82.20). Each patient's chart was then reviewed to determine whether they met the inclusion criteria.

We collected demographic data as well as information on injury mechanism, sports participation, radiographic evaluation, fracture classification, physical examination, and treatment. Data were collected via REDCap (Research Electronic Data Capture). Fractures were classified according to the Ogden and Pandya systems by the treating surgeon (Figs. 1, 2).[17,21] The use of advanced imaging (CT and/or MRI) was recorded as was the presence of imaging findings not identified with conventional radiographs. Of note, if advanced imaging was utilized, fracture classification was typically denoted following such testing. Statistical analysis was performed with SPSS for Macintosh (v27.0, IBM Corp.; Armonk, NY). Descriptive statistical analyses were performed. χ^2 tests were used to compare the proportion of patients undergoing advanced imaging at each center. Means are reported ± SD, and statistical significance was set to $P<0.05$.

RESULTS

A total of 598 patients were included, of which 530 (88.6%) were male. Demographic details are displayed in Table 1. The mean age was 13.8 ± 1.9 years, and the mean body mass index (BMI) was 24.5 ± 5.7. The majority of injuries occurred during sports, especially basketball (Table 1). Ogden type III (252/598, 42.2%) and Pandya type C fractures (262/598, 43.8%) were most common. There were no open fractures. Ultimately, 488 (81.6%) patients were treated surgically.

Anteroposterior and lateral x-rays were obtained for all patients. Internal oblique x-rays were obtained in 267 (44.6%), CT in 158 (26.4%), and magnetic resonance imaging MRI in 64 (10.7%). There were significant differences in the frequency at which CT was obtained at the 7 centers, ranging from 7.2% to 79.4% ($P<0.001$). Similarly, the frequency at which MRI was obtained varied significantly from 1.5% to 54.8% ($P<0.001$). There were no significant differences in the rate at which CT ($P=0.10$) or MRI ($P=0.31$) were performed if an internal oblique x-ray was already obtained, likely because most oblique x-rays were taken at angles that were not actually orthogonal to the tubercle. There were no significant annual differences in the frequency of CT ($P=0.06$) or MRI ($P=0.87$) throughout the study period.

CT was ordered most frequently for Ogden type IV and Pandya type B fractures, while MRI was obtained

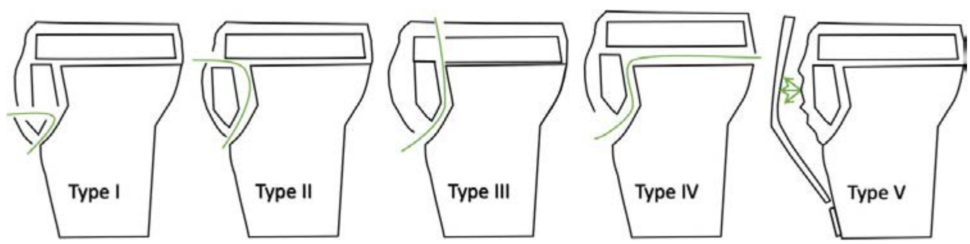

FIGURE 1. Ogden classification of tibial tubercle fractures. Type I involves the secondary ossification center near the insertion of the patellar tendon. Type II exits between the primary and secondary ossification centers. Type III crosses the primary ossification center and exits in the articular surface. Type IV exits posteriorly through the entire physis or metaphysis. Type V is a periosteal sleeve avulsion from the secondary ossification center. full color online

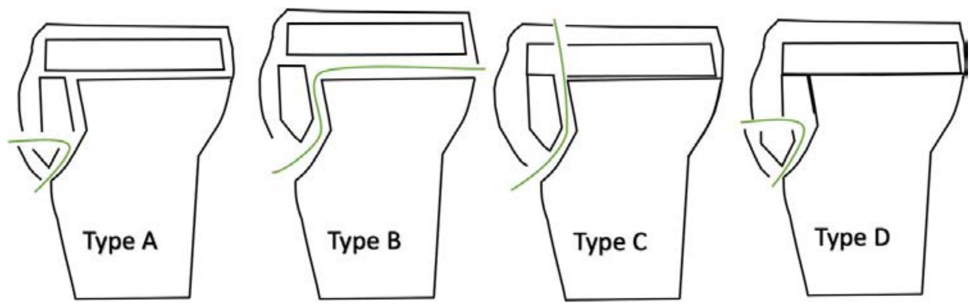

FIGURE 2. Pandya classification of tibial tubercle fractures. Type A is isolated to the ossified tip of the tubercle in young patients, where the majority of the tubercle is still cartilaginous. Type B exits posteriorly through the entire physis. Type C exits in the articular surface. Type D involves only the distal aspect of the tubercle in older adolescents, as the proximal tibial physis and most of the tubercle apophysis have closed. full color online

most frequently for Ogden type V and Pandya type A fractures (Table 2). CT yielded novel findings that were unseen or unclear on plain films in 37/158 patients (23.4%). These included intra-articular involvement (25/37), concomitant fracture lines (5/37), enhanced interpretation of fracture comminution (4/37), and other findings (3/37). New findings were most commonly seen on CT for Ogden type III and Pandya type C fractures, and least commonly for Ogden type V and Pandya type D fractures (Table 3). While our data are unable definitively determine changes in management based on CT, no additional procedures besides screw fixation were performed in the 36 of these patients that were treated surgically.

MRI yielded novel findings in 31/64 patients (48.4%). These included patellar tendon injury (11/64), intra-articular fracture involvement (8/64), identification of a nondisplaced fracture (6/64), periosteal sleeve avulsion (5/64), and lateral meniscus injury (1/64). New findings were most commonly seen on MRI for Ogden types I and V and Pandya type A fractures, and least commonly for Ogden types II and IV and Pandya type B fractures (Table 3). Although we are unable to confidently determine changes in treatment based on MRI in this retrospective study, only 3 of the 11 patients with a patellar tendon injury identified on MRI required tendon repair during surgical fracture fixation. Sixteen patients who did not have preoperative MRI underwent concomitant patellar tendon repair with fracture fixation. The lone patient with a meniscus injury on MRI did not undergo any intervention for their meniscus tear.

DISCUSSION

Given the relative rarity of tibial tubercle fractures, the literature is mostly limited to small, single-center series. This results in variations in their evaluation and treatment. Quantifying variation in practice can elucidate areas for future research and resource optimization. This multicenter evaluation of 598 tibial tubercles demonstrated substantial variation in the utilization of imaging beyond standard radiographs. CT provided information that could not be gleaned from x-rays 23.4% of the time. MRI, while obtained more selectively, yielded such findings in 48.4% of cases. New findings that were not seen on plain films were most commonly identified on CT for Ogden type III and Pandya type C fractures and on MRI for Ogden type I and V and Pandya type A fractures. CT seemed to be most helpful in identifying intra-articular fracture extension, while MRI was most useful in confirming a nondisplaced fracture or periosteal sleeve avulsion.

Previously, the 2 largest studies on tibial tubercle fractures were systematic reviews with demographic distribution of patients similar to the present study. Kalifis et al[20] included 915 patients over a span of 20 years with an average age of 14.4 years, 83% boys, and basketball as the most common sport during injury. These demographics are similar to those of our study. The authors reported that CT was obtained in 6% of patients and MRI in 1%. Before this, Pretell-Mazzini et al[6] analyzed 336 patients over a span of 43 years with an average age of 14.6 years. However, no data were collected regarding the utilization of advanced imaging. Both reviews are limited by the lack of high-level evidence and possible reporting bias. In addition, both include patients from numerous countries over long study durations, which may impact population demographics, medical and surgical technology, and research methodology likely. The present study includes more contemporary data on 598 patients from seven geographically diverse centers in the United States with consistent extraction of demographic, clinical, and radiographic variables of interest. In our study, both CT and MRI were utilized more frequently than in the aforementioned systematic review.

In a survey of pediatric orthopaedists, Fields and colleagues note that poor agreement was reached on the use of an internal rotation x-ray of the knee and only slight agreement regarding the use of CT and MRI. However, advanced imaging was more likely to be used for Ogden type III and IV fractures.[8] Similarly, the present clinical study found that CT was ordered most frequently for Ogden type IV fractures (50.5% underwent CT) even though this fracture pattern is not intra-articular. MRI was obtained most frequently for Ogden type I and V

TABLE 1. Demographic Information*

Demographic	Value
Sex, n (%)	
Male	530 (88.6)
Female	68 (11.4)
Age (y)	13.8 ± 1.9
Weight (kg)	71.1 ± 19.6
Body mass index	24.5 ± 5.7
Race, n (%)	
Black	261 (43.6)
White	151 (25.3)
Other	109 (18.3)
Asian	12 (2.0)
Unknown	65 (10.9)
Ethnicity, n (%)	
Non-Hispanic	404 (67.6)
Hispanic	137 (22.9)
Unknown	57 (9.5)
Insurance, n (%)	
Private	300 (50.2)
Public	253 (42.3)
None	10 (1.7)
Other	35 (5.9)
Mechanism of injury, n (%)	
Jumping	248 (41.5)
Fall from standing	111 (18.6)
Collision	106 (17.7)
Running	35 (5.9)
Fall from height	33 (5.5)
Other	65 (10.9)
Sustained during sports, n (%)	482 (80.6)
Sport during injury (n = 482), n (%)	
Basketball	229 (47.5)
Soccer	62 (12.9)
Football	58 (12.0)
Running	35 (7.3)
Other	98 (20.3)
Laterality, n (%)	
Left	352 (58.9)
Right	246 (41.1)
Ogden classification, n (%)	
Type I	129 (21.6)
Type II	83 (13.9)
Type III	252 (42.2)
Type IV	99 (16.6)
Type V	35 (5.9)
Pandya classification, n (%)	
Type A	128 (21.4)
Type B	105 (17.6)
Type C	262 (43.8)
Type D	103 (17.2)

*Values reported as n (%) or mean ± SD.

injuries. This was likely to confirm a subtle fracture at the secondary ossification center (type I) or a periosteal sleeve avulsion (type V), which often has little bony involvement. The specific indications for ordering advanced imaging for each patient were unclear in our retrospective data, but utilization varied widely between centers. This may be related to a lack of evidence on which to base guidelines for CT and MRI, as well as the institutional ease or difficulty in obtaining such tests. Oblique x-rays were obtained in 44.6% of the patients in this study, but the majority were "too" oblique (ie, not orthogonal to the tubercle). We recommend obtaining standard anteroposterior and lateral x-rays of the knee, with an internal rotation x-ray taken at slight obliquity compared with a lateral view to provide a better view of the tubercle. This is straightforward since it only adds a single additional radiographic view and may provide a more orthogonal view of the tubercle, which is often a somewhat lateralized structure. This may obviate the need for advanced imaging in some cases.

TABLE 2. Use of Advanced Imaging by Fracture Classification*

Fracture classification	CT	MRI
Ogden, N/n (%)		
Type I	7/129 (5.4)	30/129 (23.3)
Type II	13/83 (15.7)	5/83 (6.0)
Type III	87/252 (34.5)	11/252 (4.4)
Type IV	50/99 (50.5)	5/99 (5.1)
Type V	1/35 (2.9)	13/35 (37.1)
Pandya, N/n (%)		
Type A	4/128 (3.1)	34/128 (26.6)
Type B	49/105 (46.7)	6/105 (5.7)
Type C	89/262 (34.0)	11/262 (4.2)
Type D	16/103 (15.5)	13/103 (12.6)

*Values reported as proportion (%).
CT indicates computed tomography; MRI, magnetic resonance imaging.

Pandya et al[17] previously suggested that standard plain radiographs may underestimate the severity of the injury. The authors found that fracture classification was underestimated by radiographs alone in 50% of patients overall and 80% of those who underwent CT, with missing information regarding the degree of intra-articular involvement that impacted the treatment plan.[17] However, the study included just 40 patients, of which only 10 had advanced imaging.[17] Compared with these results, the rate at which CT impacted fracture classification was lower in publications by Haber et al[18] (6 out of 25 patients, 24.0%) and Brown et al[19] (0 out of 3 patients). In the present study, 23.4% of 158 patients who underwent CT had novel findings that were not seen on plain films. This was most commonly intra-articular involvement in Ogden type III fractures, with minimal management-changing findings for other fracture types. On the basis of our data, CT scan is most useful in assessing intra-articular involvement

TABLE 3. Prevalence of Advanced Imaging Findings Not Seen on X-rays*

Fracture classification	CT	MRI
Ogden, N/n (%)		
Type I	1/7 (14.2)	18/30 (60.0)
Type II	2/13 (15.4)	1/5 (20.0)
Type III	25/86 (29.1)	3/11 (27.2)
Type IV	9/50 (18.0)	1/5 (20.0)
Type V	0/1 (0.0)	8/13 (61.5)
Pandya, N/n (%)		
Type A	1/4 (25.0)	22/34 (64.7)
Type B	8/49 (16.3)	1/6 (16.7)
Type C	26/89 (29.2)	3/11 (27.3)
Type D	2/16 (12.5)	5/13 (38.4)

*Values reported as proportion (%).
CT indicates computed tomography; MRI, magnetic resonance imaging.

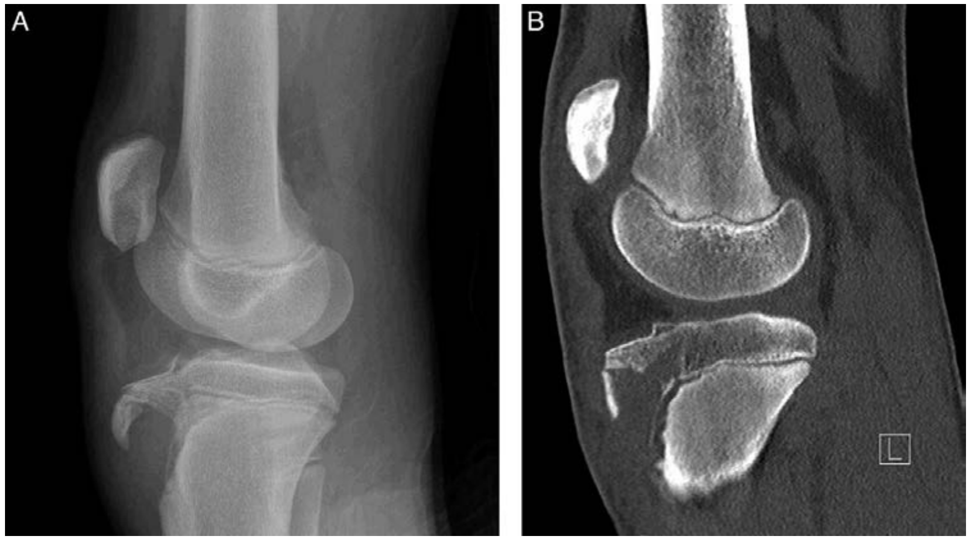

FIGURE 3. A, Lateral x-ray of a 12-year-old boy who sustained a tibial tubercle fracture. Intra-articular involvement is questionable. B, Sagittal CT of the patient in (A) demonstrating the subtle intra-articular extension of the tibial tubercle fracture.

(Figs. 3A, B), but otherwise did not yield many findings that were not already seen on x-ray. In addition, while we are unable to definitively determine the impact of CT on management or outcomes, no patients who had a CT scan underwent concomitant procedures with their fracture treatment. Therefore, assessment of intra-articular fracture extension is the primary indication for CT, with less need if high-quality radiographs clearly visualize the tubercle fracture and articular surface. The main drawbacks of CT are increased cost and radiation exposure to the patient. While CT of the knee confers more than 30 times less radiation than chest CT, it still results in twice the amount of radiation as a chest radiograph and 20 times the radiation of a knee radiograph.[22,23] These risks must be balanced against the potential benefits of this modality.

In previous literature, only 1% of patients received MRI during evaluation.[20] Both aforementioned systematic reviews suggest that concurrent soft tissue injuries occur somewhat infrequently, with rates of patellar tendon avulsion between 2% and 6% and rates of meniscus injury between 1% and 2%.[6,20] Pretell-Mazzini et al[6] also reported that all of the meniscus tears occurred with intra-articular Ogden type III fractures. In the present study, MRI identified novel findings in 48.4% of scans, which mainly included patellar tendon injury, intra-articular involvement, confirmation of a nondisplaced fracture, and diagnosis of a periosteal sleeve avulsion. These were most commonly found in Ogden type I and V fractures (Figs. 4A, B). While MRI provides enhanced soft tissue details, its use should be weighed against cost, availability, and potential delays to definitive treatment. On the basis of our findings, the most appropriate indications for MRI are likely to confirm a nondisplaced fracture or periosteal sleeve avulsion. However, a combination of patient history, physical exam, and subtle radiographic findings may sometimes be enough to identify these injuries. In addition, the incidence of clinically relevant soft tissue injury associated with tibial tubercle fractures is low and its overall impact on fracture management is unclear. In the present study, the most common MRI finding was patellar tendon injury. While this has the potential to affect management depending on the pattern and severity of tendon injury, such pathology can be identified intraoperatively by direct visualization regardless of whether MRI was obtained. Only 3 of the 11 patients with patellar tendon injury on MRI required surgical repair of the tendon. Similarly, low rates of meniscal injury were found on MRI in our study, and this can also be evaluated intraoperatively with arthrotomy or arthroscopy if preoperative MRI is difficult to obtain. Only 1 meniscus injury was diagnosed on MRI, and this patient did not undergo any concomitant meniscal procedures with their fracture fixation. As an alternative, ultrasound may be a quicker and less costly modality for confirmation of a periosteal sleeve avulsion, but is only utilized in 0.2% of cases.[24] Although the present study is a useful first step forward, further research is needed to develop evidence-based indications for advanced imaging to decrease practice variation, balance clinical impact with resource utilization, and determine the effect on clinical outcomes. A prospective, multicenter study will soon be underway to address the questions posed by the current study as well as its limitations.

Limitations of our study are largely related to biases inherent to its retrospective design. In addition, retrospective research relies on the accuracy of the medical record and can be limited by missing data or variations in reporting practices across providers and centers. Nevertheless, a retrospective approach is often more feasible for rare diagnoses like tibial tubercle fractures, especially when a large study population is needed. In addition, multicenter studies can have heterogeneity in clinical practice and documentation despite having greater gen-

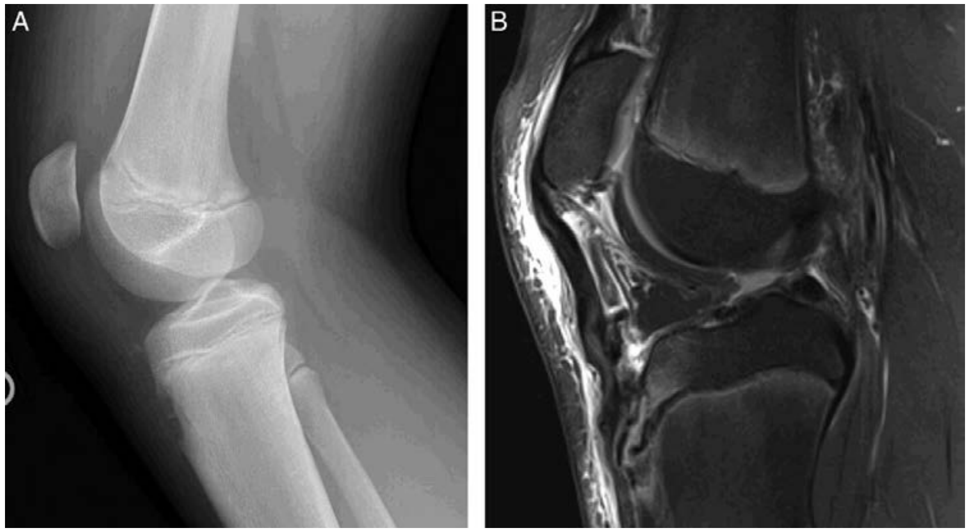

FIGURE 4. A, Lateral x-ray of a 12-year-old boy who sustained an acute knee injury. No obvious fracture is noted. B, T2 sagittal MRI of the patient in (A) demonstrating a tibial tubercle avulsion and increased intrasubstance signal within the patellar tendon.

eralizability of the data. While we collected details on diagnostic practices, we were unable to determine who directed the testing or the specific indications for each exam. For example, it is unclear whether oblique x-rays or advanced imaging was obtained based on the preferences of orthopaedic or emergency department clinicians. In addition, given the retrospective design of this study, we are unable to definitively determine how frequently advanced imaging changed treatment plans or clinical outcomes. Finally, since fractures were classified after the use of advanced imaging (when obtained), we are unable to determine how frequently such testing changed classification. The data in Table 3 suggest that this was likely infrequent since the main finding that would prompt a change in classification is intra-articular fracture extension, and few concurrent procedures were performed on patients with advanced imaging.

This large, multicenter study of 598 patients found variations in diagnostic practices for tibial tubercle fractures, particularly with regard to the use and impact of advanced imaging. CT was most helpful in identifying intra-articular involvement, while MRI identified patellar tendon injury, periosteal sleeve avulsion, and nondisplaced fractures. This study provides an improved understanding of tibial tubercle fracture diagnostic practices, which in turn highlights areas for future research and is a starting point for developing evidence-based indications to improve resource utilization.

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