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The Role of 3D Laser Scanning and Printing in Veterinary Anatomy Education: A Study on Feline Scapula and Humerus

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ABSTRACT

Background: The study explores integrating three-dimensional (3D) printing technology into veterinary anatomy education, focusing on the development and application of feline scapula-humerus models. Precise anatomical replicas were produced using 3D scanning and printing process to support hands-on learning experiences.

Methods: A controlled experiment was conducted with 102 first-year veterinary students, divided into experimental and control groups. The experimental group used 3D-printed models, while the control group utilized real bones for anatomy lessons.

Result: Comparative assessment through bell-ringer examinations demonstrated no significant difference in performance between the groups, validating the effectiveness of 3D-printed models as educational tools. The study highlights the advantages of 3D technology, including cost-effectiveness, reusability and its potential to overcome limitations associated with traditional teaching materials. This research contributes to the growing evidence supporting 3D printing as a transformative tool in enhancing spatial understanding and practical knowledge in veterinary and medical education.

Key words: 3D scanning, Bones, Cat bones, Veterinary anatomy education.

INTRODUCTION

The rapid advancement of technology has brought significant changes to the field of education. In this context, 3D printing technology has emerged as a prominent tool for the implementation of innovative education methods. By transforming digitally designed objects into physical prototypes, 3D printing enables the concretization of abstract concepts (Karaduman, 2017). This technology fosters students' imagination, enhances critical thinking and improves problem-solving skills (Kökhan and Özcan, 2018).

Advanced imaging and 3D reconstruction techniques have proven highly effective in the anatomical study of large avian species such as the ostrich, enabling detailed visualization of musculoskeletal structures and offering valuable insights for veterinary education and biomechanical research (Zhang *et al.,* 2016)

The integration of three-dimensional (3D) printing technology into veterinary anatomy education has revolutionized traditional teaching methods by providing highly accurate, cost-effective and customizable models. This advancement not only enhances students' spatial understanding and engagement but also addresses challenges such as limited access to cadaveric specimens, making it a valuable tool for modern veterinary training (Lim *et al.,* 2015; Ye *et al.,* 2023).

The integration of artificial intelligence (AI) and three-dimensional (3D) printing technologies into veterinary education has revolutionized traditional teaching methodologies by enhancing diagnostic accuracy, facilitating surgical planning and improving anatomical visualization. In particular, the combination of AI-based image processing and 3D modeling offers a cost-effective and accessible alternative to traditional cadaver-based learning, thereby addressing challenges related to resource availability and ethical concerns in veterinary anatomy education (Lim *et al.,* 2015; Suñol *et al.,* 2018).

The integration of artificial intelligence (AI) and three-dimensional (3D) printing technologies into veterinary anatomy education has significantly transformed traditional teaching methods. AI-driven anatomical analysis enhances diagnostic accuracy and personalized learning, while 3D-printed models offer cost-effective, reusable and anatomically precise representations of skeletal structures. These innovations address challenges such as limited access to cadaveric materials and improve students' spatial understanding and engagement in practical learning (Choudhary *et al.,* 2025).

3D printing in education has enriched various disciplines, including mathematics, geography, art and biology, through diverse applications. For instance, designing and producing 3D objects in mathematics, creating relief models in geography, generating original

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objects in art, and producing molecular models in biology have made learning more interactive and engaging for students (Horvath, 2014).

Three-dimensional (3D) reconstruction techniques have proven to be valuable tools in veterinary anatomical studies, enabling detailed morphometric analysis and enhancing anatomical understanding across various species (Ozkadif *et al.,* 2018). These methods, which have been successfully applied to thoracic structures in wild animals such as the mongoose, provide a foundation for implementing similar approaches in veterinary education using 3D-printed skeletal models. Integrating of 3D printing technology into anatomy education has addressed critical challenges, such as limited access to cadaveric materials and financial constraints. It also provides highly accurate, customizable and durable models that enhance students' learning experiences (AbouHashem *et al.,* 2015). Moreover, 3D digitization and prototyping technologies offer innovative methods to create highly detailed anatomical models, significantly enhancing the learning experience by enabling precise visualization of complex structures (Lozano *et al.,* 2017).

In veterinary education, 3D printing has played a crucial role in anatomy and surgical training. This technology provides significant advantages, such as replicating rare anatomical specimens and producing anatomical models suitable for large class sizes (Sezer and Şahin, 2016). Additionally, patient-specific models created with 3D printing assist in surgical planning and execution (Rengier *et al.,* 2010).

Three-dimensional (3D) anatomy models have significantly transformed medical and allied health education by addressing critical challenges such as reduced anatomy teaching hours and limited access to cadaveric specimens (Azer and Azer, 2016). These models enable students to visualize spatial relationships among anatomical structures, which is essential for understanding complex anatomical dynamics and functions (Nicholson *et al.,* 2016). Unlike traditional 2D materials, 3D models provide interactive and immersive learning experiences, enhancing students' visuospatial abilities and knowledge retention (Ruisoto *et al.,* 2016). This transformative approach bridges the gap between theoretical knowledge and practical application, making it a preferred method in modern anatomy education.

Three-dimensional (3D) printing technology has emerged as a groundbreaking innovation in medical education, providing anatomically precise, cost-effective, and reusable models. Lim *et al.* (2015) demonstrated that 3D-printed models offer superior spatial visualization capabilities, enabling students to grasp complex anatomical relationships more effectively than traditional methods. These models allow for hands-on interaction, which is particularly beneficial in understanding intricate structures, thereby enhancing both comprehension and retention of knowledge.

Three-dimensional (3D) reconstruction of skeletal structures, such as the scapula, has been shown to enhance morphological understanding in veterinary anatomical research, offering detailed insights into species-specific adaptations (Ozkadif *et al*., 2019).

This study investigates the effectiveness of 3D-printed feline skeletal models in veterinary education, produced using 3D laser scanners and printers. The central hypothesis of this research is that osteological materials produced with 3D printers can be as effective as real specimens in educational contexts.

MATERIALS AND METHODS

This study aimed to model feline skeletons using 3D printing technology and evaluate their effectiveness in veterinary education. This thesis study was conducted at Erciyes University Faculty of Veterinary Medicine between the years 2022 and 2023. The materials and methods employed in this research are summarized as follows:

Animal material

The skeletal material was sourced from the Anatomy Laboratory at Erciyes University Faculty of Veterinary Medicine. The skeleton was prepared for analysis by separating and numbering all bones. Various cleaning processes, including washing, sanding and brushing, were performed to make the bones suitable for scanning (Fig 1).

Scanning

The bones were digitized using a Creality 3D Scanner. The scanning process was conducted in a dark environment to enhance the clarity of the bone shapes. Appropriate supports were used to ensure accurate detection of details. Rotating tables with varying speeds were employed to achieve detailed scans of the bone surfaces (Fig 2).

Printing

The digital scans were converted into STL file format and used to produce physical bone models with 3D printers (Fig 3). PLA filament, known for its durability and cost-effectiveness, was used as the printing material. The Creality CR-06-S printer was utilized for printing. After multiple trials, optimal printing parameters were identified, as shown in Table 1.

Training, examination and evaluation

To assess the effectiveness of 3D-printed bones in education, a study was conducted with first-year veterinary students. These students were selected because they took the anatomy course for the first time. 102 students were evenly divided into two groups based on their academic rankings.

Training process

The training was divided into two phases: theoretical and practical. In the theoretical phase, students were taught

the detailed anatomy of the scapula and humerus bones. The experimental group worked with 3D-printed bones in the practical phase, while the control group used real bones. Both groups studied the materials independently in separate areas of the laboratory. Examination Process At the end of the training, students underwent a bell-ringer examination using real bones. The exam included classical anatomy questions, such as identifying the species of the scapula and humerus bones, determining whether they were left or right and naming specific anatomical structures shown on the bones. The exam results of the experimental and control groups were compared to evaluate the effectiveness of the 3D-printed materials. The primary goal was to determine whether students who used 3D-printed materials performed comparably to those who studied with real bones.

RESULTS AND DISCUSSION

3D Scanning Results

The scapula and humerus bones of a cat were scanned under controlled conditions. During the scanning process, care was taken to ensure that the scanner accurately captured the anatomical prominences and foramina on the bone surfaces (Fig 4).

3D Printing results

The scanned bones were successfully printed (Fig 5). However, the printed bones exhibited some differences from the original bones due to the supports generated during the printing process. These supports, along with residual filament fragments on the surface, were cleaned to restore the intended shape.

Assessment and evaluation results

The average exam scores of the control and experimental groups were calculated as follows:

- Control group mean exam score: 74.90.
- Experimental group mean exam score: 75.29.

Based on this analysis, the experimental group's average exam score was slightly higher than that of the control group. These results support the hypothesis of the study, demonstrating that application-based lessons using 3D- printed materials are as effective as those conducted with real anatomical specimens.

In summary, 3D-printed products proved to be an equally effective teaching tool compared to real materials for practical anatomy lessons.

This study aimed to demonstrate the feasibility of technologically produced educational materials and their success in student applications. As noted by Peker *et al*. (2014), the growing emphasis on self-directed and personalized learning systems has increased the need for such educational tools. The feline skeletal bones produced in this study are expected to contribute significantly to student learning in this context.

As reported in the literature, the STL format, which is commonly used in 3D scanning and printing and ensures long-term preservation of objects, was also adopted in this study (Kuzu Demir *et al.,* 2016). While it is often stated that obtaining materials using 3D printers is a rapid process (Kökhan and Özcan, 2018), the two-hour printing time for a single bone may seem lengthy to those unfamiliar with the technology. However, when compared to the time, energy, and effort required to create traditional anatomical teaching materials, it is clear that 3D printing significantly reduces production time.

The findings of this study align with Ye *et al*. (2023), demonstrating that 3D-printed models significantly enhance anatomical learning outcomes and satisfaction rates among students. Despite this, challenges such as production costs and material durability need to be addressed for broader applications.

The study also employed PLA filament, recognized in the literature as the most affordable and commonly used 3D printing material (Küçüksolak, 2019). PLA's non-toxic nature makes it highly advantageous for production and subsequent usage in educational settings. Furthermore, our findings corroborate the advantages highlighted by Suñol *et al*. (2018), showing that 3D-printed models significantly enhance students' visuospatial understanding and practical anatomical knowledge, serving as a valuable complement to traditional cadaver-based methods.



Fig 1: Cleaning and numbering of the skeleton.

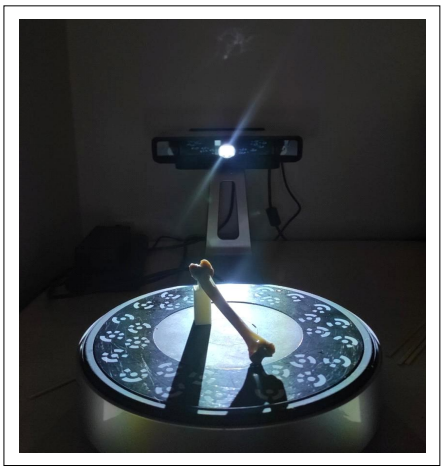


Fig 2: Scanning process.



Fig 3: Printing process - humerus.

In the literature, it is suggested that larger materials may need to be printed in parts and assembled afterward, depending on the build plate size of the printer (Küçüksolak, 2019). In this study, due to the small size of feline bones, this was not an issue. The printer used had a build plate size of 24×24×27 cm, allowing the feline bones to be printed as single pieces.

Our findings also support the conclusions of (Lozano *et al*., 2017), emphasizing that 3D-printed anatomical models are cost-effective and durable alternatives to cadaveric specimens. They also foster a deeper understanding of anatomical details among students. Additionally, this study aligns with AbouHashem *et al*. (2015), affirming that 3D-printed models not only complement traditional resources but also improve the accessibility and engagement of learners in anatomy education.

Our findings align with previous studies emphasizing the benefits of AI-assisted anatomical visualization and 3D-printed models in veterinary education (Ye *et al.,* 2023; Lim *et al.,* 2015). By providing precise and highly detailed anatomical structures, these technologies not only enhance students' spatial understanding but also contribute to improved learning outcomes and clinical preparedness. However, while AI-driven 3D modeling is a promising educational tool, further research is needed to optimize its integration into veterinary curricula and to evaluate its long-term impact on practical skill acquisition.

Findings of our study support previous research highlighting the benefits of AI-assisted anatomical visualization and 3D printing in veterinary education (Choudhary *et al.,* 2025; Lim *et al.,* 2015). Similar to prior studies, our results demonstrate that 3D-printed anatomical models can be as effective as traditional cadaver-based learning in enhancing student comprehension and exam performance. While these technologies present numerous advantages, their successful integration into veterinary curricula requires addressing challenges such as data accuracy, model refinement, and ensuring hands-on clinical training remains an essential component of education.

The findings of our study align closely with those reported by Lim *et al*. (2015), who highlighted the educational effectiveness of 3D-printed anatomical models in enhancing spatial understanding and knowledge retention. Similar to their observations, our results demonstrated that students using 3D-printed feline skeletal models performed comparably to those utilizing real specimens in assessments. This supports the notion that 3D printing technology is not only a *via*ble alternative to traditional cadaveric materials but also a valuable tool for fostering engagement and confidence in learners. Moreover, the customizable nature of 3D models, as emphasized in both studies, allows for tailored educational approaches, addressing the specific needs of students and reducing logistical challenges associated with traditional teaching methods. These combined findings underline the transformative potential of 3D printing in anatomy education, particularly in veterinary settings.

Our findings align with previous studies (Suñol *et al.,* 2018; Lim *et al.,* 2015), demonstrating that 3D-printed anatomical models can be as effective as traditional cadaver-based teaching methods in veterinary anatomy education. While these models improve accessibility and learning outcomes, their full integration into the curriculum requires further exploration to assess their long-term impact on practical skill development and clinical applications.

The effectiveness of 3D anatomy models in enhancing educational outcomes has been consistently highlighted in the literature. Studies show that these models improve spatial understanding, particularly in identifying and analyzing complex anatomical structures (Ruisoto *et al.,* 2016). Our findings align with those of Nicholson *et al*. (2016), who reported that students trained with 3D models

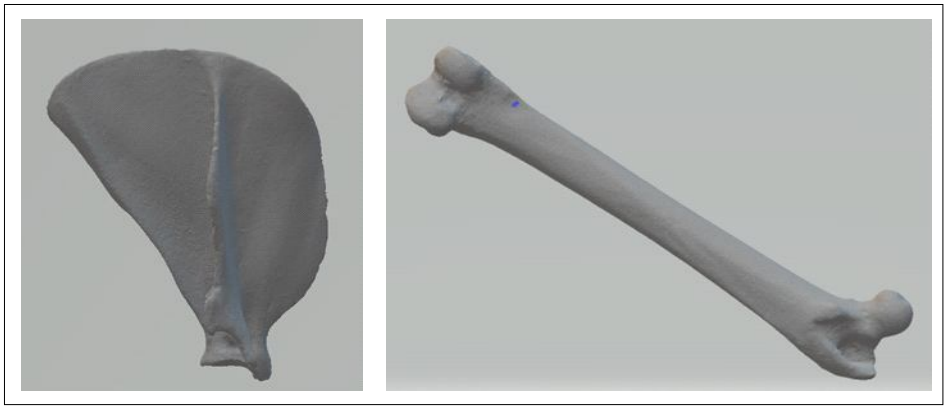


Fig 4: Scanning result of feline scapula-humerus.

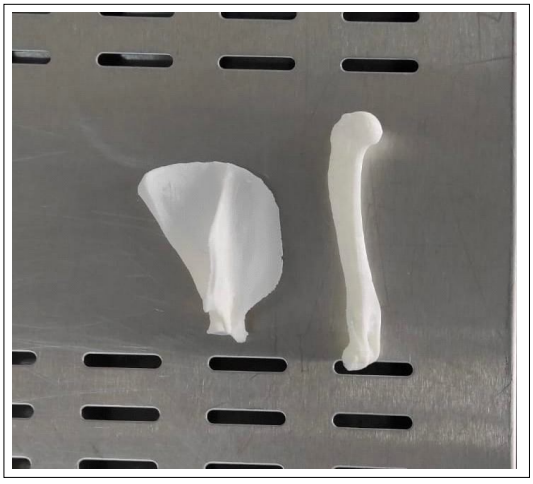


Fig 5: 3D printout of feline scapula-humerus.

Table 1: Printing parameters.

Parameter	Value
Layer height	0.2 mm
Infill density	20%
Printing speed	50 mm/s
Support structure	Normal
Support interface type	Grid
Printing temperature	200°C

demonstrated higher engagement and satisfaction levels compared to traditional methods. However, as emphasized by Azer and Azer (2016), the long-term impact of 3D models on clinical skills development and their integration into broader curricula warrants further investigation. This underscores the importance of adopting innovative teaching tools while addressing limitations such as cost and accessibility to maximize their potential in anatomy education.

CONCLUSION

This study's hypothesis was that osteology education using 3D scanning and printing technologies in veterinary medicine would be as effective as education using real materials. The lack of a significant difference in exam performance between students using 3D-printed bones and those using real bones confirms the hypothesis, demonstrating that 3D-printed models are effective educational tools for veterinary anatomy.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the University of Animal Care Committee.

Ethical statement

None.

Conflict of interest statement

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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