3D PRINTING IN SURGERY

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INTRODUCTION

- Three dimensional (3D) printing involves a number of additive manufacturing techniques that are used to build structures from the ground up.
- This technology has been adapted to a wide range of surgical applications at an impressive rate
- . It has been used to print patient-specific anatomic models, implants, prosthetics, external fixators, splints, surgical instrumentation, and surgical cutting guides. The profound utility of this technology in surgery explains the exponential growth.
- It is important to learn how 3D printing has been used in surgery and how to potentially apply this technology

INTRODUCTION

- Three dimensional printing technology has been adopted by surgeons at an impressive rate and in a large variety of applications.
- Nearly every part of human anatomy that can be operated on has had a 3D model printed of it.
- Furthermore, surgeons have gone beyond printing these impressive patient-specific anatomic models to printing patient-specific medical hardware, such as implants, prosthetics, external fixators, splints, surgical instrumentation, and surgical cutting guides.
- The recent explosion in popularity of 3D printing is a testament to the promise of this technology and its profound utility in surgery.

INTRODUCTION

- Historically, the concept of using 3D medical imaging, specifically computed tomography (CT) data, to reconstruct a physical model was first suggested in 1979 (1). At that time, there were no rapid prototyping (RP)/3D printing systems available
- Rapid prototyping is a design and fabrication process where 3D objects are ‘drawn’ using CAD software and ‘built’ using digital manufacturing technologies

Imaging modalities used for 3D printing

- A 3D digital image is an essential part of 3D printing. The most commonly used modalities used are conventional CT and MRI.
- However, a number of other 3D imaging options have been used in 3D printing, such as: Cone Beam CT, CTA, MRA, PET, MRCP, 3D echocardiography, 3D laser scanning systems, and even images captured on an iPhone (6-10)
- Gillaspie et al., 2016, combined CT and PET data to produce models that depict physiologic activity in addition to anatomy

3D MODELING WITH MEDICAL IMAGING DATA

- Data acquisition, this includes building a digital model either de-novo with CAD software or with the use of a 3D imagining modality. For constructing an anatomic model, CT or MRI data are typically used and the data set is characteristically stored as a DICOM (Digital Imaging and Communications in Medicine) file;
- 3D Visualization and selection. At this stage a volumetric dataset is calculated from the available DICOM data. This can be done with a number of software programs, including accuitomo software (i-Dixel images);
- Creation of a virtual 3D representation from the previously acquired 2D layers and subsequent image segmentation. Creation of 3D model from a 2D layer set is automatically done by software. Image segmentation involves the dividing of the image into distinct anatomic parts and requires that the user have an understanding of the anatomy of interest. MIMICS (Materialise's Interactive Medical Image Control System, Materialise, Belgium) is overwhelmingly the most common program used to accomplish these steps (12). The dataset is then exported in STL (STereoLithography, Standard Triangle Language, or Standard Tessellation Language) format, which is supported by all 3D printers available (14);
- Geometric surface preparation. At this stage the virtual 3D representation is crude and the rough surfaces need to be smoothed. Other surface refinement can also be done, such as checking for and correcting any overlying surfaces, and simplifying the image file for more efficient printing;
- Print.

APPLICATION OF 3D PRINTING IN SURGERY

- applications of 3D printing in surgery into three categories:
- (I) anatomic models;
- (II) implants, prostheses, splints, and external fixators; and
- (III) surgical instrumentation and guides.

- Anatomic models
- Anatomic model fabrication is overwhelmingly the most common use of 3D printing in surgery.
- The 3D printing of anatomic models is largely done for two purposes, pre-operative planning and education.
- *Pre-operative planning is the more common use*

ANATOMIC MODELS:PRE SURGICAL PLANNING

- Preoperative planning has been heavily impacted by 3D printing. In the pre-surgical planning stage, 3D models have been used to represent vital anatomy, simulate the procedure, and pre-shape or test surgical tools.
- Studying a patient's anatomy with a life size replica of the structures in hand has obvious benefit compared to viewing images on a computer monitor.
- The use of 3D printed models may result in improved quality of pre-operative planning for novice surgeons and be useful for improving skill outside the operating room.

- Neurosurgeons have used anatomic models of complex skull base and craniovertebral junction deformities in their planning
- Vascular surgeons have printed patient-specific celiac trunk aneurysms , patient-specific aortic models to guide graft fenestration placement for branch vessels , and techniques have been developed to print whole aortic models that most accurately represent the patient's anatomy

- In hepatobiliary surgery, 3D printing has also been employed as a method of studying variant anatomy before surgery. A group printed a patient-specific life-size liver model representing tumor and variant vasculature prior to hepatectomy .
- Furthermore, 3D printed models have been used to identify hepatic tumors intraoperatively that would otherwise be invisible on ultrasound .
- In transplant surgery, the use of 3D printed models of living donor and recipient vascular and biliary tract anatomy in pre-operative planning has been efficacious

ANATOMIC MODELS :PRE SURGICAL SIMULATION

- *In addition to using 3D printed anatomic models to simply gain a more accurate perception of the patient's anatomy, these models have also been used to perform mock surgeries pre-operatively with patient-specific anatomy.*
- *This can be highly valuable in the planning of surgery in a patient with highly complex or rare surgical pathology*

ANATOMIC MODELS:PRE SURGICAL MANIPULATION AND SELECTION OF SURGICAL EQUIPMENT

- In addition to the use of 3D printed anatomic models to study the patient's anatomy or simulate the surgery pre-operatively, patient specific anatomic models have also been used to physically shape and/or direct the appropriate choice of surgical instrumentation and implants.
- *In general, this has been an advantageous practice since it allows the surgeon to modify or shape this equipment outside of the operating room in a controlled environment*
- *This can further streamline the operation and decrease operative time while increasing implant or instrument accuracy.*

ANATOMIC MODELS: *EDUCATION*

- 3D printed anatomic models are a valuable tool in medical education, both for medical students and resident physicians
- These models have been useful for the teaching of anatomic pathology not commonly seen in cadaveric samples. Such as a variety of ventricular septal defects .
- *3D printed models have been especially beneficial for surgical resident education. The technology has been applied extensively to produce surgical simulations that more accurately represent the anatomic pathology encountered, the tactile feedback of truly operating, and practice operating on rare surgical pathology*

IMPLANTS,PROSTHESIS,SPLINTS,AND EXTERNAL FIXATORS

- RP provides a unique ability to digitally customize implants, prosthetics, splints, and external fixators to be patient-specific.
- Furthermore, computer based surgical simulations have been used to recreate optimal surgical outcome and then design and print the appropriate hardware . This technology presents the ability to customize these devices in a way not previously possible.

SURGICAL INSTRUMENTATION AND GUIDES

- The 3D printing of surgical instrumentation and surgical guides has great potential value. Given that it enables the use of customized surgical instruments, precise patient-specific surgical guides, and even the RP of surgical equipment in areas were acquisition of such equipment by conventional means is not a possibility.