Methodology of Three-dimensional Printing in Acetabular Fractures

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The aim of this paper was to present the method used for creating a 3D model of a fractured hemipelvis and its accuracy in reproducing dimensions and structural relationships between fractured fragments. A PolyLactic acid model of the hemipelvis was generated with the aid of the 3D printer. Using a 3D model of a complex fracture aids the orthopedic surgeon in planning the intervention and choosing the best fixation method. Patients with pelvic fractures are not usually operated immediately, which is why they can benefit from this technology.

Key words: three-dimensional printing; acetabular fracture

The history of three-dimensional (3D) printing, also known as additive manufacturing, began in 1980 with Hideo Kodama filing the first patent application for a technology named Rapid Prototyping and his published work from 1981 stands as proof of concept in this field [1]. The practical origins date back to the 1986 patent for the Stereolithographic apparatus (SLA) of Charles Hull, who also founded the company 3D Systems and developed the *stl* file format that is outputted to 3D printers [2].

The three-dimensional printing methods have various characteristics depending on the application and the materials used; each method has its own set of advantages and disadvantages [3].

This paper presents the stages needed to obtain a 3D print of a hemipelvis with an acetabular fracture, starting from the radiographic image obtained by computed tomography (CT).

Experimental part

After obtaining the patient's consent, we performed a CT exam of his transverse acetabular fracture using a Siemens Power Scope CT with 16 detectors. For the investigation, the following scanning parameters were used: 130kV and 90mAs; scanning was done with a slice thickness of 5.0mm and a 3.0mm increment, and the iterative reconstruction was done with a thickness of 1.0mm and an increment of 0.7mm. Thinner sections scanning can be employed (0.75mm) to obtain a higher spatial resolution of the 3D model, but the number of images will increase, thus requiring more time to process. Native-phase images were used. The CT result was obtained as a Digital Imaging and Communications in Medicine (DICOM) file, which was viewed with the RadiAnt DICOM Viewer™ program (fig. 1).

For printing, DICOM images need to be converted to the Standard Triangulation Language (STL) format. InVesalius™ 3.0 software was used for obtaining the necessary file for printing the tridimensional object.

After tuning the contrast, the adjustment of the density filter was performed for the automatic selection of bone structures, with minimum and maximum values varying for each of the structure; for the present case, the minimum value was 382 and the maximum was 1992. Further on, a mask of the bone structures from the scanned volume was generated, with multiple artifacts that needed to be manually removed.

Fig. 1. DICOM image in RadiAnt with axial, coronal, sagittal sections and 3D reconstruction

Due to the partial volume artifact, which is a consequence of different densities of the structures contained in the same CT voxel and the section's height, we observed fused areas appearing in small height joints and also areas where the cortical is interrupted; thus, manual editing with the brush was performed, individual selecting or deselecting pixels, in all 3 section planes: axial, coronal and sagittal.

In order to use the brush for manual filtering the densities, the *Manual edition* menu has to be used, where the brush dimension can be selected, together with the appropriate *Draw* or *Erase* function (fig. 2. a. , b., c.).

After manually editing the structures, we used the *Create surface* function to generate the 3D model (fig. 3). Several structures can be selected individually on this model, according to: biggest surface, wanted area and discontinuous areas.

In our case, we selected the object with the biggest surface and we generated the fractured hemipelvis, which was exported using the *Export 3D surface* function from the *Export data* menu, choosing the STL format (fig. 4).

The resulting images cannot be used in this form because the surface of the bone is not smooth, having multiple defects and artifacts which need to be removed. The surface of the digital model thus obtained needs to be continuous, smooth; otherwise, the printed model will present defects. This repair was done by means of the Meshmixer™ program; we selected the whole object with the Ctrl+A key combination and used the *Deform-Smooth*

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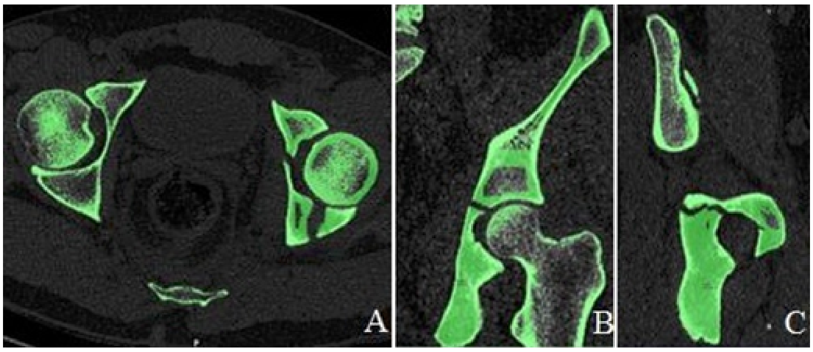

Fig. 2. Manual filtering of the densities using the *Draw* function in the axial (A), coronal (B) and sagittal (C) views

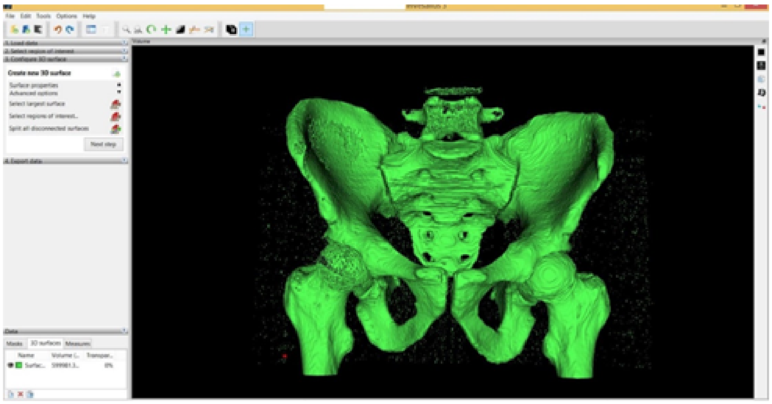

Fig. 3. 3D model in InVesalius™ software

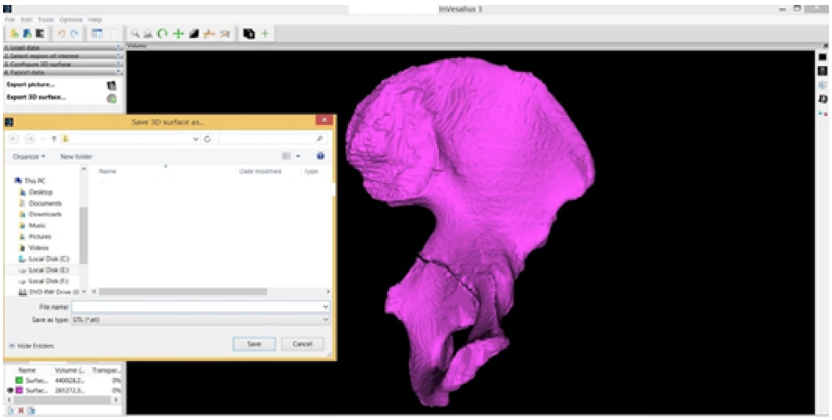

Fig. 4. 3D model of the fracture and its saving in the STL format (only the printing part)

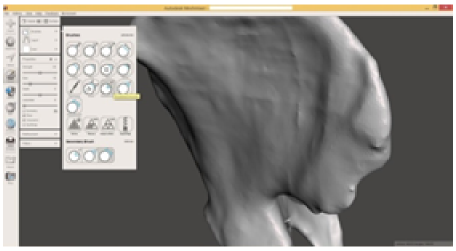

Fig. 5. Software neglected artifacts and preparing for manual smoothing.

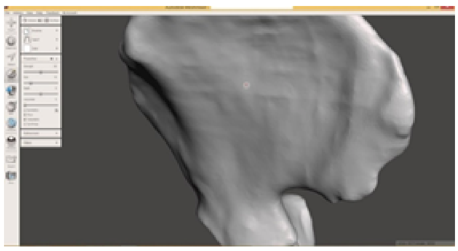

Fig. 6. The result of the manual smoothing

function. In the Smooth window, *Shape Preserving* option was chosen.

The smoothened 3D model that was thus obtained still presented some artifacts that had to be manually repaired with the *Sculpt* function, using the smooth brush (fig. 5). This was done with the Shift + left click combination applied on the desired area (fig. 6).

In the case of holes on the surface of the bone (as are those that come from vascular channels), they can be filled by using the *Select* function on the area and pressing Delete for removing it. Then, the edges of the area have to be selected by double clicking and pressing the *F* key that will fill the gap by generating an area.

In the case of objects that exceed the size of the printing surface provided by the printer, they can be cut using the *Plance Cut* window from the *Edit* section. Using arrows and arcs, the section plane is established and pressing *Accept* will keep the objects selected. For selecting and individually exporting these objects, which were 4 in our case, *Separate Shells* function was used, followed by clicking the object and pressing *File-Export*.

Results and discussions

The generated STL file was prepared for transfer to the 3D printer's software. For printing, we used the Fused Deposition Modeling (FDM) technology due to it being the most frequently used additive manufacturing method, ease of use and the possibility to obtain objects with complex geometries and cavities. This printing technique uses a filament to extrude a heated thermoplastic material in a bottom-up approach [4]. We used PolyLactic Acid (PLA) as the printing material, which is a biodegradable product made from cornstarch or sugarcane.

This material has an acceptable price and does not need extensive preparation or special deposition conditions. The only inconvenient aspect of this practice is given by material deformation at around 60-70°C.

The hip bone model was obtained using the Geeetech Prusa i3 Pro printer with the following parameters: layer thickness of 0.2mm, extruder temperature of 215°C, bed temperature of 80°C, 15% infill, the auto-generation of the vertical supports for angles over 85° and an edge helping the object to adhere to the bed (fig. 7).

The four printed pieces were glued between them exactly at the place where they were cut. In our case, the printing time was approximately 14 hours and the weight of the object was 92g (fig. 8).

In order to verify if the real dimensions were kept, we selected sections on the DICOM images, measuring the distance between different points (fig. 9), then we measured (using the goniometer) the same points on the model. The results are presented in table 1. It can be observed that the average differences between the print and the real bone are around 1-1.5mm; the only exception is the pubis-fracture distance with a difference of 1cm, which is the hardest to measure and it is not important in fracture treatment.

The technology of 3D printing is used in many areas of medicine, with most articles published in the field of orthopedics (45.18%), maxillofacial surgery (24.12%), neurosurgery and spinal, cardiovascular, dental or general surgery. Tack [5] recently published a meta-analysis involving 227 articles about 3D printing applications in medicine and noticed that 83% of these articles have been published after 2011, thus emphasizing the growing interest in this field.

In a meta-analysis based on 93 articles, Malick [6] identified which are the most frequent applications of medical 3D printing: i) anatomic models, ii) surgical instruments, and iii) implants and prostheses. Medical applications for 3D printing are also presented by Ventola [7], which suggested that this method allows customization and personalization of the implants, and anatomical models manufacturing.

Several authors used the 3D printing technology in the case of pelvic fractures. Yu [8] identified 2 patients with both columns fractures of the left acetabulum, both associated with the displacement of the quadrilateral plate. After converting DICOM in STL files, he printed, in 3D, the mirror image of the uninjured hemipelvis. Using the 3D model, the author contoured the plates for osteosynthesis. The plates matched perfectly, allowing for a minimally invasive surgical procedure. Printing of the entire mirrored pelvis is mostly useful for the modeling of a reconstruction plate. The model used in our study is mostly useful for reduction planning. Upex [9] has used 3D printing to obtain a pelvis with an acetabular fracture. Compared with our technique, he used a different conversion program – OsiriX™ and Meshmixer™ was used only for mirroring. The

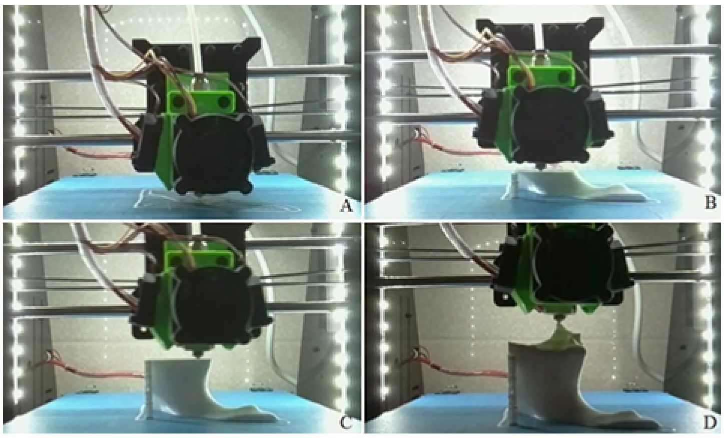

Fig. 7. Printing of one of the 4 pieces: A. object adhesion edges to the bed; B. intermediary time with beginning of the vertical support; C-D. Intermediary time and final object

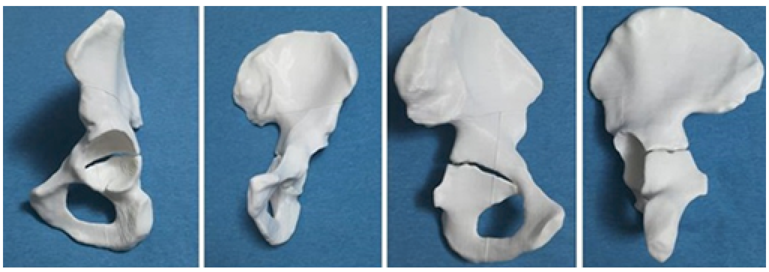

Fig. 8. The printed model

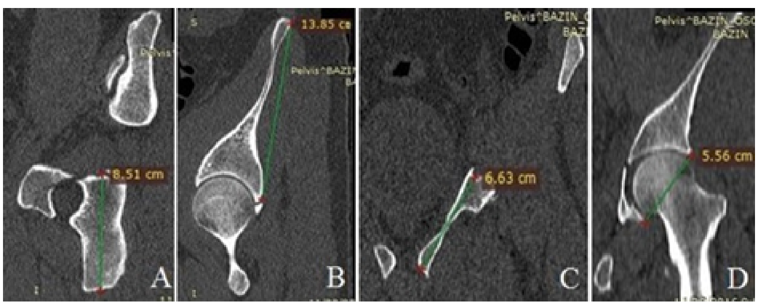

Fig. 9. Measuring points on the DICOM images: A. ischium base – fracture; B. iliac crest - fracture; C. pubis-fracture; D. acetabulum superior-inferior pole

Table 1
DISTANCE BETWEEN MEASURING POINTS ON DICOM IMAGES AND THE PRINTED MODELS

Measured distances	DICOM images	Printed model
ischium base – fracture	8.51 cm	8.60 cm
iliac crest - fracture	13.85 cm	14 cm
pubis-fracture	6.63 cm	5.5 cm
acetabulum superior-inferior pole	5.65 cm	5.80 cm

pre-contoured plate obtained on the printed model fitted perfectly after fracture reduction, and no additional intraoperative contouring was needed. Duncan [1]) created a 3D model of the pelvis for a patient with both columns acetabular fracture. The author used the model for a better evaluation of the fracture and for assessing the possibility of reduction.

Wu [1]) employed the 3D printing technique in 9 cases of old pelvic ring fractures, C type. He used the model for virtual reduction, as well as for preoperatively measuring the osteotomy and implant position, finding that this method is associated with a significant improvement of the outcome. Treating pelvic ring fractures with the aid of 3D printing technology was also performed by Zeng [1]) in 38 patients with unstable pelvic fractures. The 3D printing methods allowed for preoperatively establishing the plate position, and direction and length of the screw used in surgery. The conclusion of the author was that the preoperative 3D printing contributed to a more secure and precise pelvic ring reconstruction.

Other uses of 3D printing in the field of Orthopedics and Traumatology include: manufacturing templates for preoperative planning and plate pre-bending [13], guiding templates for osteosarcoma surgery [14], revision of complex acetabular defects using cages [15], producing custom prosthesis [16] or in complex spinal surgery [17].

The resulting models help the orthopedic surgeon to better understand the condition, to develop a correct preoperative planning and to realize a surgery simulation; they can also be used by less experienced surgeons for practice.

3D printing is a lengthy process, making it more useful in the case of chronic bone conditions. As a general rule in trauma, most surgeries must be speedily performed. For acetabular and pelvic fractures, the patient's general condition often does not allow for emergency surgery. Thus, there is enough time for creating a 3D model that can be used for preoperative planning and implant preparation. As technology evolves, the processing and printing times will most likely diminish.

Conclusions

3D printing of a fractured pelvis starting from a DICOM file obtained by means of CT scan is a method that requires a lot of exercise in mastering and choosing the adequate programs to process the data and obtain a good result.

The printing device and the material must be selected taking into account the available technical facilities and the use of the model. Our printed result can be used for preoperative planning to reduce the fracture and also for contouring the plates for osteosynthesis before the surgery. With the evolution of programs, printers and materials used for reproducing the bone structure, these models will allow for biomechanical studies with the aim of establishing the most efficient implants.

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