Knee Surgery, Sports Traumatology, Arthroscopy (2019) 27:86–92
https://doi.org/10.1007/s00167-018-5039-7

KNEE

A new, MRI-based classification system for tibial spine fractures changes clinical treatment recommendations when compared to Myers and Mckeever

Daniel Green[1] · Maria Tuca[2] · Eva Luderowski[3] · Elizabeth Gausden[1] · Christine Goodbody[1] · Gabrielle Konin[1]

Received: 6 February 2018 / Accepted: 26 June 2018 / Published online: 30 June 2018

Abstract

Purpose Tibial spine fractures (TSFs) are graded according to the Meyers and McKever (MM) classification system, which is based on a qualitative evaluation of plain radiographs. However, although MRI images can provide important information about these fractures, there is no MRI-based classification system. This study aims to (1) establish the intra- and inter-rater reliability of the MM system for use with radiographs, (2) propose a quantitative, MRI-based system and compare its reliability to the MM system, and (3) assess how often using the MRI-based system changes the classification and potential treatment plan as previously determined using MM.

Methods The MRI-based system was designed with three grades based on quantitative displacement patterns of the fractured fragment and tissue entrapment. Four raters from a tertiary care center evaluated 20 fractures according to the MM and MRI-based systems. Observers graded images at two time points at least 2 weeks apart, after which we compared the intra- and inter-rater reliability of each system (using Fleiss' kappa and weighted kappa, respectively) and assessed how often using the MRI-based system changed the fracture grade.

Results Both the MM and MRI-based systems exhibit fair to moderate intra- and inter-rater reliability (average kappa values ranged from 0.38 to 0.66). Use of the MRI-based system changed the fracture grade and as a result modified the treatment recommendations in 32.5% of cases: 6.9% were previously unnoticed fractures, 13.1% underwent a raise in grade, and 12.5% were graded as lower than before.

Conclusion The MRI-based system is as reliable as the MM system and provides specific, quantitative criteria for classifying fractures according to fragment displacement and tissue entrapment. The new MRI-based system potentially clarifies treatment indications for TSFs.

Level of evidence Diagnostic Study, Level II.

Keywords Tibial spine fracture · Knee · Imaging and radiology · Pediatric sports medicine · Clinical assessment/grading scales

Abbreviations

TSF Tibial spine fractures
MM Meyers and Mckeever

✉ Eva Luderowski
eludero1@jhmi.edu

Daniel Green
greendw@hss.edu

Maria Tuca
mjtuca@gmail.com

Elizabeth Gausden
gausdene@hss.edu

Christine Goodbody
goodbodyc@hss.edu

Gabrielle Konin
koning@hss.edu

[1] The Hospital for Special Surgery, 535 East 70th Street, New York, NY 10021, USA

[2] Clínica Alemana, Universidad del Desarrollo, Av Vitacura 5951, Vitacura, Región Metropolitana, Santiago, Chile

[3] Johns Hopkins University School of Medicine, 733 North Broadway, Baltimore, MD 21205, USA

Introduction

Tibial spine fractures (TSFs), also called tibial eminence or intercondylar eminence fractures, are bony avulsions of the tibial spine at the point of insertion of the ACL [1]. Although TSFs can occur in adults [2, 3], these injuries are most common in skeletally immature patients between 8 and 14 years old [4] in which force applied to the ACL causes failure of the incompletely ossified tibial spine rather than the ligament itself [1].

TSFs are typically classified on plain radiographs according to the Meyers and Mckeever (MM) system, which was developed in 1959 and grades fractures as Type I (non-displaced), Type II (hinged), Type III (completely displaced but not rotated), or Type III+ (completely displaced with rotation) based on the degree of displacement of the fractured fragment [5]. As MM suggested when they published their system, there is consensus that Type I fractures should be treated non-operatively, whereas Type III are typically surgical candidates [6–14]. Significant ambiguity remains regarding the treatment of Type II fractures, though many surgeons, including the authors of this study, attempt an initial closed reduction and recommend surgery only if an acceptable closed reduction cannot be achieved [3, 15–19].

Importantly, a significant portion of TSFs are accompanied by soft tissue or bony injuries. One series reported that up to 59% of a pediatric TSF cohort sustained a concomitant meniscal entrapment, meniscal tear, or chondral injury [19], and in a cohort of adults, all patients with TSFs experienced soft tissue or osteochondral injuries, the majority of which were only detectable using MRI [3]. Although treatment can be complicated by soft tissue injury, the MM system does not account for soft tissue injuries because they are difficult to visualize on radiographs.

Increasingly, MRI is used to evaluate TSFs since it allows for the identification of concomitant soft tissue injuries and a more precise characterization of the fracture pattern [20–22]. Despite the frequent use of MRI in the diagnosis of TSFs, to date no MRI-based classification system for these injuries has been reported. An MRI-based classification system for TSFs would be a valuable tool for guiding diagnosis and treatment options.

This study aims to (1) establish the intra- and inter-rater reliability of the MM system for use with radiographs, (2) propose a quantitative, MRI-based system and compare its reliability to the MM system, and (3) assess how often using the MRI-based system changes the classification and potential treatment plan as previously determined using MM. The hypothesis of this study is that the MRI-based system will be at least as reliable as MM for grading TSFs.

Materials and methods

Design of an MRI-based classification system

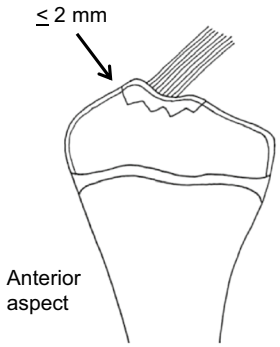
An MRI-based classification system was designed based on specific, quantitative displacement of the fractured fragment as well as tissue impingement (Fig. 1). Grade I fractures are defined as non- or minimally-displaced fractures with ≤ 2 mm of displacement. Grade II fractures are posterior-hinged fractures with > 2 mm displacement of the anterior aspect of the fracture and ≤ 2 mm displacement of the posterior aspect of the fragment. Grade III fractures are those with either > 2 mm of displacement of the posterior aspect of the fragment, meniscal entrapment (where the meniscus or intra-meniscal ligament is underneath a fracture fragment), or extension to the weight-bearing surface of the medial or lateral tibial plateau with > 2 mm of displacement.

Evaluation of the MRI-based system

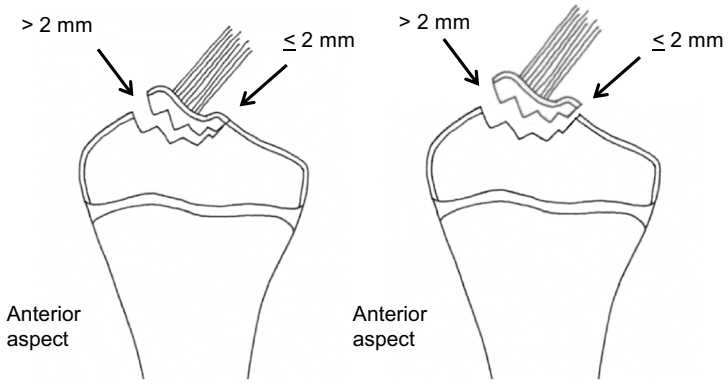
Four independent observers with a range of professional experience (a junior orthopaedic surgery resident, a senior orthopaedic surgery resident, an attending musculoskeletal fellowship-trained radiologist, and an attending orthopaedic surgeon) evaluated images of 20 TSFs using the MM and the new, MRI-based system. The 20 cases represent all available pediatric TSFs with both radiographs and MRI in the picture archiving and communication system (PACS) from a single, tertiary care center and include three Type I, nine Type II, and eight Type III fractures as scored by first author using the MM classification. MRIs were performed on 1.5 or 3-T units (GE Healthcare, Waukesha, Wisconsin) using eight-channel phased-array transmit–receive knee coils (In Vivo, Orlando, Florida). Graders were given access to all slices of each MRI sequence. Two-dimensional fast spin-echo imaging was performed in three orthogonal planes (coronal, sagittal, axial) using a high signal-to-noise ratio and high spatial resolution. A short-tau fast inversion recovery sequence was additionally obtained in the sagittal plane. Internal Review Board approval was obtained from the Hospital for Special Surgery (IRB ID 2014 – 189).

Statistical analysis

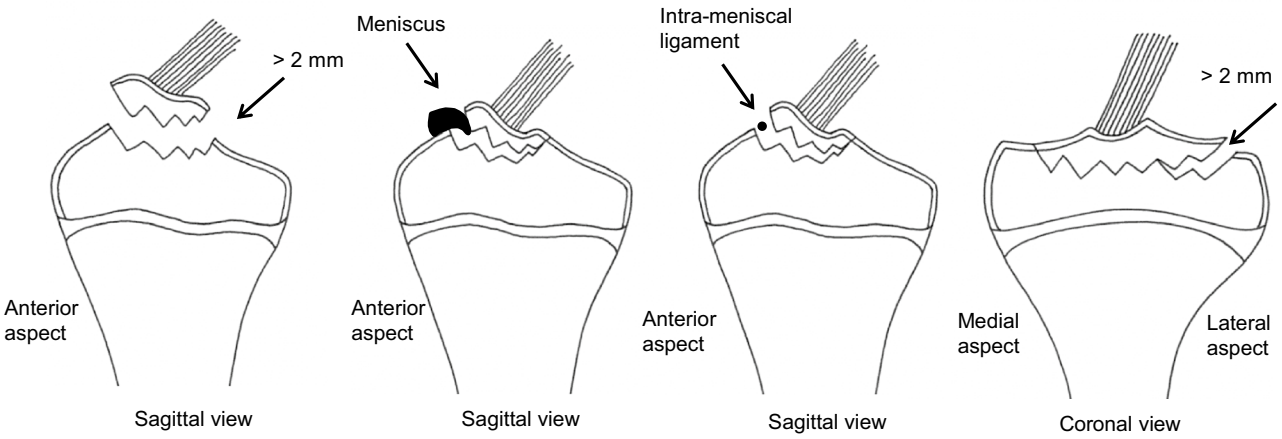
Observers first classified the radiographic images of 20 patients according to the MM, grading images at two time points at least 2 weeks apart. Next, the same raters repeated their assessments using the new, MRI-based system, grading 20 MRI images from the same patients at two time points at least 2 weeks apart for a total of 160 graded images. The inter- and intra-rater reliability of each system was assessed using Fleiss' kappa and weighted kappa, respectively (Stata



Grade 1: Non- or minimally displaced fractures (≤ 2 mm of displacement).



Grade 2: Posterior-hinged fractures (> 2 mm displacement of the anterior aspect of the fracture and ≤ 2 mm displacement of the posterior aspect of the fragment).



Grade 3: Meets any of the following criteria:
1. Displaced fracture (> 2 mm of displacement of the posterior aspect of the fragment).
2. Fracture that results in meniscal or intra-meniscal ligament entrapment (where the meniscus or intra-meniscal ligament is inferior to a fracture fragment).
3. Fracture extending to the articular surface of the medial or lateral tibial plateau with > 2 mm of displacement.

Fig. 1 The new, MRI-based system for classifying TSFs

14.0 software). Kappa values were interpreted according to Landis and Koch (Landis and Koch).

Three scenarios were considered as "changes in grade": when use of the MRI-system (1) allowed raters to identify a fracture that had been graded as "not fractured" using radiographs, (2) raised the fracture grade, and (3) lowered the fracture grade. The fractions of cases that changed grade were reported as percentages.

Results

Reliability of the Meyers and McKeever system

The inter-rater reliability of the MM system was assessed at two time points at least 2 weeks apart. Inter-rater reliability at time points 1 and 2 showed fair to moderate agreement ($k = 0.49$ and 0.29, respectively) according to Landis and Koch (Table 1) [23]. The intra-rater reliability ranged from 0.52 to 0.77 and averaged substantial agreement (average $k = 0.66$) (Table 1).

Table 1 Inter- and intra-rater reliabilities of the MM and MRI-based systems

	Meyers and McKeever system	MRI-based system
Inter-rater reliability (Fleiss' kappa)	Time 1: $k = 0.49$	Time 1: $k = 0.34$
	Time 2: $k = 0.29$	Time 2: $k = 0.41$
	Average $k = 0.39$	Average $k = 0.38$
Intra-rater reliability (weighted kappa)	Rater 1: $k = 0.77$	Rater 1: $k = 0.56$
	Rater 2: $k = 0.52$	Rater 2: $k = 0.50$
	Rater 3: $k = 0.61$	Rater 3: $k = 0.74$
	Rater 4: $k = 0.75$	Rater 4: $k = 0.85$
	Average $k = 0.66$	Average $k = 0.66$

Reliability of MRI-based system

Similar to the MM system, the MRI-based system exhibited fair to moderate inter-rater reliability at time points 1 and 2 ($k = 0.34$ and 0.41, respectively) (Table 1). The average inter-rater reliability between the MM and MRI-based systems only differed by $k = 0.01$ and were in the same category according to Landis and Koch, indicating that these two systems have comparable levels of inter-rater reliability.

The intra-rater reliability of the MRI-based system ranged from 0.50 to 0.85 and averaged substantial agreement (average $k = 0.66$), similarly to the MM system (Table 1). The intra-rater kappa values generally increased with rater experience, where experience was defined as years of practice after medical school, suggesting that raters may become more reliable as they gain experience.

Assessment of changes in grading and possibly treatment

Changes in grading were defined as when use of the MRI-system (1) allowed raters to identify a fracture that had been graded as "no fracture" using radiographs, (2) changed the grade from a lower grade to a higher grade, and (3) changed the grade from a higher grade to a lower grade.

In 11 of 160 graded images (6.9%), MRI assessment allowed the detection of fractures that were previously unrecognized using radiographs (Fig. 2). In 21 of 160 graded images (13.1%), fractures previously assessed using the MM classification were assigned a higher grade when evaluated using the MRI-based system. For example, a case with meniscal entrapment that was unnoticeable on radiographs but visible on MRI was identified as a MM Type II but reclassified as Grade 3 using the MRI-based system, which defines any fracture with tissue impingement as a Grade 3 (Fig. 3). In 20 of 160 graded cases (12.5%),

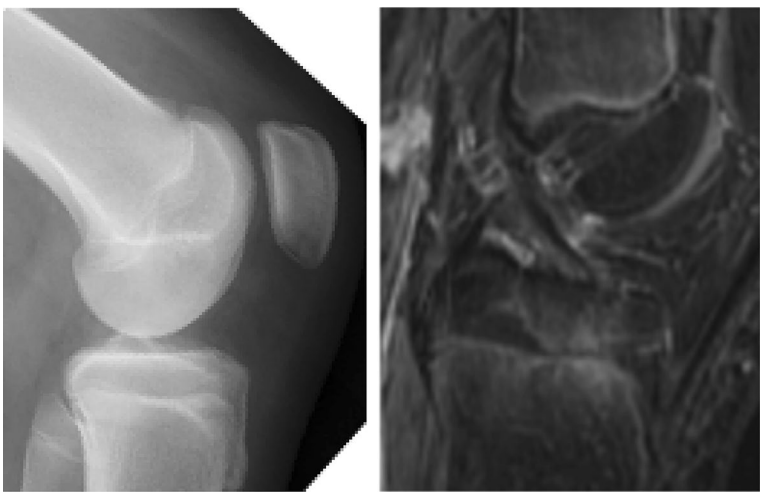


Fig. 2 An example of a case identified as "not fractured" using MM on radiographs but exhibited a non-displaced Grade 1 fracture on MRI

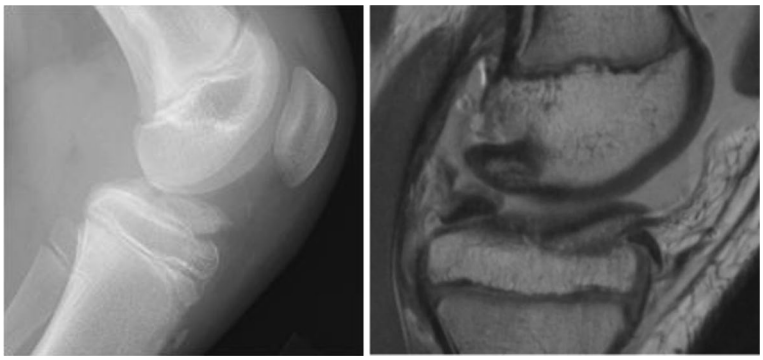


Fig. 3 A TSF initially graded as Type II using the MM on radiographs was re-classified as Grade 3 using the MRI-based system after an MRI showed meniscal entrapment

fractures previously graded using MM were given a lower grade when re-assessed with the MRI-based system. For example, a fracture with a displaced fragment was graded as Type III according to MM, yet MRI revealed a minimal, quantifiable displacement of ≤ 2 mm on the posterior hinge and the absence of soft tissue entrapment, resulting in re-classification as Grade 2 (Fig. 4). Overall, combining the three scenarios that constitute a change in treatment, use of the MRI-based system changed the classification in 32.5% of cases.

One of the most important findings is the extent to which use of the MRI-based system affected the grading of TSFs previously identified as MM Type II. Of the 64 cases that were graded as MM Type II on radiographs, 25 (39.1%) experienced a change in grade when reevaluated using the MRI-based system. Of the 25 cases that changed grade, 16 (64.0%) shifted up to Grade 3 because of previously undetected meniscal entrapment, inter-meniscal ligament entrapment, > 2 mm displacement of the fractured fragment, or extension of the fracture line to the weight-bearing aspect of the tibial surface, whereas 9 (36.0%) shifted down to Grade 1 because the fracture was ≤ 2 mm displaced. This change does not necessarily imply that the previous classification was incorrect, rather it reflects how the MRI-based system defines Type/Grade 2 more narrowly than MM, immediately categorizing fractures that require surgery as Grade 3 and reducing the ambiguity in treatment associated with Type/Grade 2 injuries.

Discussion

The most important findings of the study are that the MRI-based system is as reliable as MM, provides quantitative guidelines for classifying fractures based on fracture characteristics and soft tissue involvement, and has the potential to clarify indications for surgery. Both the MM and MRI-based systems exhibit fair to moderate intra-rater reliability and substantial inter-rater reliability, indicating that the new system provides a reliable alternative to grading TSFs on radiographs. The proposed TSF classification system uses MRI, defines grades based on quantitative assessments of fracture pattern and fragment displacement, and accounts for meniscal and inter-meniscal ligament entrapment. Moreover, use of the MRI-based system led to changes in grade in 32.5% of the cases evaluated in our study, which has implications for treatment.

There is a consensus that Type I TSFs can be treated non-operatively with immobilization. In this study, MRI allowed the detection of non-displaced fractures that were previously unrecognized using radiographs. These fractures are considered Grade 1 according to the MRI-based classification and

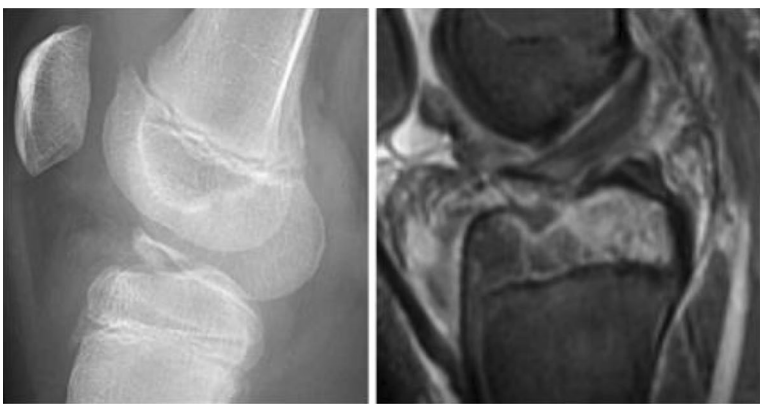


Fig. 4 A TSF initially graded as Type III using the MM on radiographs is re-classified as Grade 2 using the MRI-based system after an MRI showed ≤ 2 mm of posterior displacement and no tissue entrapment

like MM Type I injuries, are typically treated with immobilization. Based on the MM alone, these cases would have been identified as "not fractured" and may not have been properly immobilized.

There is less consensus regarding the treatment of Type II fractures [1], but the authors of this paper recommend attempting a closed reduction and only proceeding to surgery if acceptable reduction cannot be achieved. In this study, the MRI-based system assigned some fractures lower grades than previously determined using the MM classification, most notably in cases where Type III injuries were reclassified as Grade 2 after MRI revealed posterior-hinged fractures with <2 mm displacement of the anterior aspect and ≤ 2 mm displacement of the posterior aspect of the fragment without accompanying tissue entrapment. This reassessment is clinically relevant because it suggests that closed reductions may be feasible for certain patients, allowing these individuals to avoid the risks of surgery.

Importantly, closed reduction of Type II fractures produces variable results [24]. In a series of patients with Type II fractures, Kocher et al. report that closed reduction was only successful in 26 of 49 cases [24]. Moreover, any attempt to perform a closed reduction of a Type II TSF without visualization on MRI risks unknowingly attempting to reduce a knee with meniscal or ligamentous entrapment. Soft tissue entrapment frequently accompanies TSFs, particularly those identified as MM Type II and III. Mitchell et al. categorized 58 pediatric patients with TSFs according to MM and measured the fraction of each type with meniscal entrapment, reporting that 29% of Type II and 48% of Type III fractures had meniscal entrapment [19]. The study by Kocher et al. of 80 children published similar numbers, where entrapment of the anterior horn of the medial or lateral meniscus or inter-meniscal ligament occurred in 26% of Type II fractures and 65% of Type III [24]. Because of the high rate of tissue involvement, it is critical to be able to identify TSFs with accompanying tissue entrapment so that they may be treated surgically, like a Type III, rather than subject to an initial attempt at closed reduction, like a Type II. For this reason, the authors of this study recommend obtaining MRIs for all TSFs that are graded as MM Type II.

In the study, the MRI-based system assigned some fractures higher grades than previously determined using the MM classification. In particular, several former Grade II fractures were reclassified as Grade 3 when MRI provided evidence of ≥ 2 mm displacement posteriorly, fracture extension, or tissue impingement. Unlike MM, the MRI-based system immediately identifies these injuries as surgical candidates, reducing the risk of closed reductions that are likely to fail.

The MRI-based system clarifies guidelines for the treatment of TSFs. Grade 1 fractures are those with ≤ 2 mm displacement, and like MM, we suggest that these injuries are treated non-operatively. Grade 2 fractures are defined as posterior-hinged with >2 mm displacement of the anterior aspect and ≤ 2 mm displacement of the posterior aspect with no tissue entrapment. Knowing that these fractures do not have tissue entrapment or prohibitively severe displacement, we recommend attempting a closed reduction for Grade 2 injuries. Grade 3 fractures have tissue entrapment, a fracture extending to the weight-bearing surface with >2 mm displacement, or >2 mm displacement of the posterior aspect. Although in the MM system, fractures with tissue entrapment or extending to the weight-bearing surface may be classified as Type II or III depending on whether they appear "hinged" or "completely displaced" on radiographs, the MRI-based system recognizes these injuries as Grade 3, directly indicating them for surgery and reducing ambiguity in the treatment plan.

This study has a few limitations. The study was limited by a small sample size; only four observers graded cases and the sample of 20 cases was the largest cohort available from the tertiary care center at which the study was completed. It is likely due to the small sample size that this cohort had fewer instances of meniscal entrapment than reported in the literature. There was significant variation in the experience level of the graders, who range from 2 to 26 years of practice. Although this variation allowed the correlation of rater experience with inter-rater reliability, it may have also contributed to the wide range of weighted kappa values. If all four graders had more experience, the inter-rater reliability of the MRI-based system may have increased. Although the new system was as reliable as Meyers and Mckeever, the authors expect its reliability to improve with continued use. Additionally, some providers consider radiographic images to be better than MRI at assessing bony displacement. However, MRI provides reasonable bone assessment with the added advantages of less radiation and improved visualization of soft tissue.

Conclusion

The authors acknowledge that MRIs are not obtained for all patients with TSFs, especially in resource-limited settings where the high cost of MRI prohibits use. However, when feasible, because of the high rates of soft tissue injury associated with these fractures, the ability of MRI to visualize soft tissue structures, and the utility of the proposed MRI-based system for assisting clinicians with treatment decisions, MRIs should be routinely obtained for patients with Type II TSFs. The MRI-based system is as reliable as MM, the existing standard, and adds the advantage of providing a quantitative rather than qualitative set of criteria for grading based on the fracture pattern and displacement. Moreover, the new system includes guidelines for meniscal

and ligamentous entrapment, which MM does not because tissue is poorly visualized on radiographs. As a result the MRI-based system is a clinically relevant tool that has the potential to streamline treatment by helping physicians rapidly identify cases that require surgery. In total, the MRI-based system builds on the model proposed by Meyers and McKeever and provides a quantitative, comprehensive rubric that clarifies indications for treatment.

Funding No outside funding was provided for this project.

Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest to disclose.

Ethical approval The authors have followed ethical standards as outlined by their institutional review board.

References

1. Coyle C, Jagernauth S, Ramachandran M (2014)Tibial eminence fractures in the paediatric population: a systematic review. J Child Orthop. 8(2):149–159
2. Kendall NS, Hsu SY, Chan KM, (1992). Fracture of the tibial spine in adults and children. A review of 31 cases. Bone Joint J. 74(6):848–852
3. Monto RR, Cameron-Donaldson ML, Close MA, Ho CP, Hawkins RJ (2006) Magnetic resonance imaging in the evaluation of tibial eminence fractures in adults. J Knee Surg. 19(3):187–190
4. Zoints L (2009) Fractures and dislocations about the knee. In: Skeletal trauma in children. Elsevier, Amsterdam; 452–455
5. Meyers MH, McKeever FM (1959) Fracture of the intercondylar eminence of the tibia. J Bone Joint Surg. 41(2):209–222
6. Ahmad CS, Shubin Stein BE, Jeshuran W, Nercessian OA, Henry JH (2001) Anterior cruciate ligament function after tibial eminence fracture in skeletally mature patients. Am J Sports Med. 29(3):339–345
7. Anderson CN, Anderson AF (2011) Tibial eminence fractures. Clin Sports Med. 30(4):727–742
8. Janarv P, Westblad P, Johansson C, Hirsch G (1995) Long-term follow-up of anterior tibial spine fractures in children. J Pediatr Orthop. 15(1):63–68
9. Meyers MH, McKeever FM (1970) Fracture of the Intercondylar Eminence of the Tibia. J Bone Joint Surg Am. 52A(8)
10. Luhmann S (2003) Acute traumatic knee effusions in children and adolescents. J Pediatr Orthop. 23(2):199–202
11. Tudisco C (2010) Intercondylar eminence avulsion fracture in children: long-term follow-up of 14 cases at the end of skeletal growth. J Pediatr Orthop B. 19(5):403–408
12. Wiley J, Baxter M (1990) Tibial spine fractures in children. Clin Orthop Relat Res. 255:54–60
13. Willis R, Blokker C, Stoll T, Paterson D, Galpin R (1993) Long-term follow-up of anterior tibial eminence fractures. J Pediatr Orthop. 13(3):361–364
14. Zaricznyj B (1977) Avulsion fracture of the tibial eminence: treatment by open reduction and pinning. J Bone Joint Surg. 59(8):1111–1114
15. Gans I, Baldwin KD, Ganley TJ (2014) Treatment and management outcomes of tibial eminence fractures in pediatric patients: a systematic review. Am J Sports Med. 42(7):1743–1750
16. Gans I, Ganley TJ (2013) Tibial eminence fractures: a review and algorithm for treatment. Univ Pa Orthop J. 23:20–23
17. Leeberg V, Lekdorf J, Wong C, Sonne-Holm S (2014) Tibial eminentia avulsion fracture in children–a systematic review of the current literature. Dan Med J. 61(3):A4792
18. Shin Y-W, Uppstrom TJ, Haskel JD, Green DW (2015) The tibial eminence fracture in skeletally immature patients: Curr Opin Pediatr. 27(1):50–57
19. Mitchell JJ, Sjostrom R, Mansour AA et al (2015) Incidence of meniscal injury and chondral pathology in anterior tibial spine fractures of children. J Pediatr Orthop. 35(2):130–135
20. Feucht MJ, Brucker PU, Camathias C et al (2017) Meniscal injuries in children and adolescents undergoing surgical treatment for tibial eminence fractures. Knee Surg Sports Traumatol Arthrosc. 25(2):445–453
21. Ishibashi Y, Tsuda E, Sasaki T, Toh S (2005) Magnetic resonance imaging AIDS in detecting concomitant injuries in patients with tibial spine fractures. Clin Orthop Relat Res. 434:207–212
22. LaFrance RM, Giordano B, Goldblatt J, Voloshin I, Maloney M (2010) Pediatric tibial eminence fractures: evaluation and management. J Am Acad Orthop Surg. 18(7):395–405
23. Landis JR, Koch GG (1977) The measurement of observer agreement for categorical data. Biometrics. 33(1):159
24. Kocher MS, Micheli LJ, Gerbino P, Hresko MT (2003) Tibial eminence fractures in children: prevalence of meniscal entrapment. Am J Sports Med. 31(3):404–407