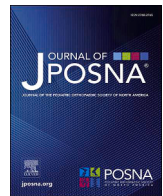




Contents lists available at ScienceDirect

Journal of the Pediatric Orthopaedic Society of North America

journal homepage: www.jposna.com

Original Research

Is Fixation Strategy Associated With Complication Risk in Ogden Type IV Tibial Tubercle Avulsion Fractures? A Multicenter Study of the Tibial Tubercle Study Database



Lee S. Haruno, MD¹; Neeraj M. Patel, MD, MPH, MBS²; Caroline L. Kim, BS³; Dustin A. Greenhill, MD⁴; Folorunsho Edobor-Osula, MD⁵; John S. Blanco, MD⁶; Lindsay M. Crawford, MD⁷; Alexander H. Griffith, BS⁵; Neil K. Kaushal, MD⁵; Abhi Rashiwala, MD⁷; John A. Schlechter, DO⁸; Evelyn S. Thomas, DO⁸; Haley N. Tornberg, MD⁴; Brendan A. Williams, MD^{3,*}

¹ Department of Surgery, Hawaii Pacific Health Kapiolani Medical Center for Women and Children, Honolulu, HI, USA

² Ann and Robert H. Lurie Children's Hospital of Chicago Division of Orthopedic Surgery, Chicago, IL, USA

³ Children's Hospital of Philadelphia Division of Orthopedic Surgery, Philadelphia, PA, USA

⁴ St. Luke's University Health Network, Bethlehem, PA, USA

⁵ Department of Orthopaedic Surgery, Rutgers-New Jersey Medical School, Newark, NJ, USA

⁶ Division of Pediatric Orthopaedics, Hospital for Special Surgery, New York, NY, USA

⁷ Department of Orthopedic Surgery, University of Texas-Houston, Houston, TX, USA

⁸ Children's Hospital of Orange County Orthopaedic Institute, Orange, CA, USA

ARTICLE INFO

Keywords:

Tibial tubercle
Avulsion fracture
Ogden type IV
Surgical complications

ABSTRACT

Background: The optimal surgical treatment of Ogden Type IV tibial tubercle avulsion fractures (TTAFs) remains controversial, given this injury pattern's rarity and its multiplanar involvement of the proximal tibial physis. Small, single-center studies suggest type IV fractures have higher complication rates and more variable fixation constructs than other TTAF types. The purpose of this study is to delineate fixation constructs among surgically managed type IV TTAFs and identify factors associated with postoperative complications.

Methods: A retrospective, multicenter cohort study was conducted across 7 institutions examining surgically managed Ogden IV TTAFs treated between 2007 and 2022. Patients treated nonoperatively were excluded. Patient demographics, injury characteristics, treatment strategy (including fixation construct), and postoperative complications were analyzed. Fisher exact tests were used to compare complication frequency among fixation techniques.

Results: Eighty-nine patients undergoing operative management of a type IV TTAF meeting study criteria were identified. The majority (72, 80.9%) were stabilized with screw-only constructs, while 9 (10.1%) were treated with pins or hybrid pin/screw constructs and the remainder (9.0%) were treated with a plate. Among screw-only constructs, 4.5 mm screws (49, 58%) with vertically stacked orientation (37, 51.3%) were the most common. Twenty-five patients (28.0%) experienced complications, the most common of which were implant irritation (14.6%) and wound problems (3.4%). One patient (1.1%) had postoperative compartment syndrome. When examining major complications (excluding implant irritation), the frequency was lower for screw-only constructs than other types of fixation (6.9% vs. 35.3%; $P = .005$). For fractures fixed with screws only, there was no difference in overall complications based on the number of screws used ($P = .21$). No implant failures or non-unions were observed.

Conclusions: In this large, multicenter cohort of surgically managed type IV TTAFs, considerable variation was observed among successful fixation constructs. Implant irritation was the most commonly observed complication. Other than implant irritation, the overall frequency of complications was low and lowest among screw-only constructs.

* Corresponding author: The Children's Hospital of Philadelphia Division of Orthopedic Surgery, 3500 Civic Center Blvd, Philadelphia, PA, 19104, USA.

E-mail address: Williamsba@chop.edu (B.A. Williams).

<https://doi.org/10.1016/j.jposna.2026.100342>

Received 1 October 2025; Received in revised form 29 January 2026; Accepted 6 February 2026

Available online 17 February 2026

2768-2765/© 2026 The Author(s). Published by Elsevier Inc. on behalf of Pediatric Orthopaedic Society of North America. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Key Concepts:

- (1) A variety of fixation options exist for type IV tibial tubercle avulsion fractures.
- (2) There was reliable healing and good outcomes in the majority of cases.
- (3) Implant irritation is the most common complication in screw-only constructs.
- (4) Anterior-to-posterior screws can provide acceptable fixation for type IV fractures.

Level of Evidence: Level III

Introduction

Tibial tubercle avulsion fractures (TTAFs) are relatively rare injuries, most often seen in the adolescent male with variable involvement of the tibial tubercle and proximal tibia physis and epiphysis depending on morphology and maturity [1–3]. Adolescents involved in jumping sports, due to concentric extensor mechanism contraction or eccentric contraction with a flexed knee, are at especially high risk [3,4]. The Ogden classification is the most widely utilized and clinically applicable means of characterizing TTAFs, with differing clinical and surgical considerations for each subtype. An Ogden IV fracture, characterized by posterior extension through the proximal tibial physis and involvement of the entire proximal epiphysis, make up an estimated 16%–18% of all TTAFs [5–7].

Previous single-center studies suggest high surgical construct variability for Ogden type IV fractures and higher rates of complications than other subtypes [6,8–11]. Implant irritation and bursitis remains the most common complication [1,4,12]. Surgery is the mainstay of treatment for displaced injuries and typically includes cannulated screws for most TTAFs, but a wider variety of fixation constructs including pin and plate constructs have been observed for type IVs given their multiplanar involvement of the nearly mature proximal tibia [6,8,10,11,13]. The risk and complication profile of these methods of fixation is poorly understood.

Given the rarity of Ogden IV TTAFs and the dearth of literature regarding their treatment-related complication profile, we sought to examine this injury pattern across a multicenter cohort. The primary aims of this study were to do the following: (1) delineate which surgical fixation strategies are commonly utilized and (2) examine implant-related factors associated with postoperative complications. We hypothesized that variation in surgical constructs would exist but complications would not vary among fixation methods.

Materials and methods

A retrospective multicenter cohort study was conducted within the Tibial Tubercle Study (TITUS) Group, which is composed of seven contributing pediatric institutions. Institutional Review Board approval was obtained at all member sites. At the time of the study, the TITUS database consisted of 598 patients and included demographic data, injury characteristics, treatment strategies, postoperative protocols, and outcomes. Study data were collected and managed using REDCap (Research Electronic Data Capture) a secure, web-based software platform hosted at the lead study [14,15]. Each TITUS site was responsible for uploading their individual data to this central repository.

Patients who sustained an Ogden type IV TTAF treated surgically at a TITUS-member institution between 2007 and 2022 were identified. Any available imaging was utilized to determine Ogden type. Patients managed nonoperatively or with incomplete follow-up data were excluded from this study. A minimum follow-up duration of six months was required for inclusion. The primary outcomes of interest were clinical or surgical complications including symptomatic implants, wound complications, neuropraxia, infection, arthrofibrosis, prolonged quadriceps weakness/inhibition, compartment syndrome, refracture, failure of fixation, need for revision surgery, and refractory pain or disability.

Patient demographics, injury characteristics, and fixation strategies were collected. Surgical fixation was categorized into screw-only fixation, pin-only fixation, hybrid (pin and screw) fixation, or plate fixation. Additional surgical technique data, including the size and number of screws and screw configuration were also noted. Radiographs depicting common screw arrangements are displayed in Fig. 1. Statistical analysis was performed with SPSS version 28.0 (IBM Corp. 2021, Armonk, NY, USA). Patient demographics, injury characteristics, and treatment variables were characterized descriptively. Kolmogorov-Smirnov tests were used to determine normality of distributions. Univariate testing evaluated differences between fixation constructs (screw-only and other fixation strategies). Independent samples t-tests were used to compare continuous variables and χ^2 or Fisher exact tests for categorical variables. A *P* value less than .05 was considered statistically significant.

Results

The TITUS database identified 99 patients with type IV TTAFs, representing about 16.5% of all TTAFs in the cohort. Of the 99 patients, 89 (89.9%) underwent operative management and met inclusion criteria for this study. The average patient age was 14.6 years. The majority of patients were male (92.1%) and identified as Black/African American (35.9%). Jumping was the most common injury mechanism (48.3%). An overview of patient demographics, treatment, and complications is depicted in Table 1.

There were no statistically significant risk factors for complications with respect to patient demographics. When comparing groups with those without a complication, there were no statistical differences in average time from presentation/diagnosis to surgery (14 h), days until full weight-bearing (40), or weeks until the patient reported full participation in sports (20). The duration of immobilization was significant, with the complication cohort immobilized for an average of 42 days compared to 28 days for patients without a complication (*P* = .03).

Fixation methods varied within the cohort. The majority of patients (72/89, 80.9%) were treated with screw-only constructs, while 13 (14.5%) had pin or hybrid fixation, and 4 (4.5%) underwent plate osteosynthesis. Most screw constructs utilized either 2 (47.2%) or 3 screws (33.3%) in a vertical or inverted triangle configuration (70.8%). The crossed (or “X”) screw configuration, unique to type IV TTAF given the nature of the fracture pattern, was utilized in 13% of screw-only constructs (Fig. 1). The most popular implants were 4.5 mm (58.3%) and cannulated (80.5%) screws. There was no documented performance of concurrent arthrotomy or arthroscopy, fasciotomy, meniscal procedures, or patellar tendon repair at the time of index surgery. An overview of fixation strategies is depicted in Table 2. Patients undergoing fixation with implants other than (or in addition to) screws had a significantly higher rate of complications: 35% of hybrid/non-screw constructs compared to 8% of screw-only constructs (*P* = .009). There was no association between complication rates and number of screws utilized. Seven patients (8%) underwent hardware removal. The rate of implant removal was higher in the hybrid or non-screw cohort (5/17 patients, 29.4%) compared to the screw-only group (2/72, 2.8%).

Among the 89 operatively treated patients, 25 (28.0%) had a documented complication. The most common complication was implant irritation, observed in 13 patients (14.6%). All 13 cases of implant

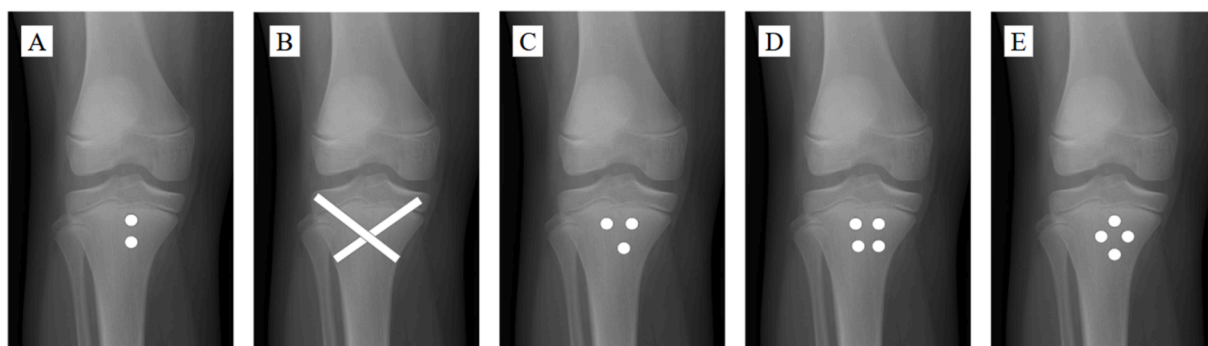


Figure 1. Anterior/Posterior radiographs depicting common methods for screw fixation of type IV tibial tubercle avulsion fractures. (A) Vertical, (B) X, (C) Inverted triangle, (D) Box, (E) Diamond.

Table 1.

Overview of patient demographics, treatment, and complications.

Variable	Overall N = 89*	No complications N = 77*	Complication N = 12*	P value†
Age	14.67 ± 1.2	14.61 ± 1.2	14.70 ± 0.9	.815
Race				>.1
White	27 (30)	26 (34)	1 (8)	
Black	32 (36)	24 (31)	8 (67)	
Asian	2 (2)	2 (3)	0 (0)	
Unknown	28 (17)	25 (32)	3 (25)	
Ethnicity				.575
Not hispanic or Latinx	56 (63)	50 (65)	6 (50)	
Hispanic or Latinx	26 (29)	21 (27)	5 (42)	
Unknown	7 (8)	6 (8)	1 (8)	
Sex				.587
Female	7 (8)	7 (10)	0 (0)	
Male	82 (92)	70 (90)	12 (50)	
Mechanism of injury				.926
Jumping	43 (48)	38 (50)	5 (42)	
Fall from standing	18 (20)	15 (20)	3 (25)	
Fall from height	9 (10)	8 (10)	1 (8)	
Collision	10 (11)	8 (10)	2 (17)	
Running	4 (5)	4 (5)	0 (0)	
Other/Unknown	5 (6)	4 (5)	1 (8)	
Method of fixation				.009
Screw only	72 (81)	66 (92)	6 (8)	
Other (plate/pin/screw + pin)	17 (19)	11 (65)	6 (35)	
Time to surgery (hours)	13.98 ± 7.0	14.01 ± 7.33	13.09 ± 5.1	.689
Postop immobilization (days)	30 (14)	28 (11)	42 (33)	.031
Time to WBAT (days)	40.20 ± 18.0	39.81 ± 18.5	42.88 ± 15.2	.653
Time to RTS (weeks)	19.96 ± 10.2	20.49 ± 10.7	16.14 ± 6.2	.431

RTS, return to sports; WBAT, weight-bearing as tolerated.

* N (%); Mean ± SD; Median (interquartile range).

† Fisher's exact test, Independent T-tests; Mann-Whitney U test.

irritation were reported in the screw-only fixation group. For the purposes of this study, symptomatic/irritating implants were deemed a minor complication. There were 12 additional complications including wound/infections (4 patients, 4.5%) and weakness/neuropraxia, (4 patients, 4.5%), and single cases each of postoperative compartment syndrome and refracture. There were no cases of implant failure or nonunion. Complications, excluding implant irritation, are summarized in Table 3.

Discussion

Within a large, multicenter cohort of a rare injury pattern, we identified notable variability in fixation strategies for Ogden IV TTAfs. These fractures ultimately demonstrated reliable healing with few major complications. Although a 28% overall rate of complications was identified, only 13.5% were unrelated to implant irritation (the most commonly reported, albeit minor, complication among type IV

Table 2.
Overview of surgical techniques.

Variable	Overall N (%)
Fixation method (N = 89)	
Screws	72 (81)
Screw + Pins	7 (8)
Pins only	6 (6.5)
Plate	4 (4.5)
Number of screws used (N = 72)	
1	4 (6)
2	35 (49)
3	24 (33)
4	7 (10)
5	2 (3)
Screw configuration (N = 72)	
Vertical ("I")	37 (51)
Inverted triangle	14 (19)
Crossed ("X") ± additional screws	9 (13)
Box/diamond	2 (3)
Other	10 (14)
Screw type (N = 72)	
Solid	13 (18)
Cannulated	58 (80.5)
Unknown	1 (1.5)
Screw sizes (N = 84)	
4.0 mm	9 (11)
4.5 mm	49 (58)
6.5 mm	10 (12)
7.3 mm	12 (14)
Other	4 (5)
Hardware removal (N = 89)	
No	82 (92)
Yes	7 (8)

Table 3.
Overview of complications.

Complication type (<i>implant irritation excluded</i>)	Overall N (% of total patients)	Screws only N (% of patients in fixation group)	Hybrid/non- screw N (% of patients in fixation group)
Wound complications	3 (3)	2 (3)	1 (6)
Prolonged quadriceps weakness	2 (2)	2 (3)	0
Neuropraxia	2 (2)	1 (1)	1 (6)
Infection	1 (1)	0	1 (6)
Arthrofibrosis	1 (1)	0	1 (6)
Compartment syndrome	1 (1)	1 (1)	0
Refracture	1 (1)	0	1 (6)
Refractory/persistent pain	1 (1)	0	1 (6)
Total	12 (13.5)	6 (8)	6 (35)

fractures [1,4,12]. Compartment syndrome among our cohort was very rare (1%). Patients experiencing a complication were immobilized for a significantly longer duration than those who did not. A recent study identified that immobilization longer than 4 weeks resulted in a higher risk of developing stiffness (persistent flexion deficit) 3 months after surgery [16].

When evaluating fixation strategies, screw-only constructs had a lower rate of non-irritation-related complications when compared with other fixation strategies. There was a significantly higher incidence of major complications in patients fixed with implants other than screws alone. Overall, outcomes for all strategies were devoid of nonunion or implant failure suggesting that fixation of type IV TTAFs may be reasonably approached at the discretion and comfort of the treating surgeon.

It is notable that screw-only constructs did appear to have an overall lower serious complication profile but did account for all instances of symptomatic implants. A recent study from our same TITUS group reported a 13% rate of symptomatic implants across all TTAF morphologies and a removal rate of approximately 11% in a multicenter cohort of 475 patients. These rates were similar among type IV TTAFs in our focused cohort (14.5% and 8%, respectively). In the previous study, screw number, size, configuration, and washer use were not found to be significantly associated with implant irritation. Symptomatic implants were more common in White patients and those weighing less than 70 kg [17]. In our cohort, despite symptomatic implants being more common in screw-only fixation, the relative rate of hardware removal was higher in the hybrid/non-screw fixation group (29.4% vs 2.8%).

A recent biomechanical study by Peez et al., simulating Ogden type III/IV TTAFs on cadaveric specimens, determined that type IV fractures were more unstable than type III, based on axial displacement and cycles/load to failure of fixation. In addition, they reported that augmenting standard anteroposterior tubercle apophyseal screws with epiphyseal fixation (with either epiphyseal screws or a medially based plate) significantly improved the stability of the construct [13]. As such, the authors would not routinely advocate for plate fixation of this injury. In older patients, plate fixation may be considered in a type IV variation; when the treating surgeon is concerned, the injury will behave more like a displaced tibial plateau fracture and increased stability is required. However, based on the experience of this group, this is infrequent and alternative constructs appear capable of safely achieving union in this fracture pattern. However, this occurred in a cadaveric model which does not account for supplemental immobilization typically utilized (for example, a hinged knee brace) or early fracture healing that may minimize these observed differences in the postoperative patient. While our cohort size limited analysis of screw-specific constructs, we did observe reliable healing and low complication rates among a variety of screw-only constructs. This suggests that while stability may be enhanced in certain circumstances by screws with both epiphyseal and metaphyseal purchase, many construct options appear to be appropriate for this fracture pattern.

A case series of 10 patients with type IV TTAFs published by Park et al. emphasized the importance of appropriate reduction, often facilitated by removal of entrapped periosteum in the anteromedial physis, given the limited remodeling potential and older average bone age of patients sustaining this injury. They also noted that all patients reached skeletal maturity within 2 years of the injury [18]. All patients in this series underwent fixation with good outcomes and no significant leg length difference or angular deformity reported across variable timer periods of follow-up.

Another recently published study by Segal et al. of 37 patients advocated for a distal cortical fixation screw to achieve better stabilization of the fracture. This screw, oriented to achieve bicortical fixation using the posterior tibial cortex distal to the Thurstan Holland fragment

was found to be a safe and effective alternative with good short-term outcomes. The authors theorized a more biomechanically sound fixation method by capturing posterior tibial cortex remote to the Thurstan Holland fragment, which would otherwise limit screw fixation to tibial metaphysis only and bicortical purchase within the same fracture fragment [8]. The present study did not include patients with this particular construct and therefore comparisons to this technique are not feasible. However, this appears to be another viable option to consider for surgeons treating this injury pattern.

While anteroposterior-placed cannulated screws are often used to treat tibial tubercle fractures, unique to fixation of type IV injuries is the “X” or crossed screw configuration, which serves to stabilize the epiphyseal component of the fracture when the entire epiphysis is involved and especially when the characteristic posterior metaphyseal Thurstan Holland fragment is large or present. This technique likely achieves improved stability but necessitates crossing the proximal tibial physis (rather than just the apophysis). This increases the likelihood of iatrogenic physeal arrest in patients far from skeletal maturity but is often less of a concern in patients nearing physeal closure. Further work is necessary to clarify these operative decisions using future prospective cohorts.

Limitations of this study include those inherent in a large, multicenter, retrospective database. Variation in classification, documentation, and complication recording in a retrospective chart review introduces bias. Given that 7 institutions were involved in this study group, there were also no standardized perioperative treatment protocols and ultimately each patient was treated according to the discretion of the individual surgeon. This limitation is unavoidable but highlights the motivation to form a study group to focus on this adolescent fracture pattern that is treated by many pediatric or non-pediatric specialists. Monitoring for certain longer-term complications such as growth arrest were likely variable. Due to the size of the study cohort, we were unable to discretely analyze the impact of other clinically important factors such as time to operative treatment on the occurrence of complications. However, previous work from this study group has demonstrated that surgical treatment in TTAFs treated >24 h from injury are at increased risk of prolonged stiffness and, therefore we recommend urgent operative treatment when possible of these patients [16]. Similarly, longer-term outcomes, such as return to sport were difficult to analyze due to limited data availability and institution-dependent criteria and metrics. The authors also acknowledge that fractures addressed with additional fixation measures in addition to screws may imply increase in injury complexity and thus predispose those patients to a greater complication risk. Finally, while determining the optimal screw size or configuration for fracture fixation would be ideal, the variability and relatively small numbers within each construct cohort limited detailed subgroup analysis. Future efforts of this group will seek to address these limitations by examining these injuries in a prospective manner with standardized data collection and patient-reported outcome collection.

Conclusion

Type IV TTAFs appear to be reliably treated with a variety of fixation constructs resulting in good overall outcomes and a low rate of major complications. Thoughtfully placed screw-only constructs appear to have similar outcomes compared with hybrid and/or plate fixation but are associated with lower rates of clinically significant complications (aside from symptomatic implant irritation).

Additional links

- POSNAcademy: [ORIF of Tibial Tubercle Fracture](#)

Ethics approval and consent

The author(s) declare that no patient consent was necessary as no images or identifying information are included in the article.

Author contributions

Lee S. Haruno: Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Neeraj M. Patel:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Caroline L. Kim:** Writing – review & editing, Writing – original draft, Visualization, Investigation. **Dustin A. Greenhill:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Folorunsho Edobor-Osula:** Writing – review & editing, Investigation, Data curation, Conceptualization. **John S. Blanco:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Lindsay M. Crawford:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Alexander H. Griffith:** Writing – review & editing, Investigation, Data curation. **Neil K. Kaushal:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Abhi Rashwala:** Writing – review & editing, Investigation, Data curation, Conceptualization. **John A. Schlechter:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Evelyn S. Thomas:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Haley N. Tornberg:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Brendan A. Williams:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Data curation, Conceptualization.

Funding

None.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- [1] Reyes CD, Wu W, Pandya NK. Adolescent tibial tubercle fracture: review of outcomes and complications. *Curr Rev Musculoskelet Med Sep.* 2023;16(9):392–7.
- [2] Cole WW 3rd, Brown SM, Vopat B, Heard WMR, Mulcahey MK. Epidemiology, diagnosis, and management of tibial tubercle avulsion fractures in adolescents. *JBJS Rev Apr.* 2020;8(4):e0186.
- [3] Pandya NK, Edmonds EW, Roocroft JH, Mubarak SJ. Tibial tubercle fractures: complications, classification, and the need for intra-articular assessment. *J Pediatr Orthop Dec.* 2012;32(8):749–59.
- [4] Haber DB, Tepolt FA, McClincy MP, Hussain ZB, Kalish LA, Kocher MS. Tibial tubercle fractures in children and adolescents: a large retrospective case series. *J Pediatr Orthop B Jan.* 2021;30(1):13–8.
- [5] Ryu RK, Debenham JO. An unusual avulsion fracture of the proximal tibial epiphysis. Case report and proposed addition to the Watson-Jones classification. *Clin Orthop Relat Res Apr.* 1985;(194):181–4.
- [6] Pace JL, McCulloch PC, Momoh EO, Nasreddine AY, Kocher MS. Operatively treated type IV tibial tubercle apophyseal fractures. *J Pediatr Orthop Dec.* 2013;33(8):791–6.
- [7] Ogden JA, Tross RB, Murphy MJ. Fractures of the tibial tuberosity in adolescents. *J Bone Joint Surg Am Mar.* 1980;62(2):205–15.
- [8] Segal D, Dillenkofer M, Wall EJ, Tamai J. Type 4 tibial tuberosity avulsion fractures: surgical treatment early outcomes and a presentation of the distal cortical fixation. *J Clin Med Sep.* 2024;13(19). <https://doi.org/10.3390/jcm13195695>.
- [9] Field MW, Kaushal NK, Patel NM, McCormick SK, Eberson CP, Schmitz ML, et al. Edobor-Osula OF. Variability in evaluation and treatment of tibial tubercle fractures among pediatric orthopedic surgeons. *J Pediatr Orthop B* 2022;31:e141–6.

- [10] Andrews KA, Gillette M, Shah RV, McKean LA, Sanford CG. Type IV tibial tubercle fracture - salter-harris type II variant. *J Surg Case Rep* 2019;7:1–3.
- [11] Brey JM, Conoley J, Canale ST, Beatty JH, Warner WC, Kelly DM, et al. Tibial tuberosity fractures in adolescents: is a posterior metaphyseal fracture component a predictor of complications? *J Pediatr Orthop* Sep 2012;32(6):561–6.
- [12] Pretell-Mazzini J, Kelly DM, Sawyer JR, Esteban EM, Spence DD, Warner WC, et al. Outcomes and complications of tibial tubercle fractures in pediatric patients: a systematic review of the literature. *J Pediatr Orthop* Jul 2016;36(5):440–6.
- [13] Peez C, Zderic I, Richards RG, Drenchev L, Skulev HK, Gueorguiev B, et al. Combined apophyseal and epiphyseal fixation of ogden type IIIA/IV tibial tubercle avulsion fractures provides favorable stability compared to isolated apophyseal screw fixation - a biomechanical study. *Eur J Trauma Emerg Surg* Mar. 2025;51(1):136.
- [14] Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap) - a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform* 2009;42(2):377–81.
- [15] Harris PA, Taylor R, Minor BL, Elliot B, Fernandez M, O'Neal L, et al. The REDCap consortium: building an international community of software platform partners. *J Biomed Inf* Jul 2019;95(103208):103208.
- [16] Brnjos K, Edobor-Osula OF, Blanco JS, Crawford LM, Greenhill DA, Griffith AH, et al. Risk factors for stiffness after fixation of tibial tubercle fractures: a multicenter study from the TITUS group. *JB JS Open Access* Jul 2025;10(3). <https://doi.org/10.2106/JBJS.OA.25.00142>.
- [17] Maxwell BE, Edobor-Osula OF, Blanco JS, Crawford LM, Greenhill DA, Griffith AH, et al. Who is at risk for implant irritation after fixation of a tibial tubercle fracture? A multicenter study. *J Pediatr Orthop* Feb. 2025. <https://doi.org/10.1097/BPO.0000000000002943>.
- [18] Park J, Bae K, Park S-S, Kang MS. Ogden type IV tibial tuberosity fractures in healthy adolescents: preoperative magnetic resonance imaging and 2-year clinical follow-up study. *Clin Orthop Surg Jun.* 2023;15(3):499–507.