



# Role of 3D Printing in Surgery

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## Abstract

3D printing refers to the set of technologies through which it is possible to transform a digital model into a real object. The creation is accomplished by setting down progressive layers of a particular material until the whole item is made. Virtual surgical planning using 3D printing represents one of the greatest technological achievements of the last decades. Medical institutions are setting up laboratories equipped with cutting-edge technological tools and creating virtual models of the patient body parts using dedicated software. Virtual 3D processing takes place using printers which, with filaments and resins, allow the creation of models to assist in the planning of surgical interventions and shorten their execution times. The ability to view the final result of an intervention in 3D format rather than with 2D images facilitates the dialogue between surgeon and patient, giving the latter the possibility of an informed decision. The future of 3D printing is “bioprinting” which represents a great opportunity for biomedical research and for regenerative medicine in particular. The repair and regeneration of tissues or entire organs resulting from congenital defects like microtia or rare facial clefts or acquired diseases like defects left after ablative cancer surgery of the jaws can make use of 3D printing of biological material that allows the generation of living cell layers with the aim of repairing tissues or generating entire organs.

**Keywords** 3D printing · Stereolithography · Binder jetting · Bioprinting

## Introduction

It has been proven that the visual and tactile inspection of 3D models allowed the best anatomical understanding, with faster and clearer comprehension of the surgical anatomy. 3D-printed models help to transfer complex anatomical information, normal or altered by trauma or disease, to clinicians, thus assisting in the preoperative surgical planning, for intraoperative navigation and for surgical training purposes to the new surgeons. 3D printing was invented by

Charles W. “Chuck” Hull, who used computer-aided design software to create three-dimensional objects. Hull built a machine that used a UV laser to engrave layers of acrylic into shapes before stacking the layers to build objects. He patented the “apparatus for production of three-dimensional objects by stereolithography” in 1984, marking the birth of 3D printing in medicine [1].

## Current 3D Printing Technologies

**Stereolithography (SLA)—Stereolithography (STL)** The technology is based on the use of ultraviolet light and photosensitive resin, which is photopolymerized by UV light passing from the liquid to the solid layer. In most printers, a DLP projector is now used as a UV light source.

**Fused Deposition Modeling (FDM)** Fused deposition modeling is based on the use of filaments of plastic material, usually wound in coils, which is passed through an extruder that heats the filament and deposits it following precise trajectories, controlled by a computer, creating a drawing on a printing plate where the filament cools and solidifies again.

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Subsequent layers are printed on top of each other creating the three-dimensional object. The most used polymers are polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS). Each material has its own characteristics that modify the extrusion temperature, hardness, resistance, and elasticity.

**Selective Laser Sintering (SLS)** Selective laser sintering is a three-dimensional printing technology that uses powders of different materials, which are fused together by a high-power laser beam. Today, it is possible to use many materials from plastic polymer powders such as nylon to metals. The printing is performed inside a printing chamber full of the powder, on which the laser beam is fired, which melts the powder with micrometric precision, creating the first layer of the object, then moving the laser prints all the layers between them, creating the artifact. The whole process is controlled by a computer.

**Binder Jetting (BJ)** Binder jetting technology is a printing technology similar to SLS, because it uses powders often polymers or gypsum, to create three-dimensional objects. However, in binder jetting technology, the powders in the printing chamber are not fused, but are glued together, thanks to a binder such as acrylic resin or cyanoacrylate, which are sprayed by means of an inkjet head. The process is repeated layer by layer to form the final object.

## Clinical Use of 3D Printing in Surgery

The use of the three-dimensional printer in plastic surgery is mainly based on the ability to create accurate anatomical models starting from radiological images. Before beginning the printing phase, our data, whether from CT or MRI images, must be processed so that the anatomical parts of interest are transformed into a three-dimensional model ready for printing.

There is a great deal of software on the market to process data. Images are usually encoded in a format universally known as “DICOM” (Digital Imaging and Communications in Medicine).

### Hand Surgery

For some years now, reconstructive hand surgery has been using three-dimensional reconstruction and rapid prototyping techniques either for the reconstruction of the complex bones of the hand and wrist or for the use of customized splints for fractures correction. Honigmann used an innovative experimental approach to verify whether the use of a 3D-printed scaphoid could have the same functionality as the original bone. A cadaveric model was used through

which a ceramic replica of scaphoid bone was created with an internal tunnel to allow the passage of the flexor carpi radialis tendon [2, 3].

Another use of three-dimensional printing in which not only doctors and researchers but also many simple “makers” around the world have participated is the creation of splints or braces. Rapid prototyping has modified and expanded these devices, creating the conditions for a complete customization on the needs of the individual patient [4].

### Rhinoplasty

Both for planning and for patient education, 3D models are used. A surgeon feels that having the model next to him is particularly useful in evaluating the reduction of the back, defining the degree of rotation of the tip and the projection of the tip itself. In the final analysis, therefore, it is like having your own guide throughout the surgery. With “MirrorMe3D” (New York, NY) platform, it is possible to order real operating nasal kits that include the customized nasal profile guide and full ceramic models of the pre-op image and simulated results. In this way, the surgeon does not have to worry about the accuracy of his calculations for the guides and be sure of the result to translate the simulated surgical plan directly into the operating room to accurately obtain the desired dorsal height and nasal tip position [5].

Yen and colleagues [6] in 2019 exploited this technology for the hemi nasal reconstruction and Walton et al. [7] used it for subtotal nasal reconstruction.

### Ear Reconstruction

In 2014, Nishimoto and colleagues [8] produced a small but ingenious work on the development and use of a three-dimensional mock-up model for a chondral framework using a three-dimensional printer. The authors based on the famous Nagata method [9, 10] published in 1993, and on those indications, created a series of models that could be modified in shape and size and then printed with acrylonitrile butadiene styrene resin; moreover, the models could also be sterilized and used in the operating room as a reference.

Three-dimensional printing and rapid prototyping have not only been used as an aid for reconstruction using autologous tissues but also for the creation of customized prostheses for patients of Treacher Collins syndrome. It is possible to use rapid prototyping as a support for the creation of cartilage frameworks in MEDPOR (MEDPOR; Stryker, Kalamazoo, Mich.) for some very young patients affected by microtia of varying degrees. Each young patient was subjected to a three-dimensional scan (3dMDcranial system) of the entire skull for 360 degrees. The volumetric information thus obtained was exported in a stereolithography (\*.STL) file format. The file was then further prepared using

three-dimensional CAD software Geomagic Freeform Software (3D Systems, Rock Hill, S.C.), in order to compare the affected ear with the healthy contralateral ear.

## Reconstructive Surgery

Recently, considerable research has focused on bioprinting, in which human tissues are synthesized for use in research or implantation. Scaffold materials can be printed, populated with progenitor cells, and infused with necessary growth factors to create synthetic tissues. In 2013, Zopf et al. custom-designed and implanted a 3D-printed airway splint for a child with tracheobronchomalacia [11].

## Oculoplasty

Its earliest use in eye care included orbital models for training and surgical planning, which have subsequently enabled the design of custom-fit prostheses in oculoplastic surgery. It has evolved to include the production of surgical instruments, diagnostic tools, spectacles, and devices for delivery of drug and radiation therapy.

The term “bioprinting” has been used to describe organotypic approaches for synthesizing corneas in which hydrogel scaffolds composed of organic or synthetic materials are inlaid with cells without the use of a 3D printer [12]. The ideal printing medium, referred to as “bioink,” must have the mechanical strength to withstand the shear stress of extrusion through the nozzle, retain adequate transparency, support cell viability, allow diffusion of nutrients and oxygen, be able to hold sutures, and be biodegradable.

3D printing may offer a cheaper and more accessible solution for producing tailor-made lenses for cataract surgery. Debellemanni et al. printed a Ridley lens with 75% visible light transmission, but significant surface irregularity [13].

3D printing can streamline the production of ocular implants. A series of ten patients underwent implantation of a 3D-printed sphere following evisceration. None of the patients developed systemic or local toxicity, infection, inflammation, extrusion, or exposure [14].

## Cranio-Maxillofacial Surgery

In 1998, the first anatomical model used for planning of craniofacial reconstruction was created from a computed tomography (CT) scan [10]. Orbital anatomy is complex, difficult to conceptualize externally, and may vary significantly between patients; furthermore, the consequences of violating the intracranial space during surgery include meningitis, cerebrospinal fluid leak, and intracranial hemorrhage. Trainees can hone skills such as lateral wall decompression in a safe and easily reproducible context [15]. In pan-facial fractures, stereolithography can reproduce the injured facial skeleton

for bench surgery so that armed with prior knowledge we can perform the real surgery to perfection. Occlusal splints and surgical guides are intended for the smooth transfer of planning to the operating room. The main advantages were improvement in precision and reduction of surgical time. The main disadvantages were the cost of the objects and the manufacturing period when printed by the industry [16].

## Aesthetic Breast Reconstruction

In 2016, a study on tissue engineering for human breast reconstruction was carried out in Australia. Morrison designed an acrylic perforated dome-shaped chamber implant with 3 mm holes, ranging in size from 140 to 360 ml. Five female patients, ages 35–49 years, were selected for unilateral breast reconstruction. The specific plan was to implant it with the vascular pedicle fat flap, but it was reoperated to remove the implant 6 months after the initial operation. Analysis of the tissue removed with the implant demonstrated newly formed blood vessels, fibrous tissue, and a portion was adipose tissue. However, the implant material itself was not degradable, the texture was hard, and the resultant cosmetic assessment was poor [17]. Melchels et al. introduced the possibility of 3D printing for breast reconstruction and its favorable outcome stimulated subsequent research [18]. Although the emergence of 3D printing technology provides great potential opportunities for breast reconstructive surgeons with a more predictive precision and personalization about the size and shape for the individualized patients, there remain limitations in virtually all aspects including the materials, shape, and structure of the breast prosthesis to be printed. To date, clinical application of 3D printing technology continues to suffer from the same problems as traditional prosthetic reconstruction, such as bilateral breast asymmetry and capsular contraction.

## 3D Printing and Bioprinting

Three-dimensional (3D) printing, also known as computer-aided manufacturing (CAM), was based on digital model files using metal powder or plastic and other adhesive materials to construct objects with a computer-guided precision, printing layer upon layer. Simplistically, it uses a computer-aided design (CAD) program to convert the virtual model of an object into a printable object using an STL (Standard Tessellation Language or Stereolithography) file. The object then gradually and precisely takes shape as each thin layer is added according to the design file and composed of the desired material for that object in the form of “ink” using the 3D printer. Not only in cases of intraoperative 3D printed models serving as templates, but this technology has extended to implanted scaffolds that have been used to

correct defect-specific sites, clearly enhancing patient treatment [19]. Bioprinting is distinguished by precise control of cellular distribution and high-resolution cell deposition as well as scalability and cost-effectiveness, which is different from traditional 3D printing technology that was regularly used to print temporary cell-free scaffolds for use in surgery. For these reasons, bioprinting has achieved marvelous development during the last few years [20].

## Conclusion

3D printing applications in surgical planning including accurate anatomic biomodels, surgical planning guides in reconstruction, and patient-specific implant fabrication are being increasingly used in clinical practice. 3D printing technology offers access to well-tolerated, reproducible, and high-fidelity/patient-specific models for surgical training. Emerging research in 3D biomaterial printing have led to the development of biocompatible scaffolds with potential for tissue regeneration in reconstruction cases involving significant tissue absence or loss. Major limitations of utilizing 3D printing technology include time and cost, which may be offset by decreased operating times and collaboration between departments to diffuse in-house printing costs.

## Declarations

**Conflict of Interest** The authors declare no competing interests.

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