Type IV Tibial Tubercle Fractures in Adolescents—Is Operative Treatment Necessary?

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Background: Tibial tubercle fractures (TTF) in adolescents can be treated operatively or nonoperatively depending on fracture configuration and displacement. In the modified Ogden classification, the type IV fracture is extra-articular and exits through the posterior physis or metaphysis. No previous publications have reviewed a series of these injuries and compared clinical and radiographic outcomes of operative and nonoperative treatment.

Methods: Patients under the age of 18 with Ogden type IV TTFs treated at a single institution between 2013 and 2023 were evaluated. Mechanism of injury, weight percentile, concern for compartment syndrome, time to full weight bearing, time to return to sport/activity, method of treatment, follow-up time, and complications were collected from the electronic medical record (EMR). Posterior tibial slope angle (PTSA), medial proximal tibial angle (MPTA), and anterior fracture gap were measured from the initial injury, postreduction, and final follow-up radiographs.

Results: A total of 36 limbs in 33 patients were followed for an average of 182 days, 18 of which were treated nonoperatively and 18 operatively. The mean pretreatment PTSA was 22.4° in the nonoperative and 25.0° in the operative group ($P=0.25$). The mean final follow-up PTSA was 15.1° in the nonoperative and 14.3° in the operative group ($P=0.54$). The mean pretreatment MPTA was 84.7° for both groups ($P=0.99$). The final follow-up mean MPTA was 84.2° in the nonoperative and 85.5° in the operative group ($P=0.08$). There were no significant differences noted in time to full weight bearing, return to sport/activity, or total follow-up. There were 7 cases with complications, 4 in the nonoperative and 3 in the operative group.

Conclusions: The present study suggests that nonoperative and operative treatment for type IV TTFs are equivalent in terms of radiographic and clinical outcomes. Given that joint incongruity is not an issue in these fractures, closed reduction can be attempted unless contraindicated by impending compartment syndrome. Operative management should be performed for failure of closed reduction.

Level of Evidence: Level IV.

Key Words: pediatric, type IV tibial tubercle fracture, tibial tubercle fracture, nonoperative management, operative management, posterior tibial slope angle

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Tibial tubercle fractures (TTF) are uncommon in the pediatric population, accounting for just 0.4% to 2.7% of fractures.[1] Fractures often occur during sports, particularly basketball, which involves forceful quadriceps contraction and knee extension during the explosive phase of jumping or landing.[1–3] The Ogden classification is the most widely used classification for TTFs.[4] Many modifications have since been made to the Ogden classification, but the modification that concerns the present study is the addition of a type IV classification by Ryu and Debenham (Fig. 1). In type IV TTFs, the fracture line travels through the anterior physis and extends posteriorly where it either exits through the physis (Salter I) or through the metaphysis (Salter II).[2,5]

The goals of treatment include restoring integrity and tension to the extensor mechanism, correcting joint incongruity (type III),[6] and correcting sagittal plane deformity. Increased tibial slope has been implicated in Osgood Schlatter's Disease (OSD),[7] and OSD has been associated with tibial tubercle fractures.[1,8] Inadequate reduction of sagittal plane angulation could produce a higher posterior tibial slope angle (PTSA), which could predispose the patient to future injuries. Operative management is the most common approach, but complications are frequent, the most common being bursitis or symptomatic hardware precipitating hardware removal.[1,3,8] It is generally accepted that nonoperative management is appropriate for nondisplaced or minimally displaced fractures.[8] In a retrospective study of 236 tibial tubercle fractures by Haber et al, 79 were treated nonoperatively. In this paper, type IV and V fractures were grouped together, and it is not specified how

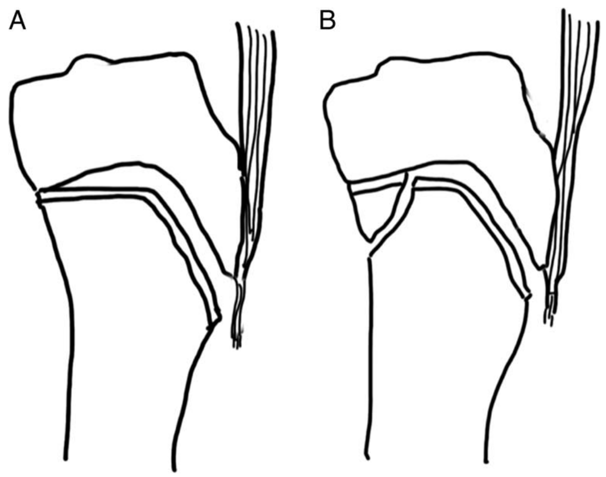

FIGURE 1. Ryu and Debenham type IV tibial tubercle fractures. A, Salter-Harris I. B, Salter-Harris II.

many of these injuries were treated, but only 21% of the IV and V injuries were treated nonoperatively.[8]

Nonoperative management carries the advantage of avoiding surgical risks and the need for future hardware removal. Recent studies have shown that type IV TTFs can be successfully managed nonoperatively, specifically with casting.[8–10] Checa et al reported on nonoperative treatment of 5 TTFs, 3 of which were type IV. They were able to obtain satisfactory results without complications.[9] To date, however, there are no large case series comparing operative and nonoperative management of type IV TTFs. It is hypothesized that nonoperative management of type IV TTFs will be noninferior to operative treatment with regard to the quality of reduction as assessed by PTSA and clinical outcomes and complications.

METHODS

This is a retrospective cohort study of patients under the age of 18 treated at a single children's hospital with Ogden type IV fractures from 2013 to 2023. After approval by the Institutional Review Board, all patients treated for tibial tubercle fractures were identified using CPT codes (27530, 27538, and 27540). All radiographs were reviewed and those with Ogden type IV tibial tubercle fractures were included. The decision to attempt a closed reduction was at the discretion of seven fellowship-trained pediatric orthopaedic surgeons. In those who underwent closed reduction, the decision to operate was based on residual displacement/angulation. Likewise, cast versus brace placement and cast duration were at the discretion of the treating surgeon. Mechanism of injury, weight for age percentile, concern for compartment syndrome, time to full weight bearing, time to return to sport/activity, method of treatment, total follow-up, and complications were collected from the electronic medical records (EMR).

All radiographs were measured by 2 observers, 1 senior pediatric orthopaedic attending, and a research fellow who received training and assistance from the attending. PTSA was measured as described by Dejour and Bonnin.[11] Additional PTSA measurements were made on 12 patients who had available radiographs of the contralateral, uninjured limb. An intraclass correlation coefficient (ICC) measurement was obtained for each PTSA measurement to ensure agreement between observers. The medial proximal tibial angle (MPTA) was defined as the medial angle formed by the mechanical axis and a line tangential to the tibial plateau. Anterior fracture gap (AFG) was determined by measuring the gap between the proximal and distal fragments at the anterior cortex of the tibia. PTSA, MPTA, and AFG were collected from pretreatment, postreduction/fixation, and final follow-up radiographs for the nonoperative (Fig. 2) and operative (Fig. 3) groups. If no immediate postreduction film was available, the next most recent film was used in its place.

T tests and χ^2 tests were used to compare continuous and categorical variables between the nonoperative and operative groups, respectively. Analysis of covariance was

FIGURE 2. Original injury films of a 15-year-old male with type IV tibial tubercle fracture. A, Measurement of posterior tibial slope angle (PTSA). B, Measurement of medial proximal tibial angle (MPTA). C, Measurement of anterior fracture gap. D, Postreduction imaging.

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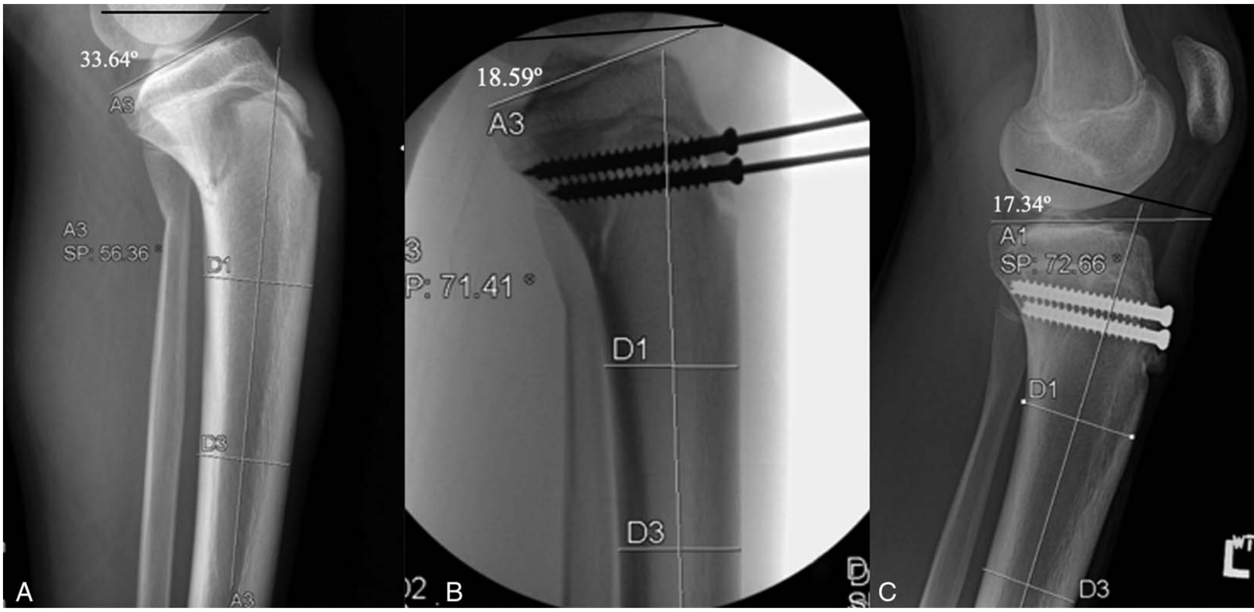

FIGURE 3. A 14-year-old male with type IV tibial tubercle fracture. A, Initial injury. B, Intraoperative lateral demonstrates improvement in posterior tibial slope angle. C, Follow-up radiograph 3 months postoperative.

used to compare changes in MPTA and PTSA between the groups. *P*-values of ≤ 0.05 (2-sided) were considered statistically significant.

RESULTS

A total of 36 fractures in 33 patients (31 male and 2 female) were enrolled in the study with 18 fractures in the nonoperative group and 18 in the operative group. Mean follow-up calculated from the date of initial injury radiographs to the last documented follow-up was 192 (43 to 814) days in the nonoperative and 172 (41 to 833) days in the operative group ($P = 0.77$). The mean weight percentile for age, mean time to full weight-bearing, and mean time to return to sport were not significantly different between nonoperatively and operatively treated groups (Table 1). ICCs for pretreatment PTSA, postreduction PTSA, final follow-up PTSA, and contralateral PTSA were 0.86, 0.93, 0.86, and 0.95, respectively, indicating high concordance between observers.

Mean pretreatment PTSA was 22.4° and 25.0° in the nonoperative and operative groups, respectively ($P = 0.25$). Postreduction, the mean PTSA was 15.5° in the nonoperative group and 15.2° in the operative fixation group ($P = 0.83$). The mean final follow-up PTSA was 15.1° with nonoperative treatment and 14.3° with operative fixation ($P = 0.54$). On average, there was a decrease in the PTSA from pretreatment to postreduction of 7.0° in the nonoperative group and 9.9° in the operative group ($P = 0.14$). From pretreatment to final follow-up, the PTSA decreased by an average of 7.3° in the nonoperative group and 10.8° in the operative group ($P = 0.12$). The mean PTSA was 13.3° in the contralateral, uninjured limbs (Table 2).

The mean pretreatment MPTA in both the nonoperative and operative groups was 84.7° ($P = 0.99$). Mean postreduction MPTA was 85.0° and 85.6° in the nonoperative and operative groups, respectively ($P = 0.39$). The final follow-up mean MPTA was 84.2° in the nonoperative group and 85.5° in the operative group ($P = 0.08$). Postreduction, the MPTA in both the nonoperative and the operative groups increased by an average of 0.4° and 0.9°, respectively ($P = 0.51$). At the end of the follow-up period, MPTA changed by an average of $< 1°$ in both the nonoperative and operative groups ($P = 0.15$). The mean pretreatment AFG was 9.8 mm in the nonoperative group and 11.2 mm in the operative group ($P = 0.35$). The mean postreduction AFG was 5.2 mm in the nonoperative group and 3.5 mm in the operative group ($P = 0.20$). The mean AFG at the final follow-up was 1.7 and 0.3 mm in the nonoperative and operative fixation groups, respectively ($P = 0.13$) (Table 2).

The most common mechanism of injury was explosive jumping or forceful landing during basketball in both groups. Of the 18 cases treated nonoperatively, closed reduction was performed in the emergency room (ER) in 11 cases, the operating room (OR) in 6 cases and in the orthopaedic clinic in 1 case. Of those treated operatively, 5 underwent attempted closed reduction, 2 in the ER, and 3 in the OR (E-Supplement, Supplemental Digital Content 1, http://links.lww.com/BPO/A853). Of those treated operatively, 8 underwent open-reduction and internal fixation (ORIF) and 10 underwent closed reduction and percutaneous screw fixation (CRPP). All patients treated nonoperatively were initially casted with an average time in a cast of 35.2 (12 to 55) days. In the operative group, 12 patients were casted for an average of 34.8 (17 to 63) days ($P = 0.93$) (Table 1). The remaining 6 operatively treated patients received either a knee immobilizer or a hinged knee brace at the time of surgery. All patients

TABLE 1. Comparison of Functional Outcomes Between Treatment Groups

Variable	Nonoperative Mean ± SD	Operative Mean ± SD	*P*
Weight for age percentile	85.0 ± 16.0	83.0 ± 20.0	0.71
Time in cast (d)	35.2 ± 15.8	34.8 ± 13.3	0.93
Time to full weight-bearing (d)	47.8 ± 13.3	43.5 ± 8.9	0.26
Return to sport (d)	103.1 ± 42.5	99.5 ± 28.2	0.79
Total follow-up	191.8 ± 195.0	172.4 ± 193.7	0.77

casted for 4 weeks or less were converted to a hinged knee brace locked in extension. In patients treated nonoperatively, 4 were admitted overnight for observation after reduction and none developed compartment syndrome. One patient with bilateral type IV TTFs underwent advanced imaging (CT with 3-dimensional reconstruction). No patients were subsequently found to have intra-articular injuries such as meniscal or ligamentous disruption.

There were 3 cases where concern for compartment syndrome was documented in the chart. One case in the nonoperative group was observed and did not ultimately manifest compartment syndrome, and 2 in the operative group received prophylactic anterior compartment fasciotomies at the time of operative treatment. These incisions were closed at the time of fracture fixation and no postoperative neurological deficits were noted. There were 7 cases with complications, 4 in the nonoperative group and 3 in the operative group. Of the complications reported in the nonoperative group, there was 1 cast sore, 1 patient demonstrating residual stiffness, 1 conversion to operative fixation, and 1 refracture. The cast sore was discovered at the end of the casting period and was managed with cast removal and standard wound care with nonadhesive bandages. The patient demonstrating residual stiffness lacked 20 to 30° of flexion at the end of a casting period of 52 days (total follow-up of 94 d) and was managed with physical therapy. The patient who was converted to operative fixation had a loss of reduction noted on the first follow-up in the clinic, as the cast had been bivalved to accommodate swelling before discharge. The refracture occurred 15 weeks after the original injury shortly after the patient returned to basketball, and presented as a type III TTF that was then treated operatively. This patient was casted for 6 weeks and converted to a hinged knee brace, but given the clearance to start the gradual return to sport at 10 weeks after physical therapy confirmed adequate hamstring and quadriceps strength.

In the operative group, there was 1 cast sore, 1 patient with residual stiffness, and 1 case of symptomatic hardware requiring removal. Again, the cast sore was discovered at the end of the casting period and managed with cast removal and nonadhesive bandages. The patient with residual stiffness lacked 5° of extension at the end of a casting period of 38 days (total follow-up of 62 d) and was managed with physical therapy. Three patients underwent hardware removal, 2 were originally managed operatively, and 1 patient was converted from nonoperative to operative treatment.

DISCUSSION

The current study was undertaken to assess the results of operative and nonoperative treatment for type IV TTFs. Before the current study, there have been no large case series assessing nonoperative treatment of these injuries. Pace et al reported on 24 type IV TTFs, 19 of which were treated operatively. They suggest that these injuries can be challenging, and in 4 patients, screw fixation alone was inadequate, necessitating supplemental plate fixation for stabilization. They did not discuss nonoperative treatment but did note that 3 patients failed closed treatment and required operative intervention. They suggest that nonoperative management may be a valid approach depending on displacement, stability, and the quality of the initial reduction. They do not report radiographic results, merely stating that there were no malunions or leg length discrepancies.[12] Interestingly, no patients in the

TABLE 2. Comparison of Pretreatment, Postreduction, and Final Follow-up Radiographic Outcomes Between Treatment Groups

Radiographic measurement	Nonoperative mean ± SD	Operative mean ± SD	*P*
Pretreatment PTSA (deg)	22.4 ± 5.1	25.0 ± 7.9	0.25
Pretreatment MPTA (deg)	84.7 ± 2.3	84.7 ± 1.8	0.99
Pretreatment anterior fracture gap (mm)	9.8 ± 4.35	11.2 ± 4.8	0.35
Postreduction/fixation PTSA (deg)	15.5 ± 5.2	15.2 ± 3.4	0.83
Postreduction/fixation MPTA (deg)	85.0 ± 2.2	85.6 ± 2.2	0.39
Postreduction/fixation anterior fracture gap (mm)	5.2 ± 4.2	3.5 ± 3.2	0.2
Final follow-up PTSA (deg)	15.1 ± 4.8	14.3 ± 3.4	0.54
Final follow-up MPTA (deg)	84.2 ± 2.1	85.5 ± 2.2	0.08
Final follow-up anterior fracture gap (mm)	1.7 ± 3.69	0.3 ± 1.3	0.13
MPTA change from pretreatment to postreduction/fixation (deg)	0.4 ± 2.3	0.9 ± 2.5	0.51
PTSA change from pretreatment to postreduction/fixation (deg)	−7.0 ± 4.3	−9.9 ± 6.9	0.14
MPTA change from pretreatment to final follow-up (deg)	−0.2 ± 2.6	0.8 ± 3.0	0.15
PTSA change from pretreatment to final follow-up (deg)	−7.3 ± 4.9	−10.8 ± 7.4	0.12

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present series underwent plate fixation. In all cases, screws provided adequate fixation.

In a small case series by Checa et al discussing the nonoperative treatment of 5 TTFs, 3 were type IV fractures. Radiographic measures were not collected, but they reported no nonunions and a full return to sports by 25 weeks.[9] In a retrospective study by Haber et al, of the 236 fractures treated, it is unclear how many type IV TTFs were treated nonoperatively. However, it is specified that 21% of the fractures belonging to the type IV to V category were managed nonoperatively. The results of nonoperative treatment are discussed for all fracture types as an aggregate and are not broken down by fracture type. The authors note that 47% of the nonoperative group experienced pain with squatting, 31% experienced patellar tendonitis or bursitis, 6% (2 patients) refractured, and 1 went on to nonunion. There were no radiographic measurements of alignment reported.[8] In a recent paper investigating variability in the management of TTFs among pediatric orthopaedic surgeons, knee radiographs were reviewed in 51 cases. Respondents recommended operative treatment in 71.9% of type IV TTFs.[13]

The current study is the largest case series of nonoperatively treated type IV TTFs and is the first series to use PTSA to compare radiographic alignment before and after intervention. Recent literature has explored the concept of increased PTSA in individuals with Osgood-Schlatter disease (OSD) and TTFs.[7,14,15] To the author's knowledge, there are no other papers on TTFs in which PTSA was used as a radiographic outcome measure to assess sagittal plane alignment. Though a clear normal has not been established for PTSA, Green et al[14] found that the mean PTSA in patients with OSD was 12.2° while the mean for controls was 8.8°. Sheppard et al[7] found that the mean PTSA in patients who sustained a TTF was 10.5° compared with a control mean of 6.6°. In a paper assessing the relationship between PTSA and anterior cruciate ligament (ACL) tears, O'Malley et al[16] found that the mean PTSA in 32 patients with ACL injuries was 10.0° compared with a mean of 8.5° in 32 uninjured controls. Webb et al[17] also explored the concept of increased PTSA in the context of ACL tears and noted that in patients with PTSA above 12°, there was a 5-fold increase in the risk of reinjury following reconstruction.

In the current study, the final follow-up PTSA was 15.1° in the nonoperative group and 14.3° in the operative group. Interestingly, the comparison PTSA from the uninjured extremity in 12 patients was 13.3°, which is consistent with Watanabe et al[15] who noted a PTSA of 13.6° in the contralateral extremity in 8 patients. Clearly, the PTSA is greater than the reference normal values from the literature[7,14,16] but may represent the best achievable alignment in these patients. PTSA is likely high at baseline before the injury, and therefore reduction to an anatomic normal of 8.8° or less is not feasible. Sheppard et al noted increased PTSA in 251 knees, including healthy controls, individuals with Osgood-Schlatter Disease, and TTFs. One hundred-one patients with TTFs were noted to have an increased PTSA of 10.5°. After excluding Ogden types IV and V fractures, the observed PTSA for this group of TTFs was 10.2°.[7] Watanabe et al[15] noted post-treatment PTSA of 19.0° and 16.8° in nonoperatively and operatively treated Watson-Jones IV/Salter-Harris II TTFs, respectively.

In the current series, there was no significant difference in preoperative MPTA in patients treated operatively or nonoperatively. Furthermore, there was no significant change in the MPTA prereduction versus postreduction in either group. This would indicate that type IV TTFs are primarily a sagittal plane injury. AFG was not significantly different between the operative and nonoperative groups before treatment. However, there was a trend for a greater pretreatment AFG in those treated operatively. Similarly, there were no significant differences in the AFG postreduction, but there was a trend towards a greater change in AFG in the operative group. On final follow-up, there were no significant differences in the AFG, but there was a trend towards greater residual AFG in the nonoperative group. The 1 patient who sustained a refracture 107 days after the original injury was noted to have a persistent AFG on the preceding clinic visit at 74 days.

One potential advantage of operative treatment is the possibility of less time in a cast or brace. In the operative group, 6 patients were treated without casting, using either a hinged knee brace or knee immobilizer. Two patients developed cast sores, 1 in the operative and 1 in the nonoperative group. Both healed uneventfully with standard wound care and nonadhesive dressings. Extended casting time could also potentially lead to stiffness. One patient in this study experienced a 20 to 30° difference in flexion compared with the normal side at a final follow-up of 94 days. This patient was treated nonoperatively and casted for 52 days. A second patient treated operatively lacked 5° of extension at the final follow-up of 62 days. Both groups demonstrated similar functional outcomes in terms of time to weight-bearing and return to sport.

The current study is not without limitations. The retrospective study design precludes the determination of a single best treatment method. Treatment selection was based on surgeon preference, rather than predetermined criteria. Therefore, this manuscript should not be misinterpreted as positing that all type IV TTFs should be treated nonoperatively. Five patients underwent attempted closed reduction that was deemed inadequate and immediately converted to operative treatment. Another patient who was discharged home with adequate alignment and a bivalved cast lost alignment and was subsequently treated operatively. In contrast, it is unclear whether all patients who underwent surgery required surgery since the mode of treatment was by attending preference, and not all patients treated operatively had an attempt at closed reduction outside of the OR. Concern for compartment syndrome may have played a role in treatment choice as operative management carries the advantage of allowing for evacuation of hematoma and prophylactic anterior compartment fasciotomies. Two patients in the operative group underwent prophylactic anterior compartment fasciotomies at the time of operative fixation, but both were closed at the time of fixation, and neither manifested postoperative neurovascular symptoms or deficits.

There may be inaccuracies inherent to radiographic measurements, but all measurements were corroborated by a fellowship-trained pediatric orthopaedic surgeon. Furthermore, all PTSAs were measured by 2 observors and ICCs showed good concordance. The concavity of the medial tibial plateau can be difficult to assess on lateral knee radiographs due to superimposition of the lateral plateau and tibial eminence. Furthermore, measurement of the AFG may be inaccurate as some lucency may represent unossified physeal cartilage. Lastly, all patients were followed to healing, but follow-up times in the current study are short. Nevertheless, ours is the only pediatric orthopaedic practice in the area, so it is likely that patients who were experiencing difficulties would have presented to our practice.

Despite the stated limitations, there is a significant opportunity to treat type IV TTFs nonoperatively, especially since there is no associated joint incongruity nor displacement of the apophysis leading to patellar tendon incompetence. The surgeon has full control of the distal fragment which can be extended against a mold or fulcrum on the anterior aspect of the proximal fragment to perform the reduction. In the event that the surgeon is unable to achieve a satisfactory closed reduction, it is most likely due to entrapment or infolding of the periosteum/patellar tendon in the anterior fracture line and would require an open reduction.[18]

CONCLUSION

Greater consideration should be given to the nonoperative management of type IV TTFs. Operative treatment should be performed when closed reduction is unsuccessful or if fasciotomy is necessary. In the current study, there was no difference in clinical or radiographic parameters, including time to return to activity and PTSA in those treated operatively or nonoperatively. Both modes of treatment resulted in a PTSA that was above that considered normal. Future studies should consider a prospective trial that compares operative and nonoperative treatment of type IV TTFs, including well-defined, predetermined radiographic parameters for conversion to operative treatment.

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