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Production and Perceptions of 3D-Printed Bone Models in Undergraduate Anatomy Practical Educations

Producción y Percepciones de Modelos Óseos Impresos en 3D en la Enseñanza Práctica de Anatomía de Pregrado

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SUMMARY: Anatomy is considered one of the cornerstones of medical curricula. Thanks to the modernization and technological developments in medical education, many innovations have been added to traditional learning tools in anatomy education, one of the most important of which is three-dimensional (3D) printed models. Determining the production properties of 3D printed models and also the perceptions of students about these models has become increasingly important. Hence, this study aimed to produce 3D printed bone models for use in undergraduate anatomy practical education and to determine students' perceptions about them. Using 3D printing technology, highly accurate 3D printed bone models were produced simply, economically and quickly. After the 3D models were used in anatomy practical education, 16-item survey (five-point Likert scale, 1 = strongly disagree to 5 = strongly agree) was performed to year-1 undergraduate two group of students (students of Faculty of Dentistry and Faculty of Health Sciences). Survey results showed that 3D printed bone models were well adopted by undergraduate students in anatomy practical education. In addition, for all items of survey, no significant statistical difference was found between both student groups ($P>0.05$). Our study suggests that 3D printing technology is useful to aid to anatomy practices and provides teaching tools for undergraduate students from different departments in learning anatomy.

KEY WORDS: 3D printing; Anatomy education; Bone model; Learning tool; Survey.

INTRODUCTION

Anatomy science forms the cornerstone of medical education. Undergraduate and graduate anatomy education has traditionally been conducted with anatomical models, two-dimensional (2D) anatomical atlas images, cadaver applications and theoretical lessons (Murgitroyd *et al*., 2015; Estai & Bunt, 2016). Among clinical practice training, a strong knowledge of anatomy is needed, especially in order to correctly apply surgical training and procedures (Garas *et al*., 2018). Cadaver-based application training is the gold standard for evaluating and examining an anatomical structure from a three-dimensional (3D) perspective and is traditionally still used frequently today (Yuen, 2020; Brumpt *et al*., 2023). Developments in today's technology have greatly affected the field of health. As a result of the decrease in education periods, the increase in the number of students, and the increase in ethical, legal, financial and religious problems related to donor donation programs, computer-aided learning tools have begun to be used more and more. In this regard, many scientists have focused on research on the production and development of 3D anatomical models (Estai & Bunt, 2016; Yuen, 2020).

3D printing technology, introduced by Charles Hull in the early 1980s, basically; it is a method of object production by combining or depositing materials such as metal, ceramic, plastic, powder, liquid, and even living cells in layers (Ventola, 2014; Chen *et al*., 2017). Today, rapidly developing 3D printing technology is used in many areas such as tissue and organ production, production of patient-specific prostheses and implants, surgical planning and creation of anatomical models (Yuen, 2020; Wilk *et al*., 2020). 3D printing technology allows the visualization of very complex anatomical structures in a simpler way (Pujol *et al*., 2016). Using 3D printed models (3DPM) instead of cadavers, which are especially difficult to obtain, provides significant convenience in anatomy courses (Rengier *et al*., 2010; Mitsouras *et al*., 2015; Fasel *et al*., 2016). Due to the different superior advantages of 3D printing

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technology, the effectiveness of 3DPM in anatomy and clinical education has been the subject of research for many scientists (Cantin *et al*., 2015; Lane & Black, 2020; Tanner *et al*., 2020; Tripodi *et al*., 2020; Chandrasekaran *et al*., 2022; Da Silva *et al*., 2023).

In this study, it was aimed to produce 3D printed bone models and to determine students' perceptions about them through a survey. In addition, it was aimed to analyze the production and cost parameters of the 3DPM.

MATERIAL AND METHOD

Printing of the 3D bone models

Fused Deposition Modelling (FDM) printing technology was used to produce 3DPM. 1.75 ± 0.05 mm white polylactic acid (PLA) (Tinylab 3D, China) was preferred as the thermoplastic material. 3D digital models were saved to the computer in STL file format from the open access website "https://commons.wikimedia.org/wiki/Category:STL_files_from_BodyParts3D". Final anatomical controls of the 3D digital models in STL file format were made in the Creality Slicer program (Creality Slicer 4.8.2, Creality 3D, China) before printing. They were transferred to the FDM printer with a nozzle diameter of 0.4 mm (Creality CR10 V2, China) in the '.gcode' file format and printed in x, y and z planes. Printing parameters of the FDM printer are indicated in Table I.

Table I. Printing parameters of 3D FDM printer.

Layer thickness	0.2 mm
Wall thickness	0.8 mm
Top/Bottom thickness	0.8 mm
Fill density	10 %
Printing temperature	210 °C
Building plate temperature	60 °C
Flow	100 %
Printing speed	50 mm/s
Retraction distance	5 mm
Retraction speed	45 mm/s
Fan speed	100 %
Support placement	Each section
Support density	20 %
Building plate type	Edge

Survey analyses

3DPM were used in undergraduate anatomy practice educations at the Cankiri Karatekin University Faculty of Dentistry and the Faculty of Health Sciences (Department of Physiotherapy and Rehabilitation, Department of Occupational Therapy, Department of Midwifery and Department of Nursing) (Fig. 1). During the last week of

Fig. 1. Stage of use of 3DPM in education.

Table II. Survey question information.

Questions (Q)	
Q1	3DPM made learning bone anatomy more interesting
Q2	3DPM were an effective educational tool that helped me learn bone anatomy
Q3	3DPM made learning bone anatomy fun
Q4	3DPM supported other learning tools in anatomy courses
Q5	I can identify any bone thanks to 3DPM
Q6	I can identify important anatomical structures on any 3DP bone models
Q7	3DPM were helpful in courses as I could touch and feel them
Q8	3DPM helped me learn because it offered an individual learning experience
Q9	3DPM were more easily understandable educational tool compared to 2D images
Q10	3DPM can solve the ethical issues brought by cadaver-based anatomy education
Q11	3DPM should be encouraged as educational tools in anatomy courses
Q12	I did not feel any odor associated with 3DPM
Q13	I was not worried about breaking 3DPM
Q14	I would like to use 3DPM in other courses of my education
Q15	3DPM motivated me to learn more
Q16	3DPM allow me to study outside of the classroom

bone anatomy practical courses, students were provided with a survey. A survey was made to evaluate student opinions concerning the use of 3DPM in anatomy practice educations. Two group of students (students of Faculty of Dentistry and Faculty of Health Sciences) responded for each survey question using a five-point Likert scale (1=strongly disagree, 5=strongly agree). A Cronbach's alpha (0.990) was performed to determine internal consistency of Likert-scale items. The survey responses were analyzed using Student t test to determine whether there were differences between two group of students. Differences with $P<0.05$ were considered statistically significant. Statistical analyses were performed using IBM SPSS Version 23.0.

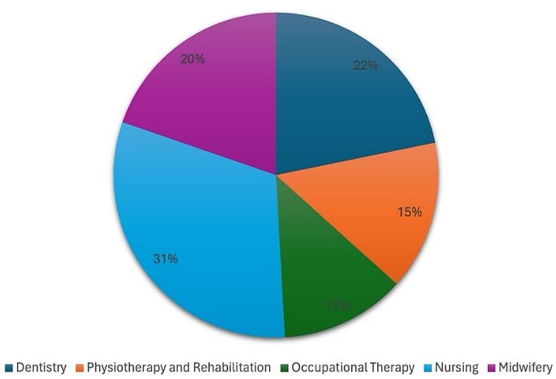

Fig. 2. Departments of students participated in the survey.

Ethical approval. The study was carried out with the ethical approval of Cankiri Karatekin University Scientific Research and Publication Ethics Board (Decision no: 29). An information form was shared to all students and they were asked to consent to the survey.

RESULTS

3DPM production

Using FDM technology, 3DPM of ossa membri superioris (upper limb bones), ossa membri inferioris (lower limb bones), ossa cranii (head bones), columna vertebralis (spine) and skeleton thoracis (thoracic skeleton) were produced (Fig. 3).

In calculating the average cost of the 3DPM, the price of 1000 grams of PLA was taken into account as $16 based on 2024, and the average electricity consumed by the FDM printer in 1 hour was taken into account as 0.15 kilowatts (kW). When the average costs of the 3DPM are evaluated, it has been determined that the 3DPM produced with FDM technology have very low costs. Product size, quality, fill density, support density, support placement type determined before printing directly affected the cost of the 3DPM, as

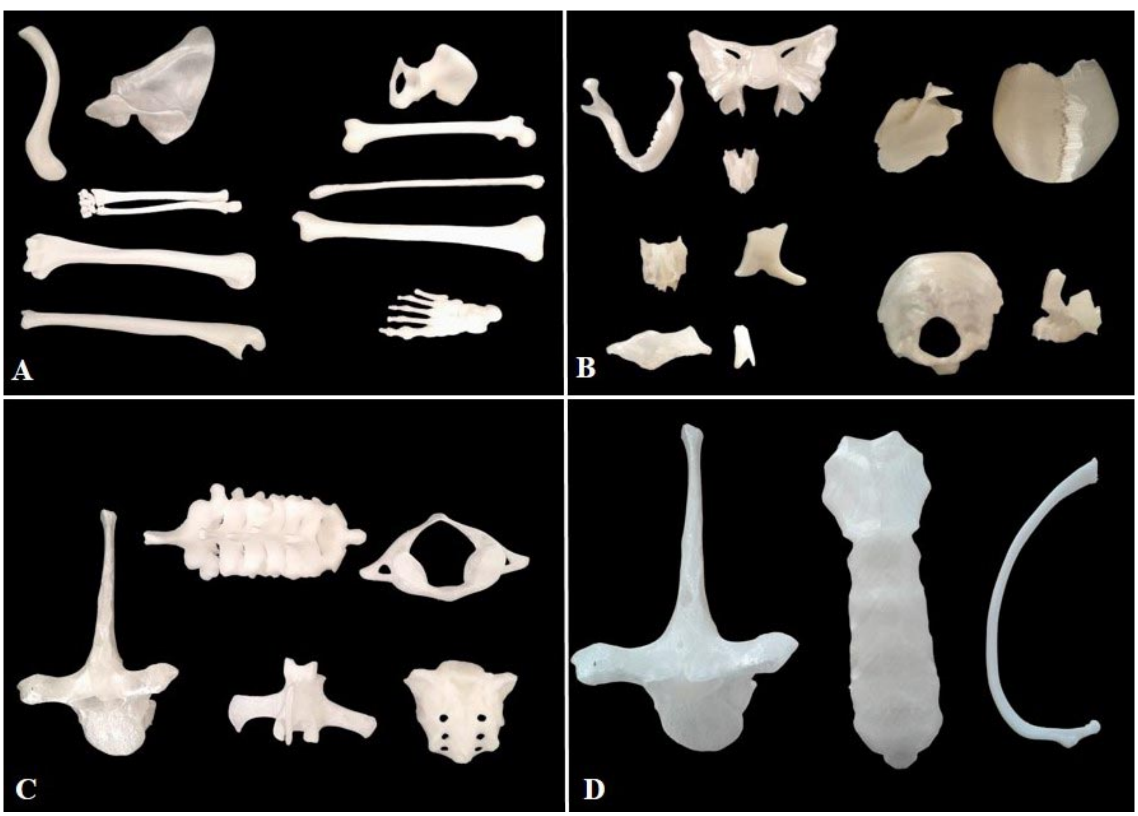

Fig. 3. Samples of 3DPM; A: ossa membri superioris (bones of upper limb), ossa membri inferioris (bones of lower limb), B: ossa cranii (skull), C: columna vertebralis (vertebral column), D: skeleton thoracis (bones of thorax).

they affected the amount of PLA consumed. Likewise, the cost of the 3DPM varies because printing and build plate temperature affected the amount of electricity consumed. The average product cost for some 3DPM produced with the values specified in Table I expressed in Table III.

Table III. Average amount of PLA consumed, printing time and cost information for some 3DPM.

3DPM	Scale of 3D Printer			Average printing time	Average amount of PLA consumed (g)	Average cost ($)
	X	Y	Z			
Atlas	90 mm	61 mm	21 mm	2 h 30 min	13 g	$0.24
Lumbar Vertebra I	70 mm	85 mm	43 mm	3 h 54 min	26 g	$0.46
Mandible	106 mm	89 mm	84 mm	4 h 51 min	29 g	$0.52
Humerus	292 mm	53 mm	48 mm	7 h 45 min	48 g	$0.86
Femur	284 mm	53 mm	63 mm	9 h 30 min	60 g	$1.08
Sternum	55 mm	174 mm	41 mm	9 h 45 min	62 g	$1.10

Survey

A total of 289 students (1st year students) participated in the survey voluntarily. Survey question information and departments of students participated in the survey can be found in Table II and Fig. 2, respectively. To identify student perception on the use of the 3DPM, students were asked to rate their thoughts on a 5-point Likert scale, where 5 was "strongly agree" and 1 was "strongly disagree'', as mentioned above. Results of survey responses were presented as a figure (Fig. 4).

The survey results demonstrated that students thought the 3DPM helped their understanding of bone anatomy. Students specified that they could identify 3DPM as well as anatomical structures on the models. They found that the 3DPM were odorless, durable and the 3DPM increased students' interest in learning. They also largely believed that that 3DPM were more understandable than the 2D educational tools used in courses. In addition to encouraging 3DPM as a learning tool in anatomy laboratory, they specified that they would like to use 3DPM in other courses of their education. When the results were evaluated in terms of all survey questions, it was determined that 3DPM would be an effective and useful educational tool for students in anatomy courses. Additionally, no significant statistical difference was found between both student groups in the survey results ($P>0.05$) (Fig. 4).

DISCUSSION

In this study, FDM technology was used to produce the 3DPM. The reason the FDM printer was preferred was that it was cost-effective compared to other printing technologies such as Stereolithography (SLA) or Selective Laser Sintering (SLS) (Dawood *et al*., 2015; Javaid & Haleem, 2019). The FDM printer model with single extruder used in the study is sold for an average of $450 based on 2024 estimates. Although increasing the number of extruders provides an advantage in terms of printing time, it increases the cost of the printer (Barger & Edwards, 2024). As stated in our study, although many factors affect the production cost of the 3DPM, it is clear that they generally are low cost. The cost effectiveness of the 3DPM has been investigated in many studies and results support our study (Chen *et al*., 2017; Werz *et al*., 2018; Shen *et al*., 2019; Barger & Edwards, 2024). However, it would be more valuable for researchers to clearly state the printing parameters. The type of thermoplastic material used in FDM technology is quite limited (Javaid & Haleem, 2019). However, the frequently preferred PLA provides the advantage of being easily accessible, durable, cheap and easy to use. At the same time, PLA can be successfully used in medical applications, because it is not metabolically harmful (Kristiawan *et al*., 2021; Cojocaru *et al*., 2022). In line with this information, PLA was preferred in the current study. Zhang *et al*. (2018), have stated that 3D printer with a nozzle diameter of 0.2 mm and a layer thickness of 1.2 mm, have satisfactory printing precision and surface effects. It has also been reported that although using a larger nozzle (0.4 mm in diameter) and increasing the layer thickness and printing speed may shorten printing time, the surface effect of the printed model may be low. In our study, 3DPM were produced with a layer thickness of 0.2 mm using a FDM printer with a nozzle diameter 0.4 mm. The selected layer thickness enabled high-resolution 3DPM production in a short time and at low cost.

Yuen (2020) reported that 3DPM offer tactile response and allow simulations of surgical and dissection techniques. It also provides extra value to the 2D anatomical learning tools currently found in classrooms (Pujol *et al*.,

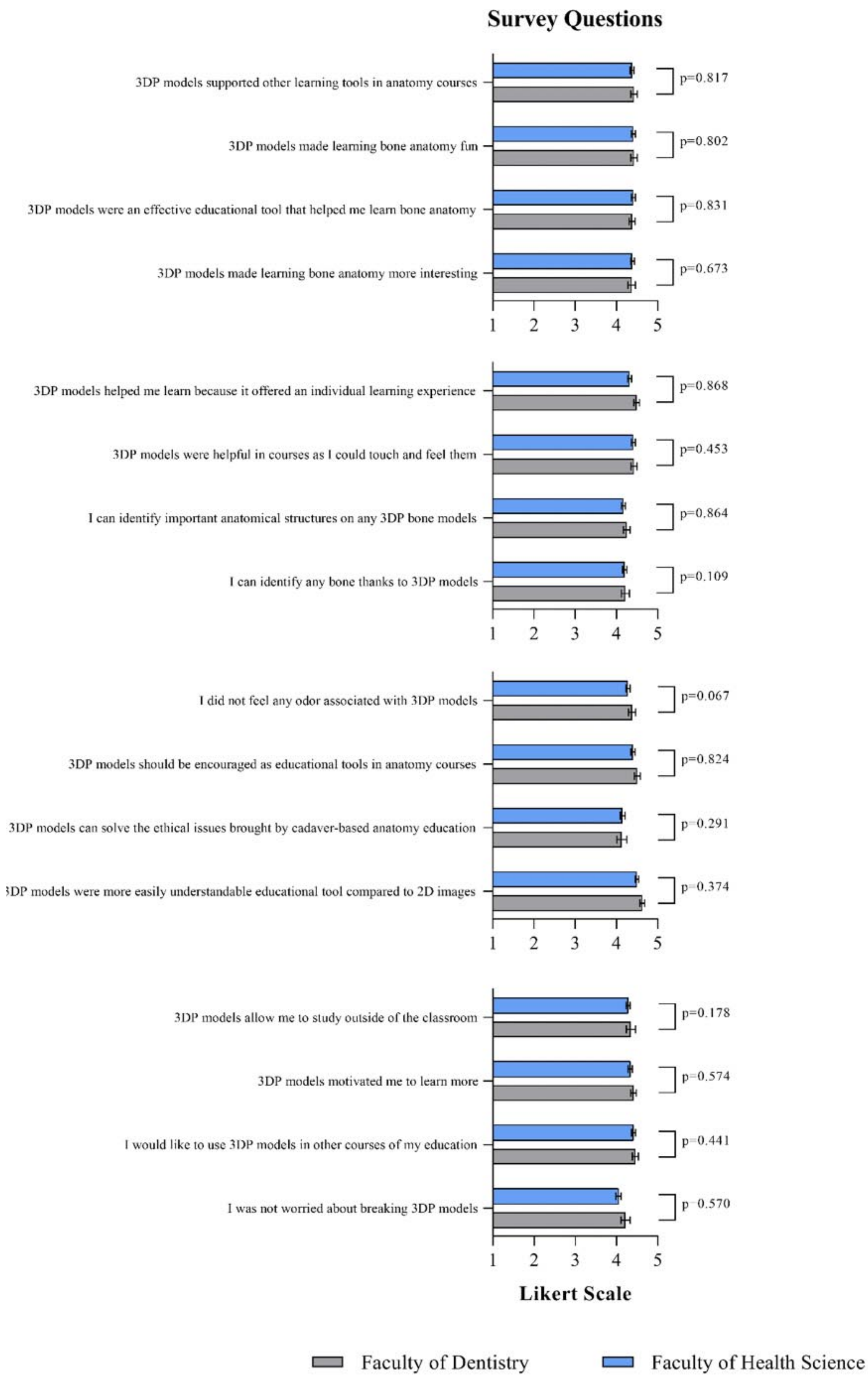

Fig. 4. Students' perception about the 3DPM. 5-point Likert scale is as follows: 1: strongly disagree, 2: disagree, 3: undecided, 4: agree, 5: strongly agree. Q1: Results by grade: (blue) n = 226, 4.39 ± 0.05, (grey) n = 63, 4.37 ± 0.09; Q2: Results by grade: (blue) n = 226, 4.41 ± 0.05, (grey) n = 63, 4.38 ± 0.07; Q3: Results by grade: (blue) n = 226, 4.41 ± 0.05, (grey) n = 63, 4.43 ± 0.08; Q4: Results by grade: (blue) n = 226, 4.38 ± 0.05, (grey) n = 63, 4.43 ± 0.08; Q5: Results by grade: (blue) n = 226, 4.20 ± 0.05, (grey) n = 63, 4.22 ± 0.10; Q6: Results by grade: (blue) n = 226, 4.17 ± 0.05, (grey) n = 63, 4.25 ± 0.08; Q7: Results by grade: (blue) n = 226, 4.41 ± 0.05, (grey) n = 63, 4.43 ± 0.07; Q8: Results by grade: (blue) n = 226, 4.32 ± 0.05, (grey) n = 63, 4.49 ± 0.07; Q9: Results by grade: (blue) n = 226, 4.50 ± 0.04, (grey) n = 63, 4.63 ± 0.06; Q10: Results by grade: (blue) n = 226, 4.15 ± 0.06, (grey) n = 63, 4.13 ± 0.12; Q11: Results by grade: (blue) n = 226, 4.40 ± 0.05, (grey) n = 63, 4.51 ± 0.07; Q12: Results by grade: (blue) n = 226, 4.28 ± 0.05, (grey) n = 63, 4.38 ± 0.09; Q13: Results by grade: (blue) n = 226, 4.05 ± 0.06, (grey) n = 63, 4.22 ± 0.11; Q14: Results by grade: (blue) n = 226, 4.41 ± 0.05, (grey) n = 63, 4.46 ± 0.07; Q15: Results by grade: (blue) n = 226, 4.33 ± 0.05, (grey) n = 63, 4.41 ± 0.07; Q16: Results by grade: (blue) n = 226, 4.28 ± 0.05, (grey) n = 63, 4.35 ± 0.11. Data are reported as Mean ± SEM.

2016; Chytas *et al*., 2020). In the current study, students have reported that 3DPM help in their education because they can touch and feel them, and that they are more understandable educational materials than 2D educational tools according to survey results (Fig. 4). McMenamin *et al*. (2014) have argued that 3D printed anatomical replicas serve as an aid to the actual dissection and not as a substitute. They have suggested that if access to cadaveric material is not an option, or unavailable to students, 3DPM could offer a new, accurate and effective alternative. As in our institution, the number of students is high and the insufficient number of real bone materials causes problems for both students and educators. In our study, it is thought that 3DPM would be an alternative to increase the number of educational bone tools per student.

3D printing technology allows not only the production of replicas of anatomical structures but also the design of abnormal structures (Bernhard *et al*., 2016; Andolfi *et al*., 2017; Lane & Black, 2020). 3DPM are effective tools in addition to anatomy training especially in surgical education and clinical practice (Jones *et al*., 2016; Low *et al*., 2019; Gadaleta *et al*., 2020; Moriles *et al*., 2021). Preoperative planning on 3DPM reduces guesswork and thus significantly reduces surgical time, blood loss, minimizes complications, improving surgical outcomes (Werz *et al*., 2018; Chaudhary *et al*., 2021). For these reasons, we believe it is important to encourage the use of 3DPM, especially in oral and maxillofacial surgical education. As a result of the survey, dentistry students largely expressed their opinions in this direction (Fig. 4).

Low quality ‘’stl.’’ file formats also result in the production of poor quality and detailed 3D printed models. The amount of details on 3D printed models depends on the resolution of the CT (Computed Tomography) or MRI (Magnetic Resonance Imaging) scans they are based on (Garas *et al*., 2018; Li *et al*., 2018; Yuen, 2020). In this study, 3D digital models in "stl." file format were accessed from the openaccess "https://commons.wikimedia.org/wiki/Category:STL_files_from_BodyParts3D". Although the digital models used for the goal of our study are sufficient, high quality and thin-section CT images are required to produce a highly detailed 3D printed bone model. Investigating student's perceptions of 3D printed bone models designed using high-quality CT, CBCT or even micro-CT data, may further contribute to the literature.

There is a clear playoff between model size and printing time/cost. The size of the product can be reduced to decrease cost and printing time. In spite of the fact that small-scale models are suitable, as in our study, full scale models are important for students associating to the real size of the model (Smith *et al*., 2018).

The lack of age and sex information of the students in this study is a shortcoming. In terms of age, younger individuals are likely to be more interested in technology-based education methods/tools. However, we thought that the gender factor would not have a significant impact on the study.

CONCLUSION

Survey results showed that 3D printed bone models which are cost-effective were widely accepted by students from different departments in undergraduate anatomy practice learning.

3D printing is an advanced technique that can provide valuable 3DPM for undergraduate anatomy learning. 3DPM may use as confident options to bone specimens in anatomy practice learning. 3DPM have the potential to assist not only students but also the lecturer. Since there are some problems related with the use of traditional anatomy learning methods, 3DPM which are high-attribute learning tool can lighten the difficulties of cadaver-based curriculum. We believe that 3D printing technology will continue to advance, which will be useful not only in undergraduate anatomy education but also in different medical learning areas. Finally, if possible, we encourage our undergraduate students to produce their own 3DPM so that they can consider using them in their professional lives.

Ethical approval. The study was carried out with the ethical approval of Cankiri Karatekin University Scientific Research and Publication Ethics Board (Decision no: 29).

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RESUMEN: La anatomía se considera una de las piedras angulares de los planes de estudio de medicina. Gracias a la modernización y los avances tecnológicos en la educación médica, se han añadido muchas innovaciones a las herramientas de aprendizaje tradicionales en la enseñanza de la anatomía, una de las más importantes de las cuales son los modelos impresos en tres dimensiones (3D). La determinación de las propiedades de producción de los modelos impresos en 3D y también las percepciones de los estudiantes sobre estos modelos se ha vuelto cada vez más importante. Por lo tanto, este estudio tuvo como objetivo producir modelos óseos impresos en 3D para su uso en la enseñanza práctica de anatomía de pregrado y determinar las percepciones de los estudiantes sobre ellos. Utilizando la tecnología de impresión 3D, se produjeron modelos óseos impresos en 3D de alta precisión de forma sencilla, económica y rápida. Después de utilizar los modelos 3D en la enseñanza práctica de la anatomía, se realizó una encuesta de 16 ítems (escala Likert de cinco puntos, 1 = totalmente en desacuerdo a 5 = totalmente de acuerdo) a dos grupos de estudiantes de primer año de la carrera (estudiantes de la Facultad de Odontología y de la Facultad de Ciencias de la Salud). Los resultados de la encuesta mostraron que los modelos óseos impresos en 3D fueron bien aceptados por los estudiantes de pregrado en la enseñanza práctica de la anatomía. Además, para todos los ítems de la encuesta, no se encontró diferencia estadística significativa entre ambos grupos de estudiantes (P>0,05). Nuestro estudio sugiere que la tecnología deimpresión 3D es útil para ayudar en las prácticas de anatomía y proporciona herramientas de enseñanza para estudiantes de pregrado de diferentes departamentos en el aprendizaje de la anatomía.

PALABRAS CLAVE: Impresión 3D; Enseñanza de la anatomía; Modelo óseo; Herramienta de aprendizaje; Encuesta.

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