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Preliminary results using patient-specific 3d printed models to improve preoperative planning for correction of post-traumatic tibial deformities with circular frames

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ABSTRACT

Background: Preoperative planning for circular external fixators is considered vital towards achieving the best results for complex post-traumatic tibial deformities, and patient-specific 3D printed (3DP) models were used here as a planning aid. The main goal was to investigate the fidelity of the preoperative planning process, by assessing the potential to reduce operative time and determining the need to adjust pre-constructed frames intra-operatively.
Patients and methods: Nine patients (10 limbs) underwent treatment for post-traumatic tibial complications using circular external fixation. These were compared to 10 similar cases where a 3DPM was not used as a pre-operative planning aide (Control group). Patient-specific models of affected bones were printed, and preoperative planning was performed using conventional techniques and Hexapod-assisted software. Detailed planning in a virtual procedure determined osteotomy levels and identified sites for wires and half-pins. The prototype of the external fixator was locked in this optimized configuration, removed from the model, and sterilized prior to the actual procedure.
Results: Nine patients with 10 limbs were treated for complications following tibial fractures. Seven were infected non-unions, and three cases were malunions. For all cases a CT based 3DP model of the full tibia was used in the preoperative planning stage. Image analysis required a mean of 1.7 h, with an average of 14.9 h to 3D print each model. In the control group (without a 3D model), the mean surgical time was 329 min (180–680). The mean surgical time in the 3DPM group was only 172.4 min (72–240), ($p = 0.024$), reducing the surgery time by 48%. For the 3DPM group it was not necessary to modify the preassembled frame in any case, while in the Control group, the pre-constructed frame required intra-operative modifications in 8 of the 10 cases ($p = 0.0007$).
Conclusion: Using patient-specific 3D models has allowed us to carry out meticulous preoperative planning sessions, eliminating the need to modify or alter the frame assembly in the operating room, saving substantial surgical time and enabling a more precise design of the apparatus. This was especially useful in multiplanar deformities and for the spatial configuration of the foot support, talus ring, and ankle ring.

Introduction

The tibia is one of the most commonly injured long bones [1], and its superficial location leaves it more susceptible to soft tissue damage [2]. Surgical management of these traumatic injuries remains a major clinical challenge [3], with the final outcome influenced by many variables including the mechanism of injury, initial injury severity, patient factors, and both initial and definitive management. The goal of treatment is to achieve bone healing without any associated complications [4]. Unfortunately, despite the progress made towards improved surgical techniques and higher quality implants over the last 25 years, outcomes are not always satisfactory. Complications are still quite common, and

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complication rates with distal tibial fractures can be as high as 50% [5,6]. Among the most frequently reported complications are septic and aseptic non-unions, osteomyelitis, and tibial deformities (malunion). Previous reports suggest the tibia is the most common site of infected non-unions and post-traumatic chronic osteomyelitis [7,8].

Circular external fixators (Ilizarov or Hexapod frames) are one of the most effective treatment strategies available for the management of such difficult post-traumatic complications. These devices can be used to treat acute fractures as well as their ensuing complications, including non-unions (infected or non-infected), residual angular deformities, and post-traumatic shortening [2,4,9–12]. Circular frames are extremely versatile and powerful devices for the treatment of post-traumatic infected segmental bone defects through distraction osteogenesis techniques [9,10,13,14]. However, despite the recognized advantages, this technique can be associated with a protracted course of treatment and is generally considered a difficult and arduous option for both patient and surgeon. There are many possible complications related to this form of treatment, including pin site infections, residual deformity, contractures, pain, scarring, and persistent non-union. Although some complications are perhaps inevitable, many of these problems could be limited or completely avoided through more accurate preoperative planning.

Mankovich et al. first described imaging as one of the potential medical applications of 3D printing in 1990, and during the intervening years this revolutionary technology has become far more accessible and affordable [15]. It is now considered mainstream in many areas of medicine, and orthopaedics is no exception [16,17]. There is a tremendous level of interest in developing new clinical uses for 3D printing, as demonstrated by the high number of recent publications [18–25]. 3D printed physical models are almost certainly a better method for transferring information to the surgeon, and should result in improved, more informed, and more detailed surgical plans [23,26–28].

The aim of this study was to investigate the potential benefits of virtual surgical planning using patient-specific 3D printed models to improve the accuracy of pre-constructed external fixators, and to determine if this subsequently reduced the need to perform intraoperative frame adjustments. The hypothesis was that 3D models would reduce the duration of surgery, while also minimizing the risk of subsequent complications. The primary outcome was surgical time, comparing the duration of surgery required for similar cases completed either with or without 3D printed pre-operative models. The null hypothesis states there would be no difference in the duration of surgery performed in either circumstance.

Materials and methods

Study design

This research was conducted as a retrospective comparative cohort study, after approval was granted by our Institutional Review Board (IRB). Between January 2016 and May 2017, 9 adult patients constituting 10 cases were treated with circular frames (either Ilizarov or Hexapod), planned using a patient-specific 3DP model preoperatively. A comparison group was constructed by identifying a set of patients with similar pathology that were treated with circular frames without using a 3DPM to assist with pre-construction of a suitable frame. This set of 19 total patients constituted the study cohort, identified here as either "3DPM" (with 3D printed models, Table 1) or "Control" (without 3D printed models, Table 2).

The medical records and radiographs were reviewed retrospectively to determine patient demographics, comorbidities, and preoperative clinical data. This included the mechanism of the initial injury, the existence of soft-tissue problems, the type of initial management, the type of stabilization method used (nail, plate, or external fixation), any prior soft-tissue reconstructive procedures, the number of previous surgeries, and the length of time following the injury. Existing complications were identified, as well as the type of external frame used, intra-operative complications, and post-operative complications. For the infected cases, relevant microbiological information including the type of pathogen and the antibiotic susceptibility profile was collected.

3D printed model procedure

The main goal of a 3DP model is to replicate patient-specific anatomy, to provide a more detailed image for the surgeon. Close

Table 1
Patient demographics and characteristics for cases using preoperative 3DPM planning. **TL** = Truelok; **Tl-Hex** = Trueloh-Hexapod.

Case	Sex	Age	Post-Traumatic Complication	Intraoperative time (minutes)	Frame	Intraoperative complications	Intraoperative frame modifications	Microorganisms	Plastic surgery
1	M	55	Septic Non-union	72	TL	No	No	Staphylococcus aureus	Gracilis free muscle flap
2	F	48	Septic Non-union	125	TL	No	No	Clostridium clostridioforme	V-Y Advancement Flap
3	M	59	Septic Non-union	210	TL	No	No	Meticillin Resistant Staphylococcus aureus (MRSA)	No
4	F	53	Septic Non-union	160	TL	No	No	Coagulase-Negative Staphylococcus	No
5	M	66	Septic Non-union	135	TL-Hex	No	No	Pseudomona aeruginosa	No
6	F	51	Deformity (R)	240	TL-Hex	No	No	Enterococcus faecium	No
7	F	51	Septic Non-union (L)	240	TL-Hex	No	No	Negative	No
8	M	39	Deformity	200	TL-Hex	No	No	Staphylococcus epidermidis	No
9	M	50	Septic Non-union	240	TL-Hex	No	No	Staphylococcus aureus	No
10	M	42	Deformity	170	TL-Hex	No	No	Negative	No