Tactile Surgical Navigation System for Complex Acetabular Fracture Surgery

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Abstract: The authors describe a tactile surgical navigation system using custom 3-dimensional (3D) models of the bony pelvis for complex acetabular fracture surgery. The bone area of interest was extracted from the Digital Imaging and Communications in Medicine (DICOM) data of computed tomography scans. A standard triangulated language file was used to create 3D models of the bony pelvis by layered manufacturing using a 3D printer and non-cytotoxic, sterilizable, acrylic-based photopolymers. No infections and no toxic or other adverse events were observed. The models were useful for preoperative assessment, planning, and simulation; intraoperative assessment; obtaining informed consent; and education. [Orthopedics. 2014; 37(4):237-242.]

An acetabular fracture is an intra-articular fracture of the hip joint, which is generally treated by open reduction and internal fixation if displaced.\textsuperscript{1-5} Anatomical reduction and stable fixation are important for good functional recovery.\textsuperscript{1-3,6} However, the anatomical complexity of acetabular fractures makes them particularly challenging and technically demanding to treat surgically.\textsuperscript{2} Precise understanding of fracture patterns is difficult because of the complex 3-dimensional (3D) anatomy of the pelvis and acetabulum, and assessment and classification of acetabular fractures can be difficult even for experienced surgeons.

Improved understanding of the anatomy and fracture patterns should improve surgical outcomes. Tools that could assist in the assessment of complicated fracture patterns would be useful. Traditional radiological assessment of acetabular fractures involves plain radiography (Figure 1) and computed tomography (CT). However, these modalities provide only 2-dimensional (2D) images of the complex 3D anatomy. The 3D digital images reconstructed from CT data (Figure 2) can be rotated and viewed from any angle, but are still viewed as 2D images on a flat screen.

The design and manufacturing industries now use computer-aided design and rapid prototyping to manufacture 3D models of the bony pelvis prior to surgery for acetabular fractures.\textsuperscript{8,17-20} However, these models were for preoperative use only. It is difficult for less experienced surgeons, and even experienced surgeons, to achieve precise intraoperative understanding of acetabular fracture patterns. Surgical teams do not always consist of experienced surgeons, and sharing information and communicating effectively are important to achieving good surgical results and educating surgeons.

The authors report the preoperative and intraoperative...
use of tactile 3D models of the bony pelvis manufactured using a 3D printer. They describe the usefulness of these models based on their experience and previous reports.

**Materials and Methods**

A preoperative 0.5-mm-slice CT scan of the pelvis was obtained using a 64-row multidetector-row CT scanner (Aquilion; Toshiba Medical Systems Corp, Otawara, Japan). After 3D reconstruction of the images (OsiriX; open-source Digital Imaging and Communications in Medicine [DICOM] application, http://osirix-viewer.com), the bone area of interest was extracted from the DICOM data using the surface rendering function and converted to standard triangulated language or stereolithography (STL) data. The STL data were imported into computer-aided design software and processed using a modeling operation to prevent separation at the fracture site. The processed STL data were used to manufacture 3D models of the bony pelvis using the layered manufacturing process on a 3D printer (Connex500; Objet Japan, Chiba, Japan). This inkjet printer uses acryl-cure-based photopolymers (FullCure720 and VeroWhitePlus FullCure835; Objet Japan) and stiffens them via ultraviolet irradiation. These materials are not cytotoxic and can tolerate gas sterilization. Polymers were layered in 16-µm-thick slices using sliced data created from the imported STL data.

**Table**

| Uses for the 3-Dimensional Models of the Bony Pelvis |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| **Preoperatively** | Assessment and understanding of the complex fracture pattern  
Surgical planning and simulation  
Pre-bending of plates  
Determining the appropriate screw trajectories and lengths  
Can be performed by the operating surgeon and assistant surgeons  
Obtaining informed consent  
Easily understood by patients and their families |
| **Intraoperatively** | Assessment of the fracture  
Can be performed by the operating surgeon and assistant surgeons |
| **Postoperatively** | Educational tool for surgeons, other physicians, and medical students  
Can be used as a library of various fracture types |

Figure 1: A plain radiograph provides only a 2-dimensional image of the complex 3-dimensional anatomy.

Figure 2: A 3-dimensional digital image reconstructed from computed tomography data is viewed on a flat screen.

Figure 3: Photographs of the model showing that the fracture can be viewed from multiple directions, and that the intra-articular surface can be visualized (same patient as in Figures 1 and 2).
eral uninjured hemipelvis was also prepared. This process was undertaken for 5 patients with acetabular fractures. Four of these patients had both anterior and posterior column fractures, and 1 had an anterior column fracture only. All patients gave written informed consent for inclusion in the study.

**Surgical Techniques**

The custom-made models were used in the operative field.
to assess the fractures. Anterior column fractures were exposed via an ilioinguinal approach, and posterior column fractures were exposed via the Kocher-Langenbeck approach. The fractures were surgically reduced and fixed using standard screws and reconstruction plates.

RESULTS

Solid, durable models were successfully manufactured in all cases. The models were gas sterilized, and no infections were observed after using them in the operative field. No toxic or other adverse events were observed.

The 3D model has 3 axes: x, y, and z. The accuracy of the authors’ manufacturing process along the z axis was 16 µm, which was the thickness of each layer. The accuracy along the x axis and along the y axis depended on the accuracy of the printer head; they were approximately 100 µm each. The minimum thickness of each CT slice was 500 µm; therefore, the authors’ manufacturing process was capable of precisely duplicating the configuration from the DICOM data. Manufacturing of the models was fast; a 1-cm width could be built in 1 hour and a full-size pelvic model in 1 day.

Postoperative CT assessments showed no screw penetration into the hip joints. Bone union was achieved in all cases with no loss of reduction. All patients regained the ability to walk.

DISCUSSION

The 3D models of the bony pelvis were useful for gaining a better understanding of many aspects of the complex acetabular fractures (Table) preoperatively, intraoperatively, and postoperatively.

The authors’ models were useful for preoperative assessment and understanding of complex fracture patterns, surgical planning, and simulation. The models assisted surgeons in understanding the anatomy of complex fractures, which could be viewed from multiple directions. Although the intraoperative view of the intra-articular fracture surface was obscured by the femoral head, the intra-articular surface was easily assessed using the model (Figure 3). The models provided both visual and tactile information for the surgeons (Figure 4). The life-size model of the mirror image of the contralateral uninjured pelvis was useful for determining the appropriate lengths and bending of the plates (Figure 5), which may be challenging in complex fractures. Use of 3D pre-bent titanium implants has been reported in craniomaxillofacial surgery.21-23 The models were also useful for deter-
mining the appropriate screw trajectories and lengths. The rapid manufacturing process allowed all surgeons on the team to assess and discuss the fracture preoperatively, ensuring that they each had a similar understanding of the fracture, and to plan the procedure (Figure 6).

Hurson et al\(^{10}\) reported using a similar process for the assessment and classification of acetabular fractures, and preoperative planning. They reported that this process significantly reduced the degree of interobserver variability in fracture classification, particularly among less experienced surgeons. Brown et al\(^{17,18}\) described rapid prototyping of an interpositioning template to facilitate screw placement during surgery for acetabular fractures. Deshmukh et al\(^{19}\) and Bagaria et al\(^{8}\) recently described the use of rapid prototyping for the treatment of acetabular fractures. They reported that modeling of the fracture helped in surgical planning and simulation and reduced operative time.\(^{8,9}\)

The authors’ technique can be used to model both the bones and the implants. Figure 8 shows a postoperative model of the pelvic bones and implants. With this technique, the authors can assess fracture reduction and the placement of implants, and can determine the direction of screws, by using a colored material for metal and a white material for bone. The authors can also use the models to create custom implants for individual patients. The actual size, configuration, and curvature vary among individuals. The authors’ technique precisely duplicates an individual’s anatomy. The model can be used to create custom hardware that fits the individual’s bone perfectly. As demonstrated in Figure 8, the authors can create a prototype of the implant. This prototyping leads to manufacturing custom-made implants.

The cost of manufacturing the models depends on the costs of materials and operating the 3D printers, as extraction of the bone area of interest and conversion of the DICOM data to STL data using open source 3D reconstruction software were performed by the authors. However, if the authors manufacture a life-size whole pelvis, the cost is approximately $1000 (US). The cost could be reduced by decreasing the amount of materials used. For example, if the model is reduced to 80% of the life-size model, the amount of materials needed decreases to 50%. If the model is reduced to 50% of the life-size model, the amount of materials needed decreases to 12.5%. The authors could manufacture a life-size hemi-pelvis model and a reduced in size full-pelvis model (Figure 9). The life-size model is necessary for determining the appropriate lengths and bending of the plates, but the cost could be reduced by making a hemi-pelvis rather than a full pelvis. A reduced in size model is sufficient for understanding the complex fracture pattern.

After surgery, the models can be used as a library of various fracture types. Such a collection is a useful educational tool for surgeons, other physicians, and medical students (Figure 10).

**CONCLUSION**

Manufacturing 3D models of the pelvis using non-cytotoxic and sterilizable material is useful for improving understanding of the anatomy of complex acetabular fractures for assisting in preoperative assessment, planning, and simulation; intraoperative assessment; obtaining informed consent; and education.

**REFERENCES**


