Injury, Int. J. Care Injured 48 (2017) 1211–1216

Contents lists available at ScienceDirect

Injury

journal homepage: www.elsevier.com/locate/injury

The "Road to Union" protocol for the reconstruction of isolated complex high-energy tibial trauma

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ARTICLE INFO

Keywords:
Tibial fractures
Complex trauma
Bone loss
Nonunion
Infection
Bone transport
Limb reconstruction

ABSTRACT

Introduction: The purpose of this study was to describe a standardized staged approach, "The Road to Union", for the reconstruction of isolated complex tibial trauma, both acute and chronic in nature.
Methods: This retrospective study included all patients treated for complex tibial trauma at a specialized limb reconstruction centre, including acute open fracture as well as infected and aseptic non-unions. This standardized approach includes eight specific steps, employed in sequence. The time in external fixation (EFT), the external fixation index (EFI), and the distraction consolidation index (DCI) were the primary outcome measures. The relationship between EFI and DCI was assessed using Pearson's moment correlations.
Results: Thirty-two patients with a mean age of 34.7 ± 14.2 years were included; 12 were treated for complex open tibial fractures with bone loss, 13 for infected non-unions, and 6 for aseptic non-union. The mean bone defect was 66 ± 32 mm. The total EFT was 42.5 ± 14.8 weeks; the EFI measured 51.9 ± 25.3 days/cm, and the DCI measured 48.3 ± 21.4 days/cm. Union was achieved in 29 out of 32 patients (91%), and there was a strong and significant relationship between EFI and DCI ($r = 0.92$, $p = 0.0001$) measurements. Pin site infections were observed in 11 patients, and 3 patients had persistent non-union. Three patients underwent delayed amputations when reconstructive procedures were unable to achieve union.
Conclusion: The findings of this study demonstrate that a standardized staged treatment protocol of debridement, circular external fixation, soft-tissue management, distraction osteogenesis, and functional rehabilitation can result in a high rate of union in cases of complex tibial trauma, both acute and chronic in nature.
Level of evidence: Level IV; case series

Introduction

The tibia is one of the most commonly injured long bones [1,2], and its superficial location leaves it more susceptible to severe open fractures with bone loss [3,4]. The reported incidence of tibial shaft fractures varies from 8.1 to 37.0 per 100,000 patients, with males having the highest incidence [5]. Larsen reported that 21% of these injuries were caused by high-energy trauma, but only 17% sustained more complex AO C type fractures.

Surgical management of these high-energy traumatic injuries remains a major clinical challenge [4]. Thorough debridement of devitalized bone, appropriate soft tissue coverage, and early stabilization are the most successful strategies for reducing complications, and increasing the chances for bony union [2,4,6] Several authors have suggested that the use of a tensioned wire circular external fixator has distinct advantages over intramedullary nailing for the most severe open injuries [3,4,7]. These devices allow more specific intra-operative reduction and correction of residual multi-planar deformities and by manipulating and

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http://dx.doi.org/10.1016/j.injury.2017.03.018

adjusting struts and other components the reduction can be further modified post-operatively, potentially reducing the need to return to the operating room [7]. However, despite these advantages this technique is associated with a number of disadvantages and possible complications. In a systematic review by Dickson, et al. the superficial infection rate was 30.9%, which was significantly higher compared to the 3% rate reported with IM nailing [3]. In contrast time to union, risk of deep infection, and reoperation rates were all significantly lower with external fixation [3].

Soft tissue management is often the most critical factor to achieve satisfactory clinical outcomes [2]. Aggressive debridement of all involved highly contaminated or necrotic bone and soft tissue, is vitally important in the early treatment phase [8]. The timing of plastic surgical flap coverage is still controversial [8], although most, studies have demonstrated higher flap survival and lower infection rates when there is early intervention [9–12].

The final outcome of complex tibial fractures is influenced by many variables including the mechanism of injury, patient factors, and both initial and definitive management. These different factors require a structured approach to achieve the best possible outcomes while reducing complication rates [13,14]. Cognizant of its importance, the British Association of Plastic, Reconstructive and Aesthetic surgeons (BAPRAS) and the British Orthopaedic Association together introduced guidelines to improve the management of complex tibial fractures in 1997 [13]. Surprisingly, several authors have reported that awareness of and adherence to these recommended standards was poor, with no significant changes noted in the last decade [13–15].

Adopting many of the above principles, a standardized approach has evolved at our institution that we consider the "Road to Union". The purpose of this study was to describe in detail our current treatment protocol for managing complex tibial fractures, including both acute open injuries as well as late presentations of either infected or non-infected non-unions. The secondary purpose was to establish the relationships between the external fixator index (EFI) and the distraction consolidation index (DCI), with respect to various clinical parameters. We hypothesized that use of a standard treatment protocol would result in a consistently high rate of success, with bone union and resolution of infection if present.

Methods

Patient identification and data collection

This study was conducted as a retrospective cohort study. All patients were identified from the departmental database who were treated for complex open tibial fractures or infected or non-infected non-unions at a specialized limb reconstruction unit and trauma centre between 2007 and 2015. Prior approval to conduct this review was obtained from the Institutional Review Board and Human Research Ethics Committee. Patients were included if they were aged between 16 and 60 years, sustained acute traumatic Grade II/III open tibial shaft fractures, complex closed AO type C tibial shaft fractures, or presented with an infected or non-infected tibial non-union, and were followed up for a minimum of 12 months. The following exclusion criteria were applied: history of previous ipsilateral tibial fractures, contralateral lower extremity fractures, polytrauma, chest or abdominal trauma, and closed head injuries.

Patient management using the "Road to Union" protocol

Surgical treatment of complex traumatic tibial pathology adhered to a standardized protocol that has been divided into eight defined steps, described in detail below. The management of open fractures, infected cases whether united or not, and cases with bone loss requiring limb reconstruction and lengthening followed all eight steps. In patients who sustained closed injuries without bone loss, the first two steps were generally omitted.

Step 1: Debridement, PMMA spacer as the Masquelet technique, and provisional stabilisation with external fixation

Initial debridement followed established principles, with resection of all necrotic and non-perfused tissue until healthy bleeding margins were observed [11,16]. Definition of involved non-viable tissue was determined by its clinical appearance, as judged by individual surgeons. Despite its subjective nature, this is consistent with prior publications, and remains the best method currently available [11,16,17]. In open fractures, or in non-unions with significant bone loss, an antibiotic impregnated cement spacer (Palacos®, Zimmer, Warsaw, Indiana USA) was inserted into the bone defect for local antibiotic delivery and to preserve space for subsequent definitive osseous reconstruction [16]. These spacers were provisionally shaped outside the body to limit thermal damage, but were inserted prior to curing completely to allow modification of the spacer slightly to achieve overlap with the bone ends [18]. Prophylactic or therapeutic fasciotomies were routinely performed when clinically indicated. Finally, temporary external fixation was applied to stabilize the fracture.

Step 2: Soft tissue coverage and wound closure

When necessary, additional debridement was performed and wound cover was generally provided within 48–72 hours of presentation to the unit by an experienced plastic and reconstructive surgeon. Soft tissue coverage was usually obtained with a vascularized free flap. For smaller defects an antero-lateral thigh flap (ALTF) was used, and for larger defects a latissimus dorsi free flap was typically employed. This step included a latency period to allow the flap to mature and the soft tissues to stabilize.

Step 3: Definite fracture fixation with a hexapod capable circular frame

Definitive fracture fixation was performed by completing the ring external fixator, and six struts were added to allow for deformity correction and bone transport. If a circular fixator was used for temporary fixation earlier, an additional proximal and/or distal ring was added to the existing external fixator ring construct. At this stage the hexapod fixator was also readjusted as required to achieve a more anatomical reduction. Thereafter, patients were allowed to mobilize as tolerated. If infected, tailored antibiotic therapy was commenced according to culture sensitivities and typically continued for 6 weeks.

Step 4: Removal of PMMA spacer and corticotomy

The cement spacer was removed at six weeks. This arbitrary cut-off period allowed the flap to mature and the soft tissue to settle so that the tibia was ready for bone transport when necessary. The spacer was removed using a mini-open approach, lifting the flap from the opposite side away from the vascular pedicle. The induced membrane was split longitudinally, and closed with resorbable sutures once the spacer was removed. At this stage a low energy percutaneous metaphyseal corticotomy was performed to prepare for distraction osteogenesis and bone transport [19,20].