Introduction of Medical Three-Dimensional Printing in Rhode Island

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ABSTRACT

Since the early 2000s, three-dimensional (3D) printing has become a well-rounded, evolving technology which has begun to revolutionize healthcare. 3D printing enables rapid creation and manufacture of individual patient models from original designs or medical imaging data. These models can be used for surgical planning, procedural training for residents and medical students, and the design and manufacture of surgical instruments, implants and prostheses. Current availability of this advanced technology at the Lifespan 3D Printing Lab permits Rhode Island physicians to utilize 3D printing in multiple, diverse settings to help improve their medical practice and optimize healthcare outcomes. This article describes three case-based examples to demonstrate varies used of 3D printing in Medicine.

KEYWORDS: 3D printing, surgical planning, patient communication, medical education

INTRODUCTION

The technique of rapidly prototyping models in three dimensions was first described by Hideo Kodama in 1981.[1] In contrast to subtractive manufacturing whereby 3D objects are created by carving, cutting or drilling, this novel process creates objects by depositing successive layers of material, an example of additive manufacturing.[2] With a unique design for creating three-dimensional (3D) models using digital data from computer-aided design (CAD) and computer-aided manufacturing (CAM), novel uses of 3D printing technology have emerged across many industries; since the early 2000s, 3D printing applications within Medicine have rapidly expanded.[3]

In healthcare, 3D printing has enabled rapid manufacture of complex, individualized patient anatomy models. This technology provides a unique tool for translating information from original designs or scanned radiographic studies into tangible, anatomically distinctive 3D models. These models can be used for patient-specific surgical planning, medical student and resident education, and medical device development.[4–11] (**Table 1**)

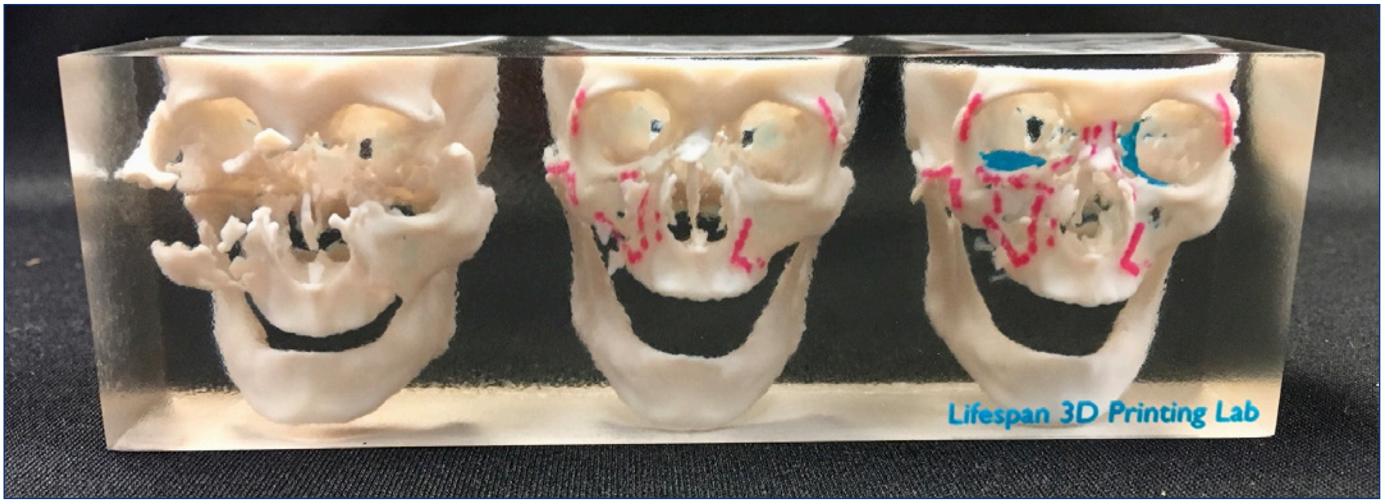
In 2016, this state-of-the-art technology was introduced at Rhode Island Hospital (RIH) with the opening of the Lifespan

Table 1. Applications of 3D Printing in Medicine

Patient-specific surgical models • Surgical planning • Communication with patients • Resident and medical student education
Implants and prostheses • Limbs • Craniofacial implants
Surgical simulators • Training in a controlled, non-operative setting
Rapid prototyping • Designing and manufacturing medical devices

Figure 1. 3D printed full-color replica of a face. This capability offers numerous potential applications in healthcare, including visual guides for complex soft-tissue reconstruction, production of customized prostheses, and less invasive development of burn masks.

Figure 2: This model shows the improvement over time in the patient's facial skeleton after his multistage surgery. The left skull shows the patient's initial severe anatomic deformity. The middle skull demonstrates successful plate fixation (titanium plates in purple), but still reveals unrepaired orbital fractures. The skull on the right shows successful placement of the titanium orbital implants (in blue).



3D Printing Lab. This lab boasts a full-color, multi-material Stratasys J750 Polyjet 3D printer among its additive manufacturing devices. The lab facilitates multiple collaborations both within and outside of RIH and Brown University, with services available for use by physicians across all specialties. In this article, we describe three case-based applications of 3D printing technology.

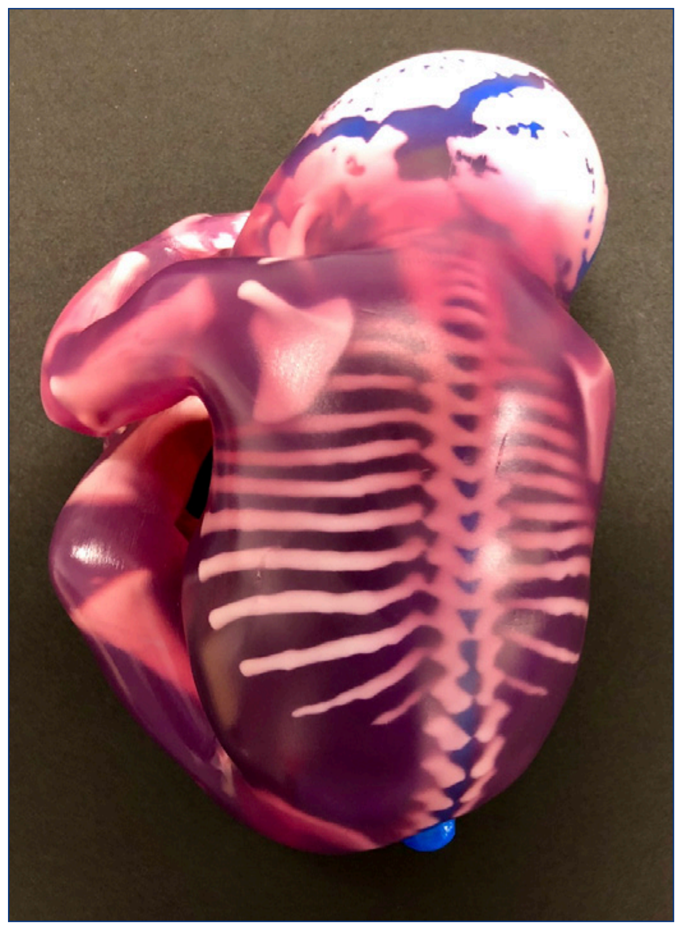
Case 1: 3D replica of complex facial anatomy

As a proof of concept, a lifelike replica of a face was produced and printed in full color (**Figure 1**). First, a stereophotogrammetric image was captured using a Vectra M5 360 imaging system (Canfield, Parsippany, NJ). The data was exported into VRML format and finalized with open source software (Blender Foundation, https://www.blender.org). This model demonstrated the powerful capabilities of the Stratasys J750 Polyjet printer, which can produce up to 500,000 colors while encompassing multiple textures, transparencies, and densities with detail down to 14 microns. The ability to replicate complex facial anatomy has numerous potential applications, including visual guides for complex soft-tissue reconstruction, production of customized prostheses, and less invasive development of burn masks[12].

Case 2: 3D anatomic models facilitate surgical planning

Surgical planning is the most common indication for 3D printing in medical environments. In this case, a trauma victim suffered severe facial injuries in a motor vehicle collision. He required multistage surgery to correct his maxillofacial deformities. The facial skeleton was 3D printed as a sterilizable on-table surgical reference for the complex anatomic deformity as it was being corrected in both procedures (**Figure 2**).

Figure 3. 3D printed model of a fetus with myelomeningocele, which includes bony structures, soft tissue, and the anatomic defect where the infant's spinal canal failed to close. The bulging myelomeningocele is clearly visible (in blue). The model was produced from both MRI and CT data.



Case 3: 3D printed model can educate patient families and residents

3D printing can play an important role in educating patients, as well as teaching medical students and residents. These benefits are demonstrated in a 23-week fetus diagnosed with a myelomeningocele in utero. To demonstrate this disease, a specific, individualized educational model was created by combining MRI and CT data. This included bony structures, soft tissue, and the anatomic defect where the infant's spinal canal had failed to close (**Figure 3**). The 3D printed model also helped surgical residents gain a 3D understanding of the critical anatomic landmarks for this rare fetal surgery.

DISCUSSION

Since the early 2000s, the use of 3D printing in medicine and surgery has expanded rapidly[3]. In RI, 3D printing services are available through the Lifespan 3D Printing Lab. This technology has improved surgical planning, communication with patients, and medical education.

With the capability to produce patient-specific models, surgeons, interventional radiologists and others can now see, feel, and even practice on what they will actually encounter in the operating room.[11,13] The 3D model provides an intuitive reference of geometrically complex structures, which adds an extra dimension to viewing X-rays, CT scans, or MRI images on 2-dimensional screens. 3D printed models can be sterilized and brought into the operating room for a real-time surgical reference. The tactile benefits of a physical model give surgeons a clear sense of spatial relations to analyze complex deformities. This enhanced preparation hopefully translates to a decrease in operating room time and improved patient outcomes.

Patient-specific models improve patient-physician communication. The process of explaining diagnoses and treatment plans can be difficult when relying solely on conventional radiology images that may be familiar only to other healthcare professionals. With the benefits of 3D printing, doctors can now provide high-level visual and tactile representations of the patient's problem and anatomy to explain a difficult diagnosis and facilitate discussions of a planned procedure.[10,11,14]

Finally, medical education may benefit from this technology. For medical students, 3D printed models can help teach anatomy and clarify spatial relationships. For residents in training, patient-specific models can demonstrate proposed surgical or interventional radiology approaches and enable practice and rehearsal of certain procedural techniques.[14]

Currently there are some limitations and barriers to 3D printing in Medicine. Namely, production of a patient-specific 3D model relies on the quality of the original medical imaging scans and is time, resource, and labor intensive. There is also a significant learning curve to master the technology. Furthermore, there is a wide range of commercially available 3D printers without a clear gold standard, and each can typically only print in one type of material. Available printing materials include biomaterials, metal or acrylic, but the ability to combine these materials into a single 3D print remains limited. Finally, because this is such a new technology, there is incomplete data on cost-benefit analysis and objective patient outcomes, although research in this area is expanding.

This article highlights some current and potential uses of 3D printing in Medicine, which will only expand in the future. RI physicians can utilize this advanced technology for multiple applications to innovate and improve their medical practice and patient healthcare outcomes.

CONCLUSION

The Lifespan 3D Printing Lab introduces the capabilities and contributions of commercial-grade 3D printing in diverse medical environments. This manuscript describes three representative cases to demonstrate how this technology can be used to enhance medical practice and training.

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