ROLE OF 3D PRINTING TECHNOLOGY IN VETERINARY EDUCATION

Shailendra Chaurasia[1*] and Amitosh Kumar[2]

[1*]Assistant Professor, Department of Veterinary Anatomy, College of Veterinary Science and Animal Husbandry, Kamdhenu University, Navsari-396 450, Gujarat, India.
*Corresponding author's e-mail: schaurasia@kamdhenuuni.edu.in
[2]Associate Professor and Head, Department of Animal Genetics and Breeding, Faculty of Veterinary and Animal Sciences, RGSC, BHU, Barkaccha, Mirzapur-231 001, Uttar Pradesh, India.
Email: amitosh@bhu.ac.in

ABSTRACT

3D printing is a rapidly emerging technology successfully utilized in different fields of medical science and its use in veterinary education is also expanding. With the invention of affordable 3D printers, the use of high quality 3D printed replicas of cadaveric material is expanding with great promise for teaching veterinary anatomy. The application of this technology has also in surgical planning, creating prosthetics, orthopedic implants, anatomical models, biological tissue engineering etc. The basic principle of this technology is the production of 3D physical solid models 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 application of 3D printing in different field of veterinary science including veterinary anatomy education and surgery practice. The application of 3D printing technology has shown promising prospects 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.

Key words: Additive manufacturing, Anatomical models, 3D printing, Veterinary education

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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, prosection, medical imaging, living anatomy, computer assisted learning and 3D printing have gained considerable popularity [1]. 3D printing or rapid prototyping is a rapid expanding technology used for the creation of anatomical models and purposes of the teaching and training [2]. The creation of digitalized and printed collections from 3D printing technology 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]. It has become possible to make physically prototype of 3D digital images and to create a real representation model. 3D printing technology is based on a processed data set acquired from sources including magnetic resonance imaging (MRI) and computed tomography (CT) [2]. With the innovations of software, hardware and materials, the 3D printing is able to produce highly accurate models at low cost and less time. It is useful 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 until the object is fully formed. These layers can be seen in thinly sliced cross section of the objects [10].

The history of 3D printing begins in the late 1970s with the invention of first technology, Stereolithography (SLA). The first inkjet printer was manufactured in the late 1970s that marked the beginning of 3D printing. 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 are 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 first commercially viable SLS printer was manufactured in 2006 and received widespread acceptance and 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 3D printing process has involved the following steps. The first step of 3D printing is creating the 3D digital data. It can be achieved by two ways *viz.,* formation of models with a computer aided design (CAD) software and data set acquired from sources including magnetic resonance imaging (MRI) and computed tomography (CT). In the second step, 3D volumetric data is created by editing of images and the final images are exported as a compatible file format such as Surface Tessellation Language (STL). STL file is a simple, portable format used by computer aided design (CAD) systems to define the solid geometry for 3D printable parts. 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. In the additive manufacturing method, model is created through a process of adding layer by layer of materials. 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 broad types of 3D printing technologies used for making plastic parts are stereolithography (SLA), selective laser sintering (SLS), and fused deposition modeling (FDM). Stereolithography is the oldest technique based on photopolymerization. In this type of technique ultraviolet (UV) light source is used to interact with the resin material (liquid photopolymer) in a selective manner to cure and solidify a cross section of the objects in thin layers [12]. SLA has been successfully used to produce specialized dental implants that can be used to oral surgery. SLA is also used 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. Fused deposition modeling is the most popular and affordable type of 3D printing method used at the consumer level today. This method uses polymer is the main material and builds parts layer by layer from the bottom to the top by heating and extruding thermoplastic filament such as acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) [19]. FDM technology uses hard plastic material in the process to produce 3D bone [20]. According to ASTM Standard F2792 [21], ASTM categorized 3D printing or additive manufacturing technologies into seven groups *i.e.,* Binder Jetting, Direct Energy Deposition, Material Extrusion, Material Jetting, Powder Bed Fusion, Sheet Lamination and Vat Photopolymerization. All forms of 3D printer works into one of these types.

III. APPLICATION OF 3D PRINTING IN VETERINARY EDUCATION

The use of 3 D printing technology in veterinary field is increasing day to day due to recent technological advancements and decreasing costs. 3D anatomical models of the tongue of domestic mammals were created for undergraduate veterinary education. The digital data of tongue was acquired by using the "3D Go SCAN" model. The generated images were exported to the STL format and edited using the software Genomagic Inc. The fused deposition modeling (FDM) technology was used and thermoplastic filament shaped material acrylonitrile-butadiene-styrene (ABS) that was deposited together with a support of resin [3]. The 3D printed models of sheep brain were produced by using magnetic resonance imaging (MRI) scanning and their effectiveness was compared with cadaveric materials. These models can be considered supplement teaching resource to cadaveric material in veterinary education [22]. 3D printing models of different hyoid bones of domestic animals were produced for veterinary anatomy education [23]. The study shows that 3D models of hyoid bone were durable, real like bone specimens could be produced with minimal equipment and manpower and 3D models and 3D reconstructed images both can be used during veterinary anatomy education [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 prints [24]. These findings suggesting that digitalized and printed skulls can be used as tools in veterinary anatomy teaching [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]. Three-dimensional printed FDA approved biomedical devices currently in use are TirboLOX-L titanium lumbar cages for spinal stabilization, DENTCA three-dimensionally printed polymer dentures and Osteofab craniofacial patient specific (polymer based) stabilization device [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 complex orthopedic procedures such as critical size bone defects, tibial tuberosity advancement, patellar groove replacement, joint replacement, limb sparing surgeries and other complex orthopedic procedures in small animals [28]. In this field, this technology 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. In neurosurgery, printed models are mainly used to guide surgical procedures, intraoperative guidance and positioning [29]. This technology can also be used to investigate new therapeutic approaches and understanding of tumor biology [30]. It is also applied for simulation training 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.

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