Egyptian Journal of Veterinary Sciences
https://ejvs.journals.ekb.eg/

The Superiority of 3D Printed Models and Digitized Radiographs of Normal and Osteoarthritic Stifle Joints over Cadaveric joints as Alternative Educational Provisions in Canine Orthopedics

Menna A. Nahla[1*], Yara S. Abouelela [2], Mohammed S. Amer[1], Marwa A. Ali[3], Abdel-Bary Prince[4, 5], Ayman Tolba [2] and Ayman A. Mostafa[1,6]

[1]*Department of Small Animal Surgery and Radiology, College of Veterinary Medicine, Cairo University, Giza, Egypt 12211.*
[2]*Department of Anatomy and Embryology, College of Veterinary Medicine, Cairo University, Giza, Egypt 12211.*
[3]*Department of Spinning and Weaving Engineering, Textile Research and Technology, Institute National Research Centre, Giza, Egypt 12622.*
[4]*Department of Biochemistry and Molecular Biology, College of Veterinary Medicine, Cairo University, Giza, Egypt 12211.*
[5]*Department of Biomedical Research, Armed Forces, College of Veterinary Medicine, Cairo University, Egypt 12211.*
[6]*Department of Veterinary Clinical Sciences, College of Veterinary Medicine, Western University of Health Sciences, Pomona, CA, USA.*

Abstract

THREE-DIMENSIONAL (3D) printing has proven its success in several fields, particularly in medical and educational fields. Any technique that aids in teaching anatomy is beneficial to developing a learning strategy, and creating a fundamental link to the clinical and surgical procedures. Our study aimed to create 3D models of normal and osteoarthritic canine stifles simulating the corresponding real (cadaveric) joints, as an alternative teaching strategy. The study also aimed to demonstrate the superlative between stifle radiographs, 3D-printed stifle models, and cadaveric stifle specimens in the educational procedure. Three cadaveric adult canine pelvic limbs were utilized to achieve the aims of the present study. The created 3D-printed models of normal and osteoarthritic stifles were nearly similar to the associated real joints in terms of sizes and anatomical details. The normal and diseased 3D models demonstrated similar gross anatomical structures and signs of osteoarthritis (OA), resembling the real healthy and OA stifle joints. Therefore, the digital models produced in the current study are considered virtual 3D representations of the actual stifles that are expected to be utilized as an alternative educational provision in canine orthopedics without using live animals or cadavers. The ability of stifle radiography to reveal detailed anatomical structures and OA changes that the 3D-printed models cannot (such as subchondral bone changes), makes the authors strongly suggest using both procedures. The provided 3D stifle models and radiographs are valuable for teaching comparative and applied anatomy, as well as for providing anatomical landmarks for canine stifle surgical procedures. Keywords: Meat quality, Cerium oxide NPs, Zinc oxide NPs, Epididymal sperms, Ram.

Keywords: 3D printed models, Normal, Osteoarthritis, Canine stifles, Education.

Introduction

Veterinary anatomical science remains a valuable branch of veterinary science that has a crucial role in clinical practice, surgical approaches, and diagnosis of many diseases and anomalies, as well as in academic research and teaching [1]. This is achieved via using advanced techniques consistent with MRI, CT, and radiography that allow for understanding the anatomy of the imaged region and the diagnosis of certain diseases [2,3]. Animal models, particularly those of canine species, have recently proven to be extremely useful in the study of animal diseases and potential therapeutic and surgical interventions [1]. From another perspective, studying anatomy using cadaveric materials in professional medical and

*Corresponding authors: Menna A. Nahla, E-mail: menna.atya@cu.edu.eg, Tel.: 01094726106
(Received 20 August 2024, accepted 12 November 2024)
DOI: 10.21608/EJVS.2024.313738.2324

allied health training has long been a source of contention in society [4]. The continuous challenge of innovating research and anatomy teaching and discussing ethical issues related to animal use is consistent with the concept of the "3Rs", which advocates the use of animals for teaching and research based on three principles: replacement, reduction, and refinement [5].

Recently, three-dimensional (3D) printing technology has been used in several fields, including engineering, art, industry, medicine, and educational models [6,7,8]. The 3D printing technology allows full information on the conformation and anatomy of an organ or region via the development of inexpensive representative models, enabling students and practitioners to train and qualify in areas that require prior planning [9,10]. Furthermore, junior surgeons can study surgical procedures on models to enrich their skills before the actual surgical interventions in clinical practice [11-15]. One of the most clinically important joints in canine species is the stifle joint, which is a complex, condylar, and synovial joint. Generally, the complexity of normal motion is directly related to the structures and functions of the anatomical components of the corresponding joint [16]. Thus, understanding the anatomy of normal canine stifles and the manifestation of diseased joints is important for better clinical and surgical intervention. Therefore, the present study aimed to create digitized, reliable, and representative 3D-printed models and radiography of normal and osteoarthritic canine stifles. The potential future outcome is to utilize these simulating 3D stifle models and corresponding radiographs for educational and research purposes, diagnostic and surgical interventions, as well as for the training of undergraduate and postgraduate veterinarians.

Material and Methods

Ethics approval and consent to participate

The study protocol was approved by the Scientific Committee of the Department of Surgery and Radiology and the Department of Anatomy and Embryology at the College of Veterinary Medicine, Cairo University. The same departments granted permission to access medical records, as needed. No ethical approval was required as the anatomical investigation was performed on euthanized dogs for reasons unrelated to the present study.

Radiographical investigation

Three adult mixed-breed cadaveric dogs, 1 year old, with normal pelvic limbs (n= 6 limbs) were euthanized in the Veterinary Teaching Hospital, College of Veterinary Medicine, Cairo University for reasons unrelated to the study. The enrolled pelvic limb specimens were collected within the first two hours following euthanasia. Medical records and digitized mediolateral and craniocaudal radiographs of normal and osteoarthritic stifle joints were retrieved from the database of the Small Animal Hospital, College of Veterinary Medicine, Cairo University. Radiographical interpretation was performed according to Arlene Coulson and Noreen Lewis's book (An Atlas of Interpretative Radiographic Anatomy of the Dog & Cat) [17].

Anatomical investigation

Each stifle joint was exposed according to the standard procedure of the traditional Osteo Technique via removing all soft tissues and leaving the bones and ligaments that support the joint [18]. The distal femoral and proximal tibial diaphyses of the cadaveric specimens were osteotomized using an oscillating saw to separate the stifle region from each corresponding limb. The anatomical descriptions were developed according to the International Committee on Veterinary Gross Anatomical Nomenclature [19]. After comparing the specimens and making sure that all stifles were grossly healthy, one joint was chosen for scanning to produce a normal 3D-printed model of a canine stifle.

3D-scanning and editing

The selected stifle joint was scanned using an "EINSCAN PRO 2X/2X PLUS" portable 3D scanner (SHINING 3D Tech Co., Ltd. Hangzhou, China). This structured light 3D scanner is accompanied by Solid Edge Shining 3D Edition software. The scan accuracy is up to 0.05 mm, with a speed of 20 frames/s, 1,100,000 points/s, and 100 data capture lines, and an ability to export watertight 3D models with extension STL that is directed to 3D printing. The obtained digital files were modified using "PrusaSlicer 2.5.2" software (Josef Prusa, Prague, Czech Republic) (Fig. 1A) that corrects images and edits models. Whereas Autodesk Meshmixer© (Autodesk Inc., California, United States) was used to reduce the image noise, as well as to construct the anatomical changes and deformations according to the parameters previously set by Mostafa and colleagues in 2009 to obtain a reconstructed 3-D printed model of an osteoarthritic stifle joint [20]. The size of the printed model was adjusted to be similar to the size of the utilized stifle joint specimen (Fig. 1B).

3D-printing procedure

The best images obtained after scanning and editing were printed on a 3D Printer (Prusa i3 MK3S+ 3D printer®) (Josef Prusa, Prague, Czech Republic) (Fig. 2A). In the present study, polylactic acid (PLA) thermoplastic filament was utilized with a temperature of 215° C, an internal fill of 50%, snug support, and a 0.15-mm nozzle diameter to construct accurate, detailed 3D printed models (Fig. 1A). The printing time for each model varied from 29 to 30 hours (Fig. 1B). The cost for each model was approximately $26. Thereafter, the printed models were colored with white, red, and blue acrylic paints to enhance the contrast and improve the differentiation of joint structures, thereby simulating the real stifle joints. The selected models were then photographed using a digital camera (Canon 2000D + 18-55mm IS II, Canon, Taiwan) and manipulated in the Photoshop ccx64 software (Adobe Inc.).

Results

Radiographicl anatomy of normal and osteoarthritic stifle joints were interpreted in Figures 3 and 4, respectively. The 3D models were created by the actual bone specifications including the size and shape (Fig. 5). The anatomical details associated with the scanned 3D models can then be easily identified for educational purposes. Two stifle joint models were printed: one representing a healthy joint without anatomical alterations (Fig. 6), and the second representing the gross manifestation of stifle osteoarthritis (Fig. 7). Regarding the 3D healthy stifle model (Fig. 6), the joint illustrated three long bones: distal femur and proximal tibia and fibula, in addition to the three sesamoid bones (patella and two fabellae). The simulated distal extremity of the femur showed femoral trochlea and lateral and medial femoral condyles. The two major articulations of the stifle joint, the femoropatellar and femorotibial joints, were also demonstrated. The simulated proximal extremity of the tibia appeared relatively flat and triangular, with the apex being positioned cranially. The tibial plateau was identified with the concomitant medial and lateral condyles being divided by a small non-articular strip and intercondylar eminence. The simulated fibula appeared as a long, thin bone that joins the proximal tibiofibular joint with the caudolateral portion of the lateral condyle of the proximal tibia. The patella (the largest sesamoid bone in the body) associated with the 3D model appeared as ovate as in the cadaveric stifle specimen with a pointed apex facing distally and a blunt broad base facing proximally. The two simulated fabellae appeared semicircular and located on the medial and lateral condyles of the femur. The major ligaments simulating the real ones that support the stifle joint include the patellar, collateral, cruciate, and femoropatellar ligaments. The patellar ligament runs between the patella and tibial tuberosity. The lateral collateral ligament extends from the lateral femoral epicondyle to the head of the fibula, whereas the medial collateral ligament originates from the medial femoral epicondyle and runs distally to join the joint capsule and medial meniscus and finally inserts on a rectangular area in the proximal medial tibia. The major intra-articular ligaments involved cranial and caudal cruciate ligaments. The cranial cruciate courses from the caudomedial part of the lateral femoral condyle to the cranial intercondylar area of the tibia, whereas the caudal cruciate attaches to the intercondylar area of the medial femoral condyle and courses caudodistally to end on the popliteal notch of the tibia. The medial and lateral femoropatellar ligaments run horizontally from the patella to each corresponding fabella. Tendon of the long digital extensor muscle which extends from the lateral epicondyle of the femur. The 3D-printed medial and lateral menisci appeared as biconcave C-shaped discs located between the femoral and tibial condyles. The simulated distal portion of the quadriceps muscle and corresponding tendon of insertion on the patella was also demonstrated in the 3D-printed model of the canine stifle joint.

As for the osteoarthritic 3D printed stifle model, the manifestation of osteoarthritis appeared as simulated osteophytic proliferation of the femoral trochlear groove and ridges, femoral condyles and epicondyles, intercondylar fossa, fabellae, and tibial condyles, as well as multiple erosions of the articular cartilages of the stifle joint (Fig. 7).

A comparison between stifle radiographs, 3D-printed stifle models, and cadaveric joint specimens, in terms of the flexibility of associated soft tissues, the accuracy of OA manifestation, cleanliness, cheapness, animal saving, durability, and the restrictions for handling and preservation, is illustrated in Table 1.

Discussion

Three-dimensional (3D) printing technology has been applied to a variety of medical fields, such as ophthalmology, orthopedics, neurosurgery, and dentistry. However, this technology has recently gained traction in veterinary medicine [10]. Many veterinary reports support the use of 3D models as an educational tool to minimize the use of live animals or cadavers [21-25]. As demonstrated in this study, 3D-printed models can supplement traditional anatomy classes that rely solely on cadaveric models. The 3D printing process can produce useful 3D models in a relatively quick and easy manner and at a lower cost than purchasing or producing plastinated specimens [4,27,28]. Furthermore, they can be used as references in orthopedic surgical planning studies [29]. Osteoarthritis (OA) of the canine stifle joint commonly develops secondary to cranial cruciate ligament deficiency [20,28]. The present study was the first to produce educational models of both normal and osteoarthritic stifles demonstrating the morphological manifestation of OA that appears in the diseased joints. These morphological changes were illustrated in the current study based on previous veterinary literature [20].

The technology of creating 3D models of a canine stifle has, however, not surpassed radiography in terms of costs, availability, and handling. Furthermore, the superiority of radiography is in revealing detailed anatomical structures and minimal OA changes that can not be visualized in 3D-printed models. Therefore, radiography remains the most crucial and handy diagnostic modality in canine orthopedics and soft tissues among practitioners and veterinary students. This may refer to the differences in energy absorption according to different tissue densities [30]. Compression of the infrapatellar fat pad (via increased synovial fluid), thickening of the synovial membrane/joint capsule, altered joint space, decreased or increased subchondral bone opacity, mineralization of soft tissue (enthesiophytes), intra- and peri-articular mineralization (osteophytes), joint displacement, or joint malformation can be more easily identified on stifle radiography compared to 3D stifle models [31]. Such a comparison between stifle radiography and 3D-tissue printing is not intended in the present study to utilize one over the other in the educational process or surgical planning; instead, the authors would recommend using both teaching procedures to achieve a comprehensive understanding of stifle anatomy and condition. However, ionizing radiation and associated biohazards should always be considered as potential limitations related to radiography.

The most prominent anatomical characteristics of the real bones were reliably replicated in the models generated in the present study. However, tiny anatomical structures, such as bone foramina, were not demonstrated in such models. Interestingly, it was reported that this limitation should not have an effect on the quality of printed materials and could be improved after printing the model [32]. Decreasing the accuracy of osteoarthritic manifestation associated with our 3D-printed models compared to the real diseased joints was considered another limitation, and that is because of the difficulty in obtaining specimens of diseased stifles. However, this limitation may be resolved in the future via scanning a real diseased joint using computed tomographic modality. The lack of flexibility of the associated printed ligaments and tendons, compared to the real ones, was also a limitation of the present study. Thus, using specific materials may produce structures resembling the real ligaments and tendons in terms of consistency and flexibility. Therefore, a future study should investigate 3D models of widely spread orthopedic problems in dogs, using flexible materials of different characteristics to simulate real specimens, thereby improving and facilitating the educational and surgical training processes. Speaking of surgical procedures, our current future educational study has already been designed to demonstrate the surgical approaches of different canine joints and bones using specimens preserved with a recent, long-lasting, and safe technique known as the Elnadi technique [33,34,35].

Conclusion

Three-dimensional (3-D) printing has been proven to be successful in simulating the normal canine stifle as well as the osteoarthritic joint. The anatomical components, as well as the manifestation of stifle osteoarthritis, can be demonstrated in 3D printed models without utilizing euthanized dogs (cadavers). The proposed 3D printed model of a canine stifle can be valuable as an educational tool for studying the normal stifle and comparing it with the osteoarthritic joint. Therefore, simulated 3D models of a canine stifle are expected to be of value for educational and research purposes, diagnostic and surgical interventions, and consequently for training of undergraduate and postgraduate veterinarians. However, few minor normal anatomical features and abnormalities associated with healthy and osteoarthritic stifle joints, respectively, did not appear in our printed models and cadaveric specimens as much as they would do in stifle radiography (i.e. intercondylar eminence, subchondral sclerosis or cysts, enthesiopathy, and joint effusion). Thus, stifle radiography, along with 3D-printed stifle models, are recommended to be utilized to achieve the teaching, research, and diagnostic objectives proposed in the present study.

Acknowledgments

The authors would like to thank all technicians in the Veterinary Teaching Hospital at Cairo University, for their assistance during the study.

Funding statement

The study was funded by the authors only.

Declaration of Conflict of Interest

The authors declare no conflict of interest related to this review article.

Ethical of approval

Not applicable.

TABLE 1. Comparison between 3D-printed stifle model and cadaveric stifle specimen.

Variable	Stifle radiographs	3D-printed stifle model	Cadaveric stifle specimen
Flexibility of soft tissues	**No**	**No**	**Yes**
Accuracy of OA manifestation	**Yes**	**No**	**Yes**
Cleanliness	**Yes**	**Yes**	**No**
Cheapness	**Yes**	**Yes**	**No**
Animal saving (3Rights)	**Yes**	**Yes**	**No**
Restrictions for preservation	**No**	**No**	**Yes**
Restrictions for handling	**Yes**	**No**	**Yes**
Durability	**Yes**	**Yes**	**No**

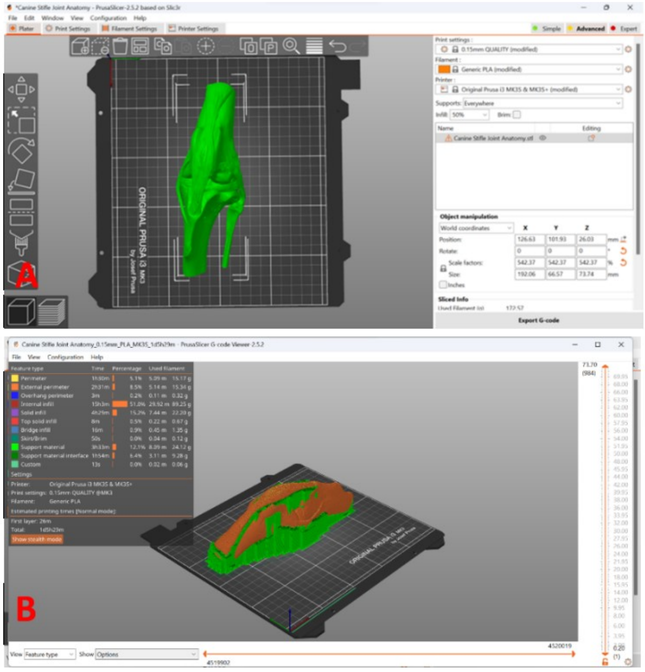

Fig. 1. Processing of a stifle model using the Prusa slicer software (A), and demonstration of the final G code prepared for the printing process.

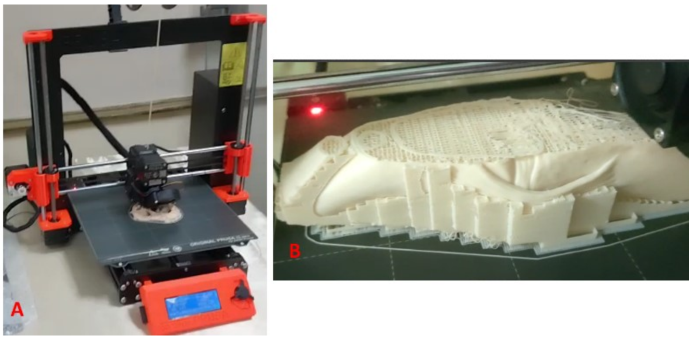

Fig. 2. The mechanism of printing illustrating the Prusa 3D Printing machine (A), and construction of the 3D model on the machine (B).

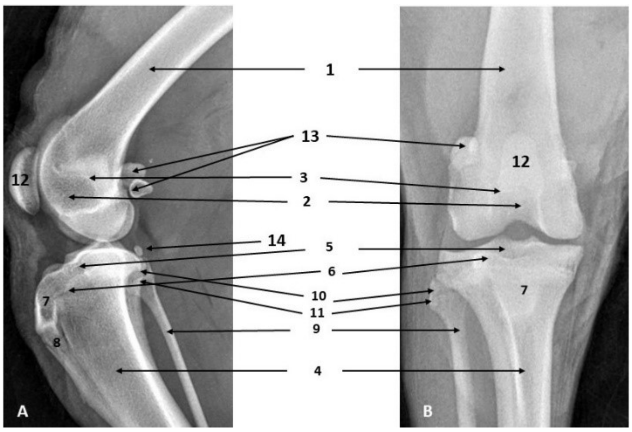

Fig. 3. Lateral (A) and craniocaudal (B) views of normal canine stifle joint radiography illustrating; femur (1), distal femoral epiphysis (2), distal femoral growth plate (remnant) (3), tibia (4), proximal tibial epiphysis (5), proximal tibial growth plate (remnant) (6), tibial tuberosity (7), tibial tuberosity growth plate to diaphysis (closing) (8), fibula (9), proximal epiphysis of fibula (10), proximal growth plate of fibula (11), patella(12), fabellae of gastrocnemius muscle (13), fabella of popliteus muscle (14).

Fig. 4. Lateral (A) and craniocaudal (B) views of an diseased (osteoarthritic) canine stifle joint radiography illustrating; (Patellar, Proximal tibial periarticular, Sesamoid bone periarticular, and Condylar periarticular) osteophytosis, (Femoral intercondylar notch, Proximal tibial subchondral, and Femoral subchondral) sclerosis, Subchondral femoral and tibial cystic lucency, and Capsular thickening.

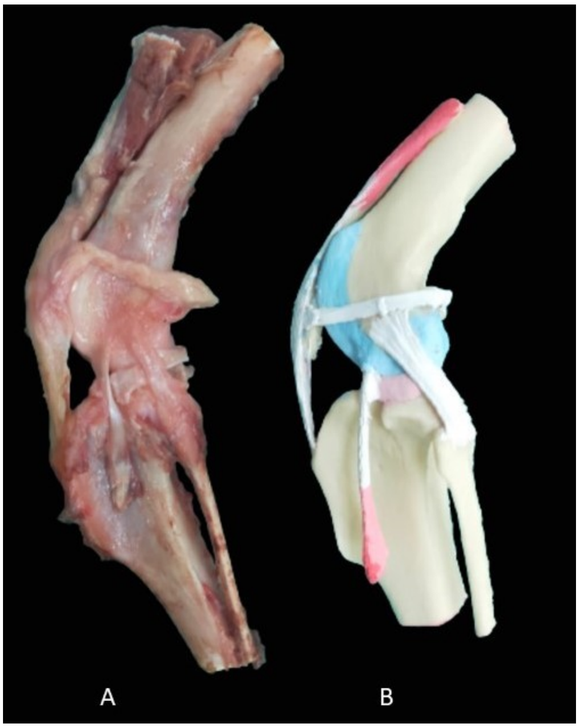

Fig. 5. Lateral views of a cadaveric normal canine stifle (A) and the corresponding 3D-printed model of a normal stifle joint (B).

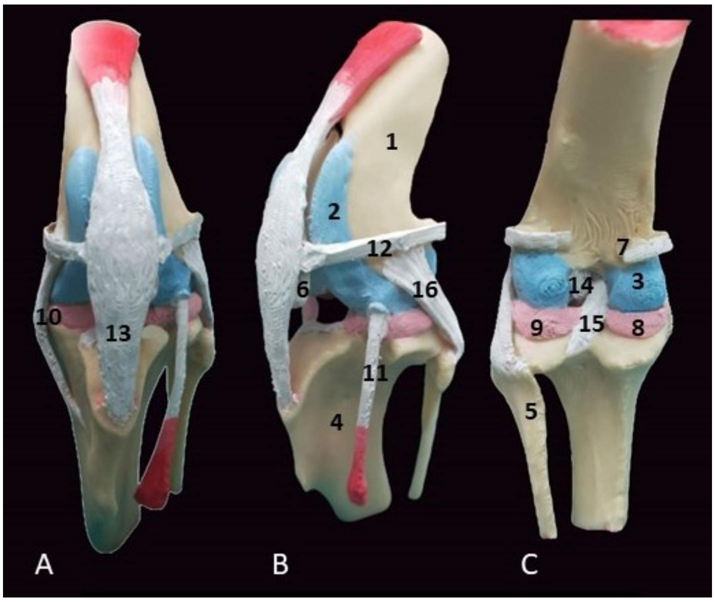

Fig. 6. Cranial (A), lateral (B), and caudal (C) views of a 3D-printed model of a normal canine stifle illustrating; femur (1), lateral femoral trochlea (2), medial femoral condyle (3), tibia (4), fibula (5), patella (6), fabella (7), medial menisci (8), lateral menisci (9), medial collateral ligament (10), tendon of long digital extensor muscle (11), femoropatellar ligament (12), patellar ligament (13), cranial cruciate ligament (14), caudal cruciate ligament (15), and lateral collateral ligament (16).

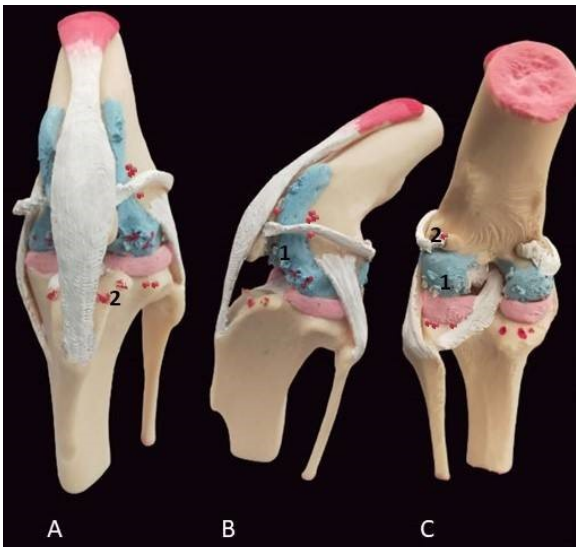

Fig.7. Cranial (A), lateral (B), and caudal (C) views of a 3D-printed model of an osteoarthritic canine stifle illustrating; erosions of the articular cartilages (1), and osseous proliferation within the joint (red spots) (2).

References

1. Bergamino, C. Etienne, A. and Busoni, V. Developing A Technique for Ultrasound-Guided Injection of The Adult Canine Hip. *Vet. Radiol. Ultrasound.*, **56**(4), 456-461 (2015). doi: 10.1111/vru.12242.

2. Jepsen-Grant, K., Pollard, R.E. and Johnson, L.R. Vertebral Heart Scores in Eight Dog Breeds. *Vet. Radiol. Ultrasound.*, **54**(1), 3-8 (2013). doi: 10.1111/j.1740-8261.2012.01976.x.

3. Paredes, M.S. and Martínez, E. S. Anatomical and Histological Description of the Right Atrioventricular Valve of the Canine Heart (Canis lupus familiaris)". *EC Clinical & Experimental Anatomy*, **2**, 185-191 (2019).

http://dx.doi.org/10.17582/journal.aavs/2021/9.5.754.760

4. McMenamin, P.G., Quayle, M.R., McHenry, C.R. and Adams, J.W. The production of anatomical teaching resources using three-dimensional (3D) printing technology. *Anat. Sci. Educ.*, **7**(6), 479–486 (2014). DOI: 10.1002/ase.1475

5. Pereira, G.G., Diéguez, J., Demirbas, Y.S. and Menache, A. Alternatives to animal use in veterinary education: A growing debate. *Ankara. Univ. Vet. Fak. Derg.,* **64**(3), 235–239 (2017). DOI: 10.1501/Vetfak_0000002804

6. Reis, D.A.L., Gouveia, B.L.R., Alcântara, B.M., Saragiotto, B.P., Baumel, É.E.D., Ferreira, J.S., Rosa Júnior, J.C., Oliveira, F.D., Santos, P.R.S. and Assis Neto, A.C. Biomodelos ósseos produzidos por intermédio da impressão 3D: Uma alternativa metodológica no ensino da anatomia veterinária. *Revista. de Graduação USP.*, **2**(3), 47–53 (2017). DOI: 10.4067/S0717-95022019000300838

7. Alcântara, B.M., Silveira, E.E., Pereira, H.C.S., Lisboa Neto, A.F.S., Santos, A.C. and Assis Neto, A.C. Digitalização e impressão tridimensional como uma ferramenta para estudo anatômico e ortopédico dos ossos da pelve e longos do membro pélvico de cães. *Acta. Sci. Vet.*, **47**(1), 1653 (2019). DOI: 10.22456/1679-9216.91076

8. Hackmann, C.H., Dos Reis, D.A.L. and Assis Neto, A.C. Digital revolution in veterinary anatomy: Confection of anatomical models of canine stomach by scanning and three-dimensional printing (3D). *Int. J. Morphol.*, **37**, 486–490 (2019). http://dx.doi.org/10.4067/S0717-95022019000200486.

9. Lim, K.H.A., Loo, Z.Y., Goldie, S.J., Adams, J.W. and McMenamin, P.G. Use of 3D printed models in medical education: a randomized control trial comparin 3D prints versus cadaveric materials for learning external cardiac anatomy. *Anat. Sci. Educ.*, **9**(3), 213–221 (2017). DOI: 10.1002/ase.1573.

10. Ribeiro Gaspar, B. and de Assis Neto, A.C. Three-dimensional printing educational anatomical model of the patellar luxation in dogs. *PLoS ON,* **16**(7), e0255288 (2021). https://doi.org/10.1371/journal.pone.0255288

11. Liaw, C.Y. and Guvendiren M. Current and emerging applications of 3D printing in medicine. *Biofabrication*, **9**(2), 204102 (2017). https://doi.org/10.1088/1758-5090/aa7279.

12. Wong, K.C. 3D-printed receiver-specific applications in orthopedics. *Orthopedic Research and Reviews*, **8**, 57–66 (2016). https://doi.org/10.2147/ORR.S99614.

13. Winer, J.N., Verstraete, F.J., Cissell, D.D., Lucero, S., Athanasiou, K.A. and Arzi, B. The application of 3- dimensional printing for preoperative planning in oral and maxillofacial surgery in dogs and cats. *J. Vet. Surg.*, **46**(7), 942–951 (2017). doi: 10.1111/vsu.12683.

14. Lima, L.F.S., Barros, A.J.B., Martini, A.C., Stocco, M.B., Kuczmarski, A.H. and Souza, A. Photogrammetry and 3D prototyping: A low-cost resource for training in veterinary orthopedics. *Ciência. Rural.,* **49**(12), e20180929 (2019). DOI: 10.1590/0103-8478cr20180929

15. Altwal, J. Utilizing Best Practices of 3D-Modeling and Printing in Veterinary Medicine to Analyze Elbow Incongruity of a Maltese Canine. *Student Scholar Symposium Abstracts and Posters. Orange, California*, 382 (2020).

16. Carpenter, D.H. and Cooper, R.C. Mini Review of Canine Stife Joint Anatomy. *Anat. Histol. Embryol.*, **29**(6), 321–329 (2000). DOI: 10.1046/j.1439-0264.2000.00289.x

17. Arlene, C. and Noreen, L. An Atlas of Interpretative Radiographic Anatomy of the Dog & Cat, (2002). DOI:10.1002/9780470690260

18. Rodrigues, H. Te´cnicas anatoˆmicas. 3. Ed, Vito´ria: Arte Visual, 229 (2005).

19. Nomina Anatomica Veterinaria. Sixth Edition, International Committee on Veterinary Gross Anatomical Nomenclature (I.C.V.G.A.N.), Published by the Editorial CommitteeHanover (Germany), Ghent (Belgium), Columbia, MO (U.S.A.), World Association of Veterinary Anatomists (W.A.V.A.), (2017).

20. Mostafa, A.A., Griffon, D.J., Thomas, M.W., Constable, P.D. Morphometric characteristics of the pelvic limbs of Labrador Retrievers with and without cranial cruciate ligament deficiency. *Am. J. Vet. Res.*, **70**(8), 498–507 (2009). DOI: 10.2460/ajvr.70.4.498

21. Hespel, A.M., Wilhite, R. and Hudson, J. Invited review- Aplications for printers in veterinary medicine. *Vet. Radiol. Ultrasound.*, **55**(4):347–58 (2014). DOI: 10.1111/vru.12176

22. Suñol, A., Aige, V., Morales, C., Lo´pez-Beltran, M., Feliu- Pascual, A.L. and Puig, J. Use of Three-Dimensional Print- ing Models for Veterinary Medical Education: Impact on Learning How to Identify Canine Vertebral Fractures. *J.V.M.E.,* **46**(4):523–532 (2019). DOI: 10.3138/jvme.0817-109r

23. Silveira, E.E., Lisboa Neto, A.F.S., Pereira, H.C.S., Ferreira, J.S., Santos, A.C., Siviero, F., da Fonseca, R. and de Assis Neto, A.C. Canine Skull Digitalization and Three-Dimensional Printing as an Educational Tool for Anatomical Study. *J.V.M.E.*, **21**(6), e20190132 (2020). DOI: 10.3138/jvme-2019-0132

24. Chen, S., Pan, Z., Wu, Y., Gu, Z., Li, M., Liang, Z., Huijuan, Z., Yong, Y., Wuyang, S., Zhen, S., Jun, Z. and Hui, P. The role of three-dimensional printed models of skull in anatomy education: a randomized controlled trial. *Scientific Reports,* **7**, 1–11 (2017). DOI: 10.1038/s41598-017-00647-1

25. Cone, J.A., Martin, T.M., Marcellin-Little, D.J., Harrysson, O.L.A. and Griffith, E.H. Accuracy and repeatability of long-bone replicas of small animals fabricated by use of low-end and high-end commercial three-dimensional printers. *Am. J. Vet. Res.*, **78**(8), 900–905 (2017). DOI: 10.2460/ajvr.78.8.900

26. Li, F., Liu, C., Song, X., Huan ,Y., Gao, S. and Jiang, Z. Production of accurate skeletal models of domestic

animals using three-dimensional scanning and printing technology. *Anat. Sci. Educ.*, **11**(1), 73–80 (2018). DOI: 10.1002/ase.1725

27. Tack, P., Victor, J., Gemmel, P. and Annemans, L. 3D-printing techniques in a medical setting: a systematic literature review. *BioMedical Engineering Online*, **15**(1), 115 (2016). https://doi.org/10.1186/s12938-016- 0236-4

28. Lohmander, L.S., Englund, P.M., Dahl, L.L. and Roos, E.M. The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. *A.J.S.M.*, **35**(10), 1756–69 (2007). https://doi.org/10.1177/0363546507307396

29. Schoenfeld-Tacher, R.M., Horn, T.J., Scheviak, T.A., Royal, K.D. and Hudson, L.C. Evaluation of 3D Additively Manufactured Canine Brain Models for Teaching Veterinary Neuroanatomy. *J.V.M.E.*, **44**(10), 612–619 (2017). https://doi.org/10.3138/jvme.0416-080R

30. Marino, D.J. and Loughin, C.A. Diagnostic Imaging of the Canine Stifle: A Review. *J. Vet. Surg.*, **39**(3), 284–295 (2010). DOI:10.1111/j.1532-950X.2010.00678.x

31. Thrall, D.E. Textbook of Veterinary Diagnostic Radiology (ed 4). Philadelphia, PA, W. B. Saunders, (2002).

32. Thomas, D.B., Hiscox, J.D., Dixon, B.J. and Potgieter, J. 3D scanning and printing skeletal tissues for anatomy education. *J. Anat.*, **229**(3), 473–481 (2016). DOI: 10.1111/joa.12484

33. Elnady, F.A. The Elnady Technique: An innovative, new method for tissue preservation. *ALTEX*, **33**(3), 237–242 (2016). https://doi.org/10.14573/altex.1511091

34. Tolba, A., Fargali, H.A. and Daghash, S.M. Gross anatomical and radiographic findings of museum preserved buffalo calves conjoined twin for learning purposes. *J. Adv. Vet. Anim. Res.*, **7**(1), 56-61 (2020). doi: 10.5455/javar.2020.g393

35. El-Shafey, A., Magdy, Y., Hamad A, et al. Modified form of the Elnady Technique for tissue preservation. *Benha. Vet. Med. J.*, **41**(2), 56-60 (2022). DOI: 10.21608/bvmj.2021.95641.1470

تفوق استخدام كلا من النماذج المطبوعة ثلاثية الأبعاد وصور الاشعة الرقمية لمفاصل الركبة الطبيعية والمصابة على استخدام عينات الجيفة كوسائل تعليمية بديلة في جراحة عظام الكلاب

منة الله عطية نحلة*[1] ، يارا سيد أبو العلا[2] ، محمد سعيد عامر[1] ، مروة علي[3] ، عبد الباري برنس [4،5] ،أيمن طلبة[2] وأيمن مصطفي[1، 6]

[1] قسم الجراحة والتخدير والاشعة - كلية الطب البيطري- جامعة القاهرة - مصر.

[2] قسم التشريح والأجنة - كلية الطب البيطري- جامعة القاهرة - مصر.

[3] قسم هندسة الغزل والنسيج- بحوث تطوير النسيج- المركز القومي للبحوث- مصر.

[4] قسم الكيمياء الحيوية والبيولوجيا الجزيئية، كلية الطب البيطري- جامعة القاهرة- مصر.

[5] قسم البحوث الطبية الحيوية، القوات المسلحة - كلية الطب البيطري- جامعة القاهرة - مصر.

[6] قسم العلوم الطبية البيطرية - كلية الطب البيطري- جامعة ويسترن – كاليفورنيا- الولايات المتحدة الامريكية.

الملخص

أثبتت الطباعة الثلاثية الأبعاد نجاحها في عدة ميادين، لا سيما في المجالين الطبي والتربوي.حيث أن أي تقنية تساعد في تدريس علم التشريح مفيدة لوضع استراتيجية للتعلم، ولإقامة صلة أساسية بالإجراءات التعليمية والجراحية. واستهدفت دراستنا وضع نماذج ثلاثية الأبعاد لمفاصل الركبة الطبيعية والمصابة التي تحاكي المفاصل الحقيقية المناظرة، كاستراتيجية تعليمية بديلة. واستهدفت الدراسة أيضاً توضيح الفارق بين مفصل الركبة في التصوير الإشعاعي، والنماذج ذات الأبعاد الثلاثية ، وعينات الجثث في الإجراءات التعليمية. وقد استُخدمت ثلاثة أرجل خلفية من أجل تحقيق أهداف هذه الدراسة . وكانت النماذج المطبعية الثلاثية الأبعاد للمفاصل الطبيعية والمصابة شبه مماثلة للمفاصل الحقيقية المرتبطة بها من حيث الأحجام والتفاصيل التشريحية. وأظهرت النماذج العادية والمرضية الثلاثية الأبعاد وجود هياكل تشريحية تشريحية إجمالية مماثلة وعلامات على التهاب المفصل(OA) ، مما يشبه المفاصل الصحية الحقيقية والمفاصل الخانقة. ولذلك، فإن النماذج المطبوعة التي أنتجتها الدراسة الحالية تعتبر صوراً افتراضية ثلاثية الأبعاد للمفاصل الفعلية التي يتوقع أن تستخدم كتوفير تعليمي بديل لدراسة عظام الكلاب دون استخدام الحيوانات الحية أو الجثث. وقدرة الرسم الإشعاعي على الكشف عن الهياكل التشريحية التفصيلية والتغييرات في الزراعة العضوية التي لا تستطيع النماذج ذات الأبعاد الثلاثة (مثل التغيرات في العظام الفرعية)، تجعل المؤلفين يقترحون بقوة استخدام كلا الإجراءين. يعد كلا من النماذج المطبوعة الثلاثية الأبعاد والتصوير الإشعاعي ذو قيّمة في تدريس علم التشريح المقارن والتطبيقي، فضلا عن توفير معالم تشريحية للإجراءات الجراحية المتعلقة بمفصل الركبة في الكلاب.

الكلمات الدالة: نماذج مطبوعة ثلاثية الأبعاد، الطبيعي ، التهاب مفصلي، مفصل الركبة ، التعليم.