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Case Reports and Series

Three-Dimensional Printing and Surgical Simulation for Preoperative Planning of Deformity Correction in Foot and Ankle Surgery

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A R T I C L E I N F O

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A B S T R A C T

A paucity of published data is available describing the methods for the integration of 3-dimensional (3D) printing technology and surgical simulation into orthopedic surgery. The cost of this technology has decreased and the ease of use has increased, making routine use of 3D printed models and surgical simulation for difficult orthopedic problems a realistic option. We report the use of 3D printed models and surgical simulation for preoperative planning and patient education in the case of deformity correction in foot and ankle surgery using open source, free software.

The creation of a physical model from a computer-generated data set is a manufacturing concept called rapid prototyping. The application of this concept within medicine is not new, and the adoption of this technology thus far has largely been in the setting of patient-specific instrumentation in joint arthroplasty, preoperative planning, procedure rehearsal, educational tools, and patient communication (1–9). It is particularly useful when complex 3-dimensional (3D) spatial relationships are important. In recent years, the cost of 3D printing has decreased significantly. The purpose of the present project is to report and describe the potential for application of this technology within foot and ankle surgery.

Case Report

A 46-year-old male patient presented with chronic pain of 12 months' duration after a motorcycle accident in which he had sustained multiple cervical and thoracic spine fractures and a left bimalleolar ankle fracture. The ankle fracture had been treated nonoperatively by the referring orthopedic surgeon. His pain was located medially and laterally and elicited a score of 8 on a 10-point visual analog scale. His preoperative American Orthopaedic Foot and Ankle Society ankle-hindfoot score was 47 of 100 (10,11). The radiographs are shown in Fig. 1. Nonoperative management failed, and the patient elected to undergo corrective osteotomy of the fibula and excision of the medial malleolus fragments.

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Weightbearing radiographs and bilateral computed tomography (CT) scans were obtained. The CT scan data were created using standard Digital Imaging and Communications in Medicine and imported into a free, open source software program capable of performing reconstruction algorithms for bone and soft tissue (3D Slicer; www.slicer.org). A 3D surface model and compatible file were created, and surface imperfections were smoothed using MeshLab (MeshLab, version 1.3.3; www.meshlab.sourceforge.net). The CT data for the contralateral ankle were similarly modeled and mirrored to show the ideal shape of the abnormal side postoperatively. Both models were printed using a commercially available 3D printing service (Shapeways Inc, New York, NY; www.Shapeways.com). The printed 3D models allowed manipulation and a thorough understanding of the deformity (Fig. 2).

A preoperative plan was developed to perform a corrective Z-shaped osteotomy (Fig. 3). The surface models were converted into 3D solid models. Subsequently, the osteotomy was simulated using Boolean operations and translation and rotation of the distal fibular fragment with a freely available CAD software program, FreeCAD, version 0.14 (www.freecadweb.org) from the previously created 3D model file. From these manipulations, we noted that the deformity magnitude was 7° of external rotation, a 6-mm loss of fibular length, and 5 mm of posterior translation (Fig. 4). It was determined that 7° of internal rotation could be achieved with a posteriorly based 3-mm wide bone wedge (Fig. 5).

The surgery was performed as planned, and the patient achieved union at the osteotomy site (Figs. 6 and 7). At the final follow-up visit at 7 months postoperative, the patient's visual analog scale score had improved to a score of 2 of 10, depending on the activities performed; his American Orthopaedic Foot and Ankle Society ankle-hindfoot scale score was 89 of 100.

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Fig. 1. (*A*) Anteroposterior and (*B*) lateral radiographs of the preoperative deformity.

Discussion

3D printing was first used in foot and ankle surgery in 1997 for the evaluation of intra-articular calcaneal fractures (12). Although in this seminal work the 3D printed models were not found to be statistically superior to software-based 3D reconstructions, we, and others, feel that the physical models are helpful in preoperative planning (9). In the present study, we report a method to create virtual and physical 3D models from CT data sets using open source software, open data formats, and a commercially available printing source for use in foot and ankle surgery. We believe these types of models will be invaluable for the preoperative planning of difficult

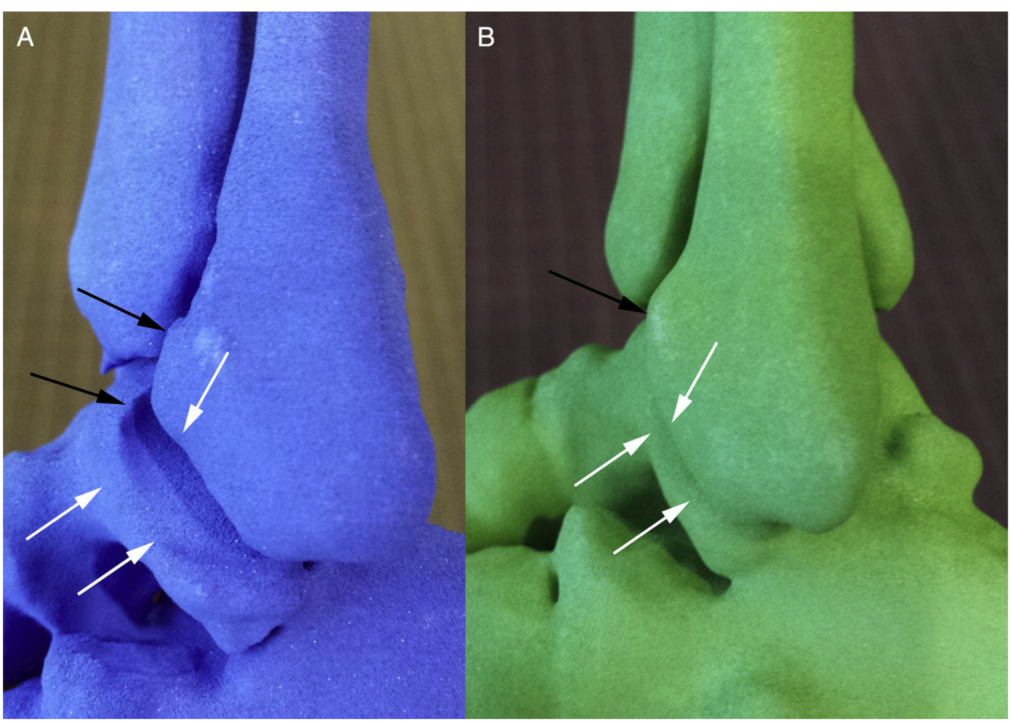

Fig. 2. (*A*) Lateral view of the abnormal and (*B*) normal sides demonstrating malunion of the fibula with posterior translation relative to the talus *(white arrows)* and loss of fibular length *(black arrows).*