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Review / *Derleme*

3D Printing in Veterinary Medicine

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Abstract: The use of 3D printing technology in the field of medicine, which started with the millennium, continues to increase today. Depending on the technological developments in this field, the use of rapid prototyping technology in the field of veterinary medicine is becoming widespread with the development of 3D printers, increasing material variety, cheaper printing costs and being more accessible. Additive manufacturing is used in veterinary education and training, experimental research and clinical studies, and its area of use is expanding day by day. In this review, both the current usage potential will be evaluated and the expected developments in the near future will be revealed.

Keywords: Additive manufacturing, Bioprinting, Rapid prototyping, three-dimentional printing, veterinary medicine.

Veteriner Hekimlikte Üç Boyutlu Baskı

Özet: Milenyum ile birlikte başlayan 3 boyutlu baskı teknolojisinin tıp alanında kullanımı, günümüzde artarak devam etmektedir. Bu alandaki teknolojik gelişmelere bağlı olarak 3 boyutlu yazıcıların gelişmesi, malzeme çeşitliliğinin artması, baskı maliyetlerinin ucuzlaması ve daha kolay ulaşılabilir olmaları ile hızlı prototipleme teknolojisinin veteriner tıp alanındaki kullanımı da yaygınlaşmaktadır. Katmanlı üretim, veteriner hekimlikte eğitim, deneysel araştırmalar ve klinik çalışmalarda kullanılmakta, kullanım alanı her geçen gün genişlemektedir. Bu makalede hem mevcut kullanım potansiyeli değerlendirilecek, hem de yakın gelecek beklentileri irdelenecektir.

Anahtar sözcükler: Biyobaskı, hızlı prototipleme, katmanlı üretim, üç boyutlu baskı, veteriner tıp.

Introduction

A high-resolution 3-dimentional (3D) image can be created digitally in a short time through CAD programs, by either directly designing a model or by using 3D surface scanners, or by reconstruction of cross-sectional medical imaging data such as ones created with computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound (USG). It has been shown in many studies that these 3D data could help in veterinary medical education, training and surgical planning (8, 11, 17, 19, 23, 28). In addition, artificial intelligence (AI), virtual reality (VR) and augmented reality (AR) applications, e-learning and long-distance learning facilities that have come into our lives with the results of digitalisation in recent years have taken the use of 3D digital data to a higher level in medicine (17). Despite all the advantages of these applications, the use of digital data in applied sciences is limited at some point. 3D printing constitutes a promising approach by which it has become possible to physically prototype these 3D digital images and to create a real representation model. After the first applications of 3D printing in the medical field in the current millenium, 3D printed models for both clinical and research purposes have also started to be used for animals. In recent years, with the innovations in both software, hardware and materials fields, the use of 3D printing in veterinary medicine is expanding (29, 30, 63).

This article will review the basic principles of 3D printing technology and its educational, experimental and clinical applications in veterinary medicine.

What is 3D Printing?

3D printing, also known as additive manufacturing or rapid prototyping, is simply a process of making 3D solid objects from a digital file.

The manufacturing process of a 3D model consists of four key steps; (1) Creating the 3D digital data, (2) Image processing, (3) Modeling, and (4) 3D printing. The first step in creating a 3D object with this workflow is the formation of the 3D digital data. There are two main methods for creating the 3D digital data including (1) creating the models with a computer assisted design (CAD) software, and (2) using scanners (surface scanners or transmissive medical scanners such as CT, MR or USG). In the second step of production cascade, 3D volumetric data is created by rendering and segmentation of 3D images and then the images are exported as a compatible file format such as Surface Tessellation Language (STL). The next step is slicing the 3D digital object into layers, then, the workflow for 3D printing is created by giving g-codes for each layer. The object can also be modified according to the printing settings. The final step of 3D printing is achieved by using additive processes performed by equipment called 3D printers. As the main principle for the additive manufacturing method, the object is created by laying down successive layers of material until the object is fully created. Each of these layers can be seen as a thinly sliced cross-section of the object.

Charles W. Hull, who was an American furniture builder, filed the first patent for Stereolithography (SLA) in 1986. Hull developed a system for creating 3D models by curing photosensitive resin layer by layer. After the first 3D printer hit the marketplace commercially in 1988, many different 3D printing techniques were developed in a short time.

Although many 3D printing technologies are offered today, it can be said that the most frequently used ones in the medical field are classified into 3 according to the print material and machining technology. These include SLA, as the oldest technique, selective laser sintering (SLS), and fused deposition modeling (FDM) (59). SLA printers work based on polymerization. They use UV light and a liquid photopolymer, referred to as resin material, that is solidified and formed by crosslinking of the resin with the activity of light. SLS printers work based on binding. They use the laser as a power source and powder material that can be either metallic, ceramic or polymeric in nature. FDM 3D printers are easily the most affordable and most popular printing device in use today. They are extrusion based systems that use either molten thermoplastics that are deposited on a built plate, or cross-linkable hydrogel-based materials that are 3D printed into crosslinker baths. In the latter, the material can be loaded with cells, therefore a bioink is used during 3D printing, which is referred to as bioprinting. Bioprinting represents a new frontier of 3D printing technology. This is the realization of robotic tissue production by combining live cells and other biological elements together with biomaterials (21, 44).

Applications on Veterinary Medicine

Education and Training: Accurate anatomic models used in learning and training facilities are essential for all levels of the veterinary education system such as undergraduate and postgraduate courses, clinical skills trainings and client education (37, 45, 53, 60). Compared to other commercial production methods such as molding and machining, 3D printing is one of the most practical and costly effective methods for production of solid replicas (12, 41). Also, these models which are produced using less toxic and more resistant materials against deterioration, contribute to human health and environmental health as well as the protection of valuable and scarce anatomical specimens (5, 33).

Bakıcı et al. (3) produced 3d replicas of the hyoid bone in domestic animals and used them in comparative anatomy education. 3d volumetric data of the bones were obtained by open source CAD software from CT images. FDM printer and polylactic acid (PLA) filament was used for printing. The authors stated that it is important for veterinary anatomy education to obtain easily and cheaply accurate replicas of the hyoid bone, which is difficult to macerate and very fragile. In other studies conducted with a similar scanning and printing method, Bakıcı et al. (4) modeled digit bones both the forelimb and hindlimb in horses, Alcântara et al. (1) also produced 3D prints of the foreleg skeleton in horses. Lima et al. (37) created anatomy and fracture models on the canine mandible. Bertti et al. (7) used dog skull prints for educational purposes. Unlike the above studies, Li et al. (36) scanned the cattle bones with a surface scanner instead of the tomography images, and obtained 3d copies. Besides the anatomy education, the 3d replicas are also used in the education of other disciplines of veterinary science with regards to a subject like orthopedic surgery (26, 46), equine podiatry (50), zooarchaeology (42), pathologic specimens (35), and forensic science (31, 32, 48). In the literature review, it was seen that bone samples were often preferred in the production of 3d anatomical models for educational purposes. The reason for this can be considered both to increase the printing quality of high resolution bone tissue images obtained with CT, and easy to find the orientation of bone structures compared to soft tissues in scanning and 3d reconstruction stages. In addition, the printing time of soft thermoplastic materials such as TPU is longer and the cost is higher. 3D brain models printed from scanning files (47, 56), dog stomach models obtained from surface scanning (24), and 3d organ replicas (6) are examples of a small number of studies with soft tissue printing models.

All these studies emphasized that accurate anatomical replicas obtained by 3d printing can be used as an alternative to traditional methods and original specimens in veterinary education.

As known, clinical skills training and simulators are an important part of the veterinary education system. For this purpose, patients, cadavers, animal models or virtual applications are often used. The most of challenges here arise from the difficulties in obtaining models, cost and sustainability, as well as ethical responsibilities. 3D printed anatomical models are also widely used for clinical skills training and simulations. For this purpose, dog and cat intubation models, injection models (62), bronchoscopy (54) and endoscopy models, fracture bone models for simulation can be created. Our experience shows that replicas created from CT and MR images in training models are superior in detail and accuracy to copies obtained using a surface scanner.

Clinical Studies: Clinical applications of 3D printing in veterinary medicine can be grouped as preoperative planning, custom-made surgical tools, laboratory devices and special guides, patient specific surgical implants and prostheses, and client education.

Today, images obtained through medical imaging methods and virtual applications are widely used in presurgical planning and provide great advantages to surgeons. However, interpretative differences between real anatomical structures and 2D images or 3D reconstructed virtual applications still continue, especially in surgical procedures to be performed on structures with complex anatomy, and there may be problems in understanding the details. At this point, the importance of case-specific models obtained with 3D printing in preoperative planning becomes clear (20, 25, 40, 49, 57). Patient specific 3d printed models of the anatomical region that require surgical repair can provide the surgeon with better visualization of the abnormalities and thus help prepare for surgery (51). These 3D models offer advantages such as tactile sensing of an object, creating surgical routes, determining and preparing the implant or prosthesis to be used, designing surgical guides if necessary, and providing a more understandable communication with the patient owner for the operation to be performed.

The study is a good example for using 3d printed models in presurgical planning and operation management that the surgeons produced a full-size 3D model based on CT images in a 10-week-old female puppy with 5 different congenital cardio-thoracic vascular anomalies. The replica was used for planning surgical angles and routes, selection of surgical tools, stapling devices and clamp sizes, the orientation of abnormalities and team coordination (15). The authors emphasized that in the surgery of complex anatomical structures, especially in terms of intraoperative orientation success, a complete comparison can only be achieved with a physical model.

Winer JN et al. (64) studied 3D printed skull models in 28 dogs and 4 cats for preoperative planning purposes before oral and maxillofacial surgery. They produced plastic replicas created on CT images of cases for mandibular reconstruction, temporomandibular joint ankylosis, palatal defects and neo plastic surgeries. Dorbandt et al. (14) also printed 3d models of 3 dog skulls for preoperative planning in case of orbital and peri-orbital mass.

3D printing models are used for preoperative planning in orthopedic studies especially in bone fracture (2, 38), leg deformities (52), and tumor surgery (64).

The studies emphasized that using 3D printed models in presurgical planning provides shortened surgery time, improved surgical accuracy and surgical success, and reduced perioperative risks and postoperative complications. They stated that 3D printed models are also a valuable resource to improve clients' understanding of the pet's disorder and the recommended treatment. Therefore, the 3D models help the clients education and communication.

3d printing technology is used in different fields of veterinary medicine to produce custom-made equipment for both users and patients. Surgical tools and equipments (43, 51, 65) or guides (22) for surgeons or patients can be produced by 3D printer. Similarly, tailor-made equipment and custom-made drugs can be produced for use in laboratories (16, 18, 39, 58, 61). Another using area is the creation of surgical guides. The case-specific guides can be very effective in terms of the success of the operation (22).

Santos et al. (55) performed external orthoses for metatarsal fractures in a calf. The area was scanned by a surface scanner and printed with petG filament on an FDM printer. It was observed that the animal was able to walk again when the leg was supported with the orthosis.

In their experimental study, Bolanos et al. (9) scaffolded and implanted bioceramic material to heal the tuber coxae defect in the horse. The researchers demonstrated that a brushite-based implant was able to promote new bone growth and the horse as a bone model is an encouraging tool for in vivo studies of biomaterials.

Kamishina et al. (34) produced a patient-specific ed printed model which was made of titanium to support the spine and used it as a surgical implant in order to provide stabilization in the surgical treatment of atlantoaxial joint subluxations, which can be seen especially in small breed dogs. Hayes et al. (27) also created a custom-made titanium plate for the cranioplasty of a dog which was suffered from osteochondrosarcoma. The presented studies showed that the accuracy of 3d printed implants had great importance especially the production of case specific models by printers.

The sterilization of implants placed in the body is also another limitation for using 3d printed implants. Implantation of these models has great importance, especially at the point of surgery (13). While heat-induced sterilization may be appropriate for metal implants, different sterilization methods have been tried for 3D printed implants made of thermoplastic material (10).

Conclusion

This technology may prove to be worth the investment as it will bring many creative possibilities for educational enhancement, research, professional development, and for thinking outside of the box. As the technology continues to improve, 3D printing is destined to rise in applications across all disciplines of veterinary medicine.

Conflict of Interest

The authors declared that there is no conflict of interest.

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