Three-Dimensional Printing Role in Neurologic Disease

Adrien-Maxence Hespel, DVM, MS

KEYWORDS

- Three-dimensional printing • Rapid prototyping • Presurgical planning
- Stereolithography • Fused deposition modeling

KEY POINTS

- Most commonly in veterinary medicine, 3-dimensional (3D) printing involves the acquisition of raw data using computed tomography MRI or ultrasound. The raw data are processed through different software to create the 3D models.
- Different 3D printing technologies employ various material offering an array of options and cost depending on the purpose of the print.
- 3D printing is used for educational, research and pre-surgical planning purposes.
- 3D printing is becoming a versatile and accessible tool for the clinical floor.

This article, after briefly reviewing the different types of 3-dimensional (3D) printing technologies available and the processes involved in the creation of a prototype, focuses on the applications of 3D models in both human and veterinary neurosurgery.

Currently, 3D images can be created almost instantaneously with the use of advanced imaging technologies such as computed tomography (CT), 4-dimensional ultrasound scan, or MRI. These 3D representations are displayed on computer screens in a 2-dimensional environment but are found to improve surgical planning and the learning experience.[1]

Three-dimensional printing, also known as rapid prototyping, emerged in human medicine in the 1980s. All 3D printing techniques are grouped under the category of additive technologies and are based on the construction of models by addition of successive layers of material on top of the one before. This process could be compared with the construction of toy models using building blocks. The initial additive technology used was a process called *stereolithography* (SL, also known as SLA). Since then, numerous new technologies have emerged and currently include selective laser sintering, multijet modeling, and fused deposition modeling (FDM).[2] This article reviews 2 of the technologies that are most commonly encountered: SL and FDM.

SL relies on the use of an ultraviolet laser to solidify a liquid acrylic photopolymer, or epoxy resin, contained in a tank. The hardened acrylic is anchored on a build plate, which is lowered at the end of each completed layer so that uncured material remains at the surface to create the upcoming layer. At the time of completion of the model, the build plate is raised, and the surrounding unexposed liquid material is drained. Finally, the model is fully cured in an ultraviolet oven.[3] Selective laser sintering relies on a similar principle, but the raw material is in a powdered form and is being sintered by a high-power laser. The substrate can be plastic, metal, glass, or ceramic and does not require ultraviolet curing.[3]

FDM printers are probably the most widely known, advertised, and accessible printers. They use a roll of raw thermoplastic, commonly polylactic acid (PLA) or acrylonitrile butadiene styrene, which is being fed into a heated extrusion nozzle. When passed in the nozzle, the plastic is melted into a hairlike thin filament, which is then deposited on the build plate 1 layer at a time.

From the data acquisition to the production of the 3D models, there are 4 essential steps.[4]

In the medical field, the data are initially obtained through advanced imaging technologies such as CT, MRI, or ultrasound scan. These techniques are referred to as *transmissive*, and allow the evaluation and reproduction of both the surface and inner structures of an object.[4] In other domains, such as engineering or architectural design, nontransmissive techniques are more common and rely on the use of laser scanners and triangulation. These techniques allow only the surface of an object to be reproduced.[4]

Studies evaluating the ideal parameters for CT acquisition found that data acquired with 2-mm slice thickness, 25% to 75% overlap, and a pitch of 1.5 were adequate for the creation of 3D models.[5–7] However, in the author's experience and in a more recent publication,[8] and with the progression of CT and printer technologies, thinner slices such as 0.65 to 1 mm, provide much more detailed and accurate models. MRI was also evaluated as a way to acquire 3D data but the models created were smaller, more likely to contain artifacts, rougher, and more likely to have a discontinued appearance when compared with models created from CT.[8]

The second step on the path to 3D printing involves the importation and processing of the raw data in a 3D software program. These programs come in a variety of prices and abilities (eg, Mimics, Materialise, Leuven, Belgium and OsiriX, Bernex, Switzerland). After importation, the data to be reproduced are identified and selected based on their density (thresholding) and/or topography (segmentation).[6] These processes allow the elimination of nondesirable information, such as electrocardiogram leads or feces. At this point, a digital 3D mesh is created within the software and is the representation of the structure to be printed under the form of numerous continuous and contiguous polygons (Fig. 1).[9] The number of polygons directly influences the resolution of the model; an increase in the number of polygons results in an improvement in resolution. However, this improvement also results in an increase in computational power needs.

The third step is focused on optimization and depends on the prototype's purpose and the printer's potential limitations. The most common alterations are edge smoothing and reducing the object's size to fit the printer's build envelope. After being created, the mesh is exported as a CAD (computer-aided design) or an STL (surface tessellation language) file.

Lastly, the CAD or STL file is imported into a software program that is able to communicate with the 3D printer such as Makerware (Makerbot, Brooklyn, NY), ReplicatorG (open source) or Cura (Ultimaker, Geldermalsen, Netherlands). In this step,