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ORIGINAL ARTICLE

Management of aseptic nonunions of bicondylar tibial plateau fractures

Andrew M. Hresko[1] · Mihir Dekhne[2] · Phillip Grisdela Jr.[1] · Sravya Challa[1] · Theodore Guild[1] · Upender M. Singh[3] · Michael J. Weaver[2] · Derek Stenquist[2] · Arvind von Keudell[2,4]

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Abstract

Purpose Nonunion of bicondylar tibial plateau (BTP) fractures following open reduction internal fixation (ORIF) is rare but challenging. We report a case series of aseptic BTP nonunions, approaches to treatment, and long-term outcomes.

Methods Retrospective case series of aseptic nonunion in operatively treated BTP fractures. Cases with deep infection prior to a revision were excluded. Demographic, injury, and initial fixation characteristics were collected. Clinical course following diagnosis of nonunion was reviewed. Revision operation characteristics, timing, and outcomes were recorded.

Results 13 patients with aseptic nonunion were identified from 508 BTP fractures. Mean (SD) follow-up was 5.2 years (4.6) from the first revision operation for nonunion. Nine patients underwent revision ORIF, which led to union in 6/9 cases. Two patients had total knee arthroplasty (TKA) performed as the initial revision operation for nonunion. One patient was treated with bone grafting without revision of implants and one patient was lost to follow-up after diagnosis of nonunion. Three patients subsequently had TKA performed following failed revision ORIF. In total 5/13 patients underwent TKA.

Conclusions Revision ORIF of aseptic nonunion of a BTP fracture often leads to successful union. However, TKA may be utilized in select cases and at a higher rate than in primary tibial plateau fractures.

Keywords Bicondylar tibial plateau fracture · Nonunion · Revision surgery · Total knee arthroplasty

Introduction

Bicondylar tibial plateau (BTP) fractures are relatively uncommon, accounting for between 18–39% of tibial plateau fractures overall, yet are complicated injuries that pose many challenges for surgeons [1]. They include substantial bony disruption of the proximal tibia with complex fracture patterns often involving multiple planes and are frequently associated with severe injury to the soft tissue envelope and important ligamentous structures [1, 2]. BTP fractures are typically treated with open reduction internal fixation (ORIF) that may require multiple incisions and multiple plates [3]. Goals of ORIF are to reestablish a congruent articular surface and mechanical balance of the limb to reduce the risk of post-traumatic arthritis.

Nonunion occurs in 1.9% of all fractures across all bones regardless of treatment, though it can occur in up to 9% of fractures in higher-risk bones [4]. Nonunion is most often associated with diaphyseal fractures and fractures of vascular watershed areas. Incomplete healing in metaphyseal segments of long bones, such as the tibial plateau, occurs less frequently due to the robust vascular supply in these regions. High energy mechanisms and extensive soft tissue injury – conditions often present in BTP fractures—are both recognized as significant risk factors for the development of nonunion [5]. An important step in management of nonunion is to determine if infection is present as infected nonunions require a greater number of surgeries and experience longer time-to-union compared to aseptic nonunions. [6, 7]

Few cases of aseptic nonunion of BTP fractures have previously been reported in the literature and targeted treatment

✉ Andrew M. Hresko
ahresko@mgb.org

1 Harvard Combined Orthopaedic Residency Program, Boston, MA, USA

2 Harvard Orthopaedic Trauma Initiative, Harvard Medical School, Boston, MA, USA

3 Department of Orthopaedic Surgery, Rigshospitalet, University of Copenhagen, Copenhagen, Denmark

4 Bispebjerg Hospital, University of Copenhagen, Copenhagen, Denmark

strategies are ill-defined. The purpose of this study was to evaluate treatment for aseptic nonunion of BTP fractures. We utilized a database of BTP fractures treated at two level 1 trauma centers to review the interventions employed and post-operative outcomes for 13 aseptic BTP fracture nonunions.

Materials and methods

A retrospective review of patients treated at two American College of Surgeons (ACS) level 1 trauma centers was conducted. All adult patients who were treated for a complete articular bicondylar tibial plateau fracture (OTA/AO 41-C, Schatzker V or VI) and underwent open reduction internal fixation (ORIF) between January 1, 2001 and December 31, 2018 were identified from the electronic medical record. All were treated by fellowship-trained orthopedic trauma surgeons. Patients were excluded from initial review if they were age < 18 years at the time of injury or had < 6 months follow-up from their initial ORIF. Generalized research consent was obtained from all subjects at time of injury, and approval was granted by the Institutional Review Board.

The records of 508 identified patients with bicondylar tibial plateau (BTP) fractures were then reviewed for inclusion in the current analysis. Patients were included if they were found to have a nonunion after initial ORIF of the BTP fracture. Nonunion was defined as a fracture that remained nonunited after 6 months (182 days) as determined by the treating surgeon. Two patients who underwent revision ORIF at earlier than 6 months were also identified. A patient who had revision ORIF at 140 days was included as pre-revision imaging revealed no callus formation on two subsequent radiographs taken at intervals of at least 6 weeks. A patient who underwent revision ORIF at 158 days was excluded as there was not similarly sufficient imaging showing a lack of callus progression prior to revision. Ten of the 13 patients ultimately identified as having a nonunion had a CT scan prior to diagnosis of nonunion and 4 had inflammatory markers (erythrocyte sedimentation rate [ESR], C-reactive protein [CRP]) measured prior to revision. Patients were excluded if they had a diagnosis of a deep infection prior to a revision operation. Deep infection included any of the following occurring at any time after definitive ORIF: purulent drainage from the surgical site, unexpected return to the operating room for irrigation and debridement (I&D) with positive surgical cultures, unexpected return to the operating room for I&D with documented suspicion of deep infection despite negative surgical cultures, or documentation of a suspected deep infection treated with suppressive antibiotics.

Medical records of patients identified for inclusion were further reviewed for the treatment course following diagnosis of nonunion including revision operations, post-operative complications following revision, and conversion to total knee arthroplasty (TKA). Radiographs from the date of diagnosis of nonunion and post-operative follow-up after revision surgery were independently reviewed by 3 fellowship-trained traumatologists for anatomic location of the nonunion and evidence of union following revision operations. Images were also reviewed to determine if the nonunion was single-planar or multiplanar.

Results

Thirteen patients with aseptic nonunion were identified from 508 treated BTP fractures. Injury information, initial management, and revision operations for each identified patient are reported in Table 1. Mean (SD) follow-up was 5.6 years (4.5) from injury and 5.2 years (4.6) from the date of the first revision operation for nonunion (Table 2). Included patients had a mean age of 53.9 years (13.4) at the time of injury. The initial fixation construct included dual plating in 4 cases and triple-plating in 1 case. Detailed patient, injury, and initial treatment characteristics are reported in Table 3.

Characteristics and Treatment of Nonunion

Aseptic nonunions were found to occur at several locations within the tibia. Four nonunions involved the articular surface, 6 were isolated to the metaphysis, 2 were at the junction of the metaphysis and diaphysis, and 2 involved the diaphysis as an extension of the tibial plateau fracture (Table 4). Three nonunions were multiplanar, involving multiple nonunited fragments. Two nonunions were associated with hardware failure. Among nonunions involving the articular surface, 2 involved a single shear fragment in the lateral tibial plateau and 2 were multiplanar with multiple nonunited articular pieces. Among metaphyseal and metadiaphyseal nonunions, 3 involved a single oblique nonunion line, 4 were transverse, and 1 was multiplanar. Nonunions were first addressed operatively at a mean of 275.2 (106.2) days following the initial ORIF for the index BTP fracture.

Revision ORIF was performed in 9 patients (Table 4). This occurred at a mean of 272.0 (91.5) days following the initial ORIF and involved a corrective osteotomy of the tibia in 2 cases and use of autologous bone graft in 4 cases, 3 using iliac crest bone graft (ICBG) and 1 using a reamer-irrigator-aspirator (RIA). Six patients treated with revision ORIF went on to union, which was documented at a mean 262.7 (200.1) days (range 62–520 days) following revision ORIF and 528.8 (235.1) days after the initial BTP fracture. There were no cases of infection following revision ORIF and all intraoperative cultures remained negative.

All three patients who did not achieve union after revision ORIF were ultimately converted to TKA at a mean 684.0

Table 1 Summary of injuries and treatments of included cases

Age at injury, gender	Injury pattern (AO/OTA, Schatzker)	Open fracture class (Gustilo)	Primary ORIF construct	Nonunion location & pattern	Initial revision procedure	Supplemental treatments used in revision ORIF	Days from revision to union	TKA after failed revision ORIF	TKA components & constraint	Days from revision ORIF to TKA
40 M	41C3, VI	3B	Lateral plate	1) Meta-diaphysis, oblique 2) Diaphysis, oblique	Bone grafting, no hardware revision	ICBG	4111*	No	N/A	N/A
29 M	41C3, VI	N/A	Lateral plate	Meta-diaphysis, transverse	Revision ORIF	None	197	No	N/A	N/A
55 M	41C3, VI	N/A	Dual plating (lateral, medial)	Articular, multiplanar	Revision ORIF	RIA	Did not unite	Yes	Femoral and tibial stems, hinge	617
77 F	41C3, VI	N/A	Lateral plate	Articular, sheer	TKA	N/A	N/A	N/A	Femoral and tibial stems, constrained polyethylene	N/A
58 M	41C3, VI	N/A	Lateral plate, independent articular screws	Diaphyseal, oblique	Revision ORIF	None	520	No	N/A	N/A
39 F	41C3, VI	N/A	Dual plating (lateral, medial), tibial tubercle cerclage	Metaphysis, multiplanar	Revision ORIF	Tibial osteotomy	265	No	N/A	N/A
58 M	41C3, VI	3B	Lateral plate, independent articular screws	Metaphysis, oblique	Revision ORIF	ICBG	Did not unite	Yes	Femoral stem, proximal tibia replacement, hinge	1134
60 F	41C3, VI	N/A	Lateral plate, tibial tubercle cerclage	Metaphysis, transverse	Revision ORIF	Tibial osteotomy	477	No	N/A	N/A
58 F	41C3, VI	N/A	Tripple plating (lateral, medial, posterior)	Articular, sheer	Revision ORIF	ICBG	Did not unite	Yes	Tibial stem, standard polyethylene	301
57 F	41C3, VI	N/A	Lateral plate, independent articular screws	Articular, multiplanar	TKA	N/A	N/A	N/A	Femoral and tibial stems, constrained polyethylene	N/A
49 F	41C, VI	N/A	Lateral plate, independent articular screws	Metaphysis, transverse	Revision ORIF	None	45	No	N/A	N/A

Table 1 (continued)

Age at injury, gender	Injury pattern (AO/OTA, Schatzker)	Open fracture class (Gustilo)	Primary ORIF construct	Nonunion location & pattern	Initial revision procedure	Supplemental treatments used in revision ORIF	Days from revision to union	TKA after failed revision ORIF	TKA components & constraint	Days from revision ORIF to TKA
47 F	41C1, VI	N/A	Dual plating (lateral, posteromedial)	Metaphysis, oblique	None**	N/A	N/A	No	N/A	N/A
74 F	41C2, VI	N/A	Dual plating (lateral, medial)	Metaphysis, transverse	Revision ORIF	ICBG	72	No	N/A	N/A

M Male, *F* Female, *N/A* Not applicable, *ORIF* Open reduction internal fixation, *TKA* Total knee arthroplasty, *ICBG* Iliac crest bone graft, *R/A* Reamer–irrigator–aspirator reamings

*Patient lost to follow-up prior to union at 400 days after revision, represented 11.3 years later with united fracture

**Nonunion diagnosed after removal of symptomatic hardware, lost to follow-up thereafter

Table 2 Demographics of 13 Patients with Nonunion

	N
Age[a]	53.9 (13.4)
Female	8
Comorbidities	
PVD	1
Diabetes	3
Cardiac (CAD/CHF/MI)	2
Liver Disease	1
COPD	0
Connective tissue disease	1
Tobacco use	2
Alcohol use	3
Drug use	1
Follow-up from initial injury (years)[a]	5.6 (4.5)
Follow-up from initial nonunion intervention (years)[a]	5.2 (4.6)

PAD Peripheral vascular disease, *CAD* Coronary artery disease, *CHF* Congestive heart failure, *MI* Myocardial infarction, *COPD* Chronic obstructive pulmonary disease

[a]Denotes mean, standard deviation

(420.5) days after the revision ORIF procedure. In 2 cases, TKA was the first revision operation performed after nonunion was diagnosed. In these cases, TKA occurred at a mean 349.5 (187.4) days following the initial ORIF of the BTP fracture.

Two patients did not undergo revision ORIF or TKA (Table 4). One patient developed nonunion at both the metadiaphyseal junction and in the mid-diaphysis with united cortex in-between. Both nonunion sites were treated with placement of ICBG without hardware revision. This patient had not achieved union at final follow-up at 400 days post-op and was then lost to follow-up for approximately 10 years. The fracture was later found to be united when he later represented 11.3 years after bone grafting. One patient had a nonunion of the lateral cortex of the proximal tibial metaphysis diagnosed when she reported continued pain after removal of hardware but was lost to follow-up thereafter.

Discussion

Aseptic nonunion is a rare outcome following ORIF of a BTP fracture that can be challenging to manage. In this study, we reviewed the treatment course and outcomes for 13 aseptic nonunions treated at two level 1 trauma centers over an eighteen-year period out of a total of over 500 patients with BTP fractures. Revision ORIF was the initial treatment of choice in the majority of patients and was successful in achieving union in 6/9 of cases. There were no instances of infection following revision ORIF. Five of 13 BTP

Table 3 Injury, Fracture, and Initial Surgical Fixation Characteristics

	N
Mechanism of injury	
Motorcycle crash	2
Motor vehicle crash	1
Pedestrian or cyclist struck	3
High-speed recreational (Skiing)	1
Fall—height	1
Fall—ground Level	5
Polytrauma	5
Energy of mechanism	
High	8
Low	5
OTA/AO Classification	
41C1	1
41C2	1
41C3	10
Unknown	1
Schatzker VI	13
Right/Left	5/8
Open fracture	2
Gustilo 1	0
Gustilo 2	0
Gustilo 3A	0
Gustilo 3B	2
Gustilo 3C	0
Compartment syndrome	2
Fasciotomy	4
Initial external fixation	4
Time from injury to ORIF (Days)[a]	4.2 (5.4)
Multiple plates	5
Supplemental soft tissue coverage	
Split-Thickness skin graft	1
Gastroc flap	1
Anterolateral thigh flap	1

ORIF Open reduction internal fixation

[a]Denotes mean, standard deviation

nonunions went on to TKA. Patients successfully treated with revision ORIF and those ultimately converted to TKA both had prolonged clinical courses requiring 1–2 years of treatment and close follow-up.

We identified 13 aseptic nonunions from a database of 508 BTP fractures, for a rate of 2.6%. Previous studies of tibial plateau fractures have found varying nonunion rates. Weaver et al. reviewed 140 BTP fractures that had a nonunion rate of 5%, but this included both septic and aseptic cases [8]. Kugelman et al. reviewed all operative tibial plateau fractures of any pattern at their institution and found a nonunion rate of 0.7% [9]. In Ruffalo et al.'s study of BTP fractures undergoing dual plating via 2-incision approaches, there was an overall nonunion rate of 10% with 4.2% being aseptic [10]. Despite the heterogeneity of these studies, it is clear that nonunion – and especially aseptic nonunion – is a relatively rare outcome of these complex injuries. A recent systematic review of tibial plateau nonunion management identified only 31 cases among eight studies that met inclusion criteria, over half of which were high-energy, bicondylar fractures. [11]

When aseptic nonunion did occur, it most often involved fracture lines in the metaphysis or at the articular surface. Though all included fractures were comminuted at the time of injury, the majority of nonunions were uniplanar with a single oblique or transverse nonunited fracture line in the metaphysis or metadiaphysis. This is in accordance with the unified theory of bone healing (BHN theory) proposed by Elliott et al. in 2016 [12]. According to the BHN theory, mulitfragmented fractures coalesce during healing, leaving a single fracture line along the plane of highest strain; nonunions occur when fixation does not adequately address shear force and reduce strain in this plane [12]. Revision fixation of nonunions should primarily aim to reduce strain along the nonunion plane using lag screw fixation and stiff plates.

Revision ORIF is the preferred surgical strategy for the majority of tibial plateau nonunions and should be performed with adherence to well-established principles of nonunion management. Nine of the 12 aseptic nonunions treated surgically in our cohort underwent revision ORIF as the initial intervention. Infection is a leading risk factor for nonunion and must always be considered [6, 9]. A pre-operative white blood cell count (WBC), erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP) should be obtained in all cases. Even if pre-operative testing is not suggestive of infection, at least 5 intraoperative cultures should be obtained. "Surprise" positive cultures identifying latent infection have previously been reported in up to 5% of patients with no pre-operative suspicion of infection and 20% of patients with a risk factor for infection [13, 14]. The nonunion and any associated deformity should then be addressed. For nonunions of the tibial plateau, the goals of reoperation are to achieve an anatomic reduction of the articular surface, restore mechanical alignment of the lower extremity, and provide sufficient stability to promote bone healing [15]. Restoration of the mechanical axis may require tibial osteotomy, which was performed in 2 patients in our cohort at the time of revision ORIF. BTP fractures are frequently high-energy injuries with extensive associated soft tissue injury. As such, BTP nonunions tend to be atrophic and may require biologic augmentation to promote bone healing. In this series, 4 patients had autograft bone grafted to the nonunion site during revision ORIF. ICBG was the preferred source of autograft, though RIA was alternatively used in 1 case. A previous randomized controlled trial has shown equivalent rates of union when ICBG and

Table 4 Characteristics, Management, and Outcomes of Nonunion (N = 13)

	No
Anatomic location of nonunion	
Articular surface	4
Metaphysis	6
Meta-Diaphysis	2
diaphysis	2
Initial revision procedure	
Revision ORIF	9
TKA	2
Bone grafting (No Hardware Revision)	1
None/lost to follow-up	1
Revision ORIF	
Time (Days) from initial ORIF to revision ORIF (mean, SD)	272.0 (91.5)
Bone graft used in revision ORIF	4
Iliac crest bone graft (ICGB)	3
Reamer–Irrigator–Aspirator (RIA) Reamings	1
Tibial Osteotomy performed at revision ORIF	2
Achieved union at final follow-up	7
Time (Days) from revision operation to union (mean, SD)	812.4 (1466.0)
Time (Days) from injury to union (mean, SD)	1079.8 (1465.7)
Achieved union following revision ORIF	6
Time (Days) from revision ORIF to union (mean, SD)	262.7 (200.1)
Time (Days) from injury to union with revision ORIF (mean, SD)	528.8 (235.1)
Total Knee Arthroplasty (TKA)	
TKA at any time following diagnosis of nonunion	5
TKA following revision ORIF	3
Time (Days) from revision ORIF to TKA (mean, SD)	684.0 (420.5)
TKA as Initial intervention for nonunion	2
Time (Days) from initial ORIF to TKA (mean, SD)	349.5 (187.4)
Components used	
Femoral stem	4
Tibial stem	4
Proximal tibia replacing megaprosthesis	1
Constraint	
Hinge	2
Constrained polyethylene	2
None	1

ORIF Open reduction internal fixation, *TKA* Total knee arthroplasty, *ICBG* Iliac crest bone graft, *RIA* Reamer–irrigator–aspirator

RIA are used in nonunion repair [16]. Stability is provided by achieving as much compression across the nonunion site as possible. Inherent throughout the procedure is careful soft tissue handling and management of dead space to reduce the risk of post-operative infection.

Revision ORIF resulted in successful union in 6/9 of patients in this series. The most comprehensive prior study of tibial plateau nonunions is the case series by Toro-Arbelaez et al., who reported on outcomes of 5 intra-articular nonunions treated with revision ORIF. All 5 patients successfully healed the nonunion site with mean time to union of 12.8 weeks [17]. Comparatively, neither of the two patients with articular surface nonunions undergoing revision ORIF in our cohort achieved union at final follow-up. Among the 6 patients who did heal the nonunion, union was documented radiographically at a mean 262.7 days (37.5 weeks) following revision ORIF and 582.8 days (83.3 weeks) following their initial injury.

There was high utilization of TKA among patients in this series. Wasserstein et al. previously reported TKA rates of 0.32%, 5.3%, and 7.3% at 2-, 5-, and 10-years following tibial plateau fracture surgery. Bicondylar fracture was the strongest predictor of eventual TKA (hazard ratio 1.53) [18]. Ochen et al. looked at long-term outcomes of bicondylar tibial plateau fractures specifically and found eventual conversion to TKA in 3% [19]. The rate of TKA in our cohort of BTP fracture nonunions was 5/13 cases. TKA for failed revision ORIF was performed at a mean 684.0 days (22.5 months) after the revision operation, a full year later than those who had TKA as the first revision procedure after diagnosis of nonunion. Given the frequency of TKA in this population, patients with BTP nonunions may benefit from early referral to an arthroplasty surgeon for consideration of TKA to reduce the time to definitive treatment.

This study has several important limitations. As previously discussed, nonunion of a BTP fracture is a relatively uncommon outcome and the size of this case series is therefore small. The number of included cases was further limited by our decision to exclude cases with documented deep infection, as infection is a leading risk factor for the development of nonunion. However, given the many additional variables and interventions required to address infection in the case of infected nonunion, these cases were excluded to create a more comparable cohort. Despite the relatively small size of this series, the 13 cases reviewed add a significant number the sparse examples in the existing literature. Additionally, no statistical comparisons were made between cases of aseptic nonunion and BTP fractures that did not experience this complication. We believe that the small size of the nonunion cohort makes this group too heterogenous for such comparisons to be meaningful or informative, particularly in relationship to risk factors such as diabetes and smoking. Finally, we were not able to include patient reported outcome measures of function after treatment for a BTP nonunion. Strengths of this study include the long follow-up with mean 5.6 years, which allowed us to assess for long-term outcomes including conversion to TKA. Limiting cases to two institutions with a shared electronic medical record allowed us to comprehensively assess the treatment course for patients with this complex clinical problem.

Conclusion

BTP fractures are complex injuries. Aseptic nonunion is a rare outcome requiring aggressive treatment strategies. Revision ORIF is the mainstay of treatment and was successful in 6/9 of the cases in this cohort. After ruling out infection, revision ORIF should focus on achieving an anatomic articular reduction, restoring mechanical alignment of the lower extremity, and creating a stable construct. Rates of TKA after aseptic nonunion are much higher than after primary ORIF for bicondylar BTP fractures. Further research may be helpful in determining which patients would benefit most from TKA.

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Declarations

Conflict of interest The authors have no conflict of interest to declare that are relevant to the content of this article.

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