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Intentional Temporary Limb Deformation for Closure of Soft-Tissue Defects in Open Tibial Fractures

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Objectives: (1) Evaluate intentional temporary limb deformation for closure of soft-tissue defects as a reconstruction strategy in open tibia fractures and (2) analyze the deformity parameters required for such reconstruction.

Design: Multicenter retrospective cohort.

Setting: Level I trauma center.

Patients/Participants: Nineteen patients 18 years of age and older at the time of initial trauma, with a Gustilo–Anderson type IIIB or IIIC open tibia fracture treated with hexapod external fixation and intentional bony deformity created to facilitate soft-tissue closure.

Intervention: Intentional limb deformation for soft-tissue closure, followed by gradual correction with a hexapod external fixator.

Outcome Measurements: Radiographic healing, radiographic assessment of limb alignment, and functional and bony Application of the Method of Ilizarov Group score.

Results: The average age was 45.3 (20–70), and 79% of patients were men. The most common mechanism of injury was motor vehicle accidents. The distal 1 of 5 of the tibia was the most common fracture location, with 37% of these involving the articular surface at the plafond. After wound closure, deformity correction was initiated after 30 days on average. Varus and apex posterior were the most common initial deformity required for primary soft-tissue closure. Bony and functional Application of the Method of Ilizarov Group outcomes were good or excellent in 94% of patients.

Conclusion: Intentional deformation followed by a gradual correction can be an effective strategy to obtain bone union and soft-tissue coverage in certain open fractures. This technique, in essence, converts these injuries from type IIIB to IIIA. This strategy obviates the need for flap coverage and results in satisfactory outcomes.

Key Words: open tibia, intentional deformity, hexapod, limb salvage, Ilizarov

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

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INTRODUCTION

Open tibia fractures are common injuries that can be challenging to successfully treat.[1–4] Treatment is often guided by the extent of soft tissue, vascular, and associated injuries commonly classified using the Gustilo–Anderson scheme. Open fractures requiring soft-tissue coverage (type IIIB) are associated with higher rates of infection, nonunion, and eventual amputation.[3,5] Bony stability for definitive reconstruction is usually obtained by internal fixation with a medullary device or plate and screw construct. However, this depends on creating an adequate soft-tissue envelope to immediately cover the re-established bone length and alignment without producing exposed bone or implants. Early flap coverage is used to help mitigate infection and achieve this goal and limit complications.[6–9] However, patients with severe open tibia fractures often have multiple injuries,[10] and reconstructive flaps are not possible or desirable in every circumstance because of injury, patient, or local vascular factors.[11] In this circumstance, the patient is left with few viable internal fixation options to pursue a limb salvage/reconstructive pathway. In some cases, it is possible to acutely shorten the limb over a nail to close the soft-tissue defect. This technique has good reported outcomes but always results in limb shortening, requires good bony contact, and is often not possible.[12–14] Acute limb shortening alone may not allow

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soft-tissue closure, particularly in longitudinally oriented wounds. A powerful and flexible alternative method to obtain soft-tissue closure for these otherwise problematic wounds has been described. This method involves inducing an intentional temporary deformation of the tibia at the fracture or defect site (into varus and internal rotation for example) to allow for tension free skin closure. In this scenario, delayed, gradual deformity correction with a hexapod circular external fixator with computer aided control is used in lieu of internal fixation[15] (see **Figure**, **Supplemental Digital Content 1**, http://links.lww.com/JOT/B267 and **Figure**, **Supplemental Digital Content 2**, http://links.lww.com/JOT/B268). In this report, we describe our experience with using intentional temporary limb deformity in the treatment of 19 patients who were not candidates for free soft-tissue transfer (ie, single vessel extremity, severe peripheral vascular disease, patient preference, etc.) but who would have otherwise required this for reconstruction and limb salvage.

MATERIALS AND METHODS

After institutional review board approval, a retrospective review was conducted at 3 centers specializing in the management of complex trauma and reconstruction of bone and soft-tissue defects. A cohort of consecutive patients treated for soft-tissue defects with an associated fracture was identified. The inclusion criteria were 18 years of age and older at the time of initial trauma, with a Gustilo–Anderson type IIIB or IIIC open tibia fracture treated with hexapod external fixation and intentional bony deformity created to facilitate soft-tissue closure. Patients who had local tissue rearrangement (ie, rotational flap) or skin grafting were included when a free tissue transfer would have otherwise been necessary without the limb deformation; however, patients who had a free tissue transfer as part of their reconstruction were excluded. We also excluded patients that had acute shortening without angular deformation of the leg.

The decision to pursue intentional deformation for wound closure was a shared one between the surgeon and each individual patient. Because this technique is not common, no standardized protocol was followed. However, the general principles were similar: patients underwent appropriate debridement and either acute or gradual deformation until skin edges were able to be closed primarily, based on the soft-tissue injury and neurovascular status of the leg. Once the skin was well healed, gradual correction of deformity was performed using a circular external fixator.

Patients were identified using operative log records, and data were retrospectively obtained from patient charts, radiographic imaging, and hexapod treatment schedule input parameters. Study data were collected and managed using REDCap electronic data capture tools.[16,17] REDCap (Research Electronic Data Capture) is a secure, web-based software platform designed to support data capture for research studies.

Patient variables were summarized by the group using frequency (%), mean (SD), or median (interquartile range) as appropriate for each variable's distribution. Analyses were performed using R for Statistical Computing, version 3.6.1 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

A total of 19 patients were included in our cohort for analysis. These patients underwent reconstruction by experienced, highly specialized limb reconstruction surgeons (S.M.Q., J.S.R., S.R.R., and A.T.F.) between the years 2004–2018. Cases were evenly distributed between institutions. Basic demographic characteristics are shown in Table 1. The injury patterns were evaluated carefully and separated into their bony and soft-tissue components and are depicted in Table 2. Fracture morphology was classified using the OTA/AO Classification.[18] The most common fracture location was in the distal tibia (n = 13, 68%), with the distal tibia articular surface being involved in 7 (37%) cases. The most common fracture morphology was a comminuted pattern (n = 14, 74%). Fourteen (74%) of our patients had more than 2 cm of bone loss. The location of the soft-tissue injury was also more common distally (n = 11, 58%). Wounds were, on average, 10.8 ± 6.4 cm long (range 2–30 cm) × 7.8 ± 6.8 cm wide (range 2–28 cm).

Data for the reconstruction phase of treatment are summarized in Table 3. Time from injury to soft-tissue closure averaged 26 ± 22.2 days (range 0–74 days). A negative pressure wound dressing was used in 58% of cases as a temporizing measure to the soft-tissue injury. The average time from skin closure to initiation of deformity correction was 30.1 ± 19.7 days (range 0–72 days). Fourteen (74%) patients required a corticotomy for lengthening, most (n = 10, 71%) being proximal to the zone of injury. The average external fixation time for the entire cohort was 314 days ± 89.8 (range 157–461 days). For patients who required a corticotomy for lengthening, the external fixation index (days in the external fixator/cm of lengthening) was 58.4 ± 34.3 (range 21–124).

The deformity parameters that were used to accomplish wound closure are shown in Table 4. Eighteen (95%) patients required shortening as part of the initial intentional deformation. These patients were shortened an average of 2.8 cm ± 1.4 (range 0.5–6 cm). Twelve (63%) patients required rotational deformation, with internal rotation being more common. Coronal plane deformation was needed in 15 (79%) patients, with varus being implemented in 12 (63%) of cases. Translation was needed in 10 (53%) patients, with medial and

TABLE 1. Baseline Demographic Characteristics of the Patients

Age*	45.3 ± 15.5
Male sex, n (%)	15 (79)
Body mass index†	31.5 ± 7.3
Diabetes mellitus, n (%)	2 (11)
Peripheral vascular disease, n (%)	0 (0)
Neuropathy, n (%)	0 (0)
Rheumatoid arthritis, n (%)	0 (0)
Smoking, n (%)	5 (26)

*Plus-minus values are means ± SD.

†The body mass index is the weight in kilograms divided by the square of the height in meters.

TABLE 2. Injury Characteristics

Mechanism of injury, n (%)	
Motor vehicle accident	7 (37)
Motorcycle accident	1 (5)
Fall from height	5 (26)
Pedestrian versus auto	3 (16)
Gunshot	1 (1)
Others	2 (11)
Bony injury (OTA/AO classification*), n (%)	
41A2	2 (11)
41A3	1 (5)
42A2	2 (11)
42A3	1 (5)
42C3	5 (26)
43A1	1 (5)
43A3	7 (37)
Bone loss, n (%)	
None	4 (21)
<2 cm	1 (5)
>2 cm	14 (74)
Plateau involved	3 (16)
Pilon involved	7 (37)
Soft-tissue injury†	
Location, n (%)	
Proximal	3 (16)
Middle	6 (32)
Distal	11 (58)
Orientation, n (%)	
Longitudinal	7 (37)
Transverse	9 (47)
Oblique	3 (16)
Size	
Length, cm	10.8 ± 6.4
Width, cm	7.8 ± 6.8
Total area, cm^2	112.7 ± 192.7

*Orthopaedic Trauma Association/AO Foundation (OTA/AO) fracture classification. From Fracture and Dislocation Classification Compendium—2018.

†Plus-minus values are means ± SD. Percentages may not total 100 because of rounding.

TABLE 3. Reconstruction Phase Data*

Time from injury to soft-tissue closure	26 ± 22.2
Temporary negative pressure dressing	11 (58)
Time from closure to initiation of deformity correction, d	30.11 ± 19.7
Duration of deformity correction, d	23.2 ± 9.7
Corticotomy needed	14 (74)
Proximal	10 (71)
Distal	3 (23)
Bone graft at docking site	4 (29)
Time in circular external fixator	314.3 ± 89.8
External fixator (regenerate) index (days/cm)†	58 ± 34.3
Union achieved	17 (94%)

*Numbers are presented as count (%) for each deformity and mean ± SD for the degree amount. Percentages may not total 100 because of rounding.

†Regenerate index calculated only for 14 patients who underwent lengthening.

lateral translation being equally common. Apex posterior deformation was required in most patients (n = 14, 74%).

We evaluated patient outcomes using the Association for the Study and Application of the Method of Ilizarov Group Classification (see **Table**, **Supplemental Digital Content 3**, http://links.lww.com/JOT/B269 data on Table 5).[19] We did not have long-term outcomes for 1 patient. All but 1 patient in our patient cohort went on to bony union (94%). Twelve (67%) patients had excellent final bony outcomes, and 5 (28%) patients had a good bony outcome. Nine (50%) patients had an excellent functional outcome, and 8 (44%) had a good outcome. One patient (5%) had a fair functional outcome. Four (21%) patients had complications. One patient had a nonunion treated with an intramedullary device, which subsequently developed an infection that was treated with implant removal and debridement without sequelae. A second patient had an incisional abscess treated with debridement, a third patient developed a wound dehiscence treated with reclosure without sequelae, and a fourth patient had a persistent nonunion at the fracture site, which required bone grafting and conversion to internal fixation to achieve union. Limb salvage was accomplished in all patients.

DISCUSSION

Open tibia fractures with associated soft-tissue defects are challenging to manage. These devastating injuries can lead to poor outcomes,[20] with infection rates ranging from 14.3% to 60.0%.[21–24] Meticulous debridement with wide excision of the devitalized bone is imperative to avoid osteomyelitis, but effective soft-tissue coverage is equally important. Modern "fix-and-flap" protocols advocate for early (<1 week) coverage of soft-tissue defects and emphasize the importance of this in moderating the risk of complications.[25] For example, Caudle demonstrated that for Gustilo type IIIB fractures soft-tissue coverage by <1 week resulted in lower infection (8% vs. 59%) and nonunion (23% vs. 77%) risk.[26]

Patients with such injuries, however, tend to have other associated injuries that can prevent timely coverage.[10] In addition, patients with single vessel extremities, multiple comorbidities, smoking addiction, or other poor healing risk factors may be unfit for a free tissue transfer. Another relevant factor is that some hospital systems lack reliable access to a plastic surgeon for early coverage or simply do not have the capacity to perform free tissue transfer.[27] All these factors can create situations in which a fix and flap approach is not possible, and limb salvage/reconstruction requires an alternative approach. Computer assisted hexapod circular external fixators (ie, hexapod frames) allow precise control to correct deformity, and we have found are excellent tools for inducing intentional limb deformity to allow for soft-tissue closure.[28–30] Our study is a multicenter retrospective review of patients with complex tibia fractures complicated by severe soft-tissue injuries that were not candidates for free flap soft-tissue transfer but would have

TABLE 4. Intentional Deformity Created for Wound Closure

Shortening, cm	18 (95)
	2.8 ± 1.4 cm
Rotational deformity parameters	
Internal rotation, n (%)	9 (47)
Degree amount	15.8 ± 8.1
External rotation, n (%)	3 (16)
Degree amount	11.8 ± 2.9
None, n (%)	7 (37)
Coronal deformity parameters	
Varus, n (%)	12 (63)
Degree amount	15.3 ± 10.2
Valgus, n (%)	3 (15.8)
Degree amount	5.6 ± 3.8
No deformity, n (%)	4 (21)
Translation	
Medial, n (%)	5 (26)
Amount in mm	9.6 ± 2.3
Lateral, n (%)	5 (26)
Amount in mm	13.8 ± 10.9
No translation, n (%)	9 (47)
Sagittal deformity parameters	
Apex anterior angulation, n (%)	0 (0)
Apex posterior angulation, n (%)	14 (74)
No angulation, n (%)	5 (26)
Soft-tissue closure method	
Primary, n (%)	15 (79)
Split-thickness skin graft, n (%)	1 (5)
Local flap, n (%)	3 (16)

Numbers are presented as count (%) for each deformity and mean ± SD for the degree amount. Percentages may not total 100 because of rounding or incomplete data.

TABLE 5. Functional Outcomes* and Complications

Case	Bone Outcome	Functional Outcome	Complications
1	Excellent	Good	None
2	Excellent	Excellent	None
3	Excellent	Good	None
4	Excellent	Excellent	None
5	Excellent	Good	Nonunion, infection
6	Good	Fair	None
7†	N/A	N/A	Incisional abscess
8	Excellent	Excellent	None
9	Excellent	Good	None
10	Poor	Excellent	Nonunion
11	Excellent	Good	None
12	Good	Good	None
13	Good	Good	None
14	Excellent	Excellent	None
15	Excellent	Excellent	None
16	Excellent	Excellent	None
17	Good	Excellent	None
18‡	Excellent	Excellent	Wound dehiscence
19	Good	Good	None

*Outcomes are reported as per the Association for the Study and Application of the Method of Ilizarov Group classification.

†This patient was lost to final follow-up, and data on outcomes were not available.

‡This patient is a 50-year-old smoker who sustained a severe open tibia fracture and was deemed not a candidate for a free flap by the plastic surgery team. The patient developed an area of 3 cm of wound dehiscence while undergoing bone transport after the deformity was corrected. This was treated with debridement, reclosure, and eventually healed without further sequelae.

required this for wound coverage if internal fixation had been used for definitive bone reconstruction. All these patients had wound coverage achieved with temporary intentional deformity and wound closure followed by gradual correction of the deformity with or without bone lengthening. Our aim was to evaluate the success rate of this approach and to understand the deformity parameters induced at the fracture site to achieve skin closure.

The technique of intentionally deforming a limb to achieve soft-tissue closure has been previously described as a technique and as a report of 2 cases in this journal.[31,32] This is the largest series to be reported. Shortening the length of the limb is particularly useful in transverse or circular wounds and may avoid the need for more complex soft-tissue procedures. This technique is used frequently for more mild areas of soft-tissue loss, but larger areas of skin loss, such as seen in this patient series, require additional deformity to obtain soft-tissue closure. The vascular status must be monitored during deformity creation in the operating room. If the vascular status deteriorates, the deformity is partially undone, to a point where perfusion is adequate, and the remaining deformity is created gradually with a program in the postoperative period.

Patients should be followed closely to ensure the vascular status of the leg is not compromised by the deformity that has been induced, but otherwise the deformity is increased until soft-tissue apposition for primary skin closure is attained. The intentional deformity can be performed acutely or additionally gradually as appropriate for each patient. Care must be taken to avoid arterial kinking and vascular compromise. Palpation of pules or doppler should be carefully monitored during this maneuver, and the manipulation should be stopped if the pulse is lost.

Our patient cohort had similar results to previously published series,[32] with most patients going to union. Our patient cohort experienced delay to soft-tissue closure of 26 days on average, compared with almost immediate closure as reported by Lahoti et al. Several factors accounted for this discrepancy, namely the severity of the injury, the multiple debridement necessary to obtain a clean wound bed, and the large surface area of the wounds that were treated, which sometimes required careful and gradual deformation to obtain opposed skin edges to allow for primary closure. In the same study,[32] the latency time from wound closure to starting deformity correction was 8 days on average, which is quicker than our cohort. The soft-tissue defect in our cohort, however, was significantly larger and ¾ of patients also had >2 cm bone loss. Healing rates were similar with 94% of our patient cohort going on to union and 100% achieving successful wound coverage. In our cohort, deformity correction was started once the soft tissues allow for gradual manipulation. This reconstruction stage was tailored carefully for each patient, and the duration of correction is prescribed based on the quality of the soft tissues. For our cohort, the average duration of correction of deformity was 23 days (Table 3). The deformity parameters are calculated using the fracture location as the origin[33] and using the wound as the structure at risk. The distraction rate is tailored for each patient depending on the quality of the skin closure and can be altered during the treatment period.

Bony and functional outcomes showed that most patients can achieve favorable results and return to baseline activities of daily living. Nho et al.[31] described one case of acute shortening and deformation of 6 cm and recurvatum to treat tibia osteomyelitis after an open tibia fracture in a 20-year-old man. The bone healing index was 1 month/cm, which is faster than our cohort. Reasons for this may be due to the small number of patients overall, the nature of each injury, and young age.

This is the largest published series of patients treated with this method of soft-tissue coverage. In addition, we are the first to describe in full detail the deformations needed for wound closure including both angulations and translations, the time required for both correction of deformity and completion of the entire reconstruction, and the functional and bone outcome data. Deformity parameters must be tailored for each patient based on fracture morphology and soft-tissue defect/compliance. In our cohort, varus and apex posterior (with or without some internal rotation) were the most common deformations required for primary skin closure. These parameters are consistent with the parameters used in previous studies.[31,32]

Patients in our study had an external fixator index of 58 days/cm on average, which is comparable with previously published series on tibia lengthening using classic methods, but slower compared with integrated techniques such as lengthening and then nailing.[34] There are several explanations to this based on our results. First, our patient cohort is biologically different than the patient undergoing isolated tibial lengthening. The amount of local trauma and the absence of healthy soft-tissue coverage can prolong the time to healing, as well as preclude the addition of internal fixation. Also, because of the tenuous local biologic milieu, the treating surgeon may have opted for slower distraction and for a prolonged consolidation to ensure complete healing.

This report validates and significantly expands on the concept of using shortening and deformity to achieve soft-tissue closure in injuries that would otherwise be classified as Gustilo–Anderson type 3B open fractures. Because most of these injuries did not receive soft-tissue flap coverage and none had free flap coverage, by the modern interpretation of the Gustilo–Anderson classification, these 3B injuries were converted to 3A fractures. This clearly demonstrates a shortcoming of the Gustilo–Anderson system that will cause misrepresentation of these injuries in the reported literature and future research studies. We propose that, ultimately, a new and more precise classification system is needed but that at the minimum the definition of a 3B fracture should be expanded to include these injuries. As such, by our definition a 3B fracture is one that requires soft-tissue recruitment for coverage of the fracture wound either through a local or free soft-tissue transfer or through intentional limb deformity and shortening to achieve soft-tissue closure. This new definition will help assure that these fractures are given consideration as the higher energy and more severe injuries that they represent.

Acute temporary deformation of the severely injured lower limb can be performed safely, and it may allow primary soft-tissue closure in certain open fracture wounds. Close attention should be paid to the neurovascular status of the limb in the immediate intraoperative and postoperative period after the deformity is created. Deformity correction can be performed successfully in a gradual manner after wound healing and before bone healing using software guided hexapod external fixation. Patients requiring significant shortening at the fracture site can be lengthened by extending the ring fixator either proximally or distally and performing a corticotomy in a healthy location. Using this technique, restoration of length, alignment, and rotation can be reliably achieved, with the expectation of bony union and return to baseline function. We believe that this method provides a highly feasible reconstructive pathway to a group of patients who would otherwise have very few reconstructive options.

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