Original Research

Is Nonoperative Treatment Appropriate for All Patients With Type 1 Tibial Spine Fractures?

A Multicenter Study of the Tibial Spine Research Interest Group

Jilan L. Shimberg, BA, Tomasina M. Leska, BS, Aristides I. Cruz Jr, MD, MBA, Henry B. Ellis Jr, MD, Neeraj M. Patel, MD, MPH, MBS, Yi-Meng Yen, MD, PhD, Tibial Spine Research Interest Group, Gregory A. Schmale, MD, and R. Justin Mistovich,* MD, MBA

Investigation performed at University Hospitals Rainbow Babies and Children's Hospital, Cleveland, Ohio, USA

Background: Type 1 tibial spine fractures are nondisplaced or ≤2 mm–displaced fractures of the tibial eminence and anterior cruciate ligament (ACL) insertion that are traditionally managed nonoperatively with immobilization.

Hypothesis: Type 1 fractures do not carry a significant risk of associated injuries and therefore do not require advanced imaging or additional interventions aside from immobilization.

Study Design: Case series; Level of evidence, 4.

Methods: We reviewed 52 patients who were classified by their treating institution with type 1 tibial spine fractures. Patients aged ≤18 years with pretreatment plain radiographs and ≤ 1 year of follow-up were included. Pretreatment imaging was reviewed by 4 authors to assess classification agreement among the treating institutions. Patients were categorized into 2 groups to ensure that outcomes represented classic type 1 fracture patterns. Any patient with universal agreement among the 4 authors that the fracture did not appear consistent with a type 1 classification were assigned to the type 1+ (T1+) group; all other patients were assigned to the true type 1 (TT1) group. We evaluated the rates of pretreatment imaging, concomitant injuries, and need for operative interventions as well as treatment outcomes overall and for each group independently.

Results: A total of 48 patients met inclusion criteria; 40 were in the TT1 group, while 8 were in the T1+ group, indicating less than universal agreement in the classification of these fractures. Overall, 12 (25%) underwent surgical treatment, and 12 (25%) had concomitant injuries. Also, 8 patients required additional surgical management including ACL reconstruction (n = 4), lateral meniscal repair (n = 2), lateral meniscectomy (n = 1), freeing an incarcerated medial meniscus (n = 1), and medial meniscectomy (n = 1).

Conclusion: The classification of type 1 fractures can be challenging. Contrary to prior thought, a substantial number of patients with these fractures (>20%) were found to have concomitant injuries. Overall, surgical management was performed in 25% of patients in our cohort.

Keywords: tibial spine fracture; pediatric knee; tibial eminence fracture; type 1 tibial spine fracture; concomitant soft tissue injury

Avulsion fractures of the anterior cruciate ligament (ACL) from its insertion on the tibial eminence, also known as tibial spine fractures, are relatively rare injuries with an annual incidence of 3 per 100,000.[5] In pediatric and adolescent patients, the incompletely ossified tibial eminence is subject to a fracture before the ACL ruptures because of the elastic strength of the ACL.[17] Recent epidemiological studies credit organized sports as the most common mechanism of injury for tibial spine fractures (36%), followed by bicycle accidents and falls.[1] Tibial spine fractures present with a high rate of concomitant injuries, adding further complexity to the treatment approach.[6,8,10,15]

Tibial spine fractures are classified based on the degree of fracture displacement and the presence or absence of

The Orthopaedic Journal of Sports Medicine, 10(6), 23259671221099572
DOI: 10.1177/23259671221099572

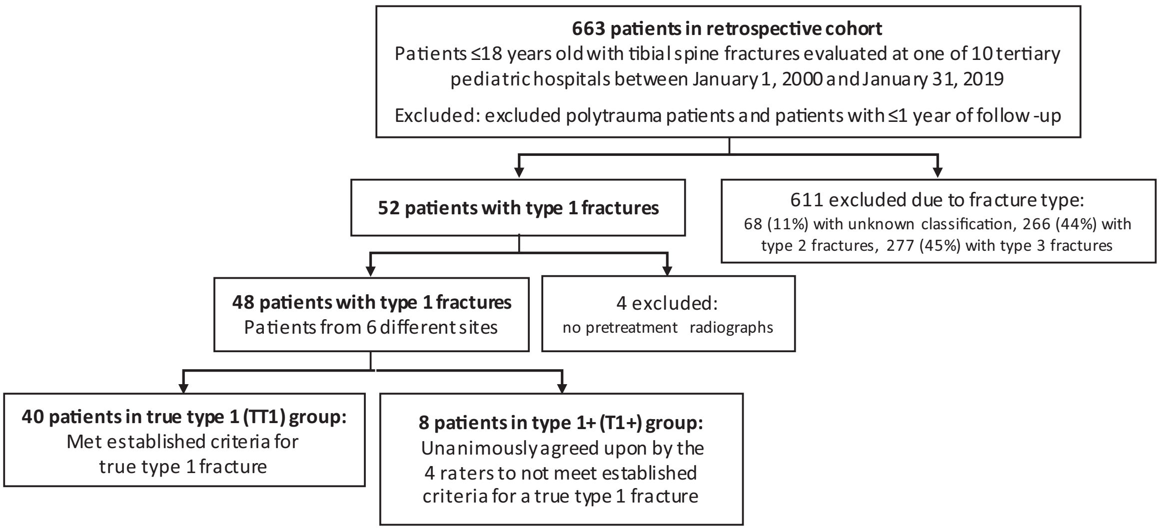

Figure 1. Flowchart of patient selection.

comminution. Meyers and McKeever[11] type 1 tibial spine fractures are nondisplaced or minimally displaced, with up to 2 mm of displacement of the anterior lip.[3] The challenge of classifying tibial spine fractures is highlighted in a recent reliability study, although the reliability of simply classifying fractures as type 1 versus non–type 1 has not been established.[3] Treatment options for tibial spine fractures vary from immobilization to operative fixation; however, it is generally agreed that type 1 fractures are appropriate for nonoperative treatment with immobilization.[4,11,14,16] It has been historically believed that type 1 fractures heal without further complications, although there is a paucity of literature on treatment complications or outcomes of patients with type 1 fractures.

Our study had several objectives. We sought to determine agreement on the classification of type 1 tibial spine fractures based on initial plain radiographs, identify the rate of concomitant injuries and their impact on treatment decision making, and report complications and outcomes of type 1 tibial spine fractures. We hypothesized that with little to no fracture displacement, type 1 fractures do not carry a significant risk of associated injuries and do not require additional interventions aside from immobilization.

METHODS

This was an institutional review board–approved retrospective cohort study of patients presenting to 10 tertiary pediatric hospitals with tibial spine fractures between January 1, 2000, and January 31, 2019. Senior authors from all institutions reviewed pretreatment plain radiographs and classified tibial spine fractures accordingly. The initial cohort of patients did not include those with polytrauma or those with ≤1 year of follow-up. Patients aged ≤18 years with tibial spine fractures were considered for inclusion in our study (Figure 1). We excluded patients with type 2, 3, or 4 fractures. We also excluded patients without available pretreatment imaging (plain radiography, computed tomography, magnetic resonance imaging [MRI]), as the fractures could not be confirmed by the study authors. Patients who met inclusion criteria were from 6 tertiary children's hospitals.

To eliminate any potential classification outliers and differences in fracture classification across institutions and/or surgeons, 4 authors (J.L.S., T.M.L., G.A.S., R.J.M.) reviewed blinded pretreatment plain radiographs for all patients classified with type 1 tibial spine fractures to confirm a true type 1 (TT1) fracture classification. We agreed

*Address correspondence to R. Justin Mistovich, MD, MBA, University Hospitals Rainbow Babies and Children's Hospital, 11100 Euclid Avenue, Cleveland, OH 44106, USA (email: justin@mistovich.net).

All contributing members of the Tibial Spine Research Interest Group are listed in the Authors section at the end of this article.

Final revision submitted January 31, 2022; accepted March 9, 2022.

One or more of the authors has declared the following potential conflict of interest or source of funding: H.B.E. has received education payments from Pylant Medical; speaking fees from Pylant Medical, Smith & Nephew, and Synthes; and hospitality payments from Arthrex. P.D.F. has received hospitality payments from Medical Device Business Services. T.J.G. has received education payments from Arthrex. I.K. has received education payments from Arthrex and Smith & Nephew and hospitality payments from DePuy Synthes. R.J.L. has received education payments from Arthrex and hospitality payments from Vericel. S.M. has received education payments from MedInc of Texas. T.A.M. has received education payments from Arthrex and consulting fees from Medtronic, OrthoPediatrics, and Zimmer Biomet. N.M.P. has received education payments from Liberty Surgical and Medwest and speaking fees from Arthrex. J.R. has received research support from Smith & Nephew and consulting fees from OrthoPediatrics. B.S. has received education payments from MidSouth Orthopedics. Y.-M.Y. has received consulting fees from Smith & Nephew and hospitality payments from Kairos Surgical. G.A.S. has received education payments from Arthrex and speaking fees from SIGN. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from the Children's Hospital of Philadelphia (No. 17-013853).

TABLE 1
Patient Demographics[a]

	TT1 Group (n = 40)	T1+ Group (n = 8)	*P*
Body mass index, mean ± SD, kg/m^2	19.9 ± 3.72	21.7 ± 7.39	.34
Age, mean ± SD, y	10.6 ± 2.95	12.9 ± 2.00	**.04**
Sex, male/female, n	29/11	5/3	.89

[a]Boldface *P* value indicates a statistically significant difference between groups ($P < .05$). TT1, true type 1; T1+, type 1+.

to define a TT1 fracture as either nondisplaced or displaced ≤2 mm. If there was unanimous agreement among the 4 raters that a fracture did not meet the aforementioned criteria of a type 1 fracture, it was assigned to the type 1+ (T1+) group, while the remainder was assigned to the TT1 group. This allowed us to report on what our colleagues were actually defining as type 1 while also adding slightly more granularity to our data with the 2 groups.

Overall, it was universally agreed by the 4 raters that 8 patients did not meet the established criteria for a TT1 fracture, and these were accordingly assigned to the T1+ group. Of note, all patients in the T1+ group were confirmed to be classified as having type 1 fractures by the respective treating surgeon and institution. The remaining 40 patients were categorized as the TT1 group. Additionally, the 4 raters reached a consensus that these 40 patients met radiographic criteria to be categorized into the TT1 group.

We collected data on patient demographics, injury mechanisms, pretreatment imaging, treatment details, presence of concomitant injuries, indications for surgery, treatment complications, and any unexpected postoperative complications necessitating surgical management in all patients. We determined the incidence of associated injuries, the need for operative interventions, and treatment outcomes for the TT1 and T1+ groups.

RESULTS

A total of 48 patients with type 1 fractures were identified by the senior authors (A.I.C., H.B.E., P.D.F., T.J.G., D.W.G., I.K., R.J.L., S.D.M., T.A.M., N.M.P., J.R., B.S., J.L.T., Y.Y., G.A.S., R.J.M.) at all centers and were included in the study. Demographics were similar between the study groups, with the exception of an older age at injury in the T1+ group compared with the TT1 group (12.9 vs 10.6 years, respectively; $P = .04$) (Table 1).

Overall, 12 of 48 (25%) patients in our cohort underwent operative management for their tibial spine fractures; 11 of the patients underwent arthroscopic reduction and internal fixation (ARIF), and 1 patient underwent open reduction and internal fixation (ORIF). Indications for surgical management included ACL tears requiring reconstruction (n = 4), additional treatment for meniscal injuries (n = 2), an evaluation for ACL laxity/injuries (n = 4), an assessment of a lateral meniscal injury identified on MRI (n = 1), the removal of an incarcerated meniscus (n = 1), and fixation of a displaced bucket-handle tear of the lateral meniscus (n = 1). One patient treated operatively did not have a clearly defined reason for operative treatment available in the medical records and lacked pretreatment MRI.

Furthermore, 4 patients had ACL tears identified preoperatively that required reconstruction, 2 patients required lateral meniscal repair, 1 required release of an entrapped medial meniscus, and 1 underwent partial medial meniscectomy. The single type 1 fracture treated with ORIF required lateral meniscectomy. Additional diagnostic arthroscopic surgery was performed in 4 patients for the assessment of possible soft tissue and ligament injuries; none of these patients were found to have ACL or lateral meniscal injuries. However, the tibial spine fractures were fixed arthroscopically. One additional patient, initially managed nonoperatively, demonstrated an ACL tear and medial meniscal tear and thus underwent ACL reconstruction and medial meniscectomy at 3 months after initial MRI. This patient's tibial spine fracture healed appropriately with nonoperative management before these operative procedures.

Of the 48 total patients, 18 (38%) underwent pretreatment MRI, of which 7 (39%) underwent surgical management. Of the 40 patients in the TT1 group, 14 (35%) underwent pretreatment MRI, and 6 (15%) were treated surgically. Of the 8 patients in the T1+ group, 4 (50%) underwent pretreatment MRI, and 6 (75%) underwent operative management (Figure 2).

Additionally, 12 of 48 (25%) had concomitant injuries, most commonly ACL injuries and lateral meniscal tears (Table 2). Most concomitant injuries were diagnosed on pretreatment MRI (n = 11; all confirmed intraoperatively), but 1 patient had a concomitant injury diagnosed initially at the time of ARIF.

Of the 40 patients in the TT1 group, 6 (15%) underwent operative management, and 9 (23%) had concomitant injuries. Of the 8 patients in the T1+ group, 6 (75%) were treated operatively, and 3 (38%) had concomitant injuries ($P = .002$ and $P = .332$, respectively). Also, 4 of the 6 patients (67%) in the TT1 group and 3 of the 6 patients (50%) in the T1+ group treated surgically underwent pretreatment MRI.

There were 5 of 48 patients (10%) who experienced treatment complications. One complication, fracture nonunion, occurred after nonoperative management (1/36 [3%]) and required a return to the operating room for definitive treatment. The other 4 complications occurred after operative management (4/12 [33%]). These included arthrofibrosis (n = 2; after ARIF), a leg-length discrepancy after ARIF, and an injury to the physis after ORIF. Of the 4 patients with complications after operative treatment, 2 required surgical

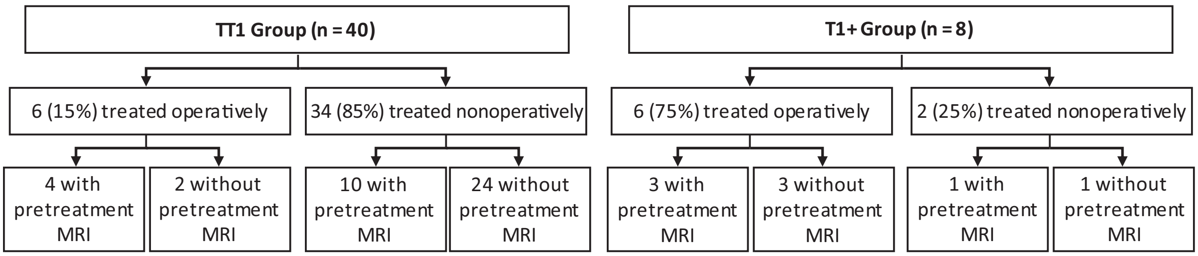

Figure 2. Patient categories.

TABLE 2
Concomitant Injuries[a]

	TT1 Group (n = 9/40)	T1+ Group (n = 3/8)	Total (n = 12/48)
Partial or complete ACL tear	6 (15.0)	1 (12.5)	7 (14.6)
Lateral meniscal tear	2 (5.0)	2 (25.0)	4 (8.3)
Medial meniscal tear	2 (5.0)	0 (0.0)	2 (4.2)
Medial collateral ligament injury	1 (2.5)	0 (0.0)	1 (2.1)
Soft tissue entrapment	1 (2.5)	0 (0.0)	1 (2.1)
Osteochondral defect	1 (2.5)	0 (0.0)	1 (2.1)

[a]Data are reported as n (%). Some patients had multiple concomitant injuries. ACL, anterior cruciate ligament; TT1, true type 1; T1+, type 1+.

management for their complications. One patient with arthrofibrosis required lysis of adhesions and manipulation under anesthesia. The patient with a partial physeal injury after ORIF underwent hemiepiphysiodesis of the proximal lateral tibia. The majority of patients (82%) had a full return to normal range of motion at final follow-up.

DISCUSSION

Type 1 fractures have historically been treated nonoperatively; however, our study demonstrates that a substantial percentage (>20%) of even TT1 fractures present with clinically significant concomitant injuries, including full-thickness ACL tears, and may therefore benefit from operative management. These findings challenge the dogma that type 1 fractures always heal appropriately with simple immobilization, do not have associated injuries, and never require operative management. Furthermore, these findings suggest that advanced imaging, even in patients with type 1 tibial spine fractures, may identify concomitant injuries requiring additional management. Our study also highlights the challenges in current tibial spine fracture classification systems.

The identification of concomitant injuries dictated surgical treatment for most type 1 tibial spine fractures in our study. Recent studies have highlighted a high rate of associated soft tissue injuries with tibial spine fractures, ranging from 35% to 68.8%.[6,7,10,13,15] A recent article discussing technical methods for managing tibial spine fractures also highlighted the authors' experience of type 1 fractures presenting with incarcerated menisci, blocking reduction of the tibial spine fracture.[9] Perhaps most surprising was the number of patients with full-thickness ACL tears requiring reconstruction (n = 5) in our cohort of type 1 fractures. All of these patients had ACL tears identified on preoperative MRI. Additionally, all concomitant injuries identified in our cohort, with the exception of osteochondral defects, required pretreatment advanced imaging for identification. Despite this finding, the majority of patients (30/48 [63%]) in this study did not undergo pretreatment advanced imaging. Associated soft tissue injuries may be missed in patients evaluated with only plain radiography, providing further evidence that MRI is important in tibial spine fractures.[15]

For example, 1 patient in our cohort presented with a type 1 nondisplaced fracture identified on initial radiography. Subsequent advanced imaging demonstrated 6 mm of fracture displacement as well as a lateral meniscal injury, thus changing the fracture classification and treatment recommendations.

It is known that tibial spine fracture classification varies among pediatric sports medicine–trained orthopaedic surgeons.[3] To ensure that our data reflected fractures that represented type 1 fractures as objectively as possible, 4 raters reviewed all pretreatment plain radiographs for the included 48 patients. We categorized the type 1 fractures classified by the treating surgeons into the TT1 group and T1+ group. Both the TT1 and T1+ groups demonstrated relatively high rates of concomitant injuries, refuting our hypothesis that type 1 fractures, confirmed radiographically, exclude the risk of associated injuries that require additional management. Additionally, as evident by the highlighted case, type 1 fractures were not free of the risk of either late displacement or missed displacement on radiographs, which was more apparent with advanced imaging. Even when excluding the 8 patients in the T1+

group, those who may not be considered as having type 1 fractures universally, there still were a significant number of patients in the TT1 group (6/40 [15%]) who required operative treatment. This finding provides surgeons with a reason to perform MRI in patients presenting with type 1 tibial spine fractures.

There were 12 patients in our cohort who underwent reduction and internal fixation for their tibial spine fracture (11 ARIF and 1 ORIF). These patients were treated at 6 different sites, suggesting that no 1 surgeon or hospital system created a selection bias for the decision to perform surgical management, but rather, there were likely identified clinical or radiographic factors that led these surgeons to recommend surgery in these uncommon cases. Additionally, while a higher percentage of patients (7/18 [39%]) who underwent surgical treatment had pretreatment MRI scans, 5 patients (5/30 [17%]) with no advanced imaging underwent operative treatment. This finding suggests that the preoperative identification of a concomitant injury may influence the decision to operate, but we call for further prospective studies to answer this clinical question.

Surgical management does not come without complications. Our study identified 2 patients who had undergone ARIF with arthrofibrosis, which has been identified as the most common postoperative complication of tibial spine fractures.[2] One required lysis of adhesions and manipulation under anesthesia to increase range of motion (0° of extension to 130° of flexion intraoperatively). In a recent study of type 2 tibial spine fractures, those treated nonoperatively were more likely to develop residual laxity and to undergo future tibial spine and ACL surgery, whereas those treated operatively were more likely to develop arthrofibrosis.[16] Trends were similar in our dataset of type 1 fractures, with 1 patient treated nonoperatively requiring later fixation for nonunion.

Limitations

We acknowledge the limited sample size (n = 48) of type 1 fractures included in this study. However, tibial spine fractures are rare; there is minimal literature focusing on type 1 fractures, and this 10-institution dataset, to our knowledge, represents the largest study to date of type 1 tibial spine fractures. Our data are also limited by the study's retrospective nature and lack of patient-reported outcome metrics. Without patient-reported metrics, we cannot fully appreciate the true number of posttreatment complications or our patients' ability to return to prior levels of activities. The mean follow-up for this cohort of patients was 1.13 years, which limits our ability to comment on long-term outcomes after treatment. The mean follow-up did not significantly differ between the TT1 and T1+ groups ($P = .77$). Not every patient included in our study underwent pretreatment MRI or an arthroscopic evaluation; thus, we could be underestimating the true rate of concomitant injuries.

With a paucity of literature on tibial spine fractures and studies limited by a small sample size, some authors have reported different rates of concomitant injuries in their cohorts. Mitchell et al[12] found a high rate of concomitant injuries in tibial spine fractures (59%) but no concomitant injuries in patients with type 1 fractures. However, that study is limited by a sample size of only 6 patients with type 1 fractures. Additionally, similar to our study, patients with type 1 fractures routinely underwent only plain radiography, and without advanced imaging, soft tissue injuries may be underrecognized in this cohort.

CONCLUSION

Contrary to prior hypotheses, the classification of type 1 tibial spine fractures was not universally agreed upon, surgical management was indicated in 25% (12/48) of patients with tibial spine fractures, and 25% (12/48) of patients had a concomitant injury. Perhaps there was an even higher rate of concomitant injuries in this cohort of patients that were not identified, as many patients did not undergo pretreatment advanced imaging or an arthroscopic evaluation. Our study suggests that type 1 fractures identified on plain radiographs are not always simple fractures and that many present with concomitant injuries requiring additional surgical management. We believe that larger prospective studies would be helpful to determine reinjury and late instability rates in type 1 fractures to further identify differences in outcomes based on operative versus nonoperative treatment and to further optimize tibial spine fracture classification and management to best guide treatment of these injuries.

AUTHORS

Jilan L. Shimberg, BA (Case Western Reserve University, Cleveland, Ohio, USA); Tomasina M. Leska, BS (Children's Hospital of Philadelphia, Philadelphia, Pennsylvania, USA); Aristides I. Cruz Jr, MD, MBA (Hasbro Children's Hospital, Providence, Rhode Island, USA); Henry B. Ellis Jr, MD (Texas Scottish Rite Hospital for Children, Dallas, Texas, USA); Peter D. Fabricant, MD, MPH (Hospital for Special Surgery, New York, New York, USA); Theodore J. Ganley, MD (Children's Hospital of Philadelphia, Philadelphia, Pennsylvania, USA); Daniel W. Green, MD, MS, FACS (Hospital for Special Surgery, New York, New York, USA); Benjamin Johnson, PA-C (Texas Scottish Rite Hospital for Children, Dallas, Texas, USA); Indranil Kushare, MD (Texas Children's Hospital, Houston, Texas, USA); R. Jay Lee, MD (Johns Hopkins Hospital, Baltimore, Maryland, USA); Scott D. McKay, MD (Texas Children's Hospital, Houston, Texas, USA); Todd A. Milbrandt, MD (Mayo Clinic, Rochester, Minnesota, USA); Neeraj M. Patel, MD, MPH, MBS (Ann & Robert H. Lurie Children's Hospital of Chicago, Chicago, Illinois, USA); Jason Rhodes, MD (Children's Hospital Colorado, Aurora, Colorado, USA); Brant Sachleben, MD (Arkansas Children's Hospital, Little Rock, Arkansas, USA); Jessica L. Traver, MD (University of Texas Health Science Center at Houston, Houston, Texas, USA); Yi-Meng Yen, MD, PhD (Boston Children's Hospital, Boston, Massachusetts, USA); Gregory A. Schmale, MD (Seattle Children's, Seattle, Washington, USA); and R. Justin Mistovich, MD, MBA (Case Western

Reserve University, Cleveland, Ohio, USA; University Hospitals Rainbow Babies and Children's Hospital, Cleveland, Ohio, USA).

REFERENCES

1. Axibal DP, Mitchell JJ, Mayo MH, et al. Epidemiology of anterior tibial spine fractures in young patients: a retrospective cohort study of 122 cases. *J Pediatr Orthop*. 2019;39(2):e87-e90.
2. Bram JT, Aoyama JT, Mistovich RJ, et al. Four risk factors for arthrofibrosis in tibial spine fractures: a national 10-site multicenter study. *Am J Sports Med*. 2020;48(12):2986-2993.
3. Ellis HB, Zynda AJ, Cruz AI Jr, et al. Classification and treatment of pediatric tibial spine fractures: assessing reliability among a tibial spine research interest group. *J Pediatr Orthop*. 2021;41(1):e20-e25.
4. Green D, Tuca M, Luderowski E, et al. A new, MRI-based classification system for tibial spine fractures changes clinical treatment recommendations when compared to Myers and Mckeever. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(1):86-92.
5. Hargrove R, Parsons S, Payne R. Anterior tibial spine fracture: an easy fracture to miss. *Accid Emerg Nurs*. 2004;12(3):173-175.
6. Ishibashi Y, Tsuda E, Sasaki T, Toh S. Magnetic resonance imaging AIDS in detecting concomitant injuries in patients with tibial spine fractures. *Clin Orthop Relat Res*. 2005;(434):207-212.
7. Kendall NS, Hsu SY, Chan KM. Fracture of the tibial spine in adults and children: a review of 31 cases. *J Bone Joint Surg Br*. 1992;74(6):848-852.
8. Kocher MS, Micheli LJ, Zurakowski D, Luke A. Partial tears of the anterior cruciate ligament in children and adolescents. *Am J Sports Med*. 2002;30(5):697-703.
9. Kushare I, Lee RJ, Ellis HB Jr, et al. Tibial spine fracture management: surgical and technical tips from the Tibial Spine Fracture Research Interest Group. *J Pediatr Orthop Surg North Am*. 2020;2(1).
10. Lafrance RM, Giordano B, Goldblatt J, Voloshin I, Maloney M. Pediatric tibial eminence fractures: evaluation and management. *J Am Acad Orthop Surg*. 2010;18(7):395-405.
11. Meyers MH, McKeever FM. Fracture of the intercondylar eminence of the tibia. *J Bone Joint Surg Am*. 1959;41-A(2):209-220, discussion 220-222.
12. Mitchell JJ, Sjostrom R, Mansour AA, et al. Incidence of meniscal injury and chondral pathology in anterior tibial spine fractures of children. *J Pediatr Orthop*. 2015;35(2):130-135.
13. Rhodes JT, Cannamela PC, Cruz AI, et al. Incidence of meniscal entrapment and associated knee injuries in tibial spine avulsions. *J Pediatr Orthop*. 2018;38(2):e38-e42.
14. Scrimshire AB, Gawad M, Davies R, George H. Management and outcomes of isolated paediatric tibial spine fractures. *Injury*. 2018;49(2):437-442.
15. Shimberg JL, Aoyama JT, Leska TM, et al. Tibial spine fractures: how much are we missing without pretreatment advanced imaging? A multicenter study. *Am J Sports Med*. 2020;48(13):3208-3213.
16. Tibial Spine Research GroupPrasad N, Aoyama JT, et al. A comparison of nonoperative and operative treatment of type 2 tibial spine fractures. *Orthop J Sports Med*. 2021;9(1):2325967120975410.
17. Woo SL, Hollis JM, Adams DJ, Lyon RM, Takai S. Tensile properties of the human femur-anterior cruciate ligament-tibia complex: the effects of specimen age and orientation. *Am J Sports Med*. 1991;19(3):217-225.