Knee Extension Does Not Reliably Reduce Acute Type II Tibial Spine Fractures

MRI Evaluation of Displacement During Extension Versus Resting Flexion

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Background: Type II tibial spine avulsion (TSA) fractures have traditionally been managed by first attempting to achieve closed reduction with extension and immobilization, with surgical indications reserved for those who fail to reduce within 3 mm. However, the frequency with which appropriate reduction can be achieved is largely unknown.

Purpose: To evaluate changes in displacement of type II TSA fractures by comparing magnetic resonance imaging (MRI) scans obtained with the knee in flexion and in extension.

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

Methods: Ten patients with type II TSA fractures were identified. Fracture displacement was measured using 3 images for each patient: (1) initial lateral view radiography, (2) sagittal-plane MRI of the knee in resting flexion, and (3) sagittal-plane MRI of the knee in passive extension. Maximum displacement of the bony fragment was measured in the 2 MRI studies for all patients, and the corresponding change in displacement was calculated. Displacement in flexion was compared with displacement in extension using a paired-sample *t* test. Statistical significance was set at $P < .05$.

Results: The displacement distance of the bony fragment was reduced by a mean of 0.97 mm on MRI when the knee was in extension compared with flexion in patients with type II TSA fractures ($P = .02$). Mean displacement with extension was 6.14 mm, with no fractures reduced below 4 mm. The largest reduction observed was 2.80 mm. The displacement distance increased in 2 knees with extension. The intermeniscal ligament (IML) was entrapped in 4 of 10 patients; however, the amount of reduction achieved did not differ based on the presence of IML entrapment ($P = .85$).

Conclusion: While the amount of tibial spine displacement warranting surgical treatment can be debated, the study findings suggest that knee extension is not reliable in obtaining adequate closed reduction for type II TSA fractures. Management decisions may need to be based on the initial displacement distance of the fracture, with a lower threshold for operative treatment than previously recognized.

Keywords: tibial spine; avulsion fracture; pediatric sports medicine; magnetic resonance imaging study

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Tibial spine avulsion (TSA) fractures, also known as tibial eminence fractures, are uncommon injuries occurring predominately in the pediatric population.[2,4,7,8,11,12,14,19] Identifiable on plain radiography, these injuries were first classified by Meyers and McKeever[14] based on the degree of displacement of the bone fragment; nondisplaced (type I), partially displaced with a posterior hinge (type II), and completely displaced (type III). Zaricznyj[25] subsequently added a category for fractures with displaced, comminuted fragments (type IV).

The mechanisms of injury include trauma, hyperextension, and forces similar to those of anterior cruciate ligament (ACL) tears in adults. However, in the pediatric population, the ossifying tibial spine often fails before the ACL.[2,8,11,12,16,19,22] Stretching of the ACL likely occurs as well and may contribute to residual instability.[2,4,8,11,13,15,19,23] While outcomes of TSA fractures are generally favorable, negative sequelae include loss of motion, stiffness, arthrofibrosis, ligament laxity, and nonunion.[2,6-8,11,17,19,21]

Interestingly, management of these injuries has remained largely unchanged, following the recommendation of Meyers and McKeever[14] to treat minimally displaced fractures with immobilization and completely displaced

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The Orthopaedic Journal of Sports Medicine, 7(7), 2325967119860066
DOI: 10.1177/2325967119860066

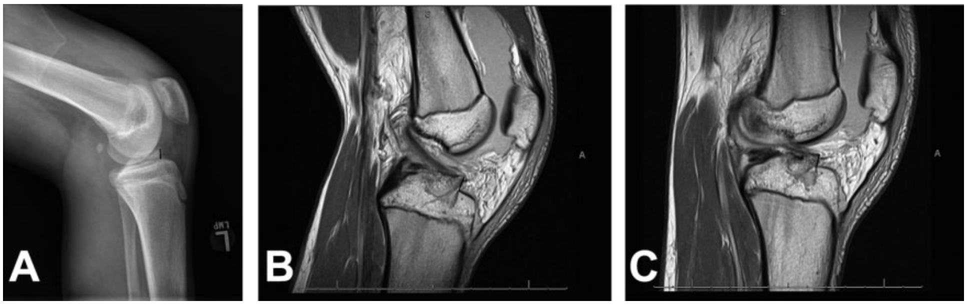

Figure 1. Maximum displacement of the fracture fragment was measured in 3 imaging studies for each patient. Example images from the same patient show displacement measured on (A) lateral view radiography, (B) sagittal-plane proton density magnetic resonance imaging (MRI) of the knee in flexion, and (C) sagittal-plane proton density MRI of the knee in extension.

fractures requiring surgical interventions.[2,6,8,11,12,25] This distinction is clear for type I (nonsurgical) compared with type III and IV fractures (surgical); however, nonoperative versus operative treatment of type II fractures is a topic that remains controversial. Classic practice guidelines recommend attempting closed reduction of type II fractures by extending the knee, with an acceptable reduction defined as less than 3 mm of displacement on extension radiography after reduction.[14] If successful, bracing or immobilization in extension for a minimum of 4 weeks is recommended.[2,4,8,11,12,19] Surgical interventions are suggested for TSA fractures that demonstrate inadequate reduction with knee extension. Advances in surgical techniques and focus on allowing early range of motion have questioned the nonoperative treatment of type II fractures, with some authors suggesting early surgical interventions for all type II, III, and IV TSA fractures.[13]

While guidelines for the treatment of type I, III, and IV TSA fractures are well established, the reliability of obtaining adequate reduction in type II fractures and its impact on management are unknown. Typically, reduction of the tibial spine is assessed by lateral radiography after reduction. One of the difficulties with this treatment algorithm is that clinicians must rely on a static 2-dimensional radiograph to determine adequate reduction. Previous studies on features such as femoral notch width[1] and landmarks for tunnel placement[27] have shown that radiographic measurements are highly sensitive to small rotational aberrations. Similarly, the appearance of the tibial spine fracture is highly susceptible to changes in knee position, and obtaining a perfect lateral radiograph, orthogonal to the most displaced region of the TSA fracture, in an acutely injured pediatric patient can be difficult. Anecdotally, the senior author (S.K.A.) had found that slight changes in patient or fluoroscopic positioning could cause a fragment to appear reduced, while additional imaging (magnetic resonance imaging [MRI] or slightly different radiographic views) would reveal that it was still in fact displaced. This observation prompted further investigation, and the purpose of this study was therefore to evaluate changes in displacement of type II TSA fractures by comparing MRI scans obtained in 2 positions: (1) resting knee flexion and (2) knee extension. We hypothesized that type II TSA fractures are often inadequately reduced with extension.

METHODS

With institutional review board approval, all patients younger than 18 years who presented to a pediatric sports medicine clinic (S.K.A., T.G.M.) with a type II TSA fracture from 2015 to 2017 were considered eligible for study inclusion. Exclusion criteria included patients unable or unwilling to undergo MRI within 10 days of injury, those unable to fully extend their knee to neutral when seen in the clinic, patients with prior ipsilateral knee surgery, and patients with concomitant injuries requiring surgery.

Patients underwent radiography and MRI of the injured knee. Three distinct images were required for study inclusion: (1) lateral view radiography, (2) sagittal-plane MRI of the knee in flexion, and (3) sagittal-plane MRI of the knee in extension (Figure 1). The MRI protocol included 2.0 mm–thick sagittal cuts of the knee. For flexion MRI, the knee was positioned on a 20° foam pad in neutral rotation. For extension MRI, the knee was placed flat on the MRI scanner with the foot in neutral rotation, with anterior thigh and tibial straps holding the knee in an extended position. Extension of the knee was performed without anesthesia. The angle between the posterior cortical line of the femur and the tibial shaft was then measured on flexion and

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One or more of the authors has declared the following potential conflict of interest or source of funding: T.G.M. is a paid speaker for Arthrex and has received hospitality payments from Aesculap Biologics. S.K.A. has received consulting fees from Stryker and Pivot Medical and has received hospitality payments from Aesculap Biologics. 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 University of Utah Institutional Review Board (No. 00075572).

TABLE 1
Patient Demographics, Maximum Fracture Displacement, and Change in Displacement[a]

Patient No.	Age, y	Sex	Flexion Angle, deg	Extension Angle, deg	Flexion Displacement, mm	Extension Displacement, mm	IML Entrapment	Change in Displacement, mm	Change in Displacement, %
1	6	F	26.00	2.00	6.10	5.60	No	–0.50	8
2	12	M	23.50	–1.50	6.85	7.25	No	0.40	6
3	8	M	27.50	–4.50	7.70	4.90	No	–2.80	36
4	16	M	32.50	2.50	10.10	8.05	Yes	–2.05	20
5	9	F	33.50	2.50	5.00	4.20	Yes	–0.80	16
6	12	M	32.00	4.50	8.10	7.15	Yes	–0.95	12
7	6	F	31.50	3.50	4.90	5.00	No	0.10	2
8	13	M	22.50	2.50	10.35	8.25	No	–2.10	20
9	12	M	28.00	2.50	5.60	5.00	No	–0.60	11
10	9	M	29.50	–3.00	6.35	5.95	Yes	–0.40	6
Mean ± SD	10.3 ± 3.2		28.65 ± 1.22	1.10 ± 0.98	7.11 ± 0.62	6.14 ± 0.46		–0.97 ± 0.33	13.7 ± 3.2

[a] Data are shown as the mean values of measurements by observer 1 and observer 2. A significant difference was determined by the paired t test between flexion displacement and extension displacement ($P = .02$). F, female; IML, intermeniscal ligament; M, male.

extension MRI scans for each patient. For each MRI study, all cuts visualizing the TSA fracture were evaluated, and the cut demonstrating the most displacement was recorded. Measurements were performed at the most anterior location of the fracture, measuring the distance from the cortical tip of the fragment to the fracture base (Figure 1, B and C). Flexion angle, extension angle, and fragment displacement in both flexion and extension were also measured. All measurements were performed by 2 blinded readers (P.C.C., S.K.A.). On MRI, the relative change in displacement of the bony fragment in knee extension compared with knee flexion was calculated. This difference was then reported as a percentage of the displacement comparing knee flexion with knee extension. Each MRI scan was evaluated for the presence of intermeniscal ligament (IML) entrapment, and additional analysis was conducted comparing the mean change in displacement between those with and without entrapment. Statistical analysis entailed a paired t test with significance set at $P < .05$. Interclass correlation coefficients with 95% CIs were calculated to determine the reproducibility of MRI measurements.

RESULTS

Seven male and 3 female patients with a mean age of 10.3 years (range, 6-16 years) met inclusion criteria (Table 1). There were no patients who had to be removed because of exclusion criteria. All patients were skeletally immature. The mean flexion angle observed on MRI was 28.65°, while the mean extension angle was 1.10°. Mean displacement of the bony fragment was 7.3 mm (range, 4.5-11.2 mm) on lateral radiographs, 7.11 mm (range, 4.90-10.35 mm) on MRI with the knee in flexion, and 6.14 mm (range, 4.20-8.25 mm) on MRI with the knee in extension. The displacement distance was reduced by a mean of 0.97 mm by extending the knee, representing a mean displacement reduction of 13.7% ($P = .02$) (Table 1). The largest reduction observed was 2.80 mm. In 2 knees, knee extension increased the displacement distance. No fractures were reduced below 4 mm of displacement.

In 4 of the 10 patients, the IML was found to be entrapped between the fracture fragment and fracture base (Table 1). The mean change in displacement with extension was –0.92 ± 0.52 mm in cases with no entrapment present and –1.05 ± 0.35 mm in cases with entrapment present, which was not a statistically significant difference ($P = .85$).

Interobserver reliability was excellent for all measurements. Statistical analysis yielded interclass correlation coefficients of 0.933 (95% CI, 0.757-0.983) for flexion angle, 0.822 (95% CI, 0.436-0.953) for extension angle, 0.970 (95% CI, 0.883-0.992) for flexion displacement, and 0.960 (95% CI, 0.847-0.990) for extension displacement. Measurements of observer 1 and observer 2 are summarized in Table 2.

DISCUSSION

The classic literature has identified an acceptable displacement of tibial spine fractures as less than 3 mm.[14] While this recommendation may not be clinically accepted by all, having a threshold of acceptable displacement is an important orthopaedic concept. The current paradigm in the treatment of type II TSA fractures has included attempted reduction with knee extension. However, an evaluation of reduction with plain radiographs is somewhat limited because of the difficulty in obtaining views that visualize both medial and lateral fragment displacement, and post-reduction displacement can be misrepresented by small variations in the knee position.

While extension of the knee significantly reduced the displacement distance of type II TSA fractures in this study, a reduction to less than 3 mm of displacement[14] was not achieved in any patient. This supports our hypothesis that closed reduction of type II TSA fractures is difficult and largely unreliable. These findings are in contrast with the traditional concept that knee extension can accomplish reduction in type II TSA fractures, and they may

TABLE 2
Mean Measurements Performed by Observer 1 and Observer 2

	Flexion Angle, deg	Extension Angle, deg	Flexion Displacement, mm	Extension Displacement, mm
Observer 1	27.00	1.00	7.00	6.19
Observer 2	30.30	1.20	7.21	6.08

suggest that initial displacement should guide treatment decisions.

Historically, nonsurgical treatment has been recommended for type II TSA fractures. In 2009, Wilfinger et al[22] presented good outcomes in 43 patients at an average 3.5-year follow-up with TSA fractures treated nonsurgically. Supporting the efficacy of closed reduction, 38% of fractures were classified as type III on presentation, with only 2% classified as type III immediately after reduction.[22] Edmonds et al[6] treated 25% of patients with type II and III TSA fractures with closed reduction, as displacement was reduced from an average of 5.3 mm to 2.3 mm. In a series by Janarv et al,[9] 60% of patients casted without reduction exhibited displacement of $\leq$4 mm at the time of cast removal compared with 83% of patients who underwent closed reduction under anesthesia. Our results do not support these findings, as adequate closed reduction was not achieved in any of the patients presented here; however, closed reduction was not attempted under anesthesia in our study. It is unclear in the methods as to whether Wilfinger et al or Edmonds et al performed reduction under anesthesia.

Despite findings suggesting the efficacy of closed reduction in the literature, there has been growing support for the surgical management of type II TSA fractures.[8,11,19] Louis et al[13] reported excellent results in 17 patients with type II TSA fractures treated with surgical arthrotomy. The authors' support for surgical interventions stems from the argument that the restoration of ACL tension is crucial.[13] Regarding the impact that these injuries have on the ACL, Mitchell et al[15] found that 19% of pediatric patients sustaining a TSA fracture went on to ACL reconstruction. Restricting their analysis to type II and III TSA fractures, they found no statistically significant difference between initial nonsurgical and surgical treatment leading to ACL reconstruction.[15] In contrast, a systematic review by Bogunovic et al[4] on the treatment of type II, III, and IV TSA fractures found that 10% of patients treated nonsurgically required ACL reconstruction compared with only 1% of those treated surgically at presentation. Those treated nonsurgically also had a higher incidence of clinical and subjective instability, but there was no difference in return to sport.[4] Most recently, a retrospective study of 43 patients by Zhao et al[26] demonstrated superior clinical outcomes for type II TSA fractures treated with arthroscopic suture fixation compared with those treated with cast immobilization alone.

Edmonds et al[6] compared the outcomes of open reduction and internal fixation, arthroscopic-assisted internal fixation, and closed management of type II, III, and IV TSA fractures. They found no differences in pain, the Lysholm score, or treatment satisfaction at an average 6-year follow-up.[6] However, surgical interventions offered significantly greater fracture reduction compared with closed management. Additionally, 16.7% of nonsurgically treated patients eventually required surgery because of residual symptoms. Of note, these patients had an average initial displacement of 6.7 mm, leading those authors to recommend surgical treatment for fractures displaced greater than 5 mm on presentation.[6] Our results support the notion that treatment decisions should be based on initial fragment displacement, as adequate reduction is difficult to achieve. An appropriate cutoff remains to be determined however, as Janarv et al[9] found no correlation between residual displacement and objective or subjective measures of knee function in type I and II TSA fractures.

The reason that TSA fractures fail closed reduction may be because of entrapment of the IML or menisci or osteochondral lesions.[3,11,17,19,20] In type II TSA fractures, up to 59% of patients have some degree of concomitant abnormalities, with meniscal or IML entrapment present in 26% to 40% of cases.[10,16,18] Surgical interventions are required in these cases for adequate fracture fixation, and they offer the opportunity for the treatment of concomitant abnormalities with early rehabilitation to prevent complications such as arthrofibrosis.[8,11,17,19,21] In our series, 4 of 10 patients had IML entrapment; however, the ability to reduce the fragment did not correlate with entrapment. In many cases, this may be caused by smaller fragments of spiculated bone impinging between the main progeny fragment and parent bone, preventing adequate reduction. For this reason, the senior authors advocate careful debridement of the fragment bed before surgical fixation to remove any blocks to reduction, which may be difficult to visualize on preoperative radiography or MRI.

It is also possible that extension or hyperextension of the knee causes movement of the avulsed fragment without necessarily achieving true reduction. It has been postulated that knee extension achieves reduction when the tibial spine fracture reduces through direct contact with the lateral femoral condyle.[19] Alternatively, in the original study by Meyers and McKeever, they state that extension or hyperextension of the knee does not provide any force that would push the fragment back into the fracture bed, and they discouraged "forceful manipulation into hyperextension." Anatomically, extension of the knee should not be expected to reduce all type II TSA fractures. Although extension of the knee reduces tension in the anteromedial bundle of the ACL, it concomitantly increases tension in the posterolateral bundle, which is tight at 0° of flexion.[5,24] In some cases, a decrease in tension in the anteromedial bundle with knee extension may be sufficient to allow the fragment to relax into a reduced position. However, there is also the potential for the fragment to be pulled or rotated because of increased tension in the posterolateral bundle. Moreover, hyperextension has the potential to displace the fragment further in some knees, given that the tibia may subluxate forward, similar to what we see in the clinical pivot-shift examination.

The main limitation of this study is the small sample size. A larger series of patients would be desirable to confirm the reproducibility of our results. Despite being a small series, the results that we observed were highly consistent, indicating good reliability. Additionally, it is not practical for all patients with TSA fractures to undergo MRI before and after closed reduction. We also did not attempt closed reduction under anesthesia, and it is unknown if this or the application of a cast with forced passive extension would have affected the amount of fracture reduction achieved. Another limitation was that we obtained sagittal cuts to evaluate displacement. While this measurement takes into account the classic evaluation of displacement in the sagittal plane, it does not take into consideration displacement in the coronal plane, as a fragment may displace laterally as well. Lateral displacement was not evaluated in our study. Last, our study focused on displacement as seen on sagittal MRI cuts and did not evaluate lateral radiographs after reduction. Previous treatment recommendations have been based on radiographs, not MRI findings.

CONCLUSION

Our findings suggest that type II TSA fractures do not reliably improve in their position when performing closed reduction with knee extension. While the threshold for tibial spine displacement requiring surgical treatment in type II TSA fractures continues to be debated, our study suggests that management decisions can be based on initial radiographic fracture displacement distance when considering operative treatment.

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