ROLE OF 3D PRINTING TECHNOLOGY IN VETERINARY EDUCATION

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**ABSTRACT**

3D printing is a rapidly emerging technology successfully utilized in different fields of medical science and in recent years 3D printed specimens have been used in veterinary education. With the invention of affordable 3D printers, the application of superior quality 3D printed models of anatomical specimen is expanding as an effective teaching tool in veterinary anatomy education. The use of this technology has also in surgical planning, creating prosthetics, orthopedic implants, anatomical models, etc. In this technology, the 3D physical solid models are produced through a process of adding layer upon layer of materials from a computer aided design (CAD) model. In this chapter, the principle of 3D printing technology is reviewed including steps involved in 3D printing, variety of printing materials, and techniques to be used for creating the anatomical models in veterinary education. This chapter emphasized the use of 3D printing in different field of veterinary science including veterinary anatomy education and surgery practice. This technology shows promising results in learning and understanding of 3D structures and their relationships, teaching and training purposes, guide surgical procedures, improve confidence of surgeons to perform complex surgical procedures and investigate new therapeutic approaches.

**Keywords:** Cadaver, Anatomical models, 3D printing, Veterinary education

 **I. INTRODUCTION**

Cadavers have been used in veterinary and medical education for teaching and training purposes as the main instruction tools for hundreds of years and it has proven that it is one of the most effective tools for studying anatomy of human and animal body. There is different view between the anatomists that in a modern education curriculum full cadaver dissection is still suitable. Using cadavers for dissection is time consuming and also to procure cadaver has been challenging with ethical issue. In recent years, many medical institutions limited the use of dissection based training and favour alternative methods to enhance the learning experience. Among these methods plastination, corrosion casts, medical imaging, computer assisted learning and 3D printing have gained considerable popularity [1]. 3D printing also known as rapid prototyping refers to the technology used to creation of anatomical models for teaching and training purposes [2]. The creation of digitalized and printed 3D anatomical specimens can be an effective tool used in teaching of undergraduate students [3]. Students can identify anatomical structures in physical models better than those of books or virtual models of teaching [4]. 3D printing has been successfully introduced in different medical fields and teaching of anatomy in the last two decades bringing several benefits includes accuracy, personalized study and easy handling [5]. 3D printing technology is depends on a processed data set obtained from sources such as magnetic resonance imaging (MRI) and computed tomography (CT) [2]. With the invention and advancement of software, hardware and printing materials, it has been possible to create more accurate anatomical specimens and reduce the cost and time. It is beneficial to enhance visual experience and understanding of 3D structures and their relationships [6]. In medical field, this technology has application in surgical practice and research, reduction in the period of anesthesia, the risks of infection, creating implantable prosthetics, biological tissue engineering, regenerative medicine etc. [7-9]. In veterinary science, anatomical models have been used since beginning of veterinary anatomy teaching, therefore 3D printed models can be a useful for practical purpose and have effective teaching tool. With the invention of 3D printing technology and demand of veterinary anatomy models, the use of 3D printed models is expanding; hence, in this chapter we will be reviewed the basic principle of 3D printing, various methods and tools for creating the anatomical models in veterinary education.

**II. 3D PRINTING TECHNOLOGY**

3D printing also known as rapid prototyping or additive manufacturing, is a method of making a three dimensional solid objects/models through a process of adding layer upon layer of materials from a digital file [10-12]. The object can be made using a variety of printing materials including thermoplastics such as acrylonitrile butadiene styrene (ABS), metals, resins, ceramics, composites, smart materials and special materials like food, lunar dust and textile [13]. The additive manufacturing method is based on creating models layer by layer till the object is entirely created and in this way model is builds up from a series of cross section [10].

 With the invention of first technology, Stereolithography (SLA) in the late 1970s, the history of 3D printing starts. Dr. Hideo Kodama published a paper on Rapid Prototyping (RP) system in 1981. He proposed a system in which layers of a model were printed on a platform and the final product was created layer by layer [14]. Parallel to Kodama’s work, Jean-Claude Andre, Alain le Mehaute and Olivier de Witte filed the application for patent of stereolithography but patent filing was abandoned. Later, in the year 1983, Charles Hull, an American engineer created the Stereolithography Apparatus (SLA), the part of first 3D printer and filed first patent the technology in 1984. Stereolithography is the first 3D printing process which was involved ultraviolet laser beam lights that solidify the resins contained in a vat. [15]. He received the patent for Stereolithography in 1986 and co-founded 3D systems. The world’s first commercial 3D printer, the SLA-1 was advented in the year 1987 and following years many 3D printing systems were developed. In 1993, Z Corp invented the Binder jetting 3D printing technology. In coming years this technology was continued to grow and show its true potential in the year 2000 when the first 3D printed organ was implanted in a human body. This was the golden period in the development of 3D printing in the medical application. In following years research was going on and in the year 2006, first commercially viable SLS printer was manufactured that received global demand from industries. During the year 2011 to 2020, this technology was form an important part of the history of 3D printing. 3D printer was available at affordable rate, accuracy getting better and its application have in multiple fields such as manufacturing plastic products, body organs, automobile industry, aviation industries, locomotive industry, in healthcare, in the field of agriculture etc. [13]. In the present scenario, 3D printing technology is uprising in different medical and allied fields [16].

**2.1 Steps of 3D Printing:** The first step of 3D printing includes scanning of anatomical specimens/structures by using 3D scanners like CT scanning, MRI etc. or to create models by computer aided design (CAD) software. In the second step, generated images are exported to the compatible file format such as Surface Tessellation Language (STL), which is commonly used for 3D printers [12]. In this step, editing of the scanned image is performed, so that the final digital image looks as possible close to the original specimen. The third step is modeling in which slicing the 3D digital object into layers then workflow for 3D printing is created by giving g-codes for each layer. The next step is 3D printing. It is carry out by the additive process performed by equipment called 3D printers. The final step is post processing where the final touches are made on the printed object [12, 17].

**2.2 Types of 3D Printing:** The three main types of 3D printing techniques are used for making 3D plastic products *viz*., stereolithography (SLA), selective laser sintering (SLS), and fused deposition modeling (FDM). Among these, stereolithography is the oldest technique based on photopolymerization. In this type of technique ultraviolet (UV) light source is used to interact with the resin (liquid photopolymer) in a selective manner to cure and solidify a cross section of the objects in thin layers [12]. The large parts can be built easily with high accuracy by use of this technology. It has been used effectively in the field of orthodontics. In addition, the other application is in the treatment of cardiovascular diseases, neurosurgery, spine surgery and traumatology [18]. Selective laser sintering produces solid structure by solidifying powder like material layer by layer by use a high power laser. The product manufactured by this process is high strength and resolution. Fused deposition modeling is the most popular and affordable type of 3D printing method used at the consumer level today. The material used in this process is mainly thermoplastic polymer. FDM process is based on extruding the heated thermoplastic filament onto a platform and forms product layer by layer from a digital file [19]. This technique has been used successfully to build distal tibia model for preoperative planning [20]. In recent years, 3D printing technology has improved and according to ASTM, it is categorized into seven groups such as Binder Jetting, Direct Energy Deposition, Material Extrusion, Material Jetting, Powder Bed Fusion, Sheet Lamination and Vat Photopolymerization [21]. The choice of the technology selection is based on the nature of required output.

**III. APPLICATION OF 3D PRINTING IN VETERINARY EDUCATION**

The use of 3D printing technology in veterinary field is increasing day to day due to recent technological advancements and decreasing costs. In veterinary anatomy, 3D printed replicas of tongue of domestic animals were produced by use of fused deposition modeling (FDM) technology. The digital data of tongue was acquired by using the “3D Go SCAN” model and generated images were exported to the STL format and edited using the software Genomagic Inc.[3]. The 3D printed models of sheep brain were created recently using magnetic resonance imaging (MRI) scanning and SLA and FDM technology. The efficacy of printed brain models of sheep were compared with real specimens. This study suggest that 3D printed brain models can be used as a supplement to teaching resources by producing accurately anatomical specimens [22]. 3D printed models of different hyoid bones of domestic animals were produced for veterinary anatomy education [23]. The 3D models of hyoid bone were durable, real like bone specimens could be produced with minimal equipment and manpower. The 3D replicas and digital images of hyoid bone both can be used during practical classes of veterinary anatomy [23]. The studies on 3D scanning and printing of dog skulls for education purpose shows that no significant difference was between the test scores of the students that did their using the real skulls and those using 3D printed models [24]. These findings suggest that digitalized and printed skull models can be used for teaching the gross anatomy of dog skull in the practical classroom [24]. The application of 3D modeling technology could use to facilitate surgical planning and correction. It increases the success of operations in regions with complex anatomical structures as the cardiovascular system. Use of 3D printing technology was carried out to facilitate surgical planning and correction of a complex cardiovascular anomaly in a dog [25]. A full scale 3D model of the heart and vasculature was prepared from the computed tomography angiography (CTA) and plasma sterilized. This model was used to facilitate surgical planning and enhance intraoperative communication and coordination between the surgical and anesthesia team [25]. A variety of biomaterials and biomedical devices to be implanted in the body of human and animals are produced through the 3D printing technology and it has becoming a standard manufacturing practice [26]. The development of 3D bioprinting plays a key role in the advancement of tissue engineering and biomedical research [27]. 3D printing technology has advantages in small animal orthopedics. Generate 3D printed implants, anatomical models and orthopedic instruments have benefited to complex orthopedic procedures in small animals [28]. In orthopedic field, it provides more accurate diagnosis, preoperative planning, selecting appropriate implant type and performing precise surgery [28]. 3D printing technology has significant development in the field of neurosurgery. The printed models are mainly used to guide surgical procedures, intraoperative guidance and positioning in neurosurgery [29]. This technology can also be used to investigate new therapeutic approaches and understanding of tumor biology [30]. It is also applied to increase learning skills, improve confidence of neurosurgeons to perform complex surgical procedures and surgical skills [31-32]. The 3D printing technology is an emerging tool that has been found efficient in veterinary education and can be multiple application in veterinary field. This technology impact the surgical procedures such as plan for procedure with models, customize tools to use during surgeries, models for bone replacement, creates prosthetics and orthopedic implants and overall decreases surgery time. There is some limitation of 3D printing technology. 3D printed parts have low strength that is created by traditional manufacturing techniques. The size of the model to be print in a printer has limitation. Production in large scale is also more expensive. The software tool chain is more complex and required a lot of 3D printing modeling training to manufacturing the complex parts. The accuracy of 3D printed models depends on process and type of machine used. This technique required post processing to create good quality of 3D printed parts. In conclusion, 3D printing is an emerging technology in the area of development of veterinary science. With the improvement of software, hardware and 3D printing materials, the use of this technology is continue to grow in veterinary education and veterinary surgical practices.

**REFERENCES**

[1] M. Estai, and S. Bunt, “Best teaching practices in anatomy education: A critical review,” Ann. Anat., vol. 208, pp. 151-157, 2016.

[2] K.H.C. Li, C. Kui, E.K.M. Lee, C.S. Ho, S.H. Wong, W. Wu, et al. “The role of 3D printing in anatomy education and surgical training: A narrative review,” MedEdPublish, vol. 6, 2017.

[3] B.A. Di Donato, A.C. Dos Santos, E.E. Da Silveira, H.C.S. Pereira, A.F.S. Lisboa Neto, M.M.O. Alcobaca et al. “Three-dimensional digitalized and printed tongue model of the cow, dog, pig and horse for undergraduate veterinary education,” Int. J. Morphol*.,* vol. 39, pp. 436-440, 2021.

[4] D.M. Preece, S.B. Williams, R. Lam, and R. Weller, “Let’s get physical: advantages of a physical model over 3D computer models and textbooks in learning imaging anatomy,” Anat. Sci. Educ., vol. 6, pp. 216-224, 2013.

[5] J.E.F. Barreto, B.S. Kubrusly, C.N.R.L. Filho, R.S. Silva, S.D. Facanho, J.C.C. dos Santos, et al. “3D printing as a tool in anatomy teaching: An integrative review,” Int. J. Innov. Educ. Res., vol. 10, pp. 58-71, 2022.

[6] P.G. McMenamin, M.R. Quayle, C.R. McHenry, and J.W. Adams, “The production of anatomical teaching resources using three-dimensional (3D) printing technology,” Anat. Sci. Educ., vol. 7, pp. 479-486, 2014.

[7] W.S. Paiva, R. Amorim, D.A.F. Bezzerra, and M. Masini, “Application of the stereolithography technique in complex spine surgery,” Arq. Neuropsiquiatr, vol. 65, pp. 443-445, 2007.

[8] P. Tack, J. Victor, P. Gemmel, and L. Annemans, “3D printing techniques in a medical setting: a systematic literature review,” BioMed. Eng. Online, vol. 15, pp. 1-21, 2016.

[9] D.B. Thomas, J.D. Hiscox, B.J. Dixon, and J. Potgieter, “3D scanning and printing skeletal tissues for anatomy education,” J. Anat., vol. 229, pp. 473-481, 2016.

[10] I. Gibson, D.W. Rosen, and B. Stucker, Additive manufacturing technologies: Rapid prototyping to direct digital manufacturing, Springer International Publishing, New York, 2010.

[11] S.A.M. Tofail, E.P. Koumoulos, A. Bandyopadhyay, S. Bose, L. O’Donoghue, and C. Charitidis, “Additive manufacturing: scientific and technological challenges, market uptake and opportunities,” Mater. Today, vol. 21, pp. 22-37, 2018.

[12] P.Y. Huri, and C. Oto, “3D printing in veterinary medicine,” Ankara Univ. Vet. Fak. Derg., vol. 69, pp.111-117, 2022.

[13] N. Shahrubudin, T.C. Lee, and R. Ramlan, “An overview on 3D printing technology: Technological materials and applications,” Procedia Manuf., vol. 35, pp. 1286-1296, 2019.

[14] H. Kodama, “Automatic method for fabricating a three-dimensional plastic model with photo hardening polymer,” Rev. Sci. Instrum., vol. 52, pp. 1770-1773, 1981.

[15] I. Paoletti, and L. Ceccon, “The evolution of 3D printing in AEC: From experimental to consolidated techniques.” in: 3D printing, IntechOpen[.79668](http://dx.doi.org/10.5772/intechopen.79668), 2018, pp. 39-69.

[16] A. Haleem, M. Javaid, and R. Suman, “3D printing applications for veterinary field.” Indian J. Anim. Hlth., vol. 58, pp. 171-173, 2019.

[17] O.A. Mohamed, S.H. Masood, and J.L. Bhowmik, “Optimization of fused deposition modeling process parameters: a review of current research and future prospects,” Adv. Manuf., vol. 3, pp. 42-53, 2015.

[18] Y. Bozkurt, and E. Karayel, “3D printing technology; methods, biomedical applications, future opportunities and trends,” J. Mater. Res. Technol., vol. 14, pp. 1430-1450, 2021.

[19] J.W. Stansbury, and M.J. Idacavage, “3D printing with polymers: Challenges among expanding options and opportunities,” Dent. Mater., vol. 32, pp. 54-64, 2016.

[20] Y.L. Yap, Y.S.E. Tan, H.K.J. Tan, Z.K. Peh, X.Y. Low, W.Y. Yeong, et al., “3D printed Bio-models for medical applications,” Rapid Prototyp. J., vol. 23, pp. 227-235, 2017.

[21] ASTM F2792-12a, Standard terminology for additive manufacturing technologies. ASTM International. West Conshohocken, PA, 2012.

[22] D. Haroglu, B. Iscan, and A. Duzler, “Use of three dimensional (3d) printed models of sheep brain in online veterinary anatomy education” Int. J. Print. Technol. Digit. Ind., vol. 6, pp. 370-381, 2022.

[23] C. Bakici, R.O. Akgun, and C. Oto, “The applicability and efficiency of 3 dimensional printing models of hyoid bone in comparative veterinary anatomy education,” Vet. Hekim. Der. Derg., vol. 90, pp. 71-75, 2019.

[24] E.E. da Silveira, A.L. Neto, H.C.S. Pereira, J.S. Ferreira, A.C. dos Santos, F. Siviero, R. da Fonseca, and A.C. Neto, “Canine skull digitalization and three-dimensional printing as an educational tool for anatomical study,” J. Vet. Med. Educ., vol. 48: e20190132, 2020.

[25] A. Dundie, G. Hayes, P. Scrivani, L. Campoy, D. Fletcher, K. Ash, E. Oxford, and N.S. Moise, “Use of 3D printer technology to facilitate surgical correction of a complex vascular anomaly with esophageal entrapment in a dog,” J. Vet. Cardiol., vol. 19, pp.196-204, 2017.

[26] S. Bose, K.D. Traxel, A.A. Vu, and A. Bandyopadhyay, “Clinical significance of three-dimensional printed biomaterials and biomedical devices,” MRS Bull., vol. 44, pp. 494-504, 2019.

[27] A. Su, and S.J. AlAref, “History of 3D printing.” in: 3D printing applications in cardiovascular medicine, S.J. AlAref, B. Mosadegh, S. Dunham, J.K. Min, Eds. New York: Academic, 2018, pp. 1-10.

[28] P. Memarian, E. Pishavar, F. Zanotti, M. Trentini, F. Camponogara, E. Soliani, et al., “Active materials for 3D printing in small animals: Current modalities and future directions for orthopedic applications,” [Int. J. Mol. Sci.](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8834768/), vol. 23, pp. 1045, 2022.

[29] P. Gargiulo, I. Amadottir, M. Gislason, K. Edmunds, and I. Olafsson, “New directions in 3D medical modeling: 3D printing anatomy and functions in neurosurgical planning,” J. Healthc. Eng., vol. 4, pp. 1-8, 2017.

[30] X. Dai, C. Ma, Q. Lan, and T. Xu, “3D bioprinted glioma stem cells for brain tumor model and applications of drug susceptibility,” Biofabrication, vol. 8:045005, 2016.

[31] J. Zhu, J. Yang, C. Tang, Z. Cong, X. Cai, and C. Ma, “Design and validation of a 3D- printed simulator for endoscopic third ventriculostomy,” Childs Nerv. Syst., vol. 36, pp. 743-748, 2020.

[32] A. S., Grosch, T. Schroder, T. Schroder, J. Onken, and T. Picht, “Development and initial evaluation of a novel simulation model for comprehensive brain tumor surgery training,” Acta Neurochir., vol. 162, pp. 1957-1965, 2020.