Comparative study between bone obtained by 3D printing and its original model

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

Abstract

3-dimensional printing, which appeared in the 1980s and has been constantly evolving since, is an innovative and very promising technology. It is a tool with wide-reaching applications in the field of osteology and anatomy and also in the world of education. Thanks to its qualities, it is possible to print entire anatomical parts in numerous copies. This experimental study examined the dimensions of 3-dimensional printing of the right femur of a sheep in comparison with its digital and printed models. A 3D scanner was used to design the digital model and a 3D printer to produce the scanned bone using polyamide (PA12) as the material. Nearly all the original anatomical features of biological bone were well resolved, except for the depth of the nourishing foramen. The measured dimensions of the 3D printed model and the digital model were compared to those of the original biological specimen, and showed no significant difference. Regarding the results obtained and the slight error of 1 mm, 3D printed models can be used as an aid in anatomy lessons and can serve as reliable alternatives to classical anatomical parts in the study of the veterinary anatomy. To the extent of our knowledge, this is the study on the use of 3-dimensional printing in veterinary medicine in Algeria.

Key words: *3-dimensional printing; anatomy; educational interest; SLS; 3D printed model; femur; sheep*

Introduction

Cadaver dissection is considered the gold standard for learning anatomy. Although the theoretical education of anatomy is extremely important, practical studies are essential to solidify the theoretical aspects. Unfortunately, some limitations are associated with this, such as cost and availability that prevent the easy acquisition and preparation of anatomical specimens, hence the use

Noufel Ouail MAROUF, National High School of Veterinary Medicine, Algiers, Algeria; Nora MIMOUNE*, (Corresponding author, e-mail: nora.mimoune@gmail.com), National High School of Veterinary Medicine, Algiers, Algeria, National Veterinary Institute of Blida University, Laboratory of Biotechnologies related to animal Reproduction (LBRA), Algeria; Aymène BENCHABANE, National High School of Veterinary Medicine, Algiers, Algeria; Walid CEDRA, Center for Development of Advanced Technologies (CDTA), Algiers, Algeria; Djamel KHELEF, National High School of Veterinary Medicine, Algiers, Algeria; Rachid KAIDI, National Veterinary Institute of Blida University, Laboratory of Biotechnologies related to animal Reproduction (LBRA), Algeria

of real animal specimens in veterinary anatomical education has declined over the past decades (Preece et al., 2013). Currently, many universities rely on the use of two-dimensional books, pictures and written information. Such teaching has been strongly associated with a detrimental increase in cognitive load, leading to decreased knowledge acquisition in students with low spatial skills (Li, 2017; de Alcantara Leite Dos Reis et al., 2019).

Some studies have attempted to develop models by hand, but found that this method took a long time and it was impossible to ensure accuracy of these models (Van Epps et al., 2015). On the other hand, the use of digitalization and 3D printing for the production of anatomical models is an innovative tool. Thanks to this technology, new methods of teaching veterinary anatomy, such as simulation (3D computer models) and 3D printed bone models offer useful and enjoyable alternatives for veterinary students (Li, 2017; de Alcantara Leite Dos Reis et al., 2019). Many 3-dimensional printers have been invented since its inception such as: stereolithography, modelling by the deposition of molten wire, and Selective Laser Sintering (Wendel et al., 2008).

In this study, a trial was made to carry out an experimental study on 3-dimensional printing by comparing the dimensions of biological bone with its printed replica. A surface scanner and 3D printer were used to make a skeletal model of a sheep's pelvic limb (right femur), to be examined to judge its fidelity compared to the original model. A discussion on the validity of this model as an educational tool for teaching osteology is given.

Materials and methods

The study was carried out between February and September 2020.

Sample

In selecting the sample for the comparison, it was initially planned to use the femur of a cat or dog, though given the extreme difficulty in finding bones of these species due to ethical reasons, it was then decided to use a sheep's femur. This also minimized the costs of 3D printing due to their small size (small object are less expensive) compared to other species such as cattle or equines. The sample (Figure 1) was obtained from a butcher.

Figure 1. Right femur of the sheep

Bone cleaning and bleaching

Large muscle portions were first cut with scissors and knife and removed. Using a scalpel blade mounted on a handle, the remaining flesh was carefully removed, avoiding scratching the bone.

In the second step, to rid the bone of traces of soft tissue (remains of macroscopically visible portions of muscles, tendons and ligaments), the bone was placed in a stainless steel container (large saucepan) filled with water. The water was brought to and kept at a boil using two benzene nozzles for a period of 60 to 90 minutes (Figure 2).

After removing, draining, and cooling the bone, we moved on to the third step which consisted of repeating the first step. The final cleaning was carried out even more carefully to avoid any damage to the bone.

For bone bleaching, the entire femur was placed into a container filled with water. When the water temperature reached 60°C, we added the most important component of this step: sodium perborate $NaBO_3$ until a more or less viscous mixture was obtained.

Figure 2. The second step

Figure 3. Femur after bleaching

Due to its properties, this product was used for cleaning, dissolving fat and whitening bones. The bone was kept submerged in the mixture for 30 minutes to 3 hours. Finally, the surface of the bone was rubbed with a sponge and rinsed thoroughly. Figure 3 shows the final result of the protocol.

3D printing of synthetic bone

Image acquisition was obtained using a 3D surface scanner. The scan leads directly to a 3D representation of the scanned object using software. In this case, medical imaging is not necessary because in this case, we were interested only in the surface of the bone. The image processing step can also be neglected. The three basic steps are: acquisition of the image or scanning, printing and post-processing.

Acquisition of the image or scanning

The bone was scanned or digitized using a 3D surface scanner (3D ROMER ARM) at the Center for Development of Advanced Technologies (CDTA, Algiers, Algeria). Scanning was performed in a dark room. The scanner was calibrated before acquisition to determine the absolute size of the scanned objects. The accuracy of the scanner was calibrated to 0.069 mm. The total scanning time was 2 hours. The data was assembled into a point cloud to give a 3D representation of a femur scanned on software (GEOMAGIC) (Figure 4) in STL format standard for all 3D printers. Once the model was ready to be sent to the printer software and to be printed in three dimensions, the software gave an estimate of the printing time and started printing in three dimensions.

3D printing

The 3-dimensional printer chosen uses Selective Laser Sintering Technology (SLS Spro60 HD 3DSystem, USA) (Figure 5). The material used is polyamide PA12 (thermoplastic polymer made from nylon). The latter results in

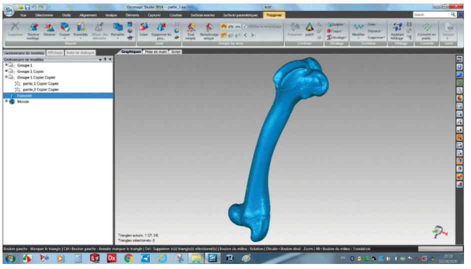

Figure 4. GEOMAGIC software home screen after scanning

Figure 5. The SLS Spro 60 HD 3D System 3D printer (USA)

Figure 6. The post-treatment step

polymerization and then solidification of the powder at the locations selected by a high-power infrared laser directed by computer to the desired location for sintering.

As the powder is composed of fine solid particles, this environment acts as a support for the part under construction. No support is therefore required during printing to maintain the object at the time of manufacture.

Post treatment

After printing and before handling, the printed part was left at room temperature for 6 hours to cool. The bone was sandblasted (Figure 6) to obtain more defined surfaces with a smoother appearance. For safety reasons, a sandblasting cabin specially designed for the post-processing of 3D printed parts using SLS technology is necessary. The bone was placed in the blast booth and the blast was exposed to sand expelled from a high speed nozzle.

Comparative analysis

In this study, the accuracy and reliability of the digital and the printed models were confirmed by the analysis of the anatomical features and dimensional measurements.

The anatomical features of the femur, digital model and 3D printed model were also analysed according to the manual of veterinary anatomy of domestic mammals (Konig and Liebich, 2014). The presence and absence of the anatomical points of the femur were noted (femoral head, trochanteric fossa, greater trochanter, lesser trochanter, trochlea, lateral and medial condyle, insertion of the round ligament, and the nourishing foramen)

The dimensions of the femur specimen and the 3D printed model were measured by a single observer using a tape measure, and the digital model was measured using software (Adobe Reader XI). Each measurement was repeated three times (Figure 7).

In this study, five measurements were selected: maximum length, maximum width of the proximal

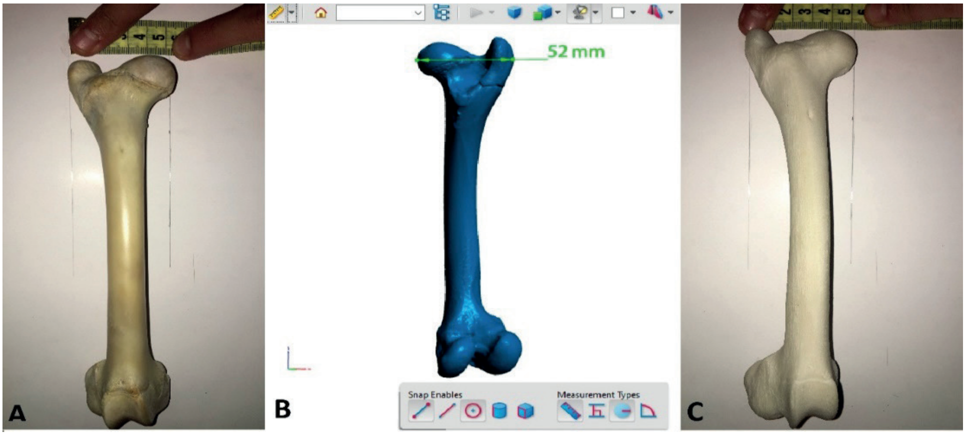

Figure 7. Measurement of the width of the proximal femoral epiphysis. A: organic bone. B: digital model. C: 3D printed bone

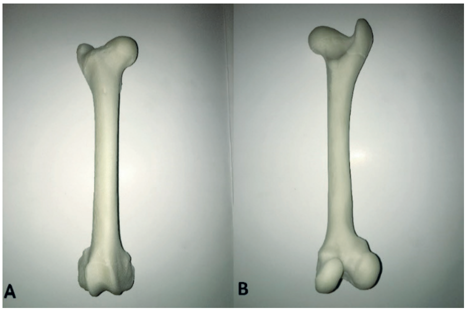

Figure 8. 3D printed femur. A: cranial view. B: caudal view

epiphysis, maximum width of the distal epiphysis, maximum width of the femoral head, and maximum circumference of the shaft.

Results

By applying the steps of preparing and printing on the selected bone, we obtained a copy of the object of study selected for comparison. The femoral model required 6 hours of printing and consumed 101 g of PA12 (Figure 8).

Regarding the comparative study, nearly all of the original anatomical features of the biological femoral specimens were well resolved, except for the depth of the nourishing foramen. The measured dimensions of the 3D printed model and the digital model were compared with those of the original biological specimen. The data showed no significant differences between the

Table 1. Comparative table of the ovine femur

Sheep femur	Biological bone	Digital model	3D printed bone	Error
Maximum length	204 mm	204 mm	204 mm	0 mm
Maximum width of the proximal epiphysis	52 mm	52 mm	51 mm	1 mm
Maximum width of the distal epiphysis	46 mm	46 mm	46 mm	0 mm
Maximum femoral head width	22 mm	22 mm	21 mm	1 mm
Maximum circumference of the shaft	58 mm	58 mm	57.5 mm	0.5 mm

original model and the replica (digital model and 3D printed bone). This suggests that 3D models could accurately display nearly all of the anatomical features of the original specimens. The results of the comparative measurements are listed in Table 1.

Discussion and conclusions

The results obtained and the slight error of 1 mm between the measurements taken on the biological sample and its printed replica indicate that three-dimensional printing, and in particular Selective Laser Sintering, could be an effective, fast, and inexpensive tool for the production of accurate anatomical models. For educational purposes, this method is very useful for teaching anatomy. Animal anatomy teachers in Algeria could obtain such models in large numbers, or even create interesting models themselves on demand quite quickly and easily after minimal operational training in using the 3D surface scanner and 3D printer.

Taking into account the characteristics of the 3D printer used and especially its precision, errors are due more to a shift in the measurement rather than to a real imprecision of the 3D printer (SLS). Thus, with the eye and tape measure, it is difficult to obtain accuracy greater than 1 mm, and an error of 1 mm is difficult to avoid with the equipment used. In order to increase the accuracy of measurements, more precise equipment such as a laser could be used. However, for the purposes of this study, this data seems sufficient to be able to confirm that 3D printing is a reliable tool for copying bones for educational purposes. These results are consistent with those reported by other authors (Giansetto, 2015; Li et al., 2017; de Alcantara Leite Dos Reis et al., 2019).

As described in previous studies (Preece et al., 2013; Van Epps et al., 2015), 3D printing is significantly cheaper than buying or producing plasticized specimens. The production costs of models were relatively inexpensive after a proper investment in 3D scanning and printing equipment. The printed model of the ovine femur costs around 2000 DA, and the entire process took less than 24 hours. In contrast, obtaining biological bone samples for anatomical purposes is a much more complex process. In the present study, it took significantly longer to obtain the bones to serve as the original biological samples than to produce the 3D models.

The Selective Laser Sintering technique produces solid parts without the need for a curing step after printing. However, this technology has a poor finish due to the size of the powder particles which remain relatively large and prevent optimal final rendering. Although few post-printing treatments are necessary, obtaining a smoother finish may require a sanding step, which was the case in our study. This could explain the loss of depth revealed on the nourishing foramen. This anatomical element is however presented contrary to what is observed in bones obtained by other printing techniques (Li et al., 2017). This confirms the interest of the chosen technique.

In our opinion, the 3D printed model in this study can therefore be used as a teaching aid during student laboratory sessions. It can clearly improve the understanding of basic skeletal anatomy and appears to be a reliable alternative teaching resource. These printed models provide an additional benefit: it is possible to enlarge the bones to make details easier to see and improve student teaching (Van Epps et al., 2015).

Finally, this study used only healthy bone, though the same approach could easily be applied to pathological bones. Students could then more easily understand pathological processes such as osteoarthritis and the resulting bone changes. To the extent of our knowledge, this is the first study on the use of 3D printing in veterinary medicine in Algeria.

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Komparativna studija kosti dobivene 3D printanjem i njezinog originalnog modela

Noufel Ouail MAROUF, National High School of Veterinary Medicine, Algiers, Algeria; Nora MIMOUNE*, National High School of Veterinary Medicine, Algiers, Algeria, National Veterinary Institute of Blida University, Laboratory of Biotechnologies related to animal Reproduction (LBRA), Algeria; Aymène BENCHABANE, National High School of Veterinary Medicine, Algiers, Algeria; Walid CEDRA, Center for Development of Advanced Technologies (CDTA), Algiers, Algeria; Djamel KHELEF, National High School of Veterinary Medicine, Algiers, Algeria; Rachid KAIDI, National Veterinary Institute of Blida University, Laboratory of Biotechnologies related to animal Reproduction (LBRA), Algeria

Trodimenzionalno printanje, koje je u uporabi od 1980-ih godina te se do danas stalno razvija, inovativna je i vrlo obećavajuća tehnologija. To je alat kojim se možemo izuzetno koristiti na području osteologije i anatomije, kao i u svijetu obrazovanja. Zahvaljujući njegovim mogućnostima, moguće je printati čitave anatomske dijelove u brojnim primjercima. Ovom smo studijom pokušali provesti eksperimentalnu studiju trodimenzionalnog printanja uspoređujući dimenzije desne bedrene kosti ovce i njezinog digitalnog i printanog modela. U tu svrhu korišten je 3D skener za dizajn digitalnog modela i 3D printer za proizvodnju skenirane kosti. Izabrani trodimenzionalni printer koristio je tehnologiju selektivnog laserskog sinteriranja (SLS Spro60 HD 3DSystem, SAD), s poliamidom (PA12) kao materijalom. S obzirom na komparativnu studiju, gotovo sva izvorna anatomska svojstva biološke kosti su dobro riješena osim dubine nutritivnog foramena. Izmjerene dimenzije 3D printanog modela i digitalnog modela uspoređene su s onima originalnog biološkog uzorka te nisu pokazivale značajne razlike. S obzirom na dobivene rezultate i malu grešku od 1 mm, 3D printani modeli mogu se smatrati pomagalom u lekcijama iz anatomije i mogu služiti kao pouzdane alternative za klasične anatomske dijelove u proučavanju veterinarske anatomije. Prema našim saznanjima, ovo je prvi rad na temu trodimenzionalnog printanja u veterinarstvu u Alžiru.

Ključne riječi: *trodimenzionalno printanje, anatomija, edukativni interes, SLS (selektivno lasersko sinteriranje), 3D printani model, bedrena kost, ovca*