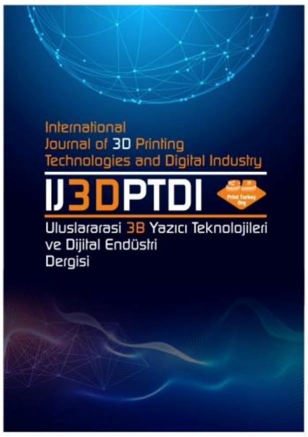


ULUSLARARASI 3B YAZICI TEKNOLOJİLERİ VE DİJİTAL ENDÜSTRİ DERGİSİ

INTERNATIONAL JOURNAL OF 3D PRINTING TECHNOLOGIES AND DIGITAL INDUSTRY

ISSN:2602-3350 (Online)

URL: https://dergipark.org.tr/ij3dptdi

USE OF THREE DIMENSIONAL (3D) PRINTED MODELS OF SHEEP BRAIN IN ONLINE VETERINARY ANATOMY EDUCATION

Yazarlar (Authors): Derya Haroglu*, Buket Iscan, Ayhan Duzler

Bu makaleye şu şekilde atıfta bulunabilirsiniz (To cite to this article): *Haroglu D., Iscan B., Duzler A., "Use of Three Dimensional (3D) Printed Models of Sheep Brain In Online Veterinary Anatomy Education" Int. J. of 3D Printing Tech. Dig. Ind., 6(3): 370-381, (2022).*

DOI: 10.46519/ij3dptdi.1113805

Araştırma Makale/ Research Article

Erişim Linki: (To link to this article): https://dergipark.org.tr/en/pub/ij3dptdi/archive

USE OF THREE DIMENSIONAL (3D) PRINTED MODELS OF SHEEP BRAIN IN ONLINE VETERINARY ANATOMY EDUCATION

Derya Haroglu[a]*, Buket Iscan[a], Ayhan Duzler[b]

[a]Erciyes University, Engineering Faculty, Industrial Design Engineering Department, TURKEY
[b]Erciyes University, Faculty of Veterinary Medicine, TURKEY

* *Corresponding Author: dharoglu@erciyes.edu.tr*

(**Received:** 08.05.2022; **Revised:** 10.10.2022; **Accepted:** 10.11.2022)

ABSTRACT

Three dimensional (3D) printing technology in veterinary anatomy education is an evolving area providing accurately, rapidly, and reproducibly anatomical specimens. In this study, 3D printed sheep brain models were produced using magnetic resonance imaging (MRI) scanning, and their effectiveness was compared with cadaveric materials by creating three groups from undergraduate veterinary students. The study was performed when veterinary anatomy lectures in Erciyes University were carried out via live fully online learning platforms in virtual classes like many other universities in the world due the Covid-19 pandemic. Participants were subjected to an approximately 30 minute online lecture on the external and internal anatomy of the sheep brain using cadaveric materials only (n=21, Group 1), 3D printed models only (n=20, Group 2), or a combination of cadaveric materials and 3D printed models (n=20, Group 3) as teaching aids. Online post-tests carried out following the online lectures showed no statistically significant difference between the scores of the groups. Furthermore, online questionnaires conducted after the post-tests demonstrated that 3D printed models helped students learn about sheep brain anatomy. The finding of this study suggests that 3D printed models can be considered as a supplement teaching resource to cadaveric materials in veterinary anatomy education particularly when students are supposed to learn more in a limited time regardless of whether or not the Covid-19 pandemic might end.

Keywords: Online Anatomy Education, 3D Printed Anatomical Models, 3D Printing Technology, Veterinary Neuroanatomy Education.

1. INTRODUCTION

Additive manufacturing, in general referred to as three-dimensional (3D) printing, is a production method in which 3D objects are manufactured using computer-aided design through layer by layer deposition of materials that can be polymers, ceramics, metals, or biomaterials (e.g., hydrogels, living cells) [1,2]. 3D printing technology enables manufacturers to fabricate customized products reproducibly with the right dimensions and geometries by reducing time and cost for small production runs [3,4]. Since the birth of 3D printing in the 1980s, 3D printing has been used by a variety of industries (e.g., aerospace, automotive), giving accurate results for parts with complex geometries [5]. Furthermore, 3D printing in medicine have increased since the 1990s, in which custom prosthetics, preoperative planning, medical education and training, and more recently patient-specific drug delivery and organ printing are the applications for various disciplines including maxillofacial surgery, cardiac surgery, neurosurgery, orthopedics, and spine surgery [6,7].

In the field of veterinary medicine, the applications of 3D printing have provided promising results as well. A 3D printed customized skull implant was developed for a dog with a cancerous skull tumor [8]. Furthermore, 3D printed models of the dog's head could assist a veterinary surgical oncologist in the planning of tumor removal and restoring the skull [8]. In addition, a 3D printed lens adapter was designed for indirect ophthalmoscopy to image the fundus in dogs and cats [9,10]. Winer et al. [10] demonstrated that using 3D printed skulls of dogs and cats with maxillofacial trauma, preoperatively, saved surgeons' time in the operating room by allowing them to plan out the surgery and determine the exact dimensions of the reconstruction plates. Oberoi et al. [11] studied 3D printed airway models of a rabbit as an anesthetic training simulator with the aim of performing nasotracheal intubation effectively. Furthermore, there have been various studies suggesting 3D printed models as valuable aids in veterinary medical education. Li et al. [12] developed 3D printed models of bovine skeletal components for veterinary anatomy laboratory sessions as an alternative to original bone samples. Schoenfeld-Tacher et al. [13] investigated the use of 3D printed models of the canine brain as an alternative to plastinated brains in teaching veterinary neuroanatomy for first-year veterinary students. They found no statistically significant difference between using 3D models and plastinated specimens for instruction considering the students' scores on a practical neuroanatomy exam [13]. Mendaza-DeCal and Rojo [14] developed a 3D printed model of an ovine stomach through a surface scanner for first year veterinary students to learn surface and topographical anatomy. They reported that the 3D printed ovine stomach model supported spatial visualization of anatomical relationships as a complement to a real stomach based on the students' assessments after studying both real and 3D printed model [14]. Assis Di Donato et al. [15] created a didactic collection from 3D printed models of tongues from a cow, dog, horse, and pig for veterinary students to improve anatomy teaching together with existing cadaveric materials. Here, new approaches to minimizing animal use for veterinary anatomy education have been offered by researchers for several decades. Resources including plastic models, plastinated prosections, simulators, interactive 3D modeling, virtual and augmented reality imaging have been introduced as alternative educational materials to avoid potential health threats due to cadaver use, such as AIDS and prion diseases, hazardous solutions (e.g., formalin) for the fixation process, and to reduce ethical concerns in sacrificing healthy animals [16–19].

Since December 2019, due to the coronavirus disease 2019 (COVID-19) pandemic caused by a novel coronavirus called as severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2), online courses have started to be implemented as an essential part of education by colleges and universities all over the world to minimize physical contact between students and between students and academic staff [20]. Although online education dates back to the 1980s, online courses related to veterinary discipline were rarely run before the COVID-19 outbreak, where the company Coursera have offered few massive open online courses (MOOCs), including "Canine Theriogenology for Dog Enthusiasts" by a partnership with the University of Minnesota, and three others: "Equine Nutrition", "Animal Behavior and Welfare", and "EDIVET: Do you have what it takes to be a veterinarian?" by a partnership with the University of Edinburgh [21–24]. Furthermore, the Purdue University Veterinary Nursing Distance Learning Program has been accredited by the American Veterinary Medical Association (AVMA) since 2006 [25]. On the other hand, e-learning resources including Wikivet, the Online Veterinary Anatomy Museum (OVAM), and Webinar Vet projects have been available for a decade to support veterinary education [26,27]. However, the COVID-19 outbreak has forced universities and colleges worldwide to rapidly develop fully online courses or noticeably reduce the number and type of in class face-to-face teaching sessions [28].

In this respect, 3D printed models could be effective materials in online veterinary anatomy education for undergraduate veterinary medical students as teaching aids. It can be challenging for students to access to cadaveric materials, and to manage their practical skills during the pandemic or online learning sessions [20,29,30]. Furthermore, 3D printing is stated to be an economical method for human anatomy teaching when compared with plastination [1,31]. However, there is limited research demonstrating that 3D prints are as valid as cadaveric materials for anatomy education [32]. Lim et al. [33] investigated the potency of 3D printed models on teaching human cardiac anatomy with 53 first-year medical students. The authors examined the students' anatomical proficiency before and after the educational intervention including a self-directed learning session following a short instructor-guided teaching session [33]. They showed that the knowledge of the students improved more when they were exposed to just 3D printed models (n= 17) in comparison to those exposed to just cadaveric materials (n= 18) and to the combination of cadaveric materials and 3D printed models (n=18) during the self-directed learning sessions [33]. Attardi et al. [34] searched the value of a fully online version of a face-to-face human anatomy course including a total of 23 hours of laboratory demonstration for third-year undergraduate students. A specialized software was used to run both face-to-face and online sections concurrently; furthermore, unlike the face-to-face laboratory demonstration containing prosections from human cadavers, an anatomy website consisting of 3D virtual anatomical models was utilized for online laboratory sessions [34]. It was observed that there was no significant difference between the final anatomy grades of face-to-face and online students [34].

Erciyes University Veterinary Faculty accredited by The European Association of Establishments for Veterinary Education (EAEVE), has followed a hybrid education system, both face-to-face and online classes if necessary, for Fall 2021, due to the Covid-19 pandemic. However, during the period from March 2020 to September 2021, the Faculty of Veterinary suspended face-to-face teaching, and courses were given at online virtual classes owing to the Covid-19 outbreak. During that period, the veterinary anatomy lectures, including demonstration sessions of cadaveric materials, were carried out via live online learning platforms.

In the first year veterinary anatomy course at Erciyes University, traditional cadaveric materials (or prosections) of sheep brains have been used as the primary teaching aids for the neuroanatomy section of small animals. However, there is not any animal plastic brain model to support students' learning of neuroanatomic concepts, although, in addition to cadavers, plastic anatomy models are available for other body systems.

In this paper, 3D printed models of a sheep brain were developed and their performance as teaching aids was compared with that of traditional cadaveric materials for the online learning of external and internal sheep brain anatomy, in an experimental setting of undergraduate veterinary students prior to formal teaching on sheep brain anatomy. We hypothesized that in a live fully online learning platform, using physical 3D printed models as teaching aids in sheep brain anatomy education would lead to equal or better gains in student learning when compared with traditional cadaveric materials. The hypothesis was tested by measuring the learning performance of first year veterinary students after an approximately 30 minute online lecture on sheep brain anatomy. Here, the students were divided into three groups, Group 1, Group 2, and Group 3, and online lectures were carried out sequentially for each group, where cadaveric materials only, 3D printed models only, and a combination of cadaveric materials and 3D printed models were used as teaching aids, for Group 1, Group 2, and Group 3 respectively.

This research can be divided into three parts. In the first part, the process of medical 3D printing of a sheep brain, including image acquisition, image post-processing, and 3D printing, was explained and the study design was clarified. In the second part, the developed 3D printed models were investigated, the statistical analysis was done to evaluate the performances of the 3D printed models and cadaveric materials in teaching sheep brain anatomy, and the analysis results were presented. In the third part, the study outputs, the limitations of the study, and future recommendations were discussed.

2. MATERIALS AND METHODS

2.1. MRI Acquisitions

The head of an approximately 3 year old Merino ewe (Ovis aries) was collected from an animal that had been slaughtered in the context of regular slaughterings. Magnetic resonance imaging (MRI) scanning was performed within 2 hours of the slaughter in a 3 Tesla MAGNETOM Trio Siemens system (Erlangen, Germany), using a 32 channel head coil. A three dimensional (3D) sagittal T2-weighted Sampling Perfection with Application-optimized Contrasts using different flip angle Evolutions (SPACE)- Fluid Attenuated Inversion Recovery (FLAIR) (T2W SPACE-FLAIR) sequence was used with the following parameters: TR 6000 ms; TE 402 ms; TI 2100 ms; FOV 229 mm; 208 sagittal slices with a thickness of 0.89 mm, which resulted in a reconstructed 3D image of a voxel size of 0.9 x

0.9 x 0.9 mm^3. The total acquisition time was approximately 2 hours.

2.2. Image Processing

The MRI data saved in Data Imaging and Communications in Medicine (DICOM) format was segmented using semi-automatically thresholding and region-growing tools to isolate the brain, and then the brain data was converted into the standard tessellation language (STL) file using Mimics Innovation Suite 23.0 software (Materialize, Leuven, Belgium). The STL file was further edited via 3-Matic 15 software (Materialize, Leuven, Belgium), a computer aided design (CAD) software, by automatically smoothing (0.7 factor, three iterations), and then, wrapping with a gap closing distance of 0.5 mm, smallest detail of 0.04 mm, and a resulting offset of 0 mm, to achieve a whole brain model and a brain model in which the cerebellum was removed to visualize the dorsal brainstem. The 3D whole brain model was then processed in the trial version of Solidworks® (Dassault Systèmes, Vélizy, France) to obtain mid-sagittal and coronal views of the brain.

2.3. 3D Printing

Stereolithographic apparatus (SLA) and fused deposition modelling (FDM) technology were used to fabricate physical 3D models. In SLA, for 3D printing a Form 3 (Formlabs, Massachusetts, USA) printer was employed in which the layer height was set to 0.1 mm, and Form Wash was used to rinse the 3D printed model in 99% isopropyl alcohol for 10 min to remove the excess resin left from the printing process. The washed printed model was postcured in Form Cure (Formlabs, Massachusetts, USA) by treating it with UV-light for 30 min at 60°C to ensure full cross-linking of the resin. The removal of the support structure was done utilizing the standard cutting tools. Furthermore, Zaxe Z1+ (Z Eksen, Istanbul, Turkey) and Ender-3 (Creality, Shenzen, China) were used as FDM type 3D printers at 0.1 mm layer thickness in which acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) filaments were 3D printing materials, respectively.

2.4. Participants

In 2020, there were 80 students enrolled in their first year of undergraduate veterinary education at Erciyes University. Participants volunteered from this first year veterinary student cohort. The study took place after the midterm exam that was managed online, covering veterinary digestive and respiratory systems, and prior to formal teaching on nervous system including sheep brain anatomy. Students in their second year of veterinary studies, or those repeating the first year of veterinary studies were excluded.

The study was announced through formal online lectures organized by the Faculty in only two weeks leading up to the study to minimize any potential biases due to students' cross-talk [35]. The students were told that the study was related to veterinary anatomy education, and they were just informed about the date, time, and estimated duration of the study. Information on the aims, benefits and other related details of the study were not provided.

2.5. Study Design

Sixty one volunteers from the first year veterinary student cohort were first sliced into small groups based on their midterm exam scores. Then, students from these small groups were randomly assigned to one of the three main groups by keeping the midterm exam mean scores of the main groups similar to avoid any bias that would be arising from the students' prior anatomical knowledge. Participants were subjected to a live online lecture using either cadaveric materials only (n=21, Group 1), 3D printed models only (n=20, Group 2), or a combination of cadaveric materials and 3D printed models (n=20, Group 3). All of the cadaveric materials (or prosections) were obtained from Erciyes University Faculty of Veterinary Medicine, which had previously been dissected by the faculty staff. Zoom (Zoom Video Communications Incorporation, San Jose, CA), a cloud-based video conferencing software, was used for online teaching sessions. The online pre- and post-test were designed before and after the online lecture, respectively, to evaluate student performance. Furthermore, after the post-test, an online survey was conducted for each group to determine overall student satisfaction regarding the learning sessions. Google Forms (Google LLC, Mountain View, CA), an open source quiz and survey administration software, was used for the pre-test, the post-test, and the survey.

The pre-test consisted of 11 multiple-choice questions, which was designed to test basic knowledge of the human brain anatomy. Participants of all groups were given 15 minutes to complete the pre-test, in which the order of the questions was different for each group, on the day of the study. Following the pre-test, each group in sequence was given an approximately 30 minute online lecture on the external and internal anatomy of the sheep brain using cadaveric materials only for the participants of the Group 1, 3D printed models only for the Group 2, and a combination of cadaveric materials and 3D printed models for the Group 3 as teaching aids. Furthermore, the same two dimensional (2D) anatomical images were delivered to the groups by PowerPoint presentation. The lecture covered the embryonic brain divisions (e.g., telencephalon, mesencephalon), the exterior of the entire brain (e.g., cerebral hemispheres, cerebellum, brainstem), the four lobes (e.g., frontal, temporal) of the brain and their functions. The live online lectures were provided first to the Group 1, then, to the Group 2, and finally to the Group 3 by the same anatomy instructor on the day of the study. Immediately following the lectures, the student learning performance was evaluated by the post-test consisting of 35 multiple-choice questions, in which the order of the correct choices was different for each group. In addition, a group specific five-item online questionnaire was conducted for each group to evaluate the student opinions related to the online lectures using a five point Likert scale (1: strongly disagree, 5: strongly agree). Participants of each group were given 45 minutes to complete the post-test and the survey. The pre-test, post-test and survey statements are provided in supplementary files.

2.6. Ethical Approval

Ethical approval was obtained from the Social And Human Sciences Ethics Committee of Erciyes University (reference: 2020/187) to recruit students for the study. Participation in the study was voluntary. Informed consent forms were signed by participants before enrolling in the study.

2.7. Data Collection

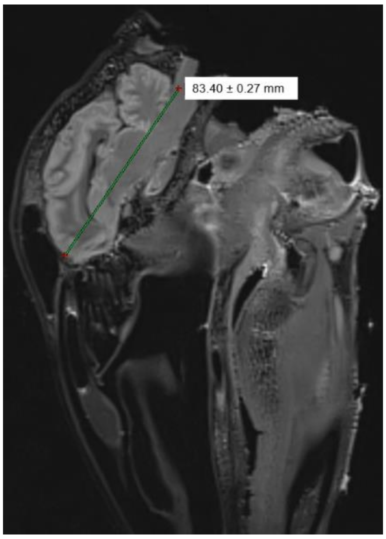
Demographic information including age and gender was collected prior to pre-testing for participants of each group. However, the participants were not asked to provide their student identification numbers so that students could feel them comfortable when completing the pre-test, post-test, and survey, avoiding sharing questions and plausible answers. This also ensured that the researchers were blinded to the names.

2.8. Statistical Analysis And Sample Size Determination

The authors estimated that a sample size of 24 per group with α level of 0.05, and standard deviation of 10% would provide a 87% power to detect a 10% difference between-groups in post-test scores (trial version of Minitab® 19 statistical software) considering recent anatomy educational studies [33,36]. The pre-test and post-test scores were expressed as percentages. On the other hand, out of 35 post-test questions, 11 questions (question no: 10, 11, 13, 14, 15, 16, 17, 22, 23, 24, and 25, the post-test questions are included in the supplementary file) were scored two times more compared to the rest 24 questions since they were more image dependent to be answered. The one way analysis of variance (ANOVA) was used for statistical analysis by utilizing the trial version of JMP® 16.1 statistical software. p-values smaller than 0.05 were considered significant. Furthermore, the internal consistency of the five-item questionnaire was calculated using Cronbach's alpha, and appropriateness of the factor analytic model was tested using Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity.

3. RESULTS

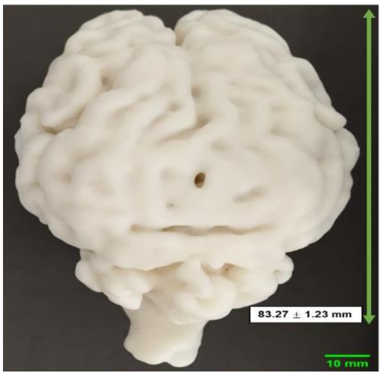
The 3D printed whole brain model was produced using SLA, and its volume was calculated to be approximately 99 cm^3. It took 8 h to print the model, which consumed 110 ml of resin. The 3D printed brain model in which the cerebellum was removed was fabricated using FDM, and it took 1 h and 43 min to print cerebellum consuming 9 gr of ABS, and 11 h and 10 min to print the rest of the brain consuming 79 gr of ABS. Furthermore, the 3D printed brain in the mid-sagittal and coronal planes were built using FDM. It took 11 h and 6 min to print the brain in the mid-sagittal plane, and 11 h and 39 min to print the brain in the coronal plane, consuming 68 gr of PLA, and 70 gr of PLA, respectively. All 3D printed brain models presented to the Group 2 (3D printed models only) and Group 3 (combination of cadaveric materials and 3D printed models) during the online teaching sessions are shown in Figure 1.


83.40 ± 0.27 mm

(a)


83.73 ± 0.29 mm
X: -0.5486mm
Y: 0.7016mm
Z: 72.63929mm

(b)


83.27 ± 1.23 mm
10 mm

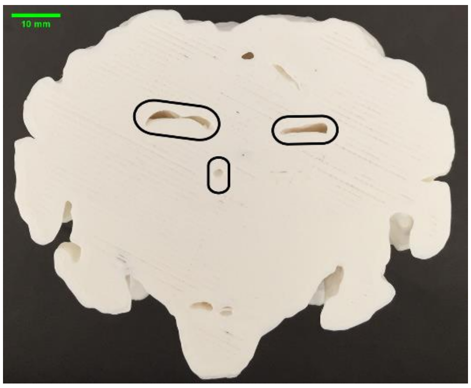
(c)


10.00 mm

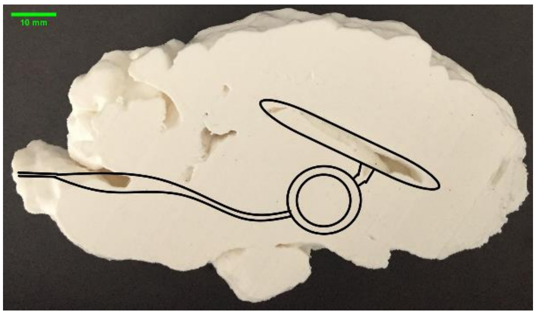
(d)


10.00 mm

(e)


10 mm

(f)



(g)

Figure 1. 3D printed models. a) Digital brain in the mid-sagittal plane in the head of the Merino ewe (the distance from the lower part of the brain to the brainstem was measured using the trial version of RadiAnt DICOM viewer software (Medixant, Poznań, Poland), 83.40 ± 0.27 mm (mean ± standard deviation)) b) Digital whole brain model (the vertical dimension of the brain up to the brainstem was measured using Solidworks®, 83.73 ± 0.29 mm (mean ± standard deviation)), posterior view c) 3D printed whole brain model (the vertical dimension of the brain up to the brainstem was measured using a Vernier caliper, 83.27 ± 1.23 mm (mean ± standard deviation)), posterior view, SLA (d) 3D printed whole brain model, ventral view, SLA e) 3D printed brain model in which the cerebellum was removed, FDM, ABS f) 3D printed brain in the mid-sagittal plane, FDM, PLA g) 3D printed brain in the coronal plane, FDM, PLA.

The measured dimension from the lower part of the brain to the brainstem, of the 3D printed model was not statistically different from those of the digital models (p= 0.748).

The cadaveric materials presented to the Group 1 (cadaveric materials only) and Group 3 during the online teaching sessions are shown in Figure 2.

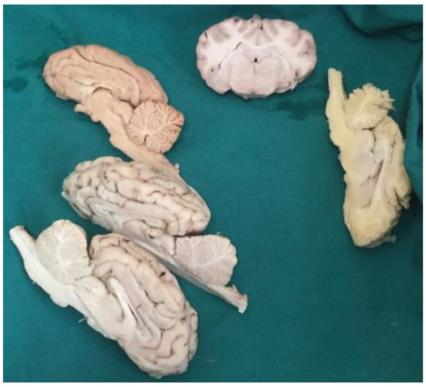


Figure 2. Cadaveric materials.

No statistically significant difference was observed in age (p= 0.7443), gender (p= 0.495), pre-test scores (p= 0.1693), and midterm exam scores (p= 0.948) between the groups as shown in Table 1. The post-test scores satisfied the assumptions of one way ANOVA in which the normality was verified by Anderson-Darling test ($p > 0.05$), and the homogeneity of variance by Levene (p= 0.06). There was no statistically significant difference in post-test scores (p= 0.827) between the groups. No statistically significant difference was observed (p=0.972) between the groups, even when just 11, more image-dependent, post-test scores were considered.

The internal consistency of the questionnaires was tested with Cronbach's alpha, where a value greater than or equal to 0.7 is generally considered to be reliable [37], and it was found to be 0.71, 0.83, 0.80 for Group 1, Group 2, and Group 3, respectively. The KMO index, which is the measure of sampling adequacy, was 0.536, 0.726, 0.772 for Group 1, Group 2, and Group 3, respectively. Here, a questionnaire with a KMO index greater than 0.5 can be accepted to be appropriate for factor analysis [38]. The Bartlett's test of sphericity for factor analysis was also significant for Group 1 (χ^2 = 34.132, p= 0.002), Group 2 (χ^2 = 57.207, p= 0.0001) and Group 3 (χ^2 = 46.141, p= 0.0001). This confirmed that the questionnaire was reliable for evaluating student opinions related to the use of cadaveric materials only, 3D printed models only, and a combination of cadaveric materials and 3D printed models in the veterinary anatomy education. Figure 3 shows the results of the questionnaires.

The results of the questionnaire demonstrated that there was no statistically significant difference in the ratings ($p > 0.05$) for each statement between the groups, which was evaluated with the nonparametric Kruskall Wallis test. However, students of Group 3 thought that there should be teaching materials other than the combination of cadaveric materials and 3D printed models with an overall rating of 3.75/5, which is the minimum rating between the groups. Furthermore, the 3D printed models only group indicated that the 3D printed models could be recognized on the computer screen with the highest rating of 4.25/5. In addition, all groups believed that the materials used in the lecture helped them understand the structure of sheep brain, focus on the lecture, and answer the post-test questions with an overall rating of 4.00/5 or more than 4.00/5.

Table 1. Statistical analysis between groups for age, gender, midterm exam, pre-test, and post-test results.

	Group 1 (n=21)	Group 2 (n=20)	Group 3 (n=20)	P-value
Age				0.7443[a]
Median (IQR)	19 (1)	19 (1)	19 (2)	
Mean ± SD	19 ± 0.98	19 ± 1.4	19 ± 0.9	
Gender				0.495[b]
Male	8	11	8	
Female	13	9	12	
Midterm exam score				0.948[a]
Mean ± SD	80.95 ± 16.85	81.25 ± 18.05	81.75 ± 15.83	
Pre-test score				0.1693[a]
Mean ± SD	85.71 ± 19.41	93.64 ± 12.55	88.18 ± 11.07	
Post-test score				0.827[c]
Mean ± SD	65.84 ± 20.48	64.35 ± 15.90	62.61 ± 12.82	

IQR: interquartile range; SD: standard deviation
[a]Kruskall Wallis test
[b]Chi-square test
[c]One way ANOVA

4. DISCUSSION

3D printing technology encourage anatomy educators to consider it as a supplement to cadaveric dissection by producing accurately, rapidly, and reproducibly anatomical specimens. Furthermore, 3D printers have become increasingly affordable particularly since 2009, when the FDM patent expired [39]. In this study, the vertical dimension, up to the brainstem, of the 3D printed model and the digital model were measured, and no statistically significant difference was observed between the models. Additionally, it took less than 13 hours to print each brain component model. However, the details of the inner brain structures (e.g., thalamus, white matter, grey matter) of the 3D printed models in the mid-sagittal and coronal planes needed to be drawn with a specialized software, where the same issue was true for the 3D models of Schoenfeld-Tacher et al. [13]. Although this point requires a further work, we think that the merits of reduced animal use, simplicity, durability, low production cost outweigh this drawback.

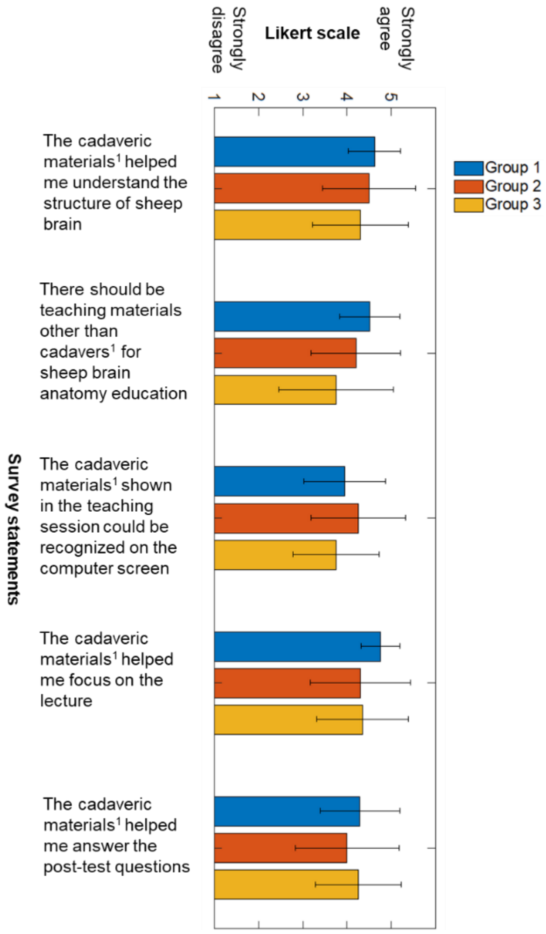


Figure 3. Student perceptions on the use of materials in the lecture ([1]Group 1: cadaveric materials, Group 2: 3D printed models, Group 3: the combination of cadaveric materials and 3D printed models; Likert scale: 1= strongly disagree, 2= disagree, 3= neutral, 4= agree, 5= strongly agree).

This study was done when a rapid transition to online education took place and the access to anatomy laboratory was completely or partially prohibited for undergraduate students worldwide to protect themselves from the Covid-19 [28,40]. Therefore, it is of value to manage the transition by applying alternative teaching strategies to contribute to anatomy learning [30]. Although there are several comparative studies including 3D printed models versus plastinated specimens, cadaveric materials, 2D images, or atlas, a comparative study with a quantitative approach in a fully online platform has not been previously carried out [32,41–43].

The results of this study showed that 3D printed models helped students learn about sheep brain anatomy by comparing these models with cadaveric materials, where there was no statistically significant difference between groups in the post-test scores and ratings for each statement of the validated questionnaire. In addition, it can be claimed that the groups had similar previous anatomical knowledge since the pre-test and midterm exam scores did not show statistically significant difference between the groups. This supports the analysis of Attardi et al. [34] who stated that regardless of course delivery format, previous academic performance was a determining factor for student performance in anatomy. Furthermore, the meta-analysis by Wilson et al. [44] concluded that the students' scores were not statistically different in case of comparing traditional dissection to other laboratory tools including 3D models, digital media, prosection, and hybrid approaches.

4.1. Limitations Of The Study And Future Work

This study focused on a 30 minute knowledge retention, and participants could not have the opportunity to directly handle both the cadaveric materials and 3D printed models. Although not measured in this study, 3D printed models can have the potential to form a common language between students, and between students and instructors since it may be easier to access to STL files, and 3D printers compared to cadaveric materials, which can result in a collaborative work, and improve student-instructor and student-student interaction in a distance education.

Furthermore, since the students' identification numbers were not asked to assure student comfort the within-subject analysis of the pre- and post-test score differences could not be evaluated for each group. In addition, the limited number of students (80 students) enrolled in their first year of undergraduate veterinary education at Erciyes University restricted the number of volunteer participants. However, a larger sample size would increase the power of the statistical analysis, and decrease the risk of type II error (failing to reject the hypothesis that all groups have equal test scores when this is actually not true), which would lead to detecting smaller differences (<10%) in groups.

Future work should focus on producing 3D printed models using materials mimicking the mechanical behaviour of real tissue, where scientific studies in this area are still in progress, and testing if these biomechanically compatible 3D printed models can create a common language between students, and between students and instructors in a fully online learning platform by extending the study time.

5. CONCLUSION

This comparative study, 3D printed models versus cadaveric materials, demonstrated that the 3D printed models could be used as adjunct teaching aids to sheep brain prosections in a fully online learning session, in a period where students were expected to learn more in a constrained time. The fact that the availability of 3D printing technology is not limited to the opening hours of an anatomy laboratory, and 3D printing technology is getting become more affordable encourages 3D models to be considered as possible teaching resources in veterinary anatomy education regardless of whether or not the Covid-19 pandemic might end.

ACKNOWLEDGEMENTS

The authors are thankful to Ergin Atalar, director of National Magnetic Resonance Research Center, Ankara, for providing the access to the medical imaging facility. The authors also appreciate Osman Tunc, and to the administration of BTech Company, Ankara, for their support related to the Mimics Innovation Suite 23.0 software. This study includes some data derived from the research of Buket İşcan for her master of science degree.

REFERENCES

1. Paul, G. M., Rezaienia, A., Wen, P., Condoor, S., Parkar, N., King, W., Korakianitis, T., "Medical Applications for 3D Printing: Recent Developments", Journal of the Missouri State Medical Association, Vol. 115, Issue 1, Pages 75–81, 2018.

2. Tappa, K., and Jammalamadaka, U., "Novel Biomaterials Used in Medical 3D Printing Techniques", Journal of Functional Biomaterials, Vol. 9, Issue 1, Pages 17, 2018.

3. Berman, B., "3-D printing: The new industrial revolution", Business Horizons, Vol. 55, Issue 2, Pages 155–162, 2012.

4. Marro, A., Bandukwala, T., Mak, W., "Three-Dimensional Printing and Medical Imaging: A Review of the Methods and Applications", Current Problems in Diagnostic Radiology, Vol. 45, Issue 1, Pages 2–9, 2016.

5. Hull, C. W., "Apparatus for Production of Three-Dimensional Objects by Stereolithography", In United States Patent, Appl., No. 638905, 1984.

6. Tack, P., Victor, J., Gemmel, P., Annemans, L., "3D-printing techniques in a medical setting: A systematic literature review", Biomedical Engineering Online, Vol. 15, Issue 1, Pages 1–21, 2016.

7. Gyles, C., "3D printing comes to veterinary medicine", Canadian Veterinary Journal, Vol. 60, Issue 10, Pages 1033–1034, 2019.

8. Ducharme, J., "Veterinarians 3D-Printed part of a new skull for a dog", Time, https://time.com/5406699/dog-cancer-3d-printed-skull/, 08 February 2022, 2018

9. Espinheira Gomes, F., and Ledbetter, E., "Canine and feline fundus photography and videography using a nonpatented 3D printed lens adapter for a smartphone", Veterinary Ophthalmology, Vol. 22, Issue 1, Pages 88–92, 2019.

10. Winer, J. N., Verstraete, F. J. M., Cissell, D. D., Lucero, S., Athanasiou, K. A., Arzi, B., "The application of 3-dimensional printing for preoperative planning in oral and maxillofacial surgery in dogs and cats", Veterinary Surgery, Vol. 46, Issue 7, Pages 942–951, 2017.

11. Oberoi, G., Eberspächer-Schweda, M. C., Hatamikia, S., Königshofer, M., Baumgartner, D., Kramer, A.-M., Schaffarich, P., Agis, H., Moscato, F., Unger, E., "3D Printed Biomimetic Rabbit Airway Simulation Model for Nasotracheal Intubation Training", Frontiers in Veterinary Science, Vol. 7, Pages 587524, 2020.

12. Li, F., Liu, C., Song, X., Huan, Y., Gao, S., Jiang, Z., "Production of accurate skeletal models of domestic animals using three-dimensional scanning and printing technology", Anatomical Sciences Education, Vol. 11, Issue 1, Pages 73–80, 2018.

13. Schoenfeld-Tacher, R. M., Horn, T. J., Scheviak, T. A., Royal, K. D., Hudson, L. C., "Evaluation of 3D additively manufactured canine brain models for teaching veterinary neuroanatomy", Journal of Veterinary Medical Education, Vol. 44, Issue 4, Pages 612–619, 2017.

14. Mendaza-DeCal, R. M., and Rojo, C., "3D-Printed Model of the Ovine Stomach by Surface Scanning: Evaluation for Teaching Veterinary Anatomy", International Journal of Morphology, Vol. 39, Issue 5, Pages 1480–1486, 2021.

15. Assis Di Donato, B., Cesar dos Santos, A., Eduardo da Silveira, E., Carlos Sabino Pereira, H., Francisco da Silva Lisboa Neto, A., Magalhães de Oliveira Alcobaça, M., Chaves de Assis Neto, A., "Three-Dimensional Digitalized and Printed Tongue Models of the Cow, Dog, Pig, and Horse for Undergraduate Veterinary Education", International Journal of Morphology, Vol. 39, Issue 2, Pages 436–440, 2021.

16. Latorre, R. M., García-Sanz, M. P., Moreno, M., Hernández, F., Gil, F., López, O., Ayala, M. D., Ramírez, G., Vázquez, J. M., Arencibia, A., Henry, R. W., "How useful is plastination in learning anatomy?", Journal of Veterinary Medical Education, Vol. 34, Issue 2, Pages 172–176, 2007.

17. Özkadif, S., Ozkadif, S., Eken, E., "Modernization process in veterinary anatomy education", Energy Education Science and Technology Part B: Social and Educational Studies, Vol. 4, Issue 2, Pages 957–962, 2012.

18. Raffan, H., Guevar, J., Poyade, M., Rea, P. M., "Canine neuroanatomy: Development of a 3D reconstruction and interactive application for undergraduate veterinary education", PLoS One, Vol. 12, Issue 2, Pages e0168911, 2017.

19. Christ, R., Guevar, J., Poyade, M., Rea, P. M., "Proof of concept of a workflow methodology for the creation of basic canine head anatomy veterinary education tool using augmented reality", PLoS One, Vol. 13, Issue 4, Pages e0195866, 2018.

20. Mahdy, M. A. A., "The Impact of COVID-19 Pandemic on the Academic Performance of Veterinary Medical Students", Frontiers in Veterinary Science, Vol. 7, Pages 594261, 2020.

21. Harasim, L., "Shift happens: Online education as a new paradigm in learning", Internet and Higher Education, Vol. 3, Issue 1-2, Pages 41–61, 2000.

22. Root Kustritz, M. V., "Canine Theriogenology for Dog Enthusiasts: Teaching Methodology and Outcomes in a Massive Open Online Course (MOOC)", Journal of Veterinary Medical Education, Vol. 41, Issue 1, Pages 9–18, 2014.

23. MacKay, J. R. D., Langford, F., Waran, N., "Massive open online courses as a tool for global animal welfare education", Journal of Veterinary Medical Education, Vol. 43, Issue 3, Pages 287–301, 2016.

24. Paterson, J., Hughes, K., Steer, L., Das Gupta, M., Boyd, S., Bell, C., Rhind, S., "Massive open online courses (MOOCs) as a window into the veterinary profession", Veterinary Record, Vol. 180, Issue 7, Pages 179–179, 2017.

25. Bill, R. L., "Purdue University's veterinary technology distance learning program", Journal of Veterinary Medical Education, Vol. 34, Issue 3, Pages 311–315, 2007.

26. Gaitskell-Phillips, G., Short, N., Stanikova, B., "Taking veterinary anatomy online", Alternatives to laboratory animals, Vol. 40, Issue 6, Pages 24-25, 2012.

27. Gardiner, A., and Rhind, S., "Taking a history on veterinary education", Veterinary Record, Vol. 173, Issue 16, Pages 388–393, 2013.

28. Sandhu, P., and de Wolf, M., "The impact of COVID-19 on the undergraduate medical curriculum", Medical Education Online, Vol. 25, Issue 1, Pages 1764740, 2020.

29. Marino, A., "The Effects of COVID-19 on the Education of Veterinary Medical Students", Journal of Avian Medicine and Surgery, Vol. 34, Issue 4, Pages 416–421, 2020.

30. Iwanaga, J., Loukas, M., Dumont, A. S., Tubbs, R. S., "A review of anatomy education during and after the COVID-19 pandemic: Revisiting traditional and modern methods to achieve future innovation", Clinical Anatomy, Vol. 34, Issue 1, Pages 108–114, 2021.

31. McMenamin, P. G., Quayle, M. R., McHenry, C. R., Adams, J. W., "The production of anatomical teaching resources using three-dimensional (3D) printing technology", Anatomical Sciences Education, Vol. 7, Issue 6, Pages 479–486, 2014.

32. Chytas, D., Johnson, E. O., Piagkou, M., Tsakotos, G., Babis, G. C., Nikolaou, V. S., Markatos, K., Natsis, K., "Three-dimensional printing in anatomy teaching: current evidence", Surgical and Radiologic Anatomy, Vol. 42, Issue 7, Pages 835–841, 2020.

33. Lim, K. H. A., Loo, Z. Y., Goldie, S. J., Adams, J. W., McMenamin, P. G., "Use of 3D printed models in medical education: A randomized control trial comparing 3D prints versus cadaveric materials for learning external cardiac anatomy", Anatomical Sciences Education, Vol. 9, Issue 3, Pages 213–221, 2016.

34. Attardi, S. M., and Rogers, K. A., "Design and implementation of an online systemic human anatomy course with laboratory", Anatomical Sciences Education, Vol. 8, Issue 1, Pages 53–62, 2015.

35. Edlund, J. E., Sagarin, B. J., Skowronski, J. J., Johnson, S. J., Kutter, J., "Whatever happens in the laboratory stays in the laboratory: The prevalence and prevention of participant crosstalk", Personality and Social Psychology Bulletin, Vol. 35, Issue 5, Pages 635–642, 2009.

36. Canty, D. J., Hayes, J. A., Story, D. A., Royse, C. F., "Ultrasound simulator-assisted teaching of cardiac anatomy to preclinical anatomy students: A pilot randomized trial of a three-hour learning exposure", Anatomical Sciences Education, Vol. 8, Issue 1, Pages 21–30, 2015.

37. Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E., "Multivariate Data Analysis", 7th Ed., Pearson Education Limited, UK, 2013.

38. Field, A., "Discovering Statistics Using IBM SPSS Statistics", 5th Ed., Sage Publications Inc., UK, 2018.

39. Crump, S. S., "Apparatus and method for creating three-dimensional objects", In United States Patent, Appl., No. US5121329A, 1989.

40. Pather, N., Blyth, P., Chapman, J. A., Dayal, M. R., Flack, N. A. M. S., Fogg, Q. A., Green, R. A., Hulme, A. K., Johnson, I. P., Meyer, A. J., Morley, J. W., Shortland, P. J., Štrkalj, G., Štrkalj, M., Valter, K., Webb, A. L., Woodley, S. J., Lazarus, M. D., "Forced Disruption of Anatomy Education in Australia and New Zealand: An Acute Response to the Covid-19 Pandemic", Anatomical Sciences Education, Vol. 13, Issue 3, Pages 284–300, 2020.

41. Kong, X., Nie, L., Zhang, H., Wang, Z., Ye, Q., Tang, L., Li, J., Huang, W., "Do three-dimensional visualization and three-dimensional printing improve hepatic segment anatomy teaching? A randomized controlled study", Journal of Surgical Education, Vol. 73, Issue 2, Pages 264–269, 2016.

42. Garas, M., Vaccarezza, M., Newland, G., McVay-Doornbusch, K., Hasani, J., "3D-Printed specimens as a valuable tool in anatomy education: A pilot study", Annals Anatomy, Vol. 219, Pages 57–64, 2018.

43. Smith, C. F., Tollemache, N., Covill, D., Johnston, M., "Take away body parts! An investigation into the use of 3D-printed anatomical models in undergraduate anatomy education", Anatomical Sciences Education, Vol. 11, Issue 1, Pages 44–53, 2018.

44. Wilson, A. B., Miller, C. H., Klein, B. A., Taylor, M. A., Goodwin, M., Boyle, E. K., Brown, K., Hoppe, C., Lazarus, M., "A meta-analysis of anatomy laboratory pedagogies", Clinical Anatomy, Vol. 31, Issue 1, Pages 122–133, 2018.