3D printer uses in veterinary medicine: a review

N. O. Marouf, N. Mimoune, A. Benchabane, D. Khelef and R. Kaidi*

Abstract

Three-dimensional printing, which appeared in the 1980s and has been steadily improving ever since, is a new and very promising technology. Thanks to its unique process of depositing material layer by layer, it differentiates itself from the rest of the traditional methods of modeling by molding and removing material. Modeling by adding material allows 3D printing to create parts with very complex geometries, and even with unprecedented precision. This last characteristic allows it to be used in many sectors including aviation, automotive, production but also science, education and medicine. With regard to these latter fields of application, printing by adding material is for some authors a real revolution. For modeling learning and training mockups, manufacturing custom prostheses, or printing biological and functional organs, the range of possible uses for 3D printing seems immense and very promising. In this study, we invite you to discover the main applications of the 3D printer in veterinary medicine.

Key words: *3-dimensional printing; medicine; veterinary; pedagogical interest; prostheses; bio-printing*

Introduction

The principle of three-dimensional printing represents a revolution in the field of the manufacture of objects. Thanks to the addition of material layer by layer, this process makes it possible to obtain geometries that are much more complex and new than what was possible before. Imagination is almost the only limit to what can be produced with a three dimensional printer (Giansetto, 2015).

Initially, three-dimensional printing was used in the field of industry, more particularly for prototyping, since its high cost does not allow it to be accessible to a wider audience. Then, as the technology developed, it became more affordable, which allowed to expand its scope. Archaeologists have become more and more interested in it (Giansetto, 2015), followed by doctors and educators. Whether it is for printing old objects, implants, prostheses and living tissues, or even powerful learning tools, three-dimensional printing is now used in many fields. To carry

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out this study and according to the context described above, a presentation of the different applications of this technology in veterinary medicine will be made, highlighting the considerable contribution of this technology in the medical field (Preece et al., 2013; Hespel et al., 2014; Anna et al., 2018; Li et al., 2018). In this work, we present a review in the field of three-dimensional printing, the third industrial revolution.

The use of 3d printer in veterinary medicine

The majority of applications in the field of veterinary medicine can be classified into the following categories: educational tools (anatomical models for medical education), surgical planning, personalized implants, prosthetic limbs and tissue, and organ bioprinting which is currently limited to the field of research.

Educational interest

Although this technology is not yet the norm in veterinary medicine, its use is growing in view of its advantages. It makes it possible to create educational materials that are often reusable, unlike certain anatomical parts that they imitate.

Material for learning general surgical procedures

Two main fields of application are described.

a) Silicone models developed from a 3D printed mold for learning sutures

The teaching of general surgery is advancing rapidly with 3D printing which has allowed the development of silicone model (Fig.1). The latter serve to provide a learning tool close to the texture of living models, available and reusable for training students and the maintenance of their clinical skills. This has the advantage of the ability to create educational models with pre-inserted incisions that the students apply to close according to different suture techniques to be mastered and which will make it possible to differentiate the levels of competence between users (Goudie et al., 2018; Goudie et al., 2019).

This technique can be used in more specific cases, among which we cite affordable, validated, standardized and anatomically correct silicone perineum models for repeat postpartum laceration repair. They are, for example, used by the Department of Obstetrics and Gynecology at Memorial University of Newfoundland for the organization of clinical training workshops (Goudie et al., 2019).

Fig. 1. Silicone model developed from a 3D printed mold (Goudie et al., 2019)

Silicone models were deemed superior to pre-existing training methods, such as simple foams, or animal corpses, materials that are closer to reality but more difficult to obtain and perishable. They have also been shown to be learning tools that are economical to manufacture and very durable because they show very few signs of wear after use, allowing reuse (Goudie et al., 2018; Goudie et al., 2019).

b) Augmented reality intravenous injection simulation based on a 3D printed model

Repeated practice is crucial to mastering the IV injection technique, but veterinary education programs do not always allow sufficient practice for all the students. In addition, repeated attempts in a dog are impossible due to vascular damage and the use of corpses in this case is of no interest because after death, openings are formed in the wall of blood vessels, the blood then escapes from the vessels and suddenly, they will lose their conformation.

Augmented reality is the superposition of reality and elements (sounds, 2D, 3D images, videos). The user can see the real world, with virtual objects superimposed or composed with it. Using this technology, the user can see the 3D graphics of the vein and the syringe overlapping with the 3D silicone model and the syringe (Fig. 2). 3D graphics move as the user moves the actual syringe and silicone model. After inserting the needle into the 3D container, he can press the button on the syringe for the simulator to determine the success of the injection.

Currently, simulation-based medical education offers a viable alternative to live animals as part of the training of veterinary medicine students and plays an effective role in reducing the use of these animals (Lee et al., 2013).

3D printed anatomical models for learning anatomy

Anatomy is a descriptive discipline with a strong focus on practical applications. Through anatomical training, students can better understand physiology, pathology, and clinical problems solving in animals. Traditionally, live animals and specimens have played an important role in teaching and learning animal structures but most animal specimens need to be preserved by a formaldehyde solution, which can be harmful and inconvenient for the technicians, students and educators. As for palatination (a technique aimed at preserving biological tissues by replacing different body fluids with silicone) of biological samples, it is clean, dry, odorless and durable, so that the samples can be handled without gloves and do not require any special storage conditions but remains a long, complex and expensive process.

In veterinary medicine, dissection has often been interpreted as the benchmark in educational anatomy. Due to various educational, ethical and economic

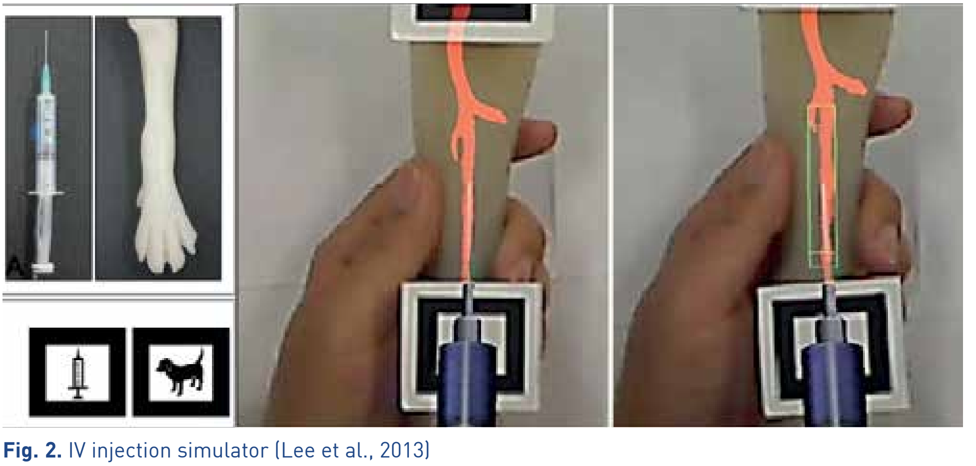

Fig. 2. IV injection simulator (Lee et al., 2013)

constraints, the use of animal specimens in the teaching of veterinary anatomy has declined over the past decades, while new resources and teaching methods requiring less use of animals have increased (Li et al., 2018; Alcântara Leite dos Reis et al., 2019).

In cases where cadaveric dissections are limited, students often rely heavily on written and oral explanation, as well as on 2D visual representations. This teaching has been strongly associated with a detrimental increase in cognitive load, resulting in decreased cognitive performances, knowledge acquisition and retention (Preece et al., 2013; Li et al., 2018; Alcântara Leite dos Reis et al., 2019). Some studies (Li et al., 2018) have shown that students believe that the 3D printed model helped them to better understand and that it improved their interest in learning.

Modern technological processes seem to offer some solutions for the acquisition of anatomical resources. A recent development that has been introduced in a wide range of biomedical fields including education, practice, and research, is 3D printing, which enables objects to be manufactured quickly and accurately based on a computer-generated model. Highly accurate 3D printed replicas have been produced for educational purposes in the field of anatomy and digital models, can be analyzed and modified prior to production. After scanning biological samples, the scale models can be 3D printed either in plaster-like powder, or in polylactic acid (PLA) filament or in filamentous thermoplastic (acrylonitrile-butadiene-styrene, ABS) (Li et al., 2018; Alcântara Leite dos Reis et al., 2019). These printed models provide an added benefit: it becomes possible to create truly larger-than-life models, enlarging the bones to make details easier to see and enhance student learning. A sphenoidal bone printed in the United States at Purdue University has caught the attention of educators to replace the bone kits (skeletons that can be dismantled into several bones) used by students in their general anatomy classes because the Conventional bone kits are expensive to purchase and create and are also easily damaged in use (Van Epps et al., 2015).

3D printed skeleton models have been used in laboratory training for learning anatomy. Samples of adult cattle skeletons: The femur (Fig.3), the fifth rib and the sixth cervical vertebra (C6) from the collections of the College of Animal Science and Veterinary Medicine of Qingdao Agricultural University (Li et al., 2018) and others from a horse: the scapula, humerus, radius and ulna, carpus and phalanges (Alcântara Leite dos Reis et al., 2019), were selected for scanning to create the 3D models. The skeletal samples were scanned using the 3D surface scanner. The digital models were processed in STL files, and then transferred to the 3D printer. The dimensions of the specimen and the 3D printed models were measured and compared, there was no significant difference between them (Li et al., 2018; Alcântara Leite dos Reis et al., 2019).

Anatomical features of bone samples, digital models, and 3D printed models, were also analyzed according to the Manual of Veterinary Anatomy of

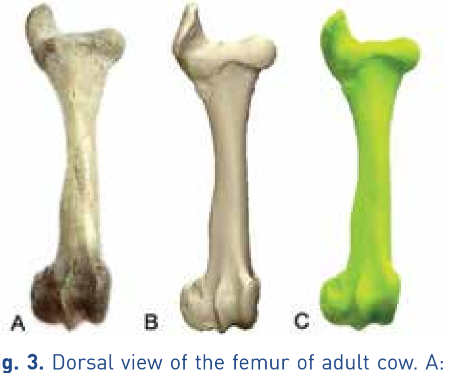

Fig. 3. Dorsal view of the femur of adult cow. A: bone specimen, B: digital model, C: 3D printed model (Li et al., 2018)

Domestic Mammals. A survey was distributed to assess the opinions of students regarding the use of 3D printed models in teaching anatomy. The results of the survey showed that the students felt that the 3D printed model helped them to better understand the material, and that the anatomical characteristics of the 3D printed models were not different from those of the real models (Bone specimens). Regarding safety and convenience, the students found that the 3D printed model was odorless, durable, and improved their interest in teach (Li et al., 2018).

Data show that 3D printed models can be a reliable alternative to bone samples in the teaching of veterinary anatomy (Li et al., 2018; Alcântara Leite dos Reis et al., 2019).

Another example illustrates this interest. Indeed, the equine foot is of enormous clinical importance. The dissection of such an area in veterinary science is extremely difficult and far beyond the capabilities of students due to the complex spatial relationships of its structures and the presence of a capsule to rigid horn. Recent studies in veterinary education have demonstrated the value of 3D models of the equine foot in improving the learning experience of students (Preece et al., 2013; Hespel et al., 2014; Alcântara Leite dos Reis et al., 2019). These studies compared the effectiveness of textbooks, computerized models and 3D printed models in teaching the identification of anatomical structures in MRI images of the equine foot. Digital reconstructions were created from MRI images and then prototyped to produce a physical model with different anatomical structures (bones, hoof cartilages, tendons, ligaments, a digital pad and a hoof capsule) (Preece et al., 2013) with different colors (Hespel et al., 2014), allowing the user to reconstruct the model several times, thus creating a 3D "puzzle" (Fig. 4).

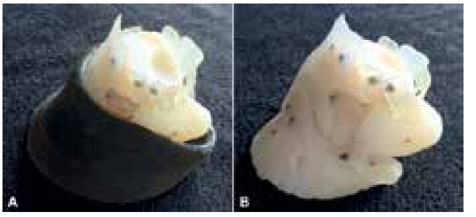

Fig. 4. The model of the equine foot printed in 3D. A, fully assembled and B, with the hoof capsule removed (Preece et al., 2013)

Students using 3D models performed better and had a better learning experience than those using digital models or textbooks (Preece et al., 2013; Hespel et al., 2014), and thus demonstrated the significant benefits associated with the use of a physical model to improve students visio-spatial appreciation and their understanding of the complex anatomical architecture of the equine foot (Preece et al., 2013; Hespel et al., 2014).

It should be reported, however, that several limitations were revealed. The models created from the 3D scanner (surface scanner), which are currently the most accessible, only describe the surface structures. The accuracy of the scanner used is 0.05 mm, while clinical CT and MRI data can resolve structures at the submillimeter scale. Thus, the details of digital models created by 3D scanning technology are inferior to those of similar models created from CT or MRI data (Li et al., 2018).

Use of 3D printed anatomical models and their impact on the recognition and characterization of fractures

A thorough knowledge of normal skeletal anatomy and the ability to identify the presence of fractures are essential to provide proper and adequate diagnosis and treatment to owners of small animals suffering from bone trauma. As such, the development and implementation of new learning methods that facilitate the teaching of pathological

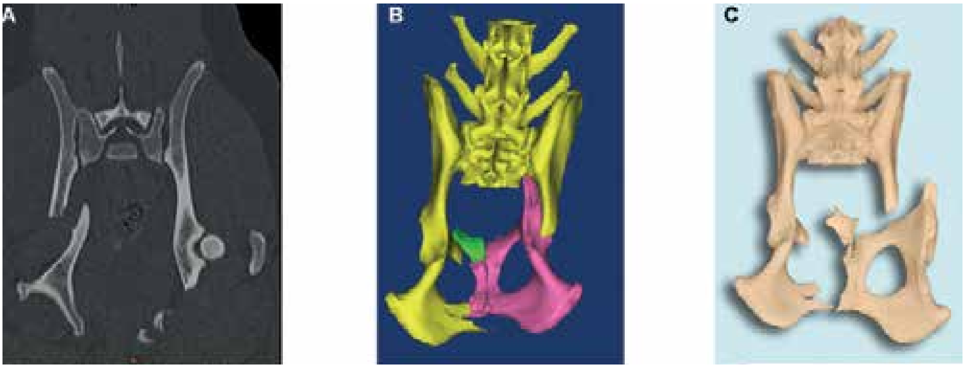

Fig. 5. (A, B and C) Evolution of the volumetric data. (A) Image acquired from TDM. (B) 3D model of segmented structures. (C) 3D printed model (Hespel et al., 2014)

anatomy to veterinary students would be of huge interest.

Today, 3D printed models have successfully enabled the learning of normal skeletal anatomy and improved identification and characterization of bone fractures (Fig. 5) in students compared to conventional means of diagnosis. Indeed, it is a simple, inexpensive teaching method which makes it possible to represent the bone stripped of its muscular envelopes, which will allow free manipulation in the three spatial planes of the various bone ends, which facilitates understanding of the student (Preece et al., 2013; Anna et al., 2018).

The ability to associate a fracture image obtained by CT, MRI or X-ray with direct observation of the corresponding 3D model allows, with training; the future practitioner to better understand the interpretation of these images for the cases with which he will be confronted in his future practice.

Surgical planning

The main steps in surgical planning are conventionally determined by the surgeon intraoperatively on the basis of a visual assessment. This can be difficult, especially when the bone conformation is abnormal. It is also clear that the ability to assess and manipulate an osteotomy from any perspective without the presence of soft tissue greatly facilitates this process. The majority of the literature on 3D printing in the surgical field is case studies or series of cases (Curtis et al., 2015; Jeong et al., 2016; Oxley and Behr, 2016; Dundie et al., 2017; Oxley, 2017; Winer et al., 2017; Hamilton-Bennett et al., 2018).

In veterinary orthopedics, 3D printing bone models can be used in many cases of corrective osteotomies in oral and maxillofacial surgery and even in cases of congenital bone anomalies (Fig. 6) to develop a precise surgical plan and perform a successful corrective osteotomy. 3D printing of an anatomical model cannot replace the interpretation of medical images (CT and MRI), but it is a complement to these images. Orthopedic surgeons have noted an added value especially in cases of bone and joint alignment disorders because it provides a better understanding of how to correct the alignment.

According to the authors' experience, 3D printed models are excellent tools for preoperative planning and resident training. Additionally, 3D printed models are a valuable resource to help clients to better understand the animal's disorder and to recommended treatment (Jeong et al., 2016; Winer et al., 2017).

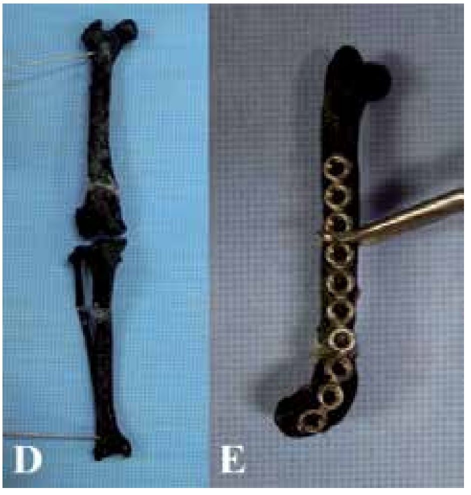

Fig. 6. (D) 3D printed bone model after corrective osteotomy. (E) The preformed bone plate on the postoperative 3D printing bone model (Jeong et al., 2016)

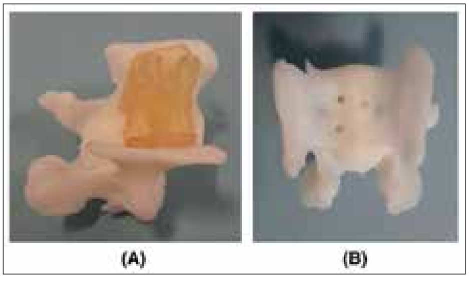

Fig. 7. 3D printed vertebral model of C6 with (A) and without (B) the corresponding patient specific 3D drill guide in place (Hamilton-Bennett et al., 2018)

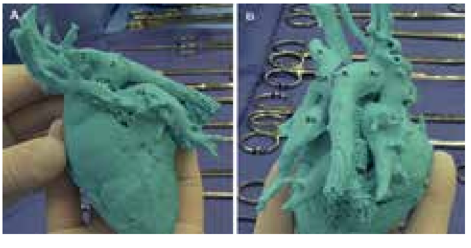

Fig. 8. 3D model using 3D printer technology, showing the model's left lateral and dorsal surfaces. A, aneurysmic dilation; PDA, arterial ductus; S, aberrant left subclavian artery; PA, left pulmonary artery; Ao, right aorta; VC, the vena cava (Dundie et al., 2017)

Currently, 3D printing technology rivals that of Computer Assisted Surgery (CAS) by allowing the creation of patient-specific surgical guides that attach to a specific part of the bone structure to guide the intraoperative cutting or drilling (Oxley and Behr, 2016; Oxley, 2017; Hamilton-Bennett et al., 2018).

Surgical guides are particularly used in hard tissue applications. The use of patient-specific surgical guides has been cited in orthopedics to facilitate the correction of bilateral shoulder osteoarthritis (Oxley, 2017) and in spine surgery for the placement of bi-pedicle screws cortices in a canine cervical vertebra (Fig. 7) (Oxley and Behr, 2016; Hamilton-Bennett et al., 2018).

The cited benefits of surgical guides as a tool for surgical planning are reduced operative time and improved precision of the surgical procedure (Oxley and Behr, 2016; Oxley, 2017; Hamilton-Bennett et al., 2018).

In another study, surgeons used a large-scale three-dimensional model of the heart and blood vessels (Fig.8) to improve surgical planning as they approach the correction of a total of five complex congenital cardiovascular anomalies in one dog.

The model facilitated surgical planning through a better understanding of the complex spatial relationships between structures, communication and coordination between the surgical and anesthesia teams. The authors also noted the high fidelity of the model with the patient's current anatomy.

Preoperatively, the model facilitated spatial orientation, atraumatic vascular dissection, sizing and positioning of instruments (Dundie et al., 2017).

The manufacture of implants and personalized prostheses

Orthopedics is an important sector for 3D printing according to the literature.

This is the surgical field with the highest proportion of articles.

Traditional manufacturing methods for implants and orthopedic prostheses need a mold or tooling that must accommodate a wide range of patients, which requires the surgeon to manipulate and deform the implant or prosthesis at the time of surgery to achieve an optimal fit for a specific patient. In comparison, computer-aided design allows the design of complex and specific 3D geometries, which are optimally configured to meet the needs of each patient. Additive manufacturing enables the realization of the computer-designed object.

The results of replacement surgery in patients indicate that individualized additively fabricated metal implants and prostheses greatly increase the chances of successful recovery process through functional replacement of skeletal structures, and that additive manufacturing techniques constitute a viable alternative to amputation in a large number of veterinary cases. This technology shows promise for treating diseases and improving quality of life, not only for pets, but also for their owners, and further offers a unique opportunity for the future development of better human implants (Harrysson et al., 2015; Jonathan et al., 2017; Julius et al., 2017; Se eun et al., 2018; Nickels, 2018; Vladimir et al., 2019).

In most cases of osteosarcoma, the affected bone and associated muscle envelope must be removed to achieve the oncological margins necessary for curative resection. This loss of skeletal support will generally have a structural and functional impact on the patient (SE EUN et al., 2018; Vladimir et al., 2019).

Metal additive manufacturing can be used to manufacture implants intended to replace parts of the mandible, maxilla (Harrysson et al., 2015; Julius et al., 2017; Nickels, 2018), the skull and the appendicular skeleton (Harrysson et al., 2015; Vladimir et al., 2019). In this case, the main indications for ostectomy are severe trauma, bone tumors, infections and congenital malformations. For example, in patients with bone defects affecting only one limb, the opposite limb is often used as a template for the design of the implant. Likewise, in patients with unilateral cranial or mandibular defects, the opposite side of the skull or mandible is used as a jig. These implants can have solid parts conforming to the contours of the remaining bones which will allow their initial fixation with screws or bolts and a porous part which will allow vascular and cell penetration in order to encourage tissue growth directly into the implant (Fig. 9). Both parts can be constructed in a single step using additive metal fabrication from various biocompatible materials (Harrysson et al., 2015; Nickels, 2018; Vladimir et al., 2019).

Fig. 9. Representative photographs of the surgical approach after placement of a patient-specific mandibular titanium implant in a dog with a mandibular tumor (Jonathan et al., 2017)

Another example is the use of a custom metal titanium implant for the treatment of large oronasal fistulas (Fig.10).

Animals with bone loss in the joints secondary to injury or tumor may also benefit from a custom-designed functional stent graft with attachment features for reattachment of ligaments

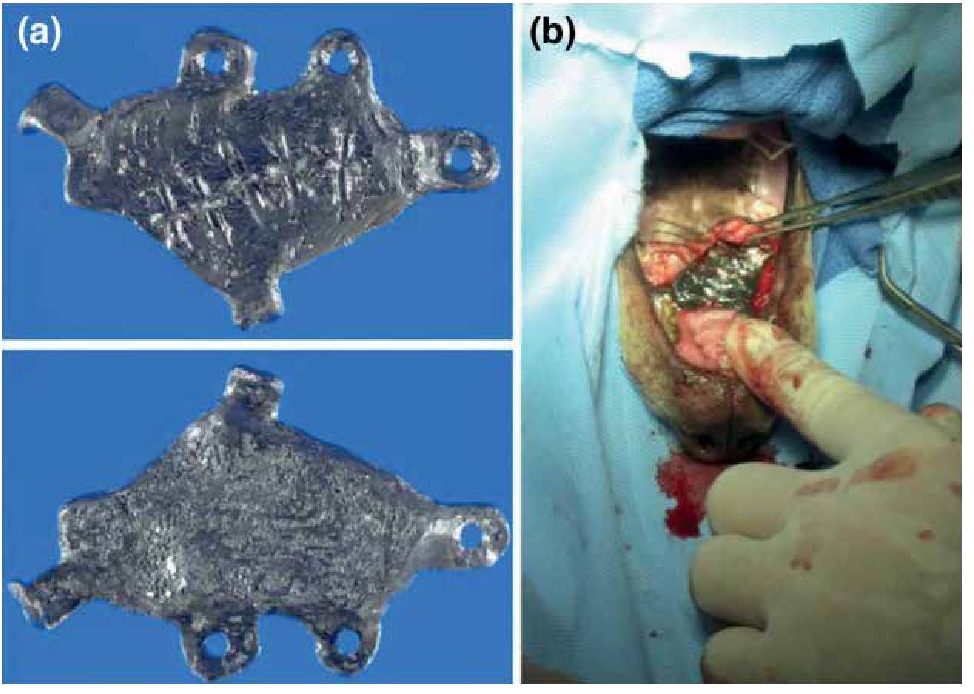

Fig. 10. (a) The plate printed in 3D. (b) The plate is inserted over the hard palate prior to screw placement (Harrysson et al., 2015)

Fig. 11. Photographic images of a dog with a prosthetic limb printed in 3D (Sean and Anthony, 2014)

and tendons to restore joint function (Harrysson et al., 2015).

3D printed prosthetic limbs

Prosthetic limbs are an emerging technology that aims to help people who have lost a limb. Humans aren't the only ones suffering from limb loss; animals around the world must be amputated or are born with limb deformities. Many of these animals never have the opportunity to regain their limb function due to the high cost of prostheses and the time required to manufacture them. As technology advances, faster and less expensive production methods are explored, such as additive manufacturing. Through accurate leg modeling and multiple trials, production of an Outer Prosthetic Limb (Fig. 11) or even wheelchairs occurs on a case-by-case basis and the products are tailored to a specific user (Sean and Anthony, 2014; Bachman et al., 2017; Susan et al., 2017).

A new approach involving part of the prosthesis implanted inside the limb (Fig. 12), called a stent, and an external part called an exoprosthesis. The stent, which is an intraosseous prosthesis, is made of an inert material that is inserted into the bone of the residual limb. This is essentially where a connection occurs between the bone and the implant, causing the prosthesis to be surgically attached to the bone. The exoprosthesis, known as the transcutaneous prosthesis, is attached to a part of the intraosseous prosthesis not immersed in the bone. This relationship of intraosseous and transcutaneous prosthesis transfers the mechanical load from the bone to the prosthetic limb unlike the external prosthetic limbs.

This is once again proof that 3D printing will revolutionize medicine by speeding up the manufacturing process and lowering the cost of prostheses, both human and animal (Harrysson et al., 2015; Bachman et al., 2017).

Bio-printing

Bioprinting is a very complicated biomedical application that requires the intervention of experienced and highly qualified experts in the field of medicine and technology. This application is based on the spatial structuring of living cells and other biological products using computer-driven bio-printers to obtain precise living tissue. It is applied in regenerative medicine for the generation and transplantation of several tissues, including skin, bones, vascular and tracheal grafts, heart tissue, cartilage structures, and vital organs. The usual method of making part of a tissue involves harvesting autologous stem cells from the patient under the best sterile conditions, then placing them in culture for multiplication in the laboratory using growth hormones to obtain a number of desired cells (Li et al., 2016; Augustine, 2018).

a) Artificial skin

The skin is the outermost protective sheath of the body, in direct contact with the external environment which makes it very susceptible to injury. Wounds

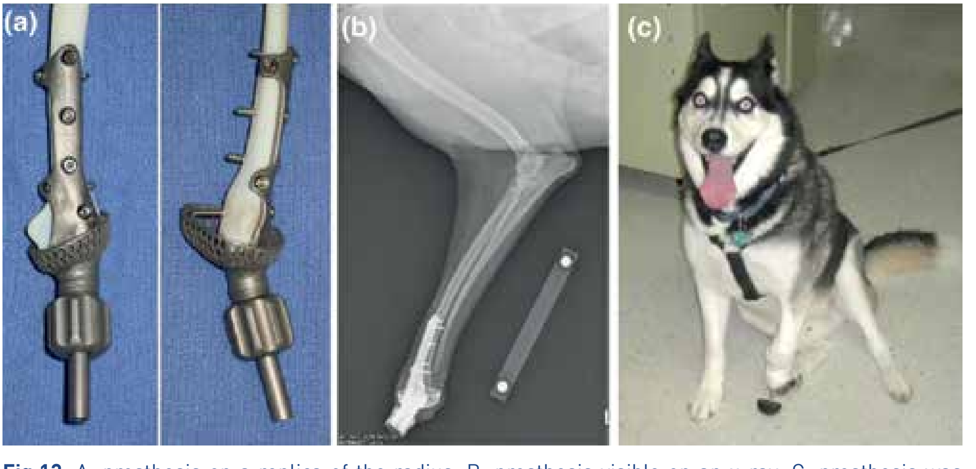

Fig.12. A: prosthesis on a replica of the radius, B: prosthesis visible on an x-ray, C: prosthesis was placed surgically (Harrysson et al., 2015)

and skin loss resulting from physical or chemical trauma can significantly compromise this skin barrier and impair its physiological functions.

Bioprinting technology is particularly essential for the preparation of skin substitutes for transplantation to repair skin lesions. The skin is bio-imprinted layer by layer by a combination of the biocompatible materials and dermal cell components such as fibroblasts and keratinocytes which are associated with a biomaterial matrix such as a silicone-based sheet and a collagen scaffold (Fig. 13) in order to obtain the piece of skin which will fill the loss of substance (Li et al., 2016; Augustine, 2018).

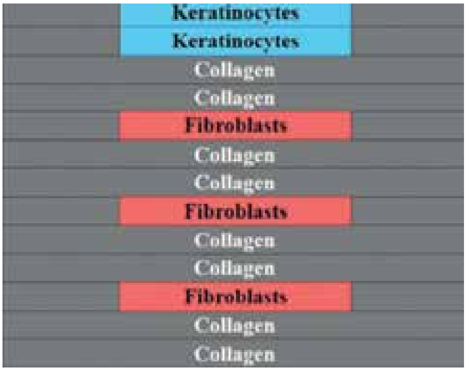

Fig. 13. 3D printed skin tissue diagram showing cross section (Lee et al., 2014)

b) Bioprinting of cartilage and bone

Bioprinting of cartilage is possible thanks to a 3D printer which is able to deposit cells and polymerize the support on which the cells are attached. Chondrocytes suspended in polyethylene glycol diacrylate are placed on a printed support in specific locations in order to reproduce the organization of natural cartilage. The support is printed with a biocompatible and biodegradable material that will be degraded (digested by the body) over time and leave space that will be colonized by neo-cartilage. A piece of functional and biocompatible cartilage could therefore be produced by 3-dimensional printing with the same mechanical properties as natural cartilage. These bio-prostheses are used, for example, in the filling of osteochondrosis lesions of the elbow.

By the same principle but with different osteoblasts and different supports, bone tissue can be printed (Li et al., 2016; Yamasaki et al., 2018). The bone tissue obtained is combined with a bioprinted cartilage tissue which will result in an osteochondral autograft of a specified shape. This type of autograft is used in osteoarthritis to compensate for the loss of bone and cartilage in the affected joint (Yamasaki et al., 2018).

c) Organ bioprinting

For now, organ bioprinting remains theoretical because of the multitude of cells, the complex vascularization, and the close links between cells allowing organ function that remain challenges that 3D printing has not yet succeeded in overcome. However, there is one exception which is the liver. The latter has a strong regeneration capacity. Primary hepatocytes and "canaliculi" structures are grown together in a collagen matrix; once the activity and functionality of primary hepatocytes cultured and hepatocytes derived from stem cells confirmed by biomimetic system. The 3D printer uses them as bio links for bioprinting liver tissue. This technology provides the exact size and shape to meet the needs of patients with liver resection. Bio-printed livers can be used not only after liver resection in patients and other liver surgeries, but also for simulated liver experiments in vitro. They can thus be used as a liver analogue to help detect drug toxicities and for other medical and laboratory tests (Li et al., 2016).

d) Other uses

- 3D printing of surgical instruments

Prolonged trips in certain constraining, austere, remote, isolated, and foreign environments do not allow you to take all the items that may be necessary in unpredictable circumstances and therefore, reduce to a minimum the equipment to be carried during this type of trip is imperative. Space missions will take place in environments where it is not possible to provide full surgical capability due to the mass, volume and weight they represent. Indeed, NASA is currently studying the use of 3D printers to print ABS (acrylonitrile butadiene styrene) thermoplastic surgical instruments on earth (Fig. 14).

Thanks to 3-dimensional printing, it is possible to obtain instruments quickly and thus avoid the waiting time involved in ordering from a supplier. The choice of material must be studied and taken into account. Material properties affect sterilization requirements and introduce safety considerations based on flammability properties. By using materials that support passage in an autoclave, surgical instruments can be printed at the request of surgeons with the same mechanical properties as usual instruments (Wong and Pfahnl, 2014).

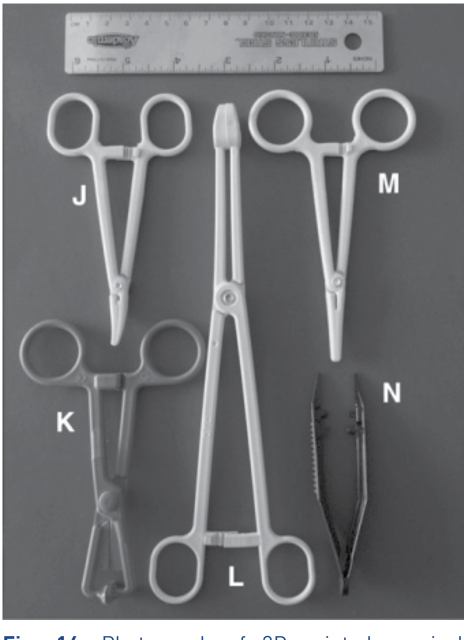

Fig. 14. Photograph of 3D printed surgical instruments (J: curved hemostasis forceps, K: clamps, L: sponge clamps, M: straight hemostasis forceps, N: forceps) (Wong and Pfahnl, 2014)

3D printed immobilizer and their use in medical imaging

An essential element in performing a correct complementary examination in animals is the positioning of the subject throughout the treatment. Few techniques for immobilizing small animals have been described in the literature.

It is shown in a study that 3D printing can be used to create an ABS immobilizer on which the animal is positioned (Fig. 15) in order to perform additional examinations such as magnetic resonance imaging and computed tomography and even for radiotherapy with optimal position and reduced anesthesia time. The ABS material is not visible on MRI and CT images (Rachel et al., 2015).

- 3D printed horseshoe specially adapted for a lame foot

Laminitis is a disease of the foot which results in intense lameness and rapid development. Its consequences

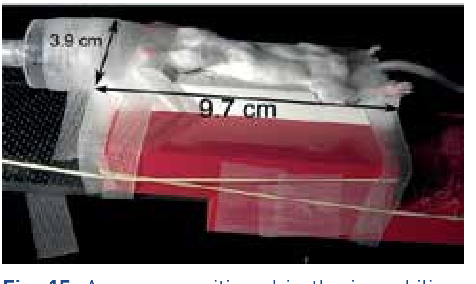

Fig. 15. A mouse positioned in the immobilizer (Rachel et al., 2015)

are often very serious and can compromise the sporting future and sometimes even the life of the horse. There have been many attempts in the past to cure laminitis, but 3D scanning and design seem to be the most effective. The digitalization of the hoof and the 3D printing of the new shoes specially adapted for a lame foot (Fig. 16) make it possible to redistribute in an adequate and specific way the weight of the painful zones of the affected foot and to give the horse the best chances of rehabilitation. This technology opens many doors and is currently helping to ease the process of rehabilitating these animals and making them walk comfortably again (Nickels, 2018).

Fig. 17. Photographic image of a 3D printed horseshoe (Nickels, 2018)

- 3D printed beak implant

A beak, in the strict sense, is an external anatomical structure that allows food intake and therefore nutrition in birds. But it also allows the nutrition of the young, the hunting of prey and the manipulation of objects, which makes it a major element in the life of birds. The loss of this structure condemns the animal. Birds that have lost their beak can now live with an artificial 3D printed beak (Fig. 17) that is extremely durable and strong and will provide a better quality of life (Nickels, 2018).

Conclusions

After studying the major technologies available in the field of three-dimensional printing and the different applications of these technologies in the different sectors of education and the world of health in general, we can see that this revolutionary process deserves attention and constitutes an interesting line of research for the future.

More particularly, in the field of veterinary medicine, the advantages of 3D printing can be enormous, not only for the preparation of complex surgical procedures or in the osteology program of students but also as a tool for communication with customers, as well as for the manufacture of implants and prosthetic limbs.

However, great efforts still need to be made, particularly in the area of bioprinting and the production of living tissues and organs. In the field of health, the most promising aim of three-dimensional printing would indeed be to

Fig. 16. Photographic image of a bird that received a 3D printed beak (Nickels, 2018)

succeed in producing living organs, but it is still far from being achieved due to the complexity of building such an object. Bioprinting remains a very interesting and very encouraging field of research because of the medical revolution it could bring. It is also necessary that this technology has a legal framework more determined in order to avoid any drift of ethics or concerning the security of people and ideas because almost everything can be copied and printed by three-dimensional printing.

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Primjena 3D pisača u veterinarstvu- pregledni članak

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Trodimenzionalni ispis koji se pojavio 1980-ih godina od tada se stalno poboljšava i predstavlja novu i vrlo obećavajuću tehnologiju. Zahvaljujući svom jedinstvenom procesu deponiranja materijala sloj po sloj, razlikuje se od ostalih tradicionalnih metoda modeliranja lijevanjem u kalupe i uklanjanjem materijala. Modeliranje dodavanjem materijala omogućuje kreiranje dijelova vrlo kompleksnih geometrija pomoću 3D ispisa, uz nikada ranije dostignutu preciznost. Ova posljednja karakteristika dopušta njegovu uporabu u brojnim sektorima uključujući: zrakoplovstvo, automobilsku industriju, proizvodnju, ali i znanost, obrazovanje i medicinu. S obzirom na ova posljednja spomenuta područja primjene, ispis dodavanjem materijala za neke autore predstavlja pravu revoluciju. Za učenje pomoću modela i uvježbavanje na modelima, proizvodnju prilagođenih proteza, ili ispis bioloških i funkcionalnih organa, raspon mogućih primjena 3D ispisa čini se neizmjernim i vrlo obećavajućim. U ovoj vas studiji pozivamo da otkrijete mogućnosti primjene 3D ispisa u veterinarstvu.

Ključne riječi: *trodimenzionalni ispis, medicina, veterinarstvo, pedagoški interes, proteze, bio-ispis*