Medical Engineering and Physics 000 (2018) 1–6

Contents lists available at ScienceDirect

Medical Engineering and Physics

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

Technical note

Three-dimensional printing as a technology supporting the treatment of lower limb deformity and shortening with the Ilizarov method

Piotr Morasiewicz[a,*], Karolina Burzyńska[b], Wiktor Orzechowski[a], Szymon Łukasz Dragan[a], Szymon Feliks Dragan[a], Jarosław Filipiak[b]

[a] Department and Clinic of Orthopaedic and Traumatologic Surgery, Wrocław Medical University, ul. Borowska 213, 50-556 Wrocław, Poland
[b] Division of Biomedical Engineering, Mechatronics and Theory of Mechanisms, Wrocław University of Technology, Łukasiewicza 7/9, 50-371 Wrocław, Poland

ARTICLE INFO

Article history:
Received 31 January 2018
Revised 27 March 2018
Accepted 10 April 2018
Available online xxx

Keywords:
3D printing
Supporting
Lower limb deformity
Lower limb shortening
Ilizarov

ABSTRACT

Background: Treatment of multiplanar deformities, especially in younger children, requires construction of a complex Ilizarov fixator, frequently with small dimensions. The aim of this study is to verify clinical application of a3D-printed bone model in treatment with the Ilizarov method.
Methods: The study involved a 6-year-old child in whom clinical and radiological examination revealed multiplanar deformity of the right leg. Then, 3D models of individual bones were printed by means of additive manufacturing and were used as a scaffold to install the Ilizarov apparatus. To compare the expected and factual axial correction and lengthening, we measured spatial orientation of bone fragments three times. The factual axial correction and lengthening were determined with a photometric technique.
Results: Ilizarov fixator with a configuration developed using a 3D model of the treated bone was mounted on the patient's leg. Corticotomy was carried out at the proximal metaphysis of the right tibia, along with osteotomy of the right talus. The treatment resulted in a 3.5-cm lengthening of the limb and a 7° correction of valgus angle. The values of actual lengthening and axial correction were 4.1% lower than the expected values of these parameters.
Interpretation: Orthopedists should consider differences between the expected and actual lengthening and axial correction in planning treatment with the Ilizarov method. Three-dimensional printing is a useful technology that can be used to support treatment with the Ilizarov method.

1. Introduction

The Ilizarov method is increasingly used worldwide, also in the management of complex multiplanar deformities in children and adults [1–6]. Due to advances in this technique, orthopedists tend to use it also in younger children, including patients with multiplanar deformities and substantial limb shortening. However, treatment of multiplanar deformities, especially in younger children, requires construction of a complex Ilizarov fixator, frequently with small dimensions. A device with such characteristics needs to be appropriately assembled and installed, and its use is associated with increased morbidity risk [1–4,7,8].

These potential difficulties can be prevented thanks to progress in additive manufacturing technologies. Use of a 3D-printed model of the treated bone can be helpful in the preoperative planning stage. Examples of preoperative planning assisted by printed bone models can be found in many fields of medicine. Mobbs et al. [9] described cases of use of 3D printing to design a plate stabilizing the cervical segments of the spine after tumor removal surgery and reconstruction of a section of the cervical spine. The authors emphasize that preoperative planning based on 3D models allows for much better fit of the implant and shorter surgery times compared to the traditional procedure. Kim and Kyung [10] described a case of application of treated bone models made by incremental method to plan popliteal osteotomy. Also in this case, the authors stress the greater precision and shorter surgery times compared to the classical technique. While discussing the results of their observations, Wang et al. [11] point out that the use of treated bone models for surgery planning contributes to greater precision of resection and reconstruction of the knee joint surface, allows to achieve the highest similarity of the biological structure to the reconstructed surface of the knee joint, and significantly increases the range of knee movement after surgery. At the same time, they emphasize that they did not observe a significant difference in the duration of the operation. In reality, however, blood loss, resection length, and percentage of complications were sig-

* Corresponding author.
E-mail address: morasp@poczta.onet.pl (P. Morasiewicz).

https://doi.org/10.1016/j.medengphy.2018.04.009
1350-4533/

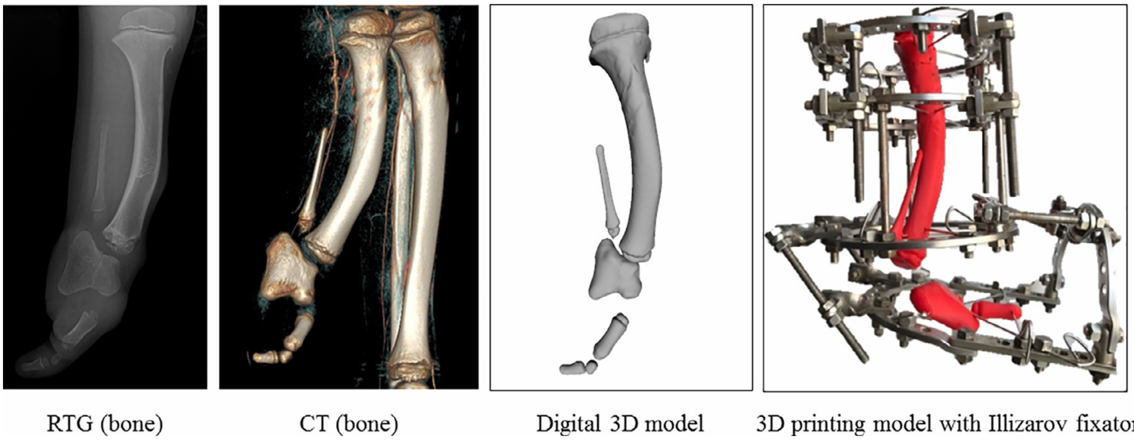

Fig. 1. X-ray image, CT, digital 3D model and 3D-printed model with installed Ilizarov fixator.

nificantly lower than those observed in the control group, which suggests that the use of a 3D-printed bone model can reduce surgical trauma. Another example are laryngological surgeries. Somijan et al. [12] described the use of 3D models made by incremental method to plan sinus augmentation procedure with the use of an implant. In their discussion of the findings, the authors emphasize that careful preoperative planning is crucial to laryngological surgeries. A valuable tool in this case is a 3D model that allows preoperative simulation, and this contributes to shorter surgery times, reduced risk of intraoperative complications, and reduced risk of error.

Although three-dimensional (3D) printing is increasingly used in orthopedics [8,13–15], to the best of our knowledge there are no published reports on its application in treatment with the Ilizarov method. In our previous paper [8], we have experimentally confirmed usefulness of 3D printing in this application [8], using a 3D bone model created with the aid of Fused Deposition Modeling (FDM) technology. This enabled us to comprehensively analyze the geometry of deformed bones as a part of preparation for proper surgical treatment. The promising results of this study stimulated us to verify practical application of 3D bone modeling in a clinical setting.

We hypothesized that the use of a 3D-printed bone model may be particularly useful for our patient, facilitating construction of a custom-made Ilizarov fixator and identification of optimal insertion sites for Kirschner wires and Schanz screws. Furthermore, we used the model to verify the actual lengthening and axial correction achieved in our patient against expected values of these parameters. Finally, we tested if the use of the 3D model resulted in shorter duration and lesser morbidity of treatment with the Ilizarov method.

The aim of this study is to verify clinical application of a 3D-printed bone model in treatment with the Ilizarov method.

2. Materials and methods

The study involved a 6-year-old child in whom clinical and radiological examination revealed multiplanar deformities of the right leg: hypoplasia of the fibula, deformity of the tibia, shortening and valgus deformity of the shin, and complex deformities of the ankle and foot (Fig. 1).

The acquisition and use of the patient's CT scan data to reconstruct 3D images of selected bone structures was approved by Wroclaw Medical University bioethics commission (Ref. KB 724 2011). After removal of artifacts and spatial smoothing with the aid of filters included in the software package, the images were saved as .stl files (Fig. 1). Then, 3D models of individual bones were printed by means of additive manufacturing and used as a scaffold to install the Ilizarov apparatus (Fig. 1). The polylactide(PLA)-based components of the model were printed with a 3D Builder device using Fused Deposition Modeling technology. The physical parameters of the 3D model, such as shell thickness (0.8 mm), layer thickness (0.2 mm), and type and degree of filling (30%) were defined with the aid of the 3D printer's software [8]. The same software was used to design a system of supporting elements stabilizing the model during printing; these elements were removed before the use of the model.

Spatial configuration of the Ilizarov apparatus was selected based on our knowledge and many years of experience. Construction of the apparatus was adjusted to the treatment plan and expected degree of correction. The Ilizarov apparatus consisted of proximal ring fixed to the tibia with 3 Kirschner wires, middle ring fixed to the tibia with 2 Kirschner wires, distal ring fixed to the tibia and fibula with 2 Kirschner wires, and U-shaped foot ring fixed to the calcaneus with 2 Kirschner wires with olives and fixed to distal part of the first metatarsal bone with 1 Kirschner wire with olives (Fig. 1). Two hinge mechanisms (threaded rods with a hinge, providing rotation axis for bone fragments, placed proximally to the long axis of the limb) and two distractors (long threaded rods, placed distally from the long axis of the limb) were mounted between proximal and middle ring of the fixator. Corticotomy was carried out at the proximal metaphysis of tibia.

In this study, prior to proper treatment with the Ilizarov method, we conducted a simulated corrective procedure, installing the fixator on a 3D bone model. This enabled us to optimize the spatial orientation of the apparatus before its installation on our patient.

To treat the patient, we have constructed a complex Ilizarov apparatus suitable for control of bone fragment migration during the lengthening and axial correction [2,7,16]. The simulation with the 3D model enabled us to analyze how changes in the construction of the Ilizarov fixator influence the migration of bone fragments, because actual lengthening and axial correction are not necessarily the same as expected values of these parameters [7].

To compare the expected and factual axial correction and lengthening, we measured spatial orientation of bone fragments three times: (1) prior to the correction, i.e. in the baseline position (Δd_0), (2) after correction a 4-mm correction at the hinge mechanisms and an 8-mm correction at the distractors (Δd_1), (3) after an 8-mm correction at the hinge mechanisms and a 16-mm correction at the distractors (Δd_2), and (4) after a 12-mm correction at the hinge mechanisms and a 24-mm correction at the distractors (Δd_3) (Fig. 2).

Please cite this article as: P. Morasiewicz et al., Three-dimensional printing as a technology supporting the treatment of lower limb deformity and shortening with the Ilizarov method, Medical Engineering and Physics (2018), https://doi.org/10.1016/j.medengphy.2018.04.009