Going to New Heights, Widths and Depths

3-D printing adds new dimensions in veterinary medicine

by Maureen Blaney Flietner

Photo: A 3-D model (resin) of the pelvis of a feline patient with a fracture of the right acetabulum. The model was printed full-scale from the DICOM images.

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> —DANIEL J. FLETCHER, PHD, DVM, DACVECC

There's a new addition to the veterinary medicine toolkit: 3-D printing technology. And it's already making a big impact in complex surgical cases, in teaching veterinary students, and in educating clients.

The technology itself is not new. Invented in the early 1980s, it has since been used in human medicine. However, it's finally been put to use in growing numbers of veterinary colleges and teaching hospitals across the country.

Although the idea of printing in three dimensions has a certain "sci-fi" vibe to it, the technology has down-to-earth applications.

"The ability to physically handle things in 3-D allows much better insight into anatomy," says Daniel J. Fletcher, PhD, DVM, DACVECC, associate professor of emergency and critical care at Cornell University College of Veterinary Medicine. "I think the ability to relatively quickly go from a scan of a patient to a physical model that can be touched and handled is very powerful."

Many different technologies

3-D printing technology allows digital files to be used to create three-dimensional solid objects. Those

objects can be true to size or scaled, and can be made accurate to less than a millimeter. But all 3-D printing is not the same.

The "printing" is actually the manufacturing method by which the solid object is created. Different printers and processes have different resolutions, speeds, and costs; they can also use different materials, such as metal, plastic, or ceramics. Appropriate software and different levels of computer-assisted drawing knowledge and experience are required, depending on the printer.

Among the printing technologies are:

- SLA, stereolithography, which converts liquid plastic into solid objects by using a low-power ultraviolet laser.
- SLS, selective laser sintering, which uses a high-power laser to heat the material so that it fuses together.
- SLM, selective laser melting, which uses a high-power laser to completely melt a powder material into a homogenous unit.
- FDM, fused deposition modeling, which sends a roll of raw filament through an extrusion nodule that melts the material to create consecutively laid fine layers.
- FFF, fused filament fabrication, which is a free, open-source equivalent of FDM.

The "image" to be printed is really not an image. It's a 3-D dataset created from an imaging modality, such as a computerized tomography (CT) or magnetic resonance imaging (MRI) scan that is loaded into the printers, explains Steve Joslyn, adjunct professor at the University of Illinois and radiologist with VetCT, Cambridge, U.K.

Printers themselves can range widely. The lab in the Department of Mechanical Science and Engineering at the University of Illinois houses industrial-grade printers, for example, that cost upwards of $200,000 per machine and require dedicated staff. They can produce special fine-resolution rapid orders for clinical cases—some as quickly as the next day. Industrial printers tend to have the upper hand for production rate and printing in advanced polymers and metals.

Alternatively, desktop 3-D printers are becoming more mainstream. They are less maintenance-intensive, with prices ranging from about $500 to $3,000. Mainly based on FDM and SLA technology, they may have a smaller build plate, but will produce adequate models for clinical use in many cases, with both outer and inner details. Some printers (especially in the $500 range) have tiny build plates and are unlikely to be adequate for clinical models.

There also is the option of 3-D printer services, such as those offered by VetCT, which will accept CT studies

Santiago Peralta, DVM, had two dog skull 3-D models printed for surgical planning purposes. In both cases, previous traumatic maxillofacial fractures resulted in fusion of bones at or in the immediate vicinity of the TMJ, leading to an inability of the dogs to open their mouths.

Photos courtesy of the College of Veterinary Medicine at Cornell University

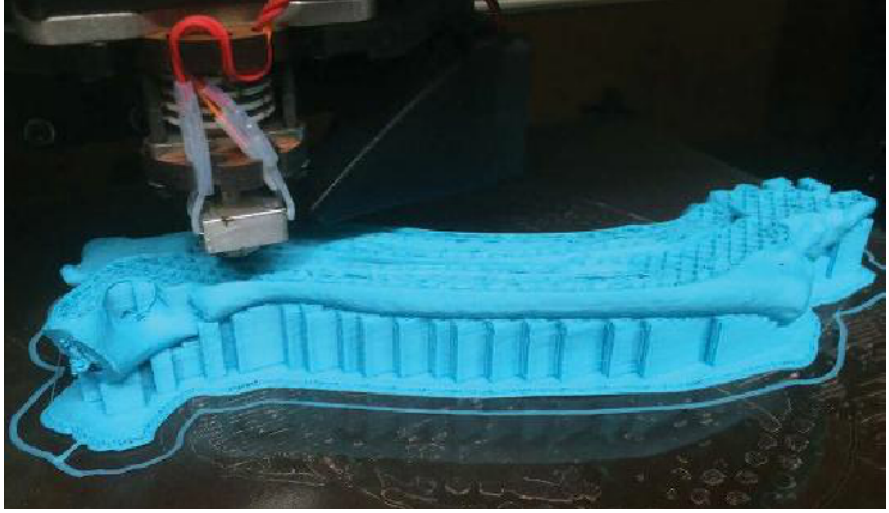

Photo: A 3-D model is being printed by Cornell's Daniel Fletcher, DVM, of an angular limb deformity in a dog. The deformity was later surgically corrected.

> The "printing" is actually the manufacturing method by which the solid object is created, which can vary greatly among the several printing technologies available.

and provide printing on high-grade industrial printers, allowing anyone with access to a CT scanner today to have 3-D prints the next week.

At The Ohio State University College of Veterinary Medicine, Tatiana Motta, DVM, assistant professor of clinical and small animal surgery, says the series of detailed 2-D images from the college's patient CT scans are processed using Materialise's Mimics software to create 3-D data files. The files are then optimized for printing using 3ds Maxx and MeshMixer software.

"Once a stable final model is created, freeware available through MakerBot called MakerWare is used to create a file that can be read by the printer," explains Motta. "The file is transferred to a Secure Digital (SD) memory card, and the printing process starts. Each bone takes 6 to 10 hours, on average, to be printed using acrylonitrile-butadiene-styrene (ABS) or polylactic acid (PLA) plastic."

Cornell used to outsource its 3-D printing, but, about a year ago, Fletcher acquired a LulzBot TAZ 4 printer at a cost of about $2,200 to provide printing services for Cornell's College of Veterinary Medicine uses. The printer can print two materials at once—hard and rubbery plastics—so one project has been a model of the canine knee so students can examine the leg and determine if the cranial cruciate ligament is intact.

"It's powerful and has a lot of potential, but it's a lot different than buying a laser printer, connecting it to your computer, and printing a bunch of things. You need some technical know-how and patience to deal with the many difficulties inherent in the technology," says Fletcher.

He says that using the printer requires significant manipulation of medical images, and the printing itself is relatively slow, taking from 8 to more than 24 hours to print a model, depending on size.

"Because, in many surgical cases, time is of the essence, we can't wait that long for the models to become available," says Cornell's Santiago Peralta, DVM, DAVDC, assistant professor of dentistry and oral surgery, Department of Clinical Sciences.

"Instead, the models are used for chronic injury cases, where waiting a few weeks will not dramatically change things, or for cases in which the complexity of the surgery and the anticipated benefits of having the model outweigh the risk of waiting for it," he explained.

Planning complex surgeries

It was one of those complex cases that first drove Cornell to start using 3-D printer technology, says Peralta.

"About 2½ years ago, a dog had what is known as a 'critical-size' defect of the mandible—a segment of the lower jaw was missing—leading to chronic dysfunction and pain. We wanted to contour the implants to reconstruct the defect with as much precision as possible, ultimately achieving a functional and comfortable reconstruction. Using a highly detailed 3-D model of the patient's skull, we were able to prebend and adapt highly specialized titanium plates prior to surgery.

"Since then, we have expanded our uses of 3-D printed models for surgical planning, including certain oral oncological and maxillofacial trauma-repair cases," he noted.

Those cases included:

- A dog that had suffered a maxillofacial traumatic injury with resultant fractures left untreated. The fractures healed on their own but were severely misaligned, causing the dog to lose the ability to open its mouth. A CT scan showed that two bones

Photo courtesy of the College of Veterinary Medicine at Cornell University

that normally do not contact each other had fused, as had the temporomandibular joint. Because the local anatomy was expected to be significantly altered and there were important vascular structures in the vicinity, a 3-D model allowed for better surgery planning to anticipate and prevent possible complications.

- A dog with a very large tumor arising from a lower canine tooth that had infiltrated and compromised an important portion of the lower jaw. To remove the tumor entirely, a large portion of the jaw had to be removed. To avoid dysfunction, the team wanted to reconstruct the jawbone using specialized titanium plates and screws and to regenerate the lost bone using a tissue-engineering-based technique. Given the complexity, a 3-D model was necessary for precise planning and prebending of the plates so that the mandible could be reconstructed as close as possible to its original shape and size.

At Cornell's Hospital for Animals, Ursula Krotscheck, DVM, DACVS, associate professor of orthopedics, uses the technology for correcting bone deformities and planning complicated joint replacements.

"Once we have the bone or joint printed, measurements are made and a rehearsal surgery performed," she says. "Occasionally, we can even contour implants prior to surgery to minimize the time the animal spends under anesthesia."

Photo: A 3-D model (resin) of the pelvis of a feline patient with a fracture of the right acetabulum.

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At the University of Illinois Veterinary Teaching Hospital, Tisha Harper, DVM, also has found success with the technology in orthopedic surgeries. She said, "We see a lot of angular limb deformities, where the bones have not developed correctly. These deformities, with their angulations and rotations, can be challenging to work with when using two-dimensional radiographs to capture all of the abnormalities."

"The 3-D technology allows us to use a CT scan from which we can print models that represent the bony deformities. Because we can make multiple copies, we can plan on one model and practice our correction on the other," she noted.

One example where Harper says the technology made a huge difference was for a tiny Chihuahua with a patellar luxation. "The displacement was severe enough to cause significant deformity in the femur. There were a number of components to consider and, in a patient with such very tiny bones, the 3-D model allowed us to better refine our calculations," she explains.

Daniel M. Dorbandt, DVM, ophthalmology resident at the University of Illinois, says he has used 3-D printing technology for the surgical removal of tumors around a patient's eye to preserve vision and decrease further spread of disease.

"With the many delicate structures involved—nerves, blood vessels, etc., and any damage to them resulting in catastrophic consequences for the

eye—our group created a physical model of the patient using 3-D printing technology," explained Dorbandt. "The 3-D model allowed us to meticulously plan the surgery, but, most importantly, it gave the client the ability to fully understand how we were going to save their beloved family member's eye."

At Auburn University, Amanda R. Taylor, DVM, DACVIM, has used 3-D technology in several ways as a neurology/neurosurgery faculty clinician at the College of Veterinary Medicine's Bailey Small Animal Teaching Hospital.

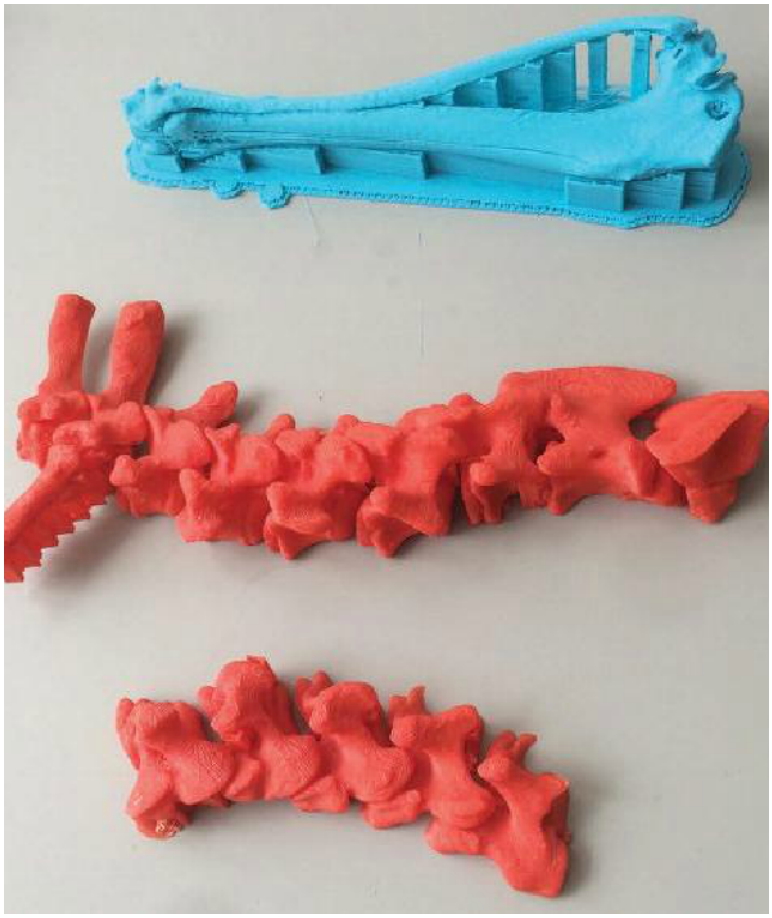
"For vertebral luxations and fractures, we print the vertebrae prior to surgery to investigate what the implants will fit and which we can use. If we are doing a craniotomy for tumor resection, we will overlay an MRI on a CT image for a 3-D model prior to surgery. We also create a 3-D model to use as a base to build a cap for a craniectomy," said Taylor.

Educating students, clients

Motta finds a lot to like about 3-D technology. She had been working with virtual 3-D for 5 years, but she had a difficult time sharing the models with students, since most computers can't accommodate virtual 3-D. With Ohio State's purchase of its first 3-D printer in August 2014 and a second printer in February 2015, the ability to print models and make them available to students seems "incredible," she said.

"It gives us the capability to print a 3-D model to allow our students to fully understand the architecture of each bone, mimic a surgical procedure, and appreciate the mechanical adaptations common to biological systems. To be able to touch, drill, pin, place a screw on a printed bone that has the same architectural design as a real canine bone has been extremely helpful to our students," she explains.

In the fracture fixation lab for third-year veterinary students, for example, each student receives a printed femur with a long oblique fracture and a printed tibia with a simple transverse fracture. The bones are models from patients and represent the anatomy of their possible future patients. The 3-D printed bones allow students to start working as professional veterinarians in a safe learning environment.



A 3-D model of a deformed canine limb in blue and part of the spine in red, the colors of the filaments being used. Daniel Fletcher's printer is able to print with two materials at once, making it possible to print different model parts in different colors or materials.

The 3-D printer also is used to print surgical simulation models developed by the teaching team. The surgical simulations significantly improve student education and surgical performance, while minimizing the use of animals during the early stages of veterinary education. Several studies have been conducted at Ohio State to validate the use of these models in surgical education, Motta notes.

In addition, she has found that clients have a much better understanding of the challenges their pets are going through once they are able to visualize and touch a 3-D printed model made from a CT of their pet.

At the University of Illinois, Matthew C. Allender, DVM, PhD, DACZM, has a special interest in box turtles and has found that 3-D printed models allow for better clinic resolution by veterinary students and student wildlife club members.

The models allow students to see the different contours of the carapace

Photo: A soft tissue surgeon studies the 3-D model of a vascular anomaly (portoazygos shunt) in a young canine patient.

> Since 3-D technology allows surgeons to further prepare for more complicated, technically challenging cases, it has the potential for reducing the overall cost of a complicated surgery and the overall complication rate for the patient.

and to make repairs—much better for learning than the broken flower pots they used to work on, he noted.

The technology has had a steep learning curve, admits Motta, especially because, she, like most veterinarians, has limited background in computer science. But she's been "extremely surprised" at how much her veterinary students can learn once they find something as exciting as 3-D printing.

Motta explains, "These students get to see client patients with limb deformities, help create 3-D models, brainstorm the best approach for printing, and complete the project by printing it. In most cases, they also participate in the surgical planning, being part of the team sawing and plating the plastic bone, and deciding on the best treatment for the patient.

"As the last step, they join our surgical team and participate in the surgical procedure as a surgical assistant. There is no better learning experience for these brilliant young minds. "Students absolutely love this technology. For me, as an educator, any situation that stimulates learning is a positive situation."

Reducing costs, complications

Despite all of the great news about 3-D, it's not for every patient, especially not for routine, straightforward cases. But it does show benefits in several areas, says Adrien-Maxence Hespel, clinical assistant professor of radiology at University of Wisconsin–Madison School of Veterinary Medicine. Hespel co-authored an article about the use of 3-D printers in veterinary medicine for a 2014 article for the American College of Veterinary Radiology.

He notes that since 3-D technology allows surgeons to further prepare for more complicated, technically challenging cases, it has the potential for reducing the overall cost of a complicated surgery and the overall complication rate for the patient.

"Anesthesia is very expensive, and the longer a patient needs to be under anesthesia, the more the surgery will cost and the greater the chances of complications for the patient," Hespel points out.

He says 3-D printing also helps improve communication with clients, pointing out that if clients can hold models of their pet's tumor or broken bones, the situation becomes real.

In the end, Hespel says, "3-D printing technology is a tool. It's not going to improve your surgical skills. But it is beneficial and more people are appreciating the advantages of it." ※

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