ORIGINAL RESEARCH

The Use of the Taylor Spatial Frame in Treating Tibial Osteomyelitis Following Traumatic Tibial Fracture

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Abstract

Introduction: Tibial osteomyelitis can follow open fractures with bacteria colonising the wound and persisting through biofilm and sequestrum formation. The treatment is complex, requiring eradication through debridement before limb reconstruction, for which the Taylor spatial frame (TSF) is one option. This study evaluates patient outcomes after reconstruction and identifies factors associated with post-operative complications.

Materials and methods: Fifty-one cases of tibial osteomyelitis were treated by the Ilizarov technique from 2015 to 2021 at a major trauma centre. Bacterial samples and treatment factors were assessed. Patient outcomes were complication rates and time to bony union. Complications were expressed as odds-ratios (OR) with 95% confidence intervals. Linear regression was used to assess factors associated with time to union.

Results: The mean follow-up was 24.1 months with the mean time to radiological union being 11 months. Post-operative complications were noted in 76.5% of patients with pin-site infections most common (52.9%), followed by fracture malunion (29.4%). Smoking was associated with increased fracture malunion (OR = 4.148, 95% confidence Interval [1.13–15.18], $p = 0.031$). The time to union was positively associated with complications, age and time to full weight-bearing (FWB). All other measured factors were found not significant.

Conclusion: Tibial osteomyelitis is treated reliably by debridement and reconstruction using the Ilizarov technique using a TSF application. The most common complication was pin-site infection. Optimising patients through cessation of smoking and encouraging post-operative weight-bearing can reduce the complication rate and improve time to union.

Clinical significance: The Ilizarov technique using a TSF can treat significant deformities that result from the management of tibial osteomyelitis.

Keywords: Distraction osteogenesis, Ilizarov technique, Osteomyelitis, Taylor spatial frame.

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Introduction

Osteomyelitis is a debilitating bone infection that is difficult to treat.[1] Poor bone vascularity promotes chronicity and decreases penetration by the host immune system and antibiotics. There is therefore a need to eradicate the source of infection, preventing sequestrum and biofilm formation promptly.[2] Although acute osteomyelitis can respond to antibiotics, the formation of a biofilm and sequestra means that surgical debridement may be needed.[1]

The goal of debridement is to eliminate necrotic bone and leave a viable, vascular environment. When it is not possible to distinguish between infected and non-infected bone intraoperatively, preoperative MRI imaging may permit radiologists to interpret to surgeons the size of the infected bone involved.[1] Following the meticulous debridement patients may require tibial reconstruction. There are several methods available of which the technique of distraction osteogenesis using an external fixator enables minimal access surgery and stable fixation.[3]

The Taylor spatial frame (TSF) is a hexapod-based circular fixator with comparable published outcomes to other hexapod fixators when used for the stabilisation of complex tibial fractures.[4] It has been shown to be better than unilateral external fixators concerning operation time and time for fracture union.[5] The computer-based adjustment system facilitates easier realignment of tibial angulation in any plane and can enable lengthening.[6] Soft tissues are exposed to less risk than the use of internal fixation in such cases as soft tissue is often already damaged from previous trauma or the underlying osteomyelitis.[7] The use of internal hardware increases the risk of further bacteria colonisation and can exacerbate the problem; *Staphylococcus aureus* and *Staphylococcus epidermidis* have been shown to colonise internal prostheses regularly.[8]

This retrospective study aims to investigate patient outcomes following the application of the TSF for the treatment of tibial osteomyelitis from trauma, with the view of identifying factors associated with poor outcomes.

Materials and Methods

This retrospective cohort study was conducted at a major trauma centre. The inclusion criteria were cases between January 2015 and January 2021 which underwent treatment of osteomyelitis post-tibial fracture using the TSF. Patients aged 18 and above

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were included. Patients with acute and chronic osteomyelitis patients were treated with the Ilizarov method and distraction osteogenesis.[9] Tibial osteomyelitis was diagnosed that had radiological or clinical signs of osteomyelitis with positive bone sample cultures obtained in theatre. Treatment included all patients receiving antibiotic therapy as per the local NHS trust policy. Treatment protocols included a regular cleaning regime for pin-sites. The exclusion criteria were any patients with less than 12 months of follow-up or who were treated primarily at a different hospital during rehabilitation.

Variables collected were the patients' demographics, diagnosis, and treatment factors. The patient demographics included age at treatment, smoking status, diabetic status, and BMI. The type of osteomyelitis was defined as acute if occurring within six weeks of the original fracture to the tibia or chronic if occurring after six weeks. Treatment factors were the time to initial debridement surgery from the initial injury, and the times to partial weight-bearing (PWB) and full weight-bearing (FWB). These weight-bearing times were defined as the time from the initial operation to when the patient was allowed to weight-bear as documented in the clinic notes. These were a joint decision between the patient and clinician with an account taken of their overall health, rehabilitation progress, clinical results and radiological imaging at the time.

The outcomes were the noted complications and time to union. The complications were recorded as a series of binary variables: pin-site infection, malunion, non-union, metalwork failure, and other types of complications. The time to union was judged by the combination of radiographic and clinical findings indicative of adequate callus formation. The external fixation index (EFI) was defined as the number of days the patient had the external fixator for each cm of bone gained through distraction osteogenesis.

A pin-site infection was defined as any type of soft tissue infection, as confirmed by clinical examination and a positive soft tissue culture, over the site in direct contact with the pins of the external circular fixator. Recurrent infection was defined as multiple positive bone or soft tissue cultures separated by at least 1 month, or an interval after cessation of the initial antibiotic treatment phase due to clinical signs of recovery. Amputation of any aspect of the lower limb below the knee due to treatment failure of the original osteomyelitis was an outcome complication. Non-union was defined as having no radiographic changes of callus formation reported at 9 months post-operation. Malunion was defined as the abnormal orientation of bone alignment that required a separate prescription of correction by the TSF or subsequent reoperation to correct the deformity.

Other types of complications were considered secondary outcomes, with the time to union the definitive outcome in this study. This was because while injury and demographic factors affected the development of different types of complications, the presence of those complications subsequently impacted the time to union. Statistical analysis was conducted with SPSS v 28.0.[10]

Results

A total of 51 cases of tibial osteomyelitis were treated using the TSF between January 2015 and January 2021. The mean follow-up time was 24.1 months. The mean time to radiological union was 11.0 months. Six patients were treated further with ankle fusions due to non-union or malunion and three patients had amputations. The mean time that the TSF was applied to the patient was 12.1 months. The demographic and treatment features of the cohort are displayed in Table 1.

Table 1: Summary of demographic features of the cohort

Factor	*Number/mean*
Age	49.78
Male:Female	38:13
BMI	29.02
Acute osteomyelitis (infection <6 weeks after initial fracture)	24
Chronic osteomyelitis (infection >6 weeks after initial trauma)	27
Admission to initial debridement (days)	3.8
Time the TSF was in for (days)	395.5
Antibiotic treatment length (days)	62.5
Time to partial weight bear (days)	82.9
Time to full weight bear (days)	139.4
Time to radiographic union (days)	333.3
Average length of debridement/corticotomy (cm)	6.63
EFI-days of circular fixator/length in cm	75.8

BMI, body mass index; EFI, external fixator index; TSF, Taylor spatial frame

About 39 patients (76.5%) experienced complications of which pin-site infection ($n = 27$), malunion ($n = 15$) and non-union ($n = 9$) were the most common. Seven patients had metalwork failure, six had recurrent infections, and three had amputations. All types of complications, as well as pin-site infection, malunion and non-union as specific complications, had their associations with various binary variables with the odds ratios (OR) detailed in Table 2.

Smoking was statistically significantly associated with malunion. Table 3 shows the results of linear regression of various factors on the time to union.

The decision to allow FWB, all types of complications, and older patients were significantly associated with time to union.

Discussion

Osteomyelitis is a devastating and challenging condition to treat. Treating the often accompanied deformity and clearing the infection is complex. Radical and meticulous debridement until the "paprika sign" is demonstrated and a reconstruction of the bone defect, whether by distraction osteogenesis or the induced membrane method, remains the mainstay treatment.[6] The "paprika sign" is the characteristic reddish-brown punctate appearance of bone typically observed after adequate debridement of necrotic and infected tissue has been performed.[11] This study comprised 51 cases of tibial osteomyelitis after a tibial fracture from trauma that were treated between January 2015 and January 2021 using the TSF.

The variety of complications in this study is in Table 2, A total of 39 (76.5%) of patients encountered a complication, with pin-site infection (27 cases) the most common. Ironically, the pins that help stabilise the defect during the treatment in an external fixator may also increase the chance of infection post-operatively. This can occur from pin loosening and thus loss of construct stability.[12] Methods to mitigate this and reduce infection risk include coating pins with hydroxyapatite.[13] Pin-site infections are common when using external fixators. Some studies have shown that ring fixators have

Table 2: Odds ratios of each demographic and infection factor's effect on specific complications

Complication	*Any complications*			*Pin-site infection*			*Non-union*			*Malunion*		
Factor	*Odds ratio*	*p-value*	*95% Confidence interval*	*Odds ratio*	*p -value*	*95% Confidence interval*	*Odds ratio*	*p -value*	*95% Confidence interval*	*Odds ratio*	*p-value*	*95% Confidence interval*
Smoking	2.588	0.143	0.666–10.053	0.702	0.383	0.218–2.258	0.203	0.119	0.023–1.779	4.148	0.031*	1.133–15.188
Diabetes	1.147	0.245	0.623–1.294	1.375	0.557	0.21–9.015	0.804	0.362	0.698–0.928	1.889	0.421	0.281–12.71
BMI over 25	1.938	0.291	0.464–8.096	2.875	0.11	0.738–11.194	1.094	0.646	0.195–6.135	0.69	0.428	0.17–2.794
BMI over 30	1.25	0.514	0.32–4.883	0.7	0.373	0.224–2.188	0.42	0.264	0.078–2.272	0.587	0.325	0.155–2.223
BMI over 35	2.406	0.386	0.265–21.813	0.87	0.567	0.192–3.936	0.791	0.185	0.678–0.922	0.861	0.619	0.152–4.874
Acute (vs chronic)	2.875	0.11	0.738–11.194	0.663	0.328	0.219–2.009	1.136	0.579	0.267–4.832	0.571	0.238	0.165–1.979

BMI, body mass index; *$p < 0.05$

Table 3: Linear regression for time to union

Factor	*Standardised beta*	*Significance level*
Smoking	0.047	0.557
BMI	–0.327	0.149
Admission to debridement	–0.037	0.564
Time to partial weight bear	–0.081	0.403
Time to full weight bear	0.6	<0.001*
Complications at all	0.401	0.001*
Diabetes	–0.038	0.57
Age	0.502	0.008*

BMI, body mass index; *$p < 0.05$

reduced the incidence of these pin-site infections as compared to hybrid and unilateral fixators.[14]

Malunion was the second most common complication, occurring in 15 cases. This complication was found to be positively associated with smoking status in patients (OR 4.148, $p = 0.031$). Smoking has been shown to decrease the rate of bone growth when treated by distraction osteogenesis.[15] Nicotine inhibits osteoblast generation and function, increasing the risk of fracture complications. Further osteoblast inhibition occurs due to other chemicals in cigarettes.[15] Smoking has also been shown to be associated with fracture non-union.[16] Advice against smoking needs emphasis to further decrease the incidence of fracture malunion and promote better healing outcomes.

The end goal of reconstruction by distraction osteogenesis is bony union and independent mobility without walking aids. The results here indicate that postoperative complications are associated with a longer time to bony union ($p = 0.001$), possibly due to interference with the mechanisms of bone and soft tissue repair. Further analysis of the data suggests older patients were associated with a longer time to bony union; this may be due to a decreased ability in bone healing compared to younger adults. With a longer time for bony union, there was a greater chance for the patient to develop other post-operative complications. With time to FWB also negatively impacting the time to bony union, weight-bearing is clearly a positive factor for bone healing. This is thought to occur through the stimulation of osteogenesis.[17] The TSF as a circular fixator that provides circumferential fracture support offers the advantage of earlier weight-bearing, promoting this osteogenesis.[18]

The EFI is a useful tool in quantifying the efficiency of bone growth and thus of the treatment method as a whole. The EFI in this series was 75.8 days/cm (Table 1). This figure is within the range quoted in the literature which reports 68.7 days/cm and 83.4 days/cm.[19] The increased EFI for patients in this study may be due to confounding factors; the majority (76.5%) of our patients encountered at least one complication which, in turn, increased the time to bony union and thus increased the length of time spent in the frame.

The TSF frame has been used successfully in the treatment of fracture non-unions following tibial infection.[14] The device can be used in treating aseptic tibial non-unions.[18] Soft tissue reconstructions, including muscle flaps, can be carried out within the support of the device.[20,21] Circular fixators, including hexapod-based devices, are often seen by limb reconstruction surgeons as a fail-safe, to be used when other options have failed, due to a

predictable nature and capability to correct deformities and treat non-union.[22]

Other techniques that could be used to treat bone defects after debridement for osteomyelitis include the induced membrane Masquelet technique. A circular fixator can also be used in the Masquelet technique. Some reports suggest bone union may not be achieved as regularly with this technique.[23,24]

This study data is limited by several factors: its retrospective nature, a small sample size, all data being collected from a single centre, and a potential selection bias in the patients chosen.

Conclusion

When bone debridement in the treatment of osteomyelitis produces a significant bone defect, reconstruction using the Ilizarov method is valid and the TSF remains a reliable tool in the surgeon's arsenal. Distraction osteogenesis through the TSF can address these defects and the device can also be used in conjunction with other techniques, including the Masquelet technique. Pin-site infections remain the major drawback and efforts to minimise the incidence have to be undertaken with this treatment method. Further factors which influence outcome have been attention to weight-bearing and the cessation of smoking.

Clinical Significance

The treatment of tibial osteomyelitis requires debridement of infected and necrotic tissue and reconstruction of the remaining defect. This study provides evidence to suggest that the Ilizarov technique using the TSF can be used. Optimisation of the patients' recovery through promotion of weight-bearing can reduce the time to bony union, and cessation of smoking helps to reduce the risk of complications.

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