Improved Surgery Planning Using 3-D Printing: a Case Study

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Abstract The role of 3-D printing is presented for improved patient-specific surgery planning. Key benefits are time saved and surgery outcome. Two *hard-tissue* surgery models were 3-D printed, for orthopedic, pelvic surgery, and craniofacial surgery. We discuss software data conversion in computed tomography (CT)/magnetic resonance (MR) medical image for 3-D printing. 3-D printed models save time in surgery planning and help visualize complex pre-operative anatomy. Time saved in surgery planning can be as much as two thirds. In addition to improved surgery accuracy, 3-D printing presents opportunity in materials research. Other *hard-tissue* and *soft-tissue* cases in maxillofacial, abdominal, thoracic, cardiac, orthodontics, and neurosurgery are considered. We recommend using 3-D printing as *standard protocol* for surgery planning and for teaching surgery practices. A quick turnaround time of a 3-D printed surgery model, in improved accuracy in surgery planning, is helpful for the surgery team. It is recommended that these costs be within 20 % of the total surgery budget.

Keywords 3-D printing · Additive manufacturing (AM) · Rapid prototyping · Surgery models and planning · Medical imaging · Software data conversion · Stereolithography

Introduction

3-D printed surgery models can benefit surgery teams carrying out these high-risk surgical procedures. Such models can be constructed using softwares and 3-D printing machines, after processing patient-specific computed tomography (CT)/magnetic resonance (MR) image data. According to a World Health Organization (WHO) study, there are 234 million major surgical procedures performed worldwide every year [1].

3-D printing has proven successful in a variety of surgical procedures (http://www.oxfordpm.com/news/article/2014-08-20_fda_approves_first_3d_printed_facial_implants.php, 20 Aug 2014) [2–4]. The benefit of 3-D printed surgery models for anomalous bronchi anatomy and for lung cancer is reported [2] (http://www.oxfordpm.com/news/article/2014-08-20_fda_approves_first_3d_printed_facial_implants.php, 20 Aug 2014). Schmauss et al. [4] report representative cases and 10-year experience using 3-D printed surgery models for cardiac surgery and interventional cardiology. Three-dimensional printed models in dental cases for occlusal splints are reported by Aalto University.

We present two cases—one in orthopedic pelvic surgery and the other in craniofacial surgery. These cases highlight benefits of 3-D printing. The second surgery case and model is that of maxilla. Such a model can be beneficial for surgery in craniofacial surgery as well as in complex neurological difficulties. These difficulties arise due to persistent, untreatable mental disorders, including *manias*. Certain populations are more prone to such disorders due to insufficient or abnormal brain development. Such 3-D printed models can

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help the surgery team define the approach, if vascular relationship with cranium is known and can be depicted beforehand.

Discussion

Anatomy of a female pelvis is presented in Fig. 1a. The first case involved a patient with significant trauma to the pelvis. This resulted into a number of pieces of ilium and disconnected femur.

Patient-specific CT image data was processed through MIMICS Software. The data is processed to highlight *hard-tissue* or bone-tissue pieces, dramatically displaced from original position (Figs. 1c–f and 2).

Surgery Model Data Processing

Medical image data processing involves segmentation (separating out region of interest) and forming a 3-D integral mesh and file. We used MIMICS Software. The file formed is saved in .stl (stereolithography) format. It can be printed in a 3-D model, on a 3-D printing machine.

Printing of the 3-D Surgery Model

3-D printing file size obtained after CT/MR image data processing can be over 1 GB. File size for the pelvic case was 14 MB, and for maxilla, it was 7.2 MB. The time for 3-D printing the final model is governed by total volume in cubic centimeter, of the model, printer resolution (down to 20 μm) and model density (10 %, to up to 100 %). We prepared these models in nylon using industry-grade 3-D printing machine. 3-D models made in such materials can be sterilized and brought in operation theater.

Materials in 3-D Printing

Time for 3-D printing pelvic surgery model was 14 h. The material consumed was 212 g. The time and the amount of material consumed for the maxilla were of similar order. Typical materials used for 3-D printing are as follows:

- 1) ABS (acrylonitrile butadiene styrene)
- 2) PLA (poly lactic acid)
- 3) Nylon
- 4) Polyamide
- 5) Thermoplastic polyurethane (TPU)
- 6) Poly-ether-ketone-ketone (PEKK) (http://www.oxfordpm.com/news/article/2014-08-20_fda_approves_first_3d_printed_facial_implants.php, 20 Aug 2014)

These materials are photopolymers or polymers curable under certain thermal conditions. In 2014, US Food and

Drug Administration has approved 3-D printed orthopedic facial implants manufactured by 3-D printing (http://www.oxfordpm.com/news/article/2014-08-20_fda_approves_first_3d_printed_facial_implants.php, 20 Aug 2014) in PEKK.

Surgery Planning

Figure 1c–f demonstrates the following fractures:

- i) the right ilium bone
- ii) the right superior pubic ramus
- iii) the right inferior pubic ramus

An orthopedic surgeon, when presented with such individual pieces and the complete 3-D printed model, is able to see and visualize how these multiple pieces will be put together using the help of surgical plates/screws. This model will possibly help them better plan the position of the screws and plates so that they get optimal fixation with added bonus of safety, if the positions of the major vascular structures are marked. This could, in turn, save lot of perioperative time which is very vital in operating pelvi-acetabular cases which otherwise would run into many hours. This would effectively mean that 3-D printing would give better fixation, prevent blood loss, reduce operative time, and improve patient outcome scores.

In maxillofacial surgery, craniofacial surgery, or neurosurgery, 3-D printed model of maxilla benefits surgeon so he/she is aware about the vascular structure, in relation to cranium. For craniofacial and maxillofacial surgery, surgeons can *also* plan reshaping of the structures, by viewing patient-specific 3-D model.

Other Cases in Surgery: Soft-Tissue, Thoracic, and Neurosurgery

Figure 3a presents making a 3-D model for patient-specific thoracic surgery case. It is desirable for surgery planning, to carry out data processing to highlight critical anatomical structures in relation to *tumor* (or *lesion*).

The neurosurgeon can visualize vascular structure relative to the cranium, investigate neurological complexities, and carry out aneurysm study, Fig. 3b. Published cases in neurosurgery and general surgery are presented in Fig. 3c, d.

Model and surgical plates can be 3-D printed in materials such as polyamide or nylon. Such plates are also 3-D printed in titanium and alloys.

Summary and Conclusions

3-D printed models for orthopedic and craniofacial surgery are presented. We also 3-D printed medical models using ABS

Fig. 1 **a** Pelvic anatomy. **b** Anteroposterior view: pelvic angiogram taken from a reference atlas. **c** Processing of medical image data software for constructing 3-D model (lower right). **d–f** Processed

images for two patient-specific pelvic surgery 3-D models demonstrating fracture in the right ilium bone, right superior pubic ramus, and right inferior pubic ramus and its extent in the right ilium

Fig. 2 Patient-specific 3-D surgery model for the maxilla shown in anterior (a), side (b), and inferior view (c)

and PLA on a low-cost desktop printer—The Creator. We report success in proof-of-concept study for *hard-tissue surgery*. We had initial success in processing MR data for *soft-tissue*, thoracic, and abdominal surgery for 3-D printed models.

Image processing *soft-tissue* anatomical structures is complex. We highlight value of 3-D printed models for *soft-tissue surgery*, in separating sacrificial versus non-sacrificial anatomical structures, which may be tangled with *tumor* or *lesion*.

Fig. 3 a Patient-specific thoracic surgery 3-D model, with sub-clavicular tumor. Critical structures such as axillary artery, axillary vein, and intercostal artery must be highlighted. b Patient-specific case in neurosurgery, for making 3-D printed model of cranium. c 3-D printed

model, demonstrating tumor in lung surgery [2]. d 3-D printed model for neurosurgery, showing vascular structure (http://www.oxfordpm.com/news/article/2014-08-20_fda_approves_first_3d_printed_facial_implants.php, 20 Aug 2014)

Fig. 3 (continued)

3-D printing can play a vital role for patients in surgery. With ease of data transmission by advanced IT methods, medical image data processing and 3-D printed surgery models can greatly benefit in saving surgery time and improved surgery quality. Such best practices can lead to increasing collaborations among clinicians, for benefiting patients worldwide.

Specifically, we conclude the following:

- 1). The cost of reliable, high-quality diagnostic imaging can go down. These methods can be made more accessible, for accurate diagnosis and for pre-operative planning.
- 2). 3-D printing approach presented are for two *hard-tissue surgeries* and other procedures—orthopedic surgery, maxillofacial surgery, dental surgery, general surgery, and neurosurgery. Patient-specific 3-D printed surgery model, if done cost-effectively, with a quick turnaround time and integrated as a *standard protocol*, will create a new paradigm in surgery planning.

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Conflict of Interest The authors declare that they have no competing interests.

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