Journal of Orthopaedic Science xxx (2017) 1–6

Contents lists available at ScienceDirect

Journal of Orthopaedic Science

journal homepage: http://www.elsevier.com/locate/jos

Original Article

Clinical experience with three-dimensional printing techniques in orthopedic trauma

Ji Wan Kim [a], Yongkoo Lee [b], Joonho Seo [b], Jai Hyung Park [c], Yong Min Seo [d], Sung Soo Kim [d], Hyun Chul Shon [e, *]

[a] Department of Orthopedic Surgery, Asan Medical Center, University of Ulsan, College of Medicine, Seoul, Republic of Korea
[b] Korea Institute of Machinery & Materials, Daegu, Republic of Korea
[c] Department of Orthopedic Surgery, Kangbuk Samsung Hospital, Sungkyunkwan University, School of Medicine, Seoul, Republic of Korea
[d] Department of Orthopaedic Surgery, Haeundae Paik Hospital, Inje University, College of Medicine, Busan, Republic of Korea
[e] Department of Orthopedic Surgery, Chungbuk National University Hospital, Chungbuk National University, College of Medicine, Cheong-Ju, Republic of Korea

ARTICLE INFO

Article history:
Received 13 January 2017
Received in revised form
10 December 2017
Accepted 19 December 2017
Available online xxx

ABSTRACT

Background: To report our experiences with the use of three-dimensional (3D) printing in the field of orthopedic trauma.
Methods: This retrospective study enrolled 24 patients from three university teaching hospitals in whom 3D printing technique was applied: 14 patients with acetabular fractures and 10 patients with clavicular shaft fractures. We summarized our experiences with 3D printed bone models.
Results: Three-dimensional printed acetabular models improved understanding of complex acetabular anatomy and fracture pattern to plan the optimal positioning of a reduction clamp and the trajectory of screws. Pre-bending of a reconstruction plate could reduce operative time. We also recorded fluoroscopic images of a simulated surgery for percutaneous screw fixation of the acetabular posterior column, with the optimal positioning of the guide wire determined during the simulation used as a reference during the actual operation. This surgical simulation was performed by a resident and served as a helpful training method. For fractures of the clavicle, we identified the optimal position of anatomical plates using 3D printed clavicle models.
Conclusion: In our experience, 3D printing technique provided surgeons with improved understanding of the fracture pattern and anatomy and was effectively used for preoperative planning, education of surgical trainees, and performing simulations to improve intra-operative technical outcomes.

1. Introduction

Developments in science and technology have been invaluable to improving medical diagnoses and treatments. In recent years, the development of three-dimensional (3D) printers, with their capacity to fabricate any object, has led to their application in various industries, including medicine.

The process of 3D printing begins with acquiring image information on the object to be fabricated. This image information can be acquired by directly drawing the desired shape. In medicine, computed tomography (CT) or magnetic resonance (MR) images are generally used for this purpose. The integration of medical images, commonly used for patient diagnoses, with the latest 3D printing technology is expected to be very helpful for diagnostic and therapeutic purposes. Various fields of medicine are currently benefiting from the use of 3D printing [1–5], including the emerging role of 3D printing in orthopedic surgery [6–9]. In this study, we report on our experience using of 3D printing for the management of orthopedic trauma cases and discuss future potential applications of this technology.

2. Material and methods

This retrospective study included 24 orthopedic trauma cases from three university hospitals in which 3D printed bone models were used to plan fracture treatment, between January 2014 and January 2017. The 24 cases included 14 acetabular fractures and 10 clavicular fractures. The study was approved by the Institutional Review Board of each research institution.

* Corresponding author. Department of Orthopaedic Surgery, Chungbuk National University Hospital, Chungbuk National University, College of Medicine, 52 Naesudong-ro, Heungdeok-gu, Cheongju 361-763, Republic of Korea. Fax: +82 43 274 8719.
E-mail address: hcshon@hanmail.net (H.C. Shon).

https://doi.org/10.1016/j.jos.2017.12.010
0949-2658/

2.1. Three-dimensional printing

Three-dimensional printing technology refers to a manufacturing technique that is used in various forms across different industries. Developed for the fabrication of prototypes, recent improvements in the precision of the 3D printing technique and the ability to print with a wide variety of materials, the printed products can now be used as prototypes or finished products. This technology involves producing 3D objects by adding materials layer by layer, according to the shape data of the object being produced (Fig. 1).

Three-dimensional printing includes three major steps. The first involves acquiring image data of the desired object. In the present study, we used 3-mm slices of CT images of each fracture. The second step involves taking stored continuous 2D images and reconstructing them into 3D images. In this step, the medical image data of each fracture were saved in digital imaging and communication in medicine (DICOM) formats and converted to stereolithography (STL) file format. STL is a file format native to the stereolithography CAD software created by 3D Systems using dedicated software. We used with Mimics 16 software (Materialise, Leuven, Belgium) for this purpose. The third step involves sending the STL data to a 3D printer. In the present study, we used a uPrint SE Plus 3D printer (Stratasys, Eden Prairie, US) to print 0.254-mm layers, and using ABSplus material, a type of plastic. This printer has a maximum printed length, width and height of 20 cm. The output time depends on the size and complexity of the shape, as well as any surface manipulation applied. The printed products in the present study required 3 h for image conversion and the output time depended on the size and shape of the model: about 4 h for the clavicle and 11 h for the hemi-pelvis.

2.2. Evaluation of trainee in understanding of fracture using a 3D printed model

We evaluated the educational value of using 3D printed model to evaluate the feasibility and optimal placement of percutaneous screw fixation of a posterior column fracture of the acetabulum. Seventeen trainees were included in this evaluation: 2 first-year residents, 2 second-year residents, 4 third-year residents, 6 fourth-year residents, and 3 fellows. Trainees first planed their surgical approach to percutaneous screw fixation using radiographs and CT images of the pelvis fracture, and subsequently re-evaluated their plan using the 3D printed model. The value of the images and 3D model for identifying the point of insertion and direction of screw implantation was evaluated using questionnaires. Satisfaction with the 3D printed model for learning, compared to medical images, was evaluated on a 5-point Likert scale as follows: 1) Not at all useful, 2) Not very useful, 3) useful, 4) Very useful, and 5) Extremely useful.

3. Results

3.1. Use of 3D printing for acetabular fractures

A preoperative plan was established for 14 patients. As shown in Fig. 2, both-column acetabular fractures present complex anatomy and difficulty in obtaining adequate bone fragment reduction. As such, the shape of the patient's fracture was drawn as is, and the 3D model was fabricated. This process facilitated understanding of the fracture pattern and, in particular, allowed identification of the optimal location for the position of the collinear clamp or reduction forceps for acetabular fracture reduction, using an ilioinguinal approach. Moreover, the model was also very helpful in estimating the ideal insertion point and angle of the lag screw being inserted from the anterior column to the posterior column. The model also allowed the long reconstruction plate, which extends from the pubic symphysis to the sacroiliac joint, to be bent preoperatively according to the shape of the patient's pelvis, which reduced the operation time and need for intraoperative radiographic imaging. The pre-operative preparation of the reconstruction plate was facilitated by creating a mirror image model from the unaffected side (Fig. 3).

Fig. 4 depicts a patient who underwent percutaneous screw fixation for a posterior column acetabular fracture. The ideal insertion position for the guide pin was directly identified on the 3D printed bone model during preoperative planning. We recorded the

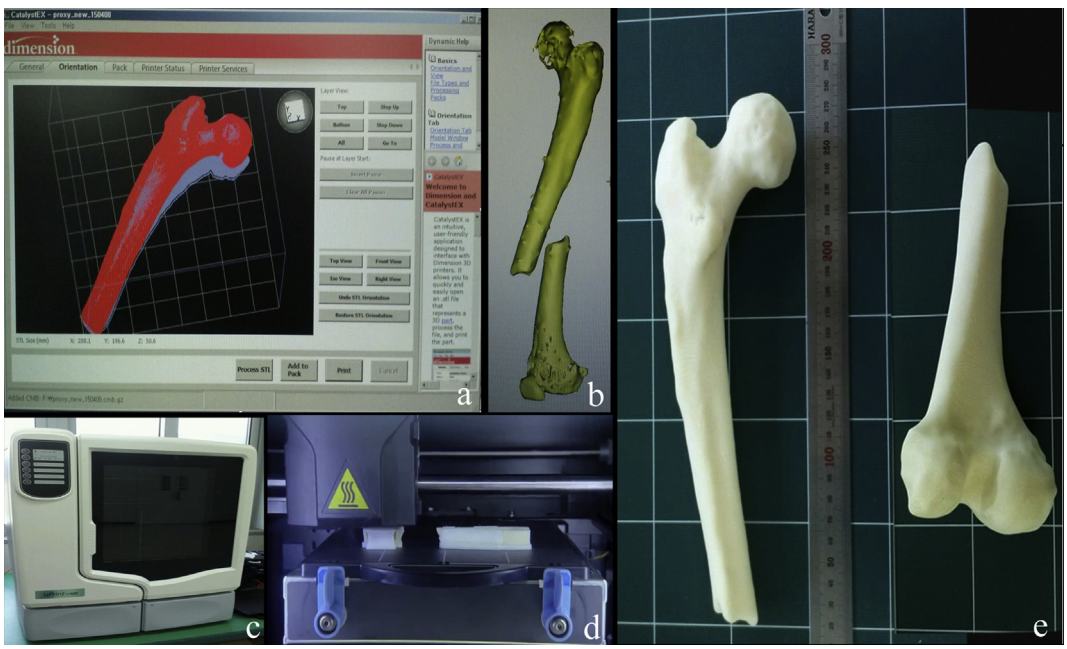

Fig. 1. Three-dimensional printing process. a). Imaging process with files in STL format. b). Reconstructed image of the femur. c). 3D printer. d). Layer-by-layer printing process. e). Solid 3D printed bone model.

Please cite this article in press as: Kim JW, et al., Clinical experience with three-dimensional printing techniques in orthopedic trauma, Journal of Orthopaedic Science (2017), https://doi.org/10.1016/j.jos.2017.12.010