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Received: March 15, 2022; Accepted: December 10, 2022
doi:10.2399/ana.22.3265139

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anatomy
An International Journal of Experimental and Clinical Anatomy

Can high resolution 3D resin printed models be used in anatomy education? A randomized controlled trial

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Abstract

Objectives: Resin printing is a rapidly growing technology with a diverse range of applications. This study aims to examine the usability of 3D resin printed models in anatomy education.

Methods: The study included 84 students who were randomly assigned to either a 3D resin print group (n=42) or a plastic model group (n=42) based on their sex, lateralization, anatomy quiz scores, and Purdue spatial visualization test rotations scores. After attending a lecture, each participant examined an original sacrum and either a 3D printed or a plastic model, depending on their group. The participants were then asked to compare the models to the original using a visual analog scale (VAS) questionnaire, which consisted of four questions about the model's weight, anatomical accuracy, level of detail, and texture quality. The participants' ability to identify the models was evaluated using a 3-point Likert scale.

Results: The results showed that the 3D printed model had significantly higher ratings than the plastic model in terms of weight, level of detail, and texture quality ($p<0.05$). There was no significant difference in accuracy scores ($p>0.05$) or the participants' ability to identify the models ($p>0.05$).

Conclusion: 3D resin printed models are superior to plastic models in some aspects. These results suggest that 3D resin printed model can be used as in the conventional anatomy training approach.

Keywords: 3D print, education, resin, spatial ability

Anatomy 2022;16(3):179–184 ©2022 Turkish Society of Anatomy and Clinical Anatomy (TSACA)

Introduction

Traditional anatomy education primarily relies on presentation materials, atlases, models, digital resources, and wet and dry plastinated cadavers.[1,2] The correct placement of anatomical structures is crucial for the success of health professionals in their practice.[3] Three-dimensional direct manipulation of the human body by touch is of great importance in anatomy education, and cadaver dissection is still considered the most appropriate source to achieve this goal.[4,5] However, there are many obstacles to use cadavers in anatomy education, including social, ethnic, religious, cultural, and donor laws and the high cost of cadaver acquisition and management for worldwide anatomy education.[6,7] Students need to take the anatomical structures, rotate, and examine them from every angle, such as the contribution of direct manipulation.[8] It is known that direct manipulation makes great contributions to students' practical knowledge.[9]

In addition to traditional methods (dissection and plastination), a modern three-dimensional (3D) printing system technique has recently been added to the anatomy curriculum.[8,10,11] This new tool looks promising and could supplement and replace more traditional methods of anatomy education. Studies evaluating the impact of different pedagogies in anatomical education highlight the potential role of new methods (such as the use of 3D printed material) in anatomical education. 3D-printed examples can be a valuable, helpful tool, especially in contexts where human dissection is hampered by lack of facilities, human material, and problematic cultural and/or religious backgrounds.[10,12]

In the last decade, 3D printing has become more accessible and affordable, with systems and materials that can be used at home. 3D printing is a technology that reduces production to individual dimensions without the need for supply systems based on a computer-generated model.[13] In the computer controlled 3D printing process, the physical material is created layer by layer until it is virtually identical to the designed one.[14] Compared with other tissue engineering methods and rapid tissue prototyping methods, 3D printing has several advantages, including high precision, fast production, low cost and good integration.[15] 3D modeling can help medical professionals or students better understand complex structures.[16] The most common materials used in 3D printers are durable nylon, aluminum, gypsum, textile raw materials, polylactic acid, and resin.[17] Among these materials, photosensitive resin provides the opportunity to produce higher quality, more complex structures that are closer to reality and smoother without showing its own raw material texture.[18]

This study aimed to examine the usability of tissues printed with a 3D resin printer in anatomy education to increase direct manipulation in applied training.

Materials and Methods

The study involved a total of 84 participants, all 2nd-year medical students. This prospective, double-blinded, and parallel-group study was performed in line with the Helsinki Declaration with permission from the ethical committee of Bolu Abant İzzet Baysal University. The inclusion criteria were to enroll in the anatomy course in both periods and participate in the cadaveric and model practical lectures. Exclusion criteria were if the candidate had upper extremity traumatic injury in the last three months, a sensory deficit in either of the hands or scar tissue on their fingertips.

Participants were randomly assigned into two, 3D print (n=42) and plastic model (n=42) groups, with stratified randomization based on Purdue spatial visualization test. Rotation (PSVT-R) scores, laterality scores, sex, and age of the participants were recorded. Sample size calculation was performed with G*Power software based on previous research, which yielded an estimated effect size of 0.701 and it was found that 33 participants were required for each group to achieve 80% power with a $p<0.05$ significance level.[19]

For 3D printing, the department's Elegoo Saturn 8k 3D resin printer (Elegoo Inc, HK, China) and Elegoo 8K grey resin were used, with a 2.5-second exposure time and 0.05mm slice layer height. The printable sacrum model was based on a human sacrum, and the interior wall was hollowed and sliced for printing using Chitubox basic software (Chitubox Inc, Guangdong, China). The hollow part of the model was filled with fast-cure resin until the model weight matched the original sacrum (**Figure 1**). After printing, the model was washed with 95% isopropyl alcohol and cured for 30 minutes under direct ultraviolet light.

Both groups received a 30-minute theoretical lecture on the anatomy and clinical implications of the sacrum. After the lecture, participants were instructed to examine

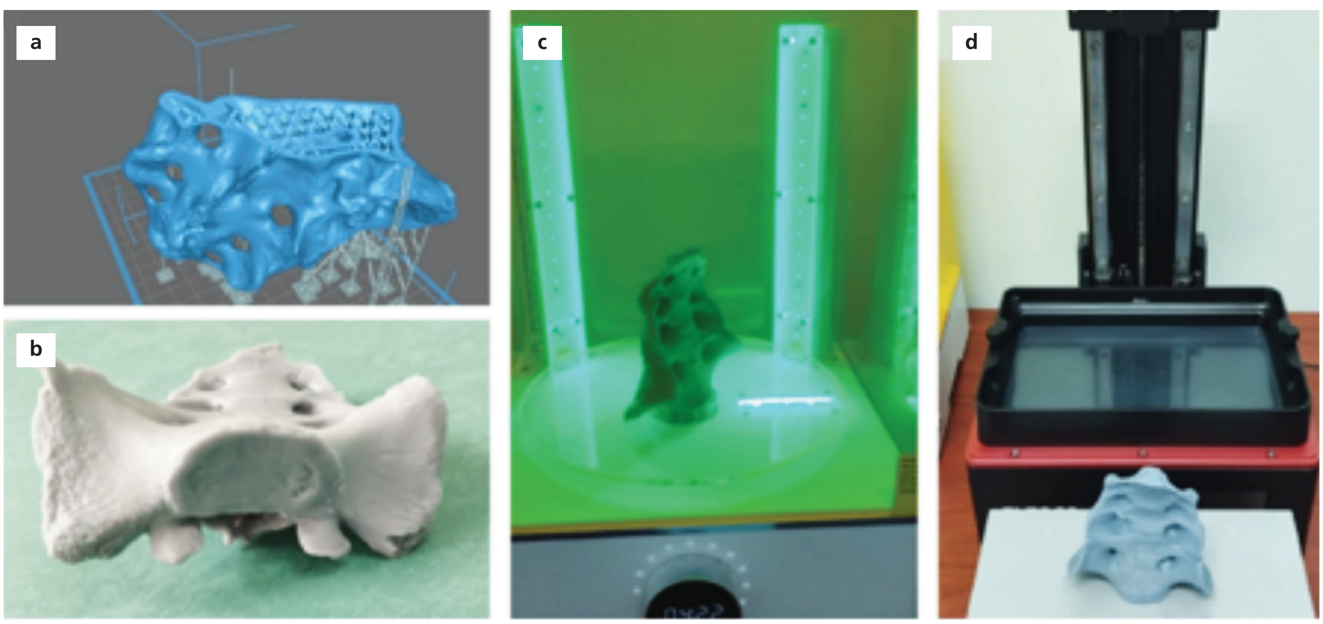

Figure 1. (**a**) Preparation of the model in the slicing program for printing; (**b**) Detailed bone texture of the printed model; (**c**) Curing process of the model with rotating ultraviolet light device; (**d**) 3D printer and completed model of the sacrum.

and identify structures on the original sacrum for 10 minutes with direct manipulation. Then, they received either a 3D or plastic model of the sacrum according to their group allocations and were instructed to examine and compare the models to the original.

The outcome assessments included a 10-question multiple-choice quiz to assess participants' post-exposure knowledge of anatomical structures after the practical lecture. Participants were also asked to compare the models to the original with a Visual Analog Scale (VAS) questionnaire consisting of 4 questions about the model's weight, anatomical accuracy, level of detail, and texture quality. After completing assessments, blinded participants were asked to identify both models as 3D printed and plastic models.

Purdue spatial visualization test-Rotation was used to assess three-dimensional perception of participants in this study. The test was developed by Guay in 1977 and revised by Yoon in 2011 and consists of 30 items. The participants were asked to solve each multiple-choice question (MCQ) rotation according to the given rotations. Low scores indicate lower spatial perception capabilities. Subjects completed the task in approximately 15 min.[20]

The hand laterality task was used to assess participants' mental motor imaginary capabilities, which is required for imaging three-dimensional objects. The test consists of 4 images of both hands and six difficulty levels. Levels consist of a 60-degree rotation for each set of images. A total score of 48 indicates perfect laterality. Subjects completed the task in approximately 10 min.[21]

The printed model's weight, anatomical accuracy, level of detail, and texture were assessed with VAS. Participants were instructed that 0 indicates no similarity to 10 indicates identical to the original model and asked to mark on a 10 cm straight line.

After completing previous assessments, participants received both 3D printed and plastic models and were asked to identify each model on a 3-point Likert scale as 0-cannot decide, 1-plastic, 2-3D printed.

The chi-square test was used to compare the distribution of sex and the participants' discernment capabilities of models. The Shapiro-Wilk test was used to test for the normal distribution of continuous variables. Normal distribution was observed for age, quiz, PSVR-T, and laterality scores. The independent t-test was used to analyze the differences between the groups. A p-value of less than 0.05 was considered statistically significant. The chi-square test was used to analyze sex distribution between groups. All statistical analyses were performed using the SPSS statistical package for Windows, version 24 (IBM Inc., Armonk, NY, USA).

Results

Eighty-four participants who met the inclusion criteria were included in this study (**Figure 2**). In the 3D print

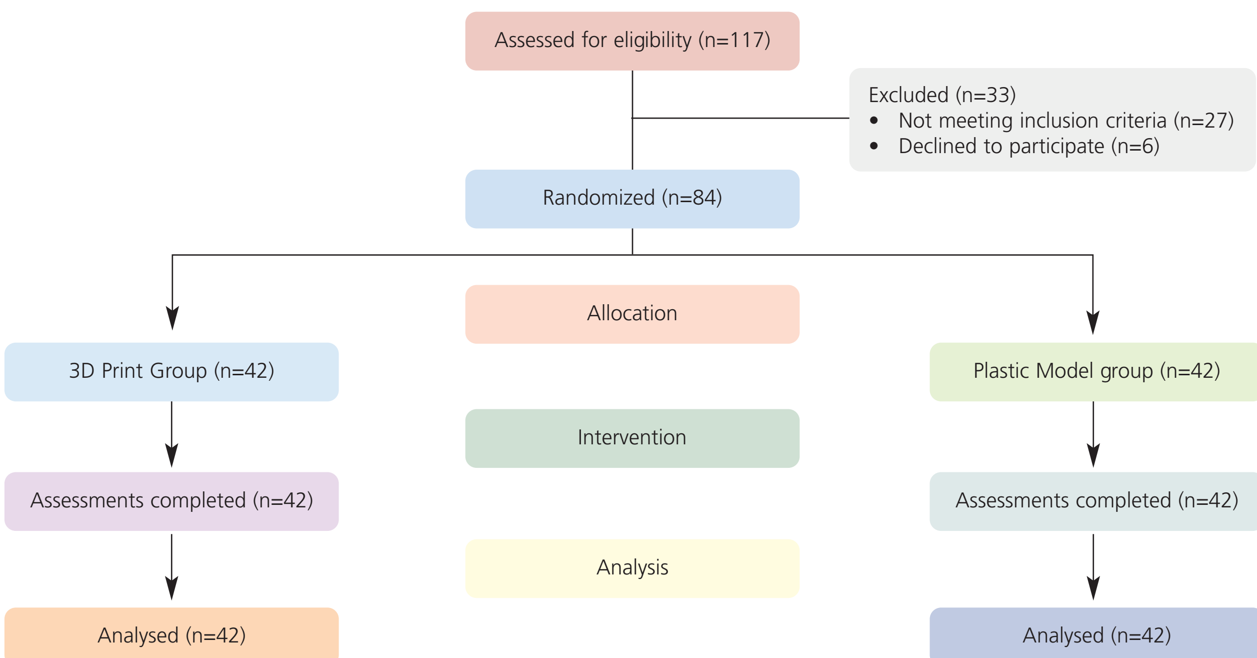

Figure 2. Flowchart of the study.

Table 1
Baseline characteristics of the participants.

		3D Print (n=42)		Plastic model (n=42)			
		X±SD		X±SD		t	p-value
Age (years)		19.90±1.33		19.38±01.41		1.743	0.085
Lateralization		34.61±7.69		35.04±10.15		-0.218	0.828
PSVT:R		24.28±3.95		23.26±3.65		1.232	0.221
		n	%	n	%	χ^2	p-value
Sex	Female	38	90.5	37	88.1	0.124	0.724
	Male	4	9.5	5	11.9		

PSVT:R: purdue spatial visualization test rotations; **t:** independent samples t-test, $p<0.05$; χ^2: Chi-square test.

group, the mean age was 19.90±1.33 years, the lateralization score was 34.61±7.69 points, and the PSVT-R score was 24.28±3.95 points. In the plastic model group, the mean age was 19.90±1.33 years, the lateralization score was 35.04±10.15 points, and the PSVRT score was 23.26±3.65 points. There were 4 (9.5%) males and 38 (90.5%) females in the 3D print group and 5 (11.9%) men and 37 (88.1%) women in the plastic model group. There was no difference between the groups in terms of age, lateralization scores, sex, and PSVRT scores (p<0.05) (**Table 1**). Participants' model assessment VAS scores and quiz scores showed a normal distribution (p>0.05).

Independent sample t-test results showed that there was no difference between the quiz scores of 3D print (6.28±2.03) and plastic model groups (6.76±2.22) (p=0.310) (**Table 2**). 3D Printed model's weight, level of detail, and texture quality VAS scores showed significantly higher scores than the plastic model (p<0.001). However, there was no significant difference between the groups regarding anatomical accuracy scores (p=0.142) (**Table 2**).

Discussion

In this study it was found that, 3D resin-printed models are superior to plastic models and resin-printed models can replicate details and textures better than plastic models. This outcome shows a high potential for creating accurate anatomical models for anatomy education with 3d resin printing.

Anatomy education requires mental imaging and spatial skills.[22] Sex-based allocation was necessary due to reported differences in the spatial abilities of male and female participants.[23] Studies investigating the efficiency of 3D-printed models showed an increase in favor of 3D-printed groups' written tests and quiz scores. In this study, a pre-test quiz was used to assess participants' anatomic knowledge after the lecture. This ensured that the initial anatomy knowledge of the groups was similar and prevented both the heterogonous distribution of reluctant/enthusiastic participants and sex distribution.

3D printing is a cheaper option compared to both cadaveric and plastic model-based education.[10] Kim et.

Table 2
Independent t-test result of mean differences between groups.

	3D Print (n=42)	Plastic model (n=42)		
	X±SD	X±SD	t	p-value
Quiz	6.28±2.03	6.76±2.22	-1.022	0.310
Weight	8.28±1.87	5.60±2.16	6.049	**<0.001**
Anatomical accuracy	7.85±2.21	7.50±3.07	1.483	0.142
Level of detail	8.14±1.49	5.51±1.53	7.948	**<0.001**
Texture quality	8.71±1.24	4.08±2.33	11.359	**<0.001**

t: independent samples t-test, $p<0.05$.

al.[6] reported that next-generation printers with higher precision capabilities increased the printed models' level of detail and accuracy. Fasel et al.[24] verified the accuracy of models and showed that scans could be adapted to 3D-printed models. In order to achieve a real-life texture, studies tried various methods, such as covering printed tissue with a silicon-based coating.[25] The main concern of 3D-printed models is their accuracy and resemblance to the original tissue.[6] A 3D upper extremity model study pointed to the same limitations and implied that with technological advancements a printed model's texture could become identical to the original.[26] In this study, we found that the resin printed model's texture closely resembled the original one. In addition, the resin model's fine slice height resulted in a smooth transition which was a main concern for previous studies which used a PLA printer that produces rough textures. Moreover, the level of detail of the 3D printed models was found to be superior compared to the plastic model which uses a mould to mass produce models.

Young et al.[27] reported that increased cognitive load might impact the effectiveness of educational material. The complexity of the pelvis region is higher and increases the cognitive load on students that examine models. Another study focusing on 3D printed organs showed that the pelvis is a more complex region than the heart and recommends higher resolution prints for complex areas.[6] Studies investigating 3D prints on anatomy education report its benefits, however these studies also remark on the low detail level of 3D printers.[6,28,29] Printed and plastic models' resemblance to the original is vital. Level of detail is a crucial parameter when comparing plastic and printed models since the moulding procedure prevents the production of fine details due to the high risk of tearing during mould release.

Studies investigating the effectiveness of 3D printed models on anatomy education report promising results. A study comparing cadaveric and 3D printed model's post-test results showed that the 3D print group scores higher marks.[6] A randomized controlled study comparing cadaveric, 3D printed and atlas found similar results in favor of the 3D printed model group.[28] Another study using color coded 3D printed models also reports high scores in favor of the printed model group.[26] Studies investigating the effect of 3D printed models based on students learning reported that 3D printing does not cause disadvantages for students' learning activities and has a positive effect on junior students who do not want to make contact with cadaveric materials and avoid direct manipulation.[30–32] Similar to the previous studies, we found that the resin printed model scores higher marks and can be used in anatomy education. Post-test scores were not collected from participants due to the design limitation of the study. Although previous studies showed that 3D models do not cause a disadvantage in anatomy learning, it was unclear whether resin models are free from the same problems.

3D printing is a cheap, accurate, feasible, and innovative way of providing anatomy teaching materials. The findings of this study show that resin printed models compared to plastic models, are more realistic and similar to originals. 3D printing is a relatively new area for anatomy education and this study showed that resin printing is a better solution compared to plastic models. The use of 3D prints can enhance anatomy education by providing a flexible tool. As students become more proficient in understanding normal anatomy, they can gradually be introduced to models that include pathological conditions. However, printing time is a downside of resin printing which can take 4-6 hours to print a single model. The cost of printing varies depending on the model's size, the resin's cost, and the inner area's hollowing. As a result, almost all bones, except cranial bones, can be printed using a small amount of resin. In this study, the cost of the sacrum was 4.7 USD, including the support for the models. This is cheaper than commercial sacrum models, typically costing 29 to 75 USD per model.

Conflict of Interest

The authors have declared that they have no conflict of interest.

Author Contributions

All authors contributed equally to protocol/project development, data collection, data analysis, manuscript writing/editing.

Ethics Approval

The study was approved by Ethical Committee of Bolu Abant Izzet Baysal University (Clinical Researches Ethics Committee NBo: 2022/322-526) and performed in accordance with the Helsinki declaration of principles.

Funding

This study was funded by The Scientific and Technological Research Council of Turkey (ID:2209-A 1919B012205918) and BAIBU Scientific Research Projects (ID: 2023-BDP-6.12.61-0003).

References

1. McBride JM, Drake RL. National survey on anatomical sciences in medical education. Anat Sci Educ 2018;11:7–14.
2. Estai M, Bunt S. Best teaching practices in anatomy education: a critical review. Ann Anat 2016;208:151–7.

3. Sugand K, Abrahams P, Khurana A. The anatomy of anatomy: a review for its modernization. Anat Sci Educ 2010;3:83–93.
4. Winkelmann A. Anatomical dissection as a teaching method in medical school: a review of the evidence. Med Educ 2007;41:15–22.
5. Kerby J, Shukur ZN, Shalhoub J. The relationships between learning outcomes and methods of teaching anatomy as perceived by medical students. Clin Anat 2011;24:489–97.
6. Lim KHA, Loo ZY, Goldie SJ, Adams JW, McMenamin PG. Use of 3D printed models in medical education: a randomized control trial comparing 3D prints versus cadaveric materials for learning external cardiac anatomy. Anat Sci Educ 2016;9:213–21.
7. Robison RA, Liu CY, Apuzzo ML. Man, mind, and machine: the past and future of virtual reality simulation in neurologic surgery. World Neurosurg 2011;76:419–30.
8. Azer SA, Azer S. 3D anatomy models and impact on learning: a review of the quality of the literature. Health Professions Education 2016;2:80–98.
9. Peeler J, Bergen H, Bulow A. Musculoskeletal anatomy education: evaluating the influence of different teaching and learning activities on medical students perception and academic performance. Ann Anat 2018;219:44–50.
10. McMenamin PG, Quayle MR, McHenry CR, Adams JW. The production of anatomical teaching resources using three-dimensional (3D) printing technology. Anat Sci Educ 2014;7:479–86.
11. Vaccarezza M. Best evidence of anatomy education? Insights from the most recent literature. Anat Sci Educ 2018;11:215–6.
12. Bergman EM, Prince KJ, Drukker J, van der Vleuten CP, Scherpbier AJ. How much anatomy is enough? Anat Sci Educ 2008;1:184–8.
13. Silver A. 3D printing in the lab. Nature 2019;565:123–4.
14. Ye Z, Dun A, Jiang H, Nie C, Zhao S, Wang T, Zhai J. The role of 3D printed models in the teaching of human anatomy: a systematic review and meta-analysis. BMC Med Educ 2020;20:1–9.
15. Jones DB, Sung R, Weinberg C, Korelitz T, Andrews R. Three-dimensional modeling may improve surgical education and clinical practice. Surg Innov 2016;23:189–95.
16. Lauridsen H, Hansen K, Nørgård MØ, Wang T, Pedersen M. From tissue to silicon to plastic: three-dimensional printing in comparative anatomy and physiology. R Soc Open Sci 2016;3:150643.
17. Sharma S, Goel SA. 3D printing and its future in medical world. Journal of Medical Research and Innovation 2019;3:e000141.
18. Arefin AM, Khatri NR, Kulkarni N, Egan PF. Polymer 3D printing review: materials, process, and design strategies for medical applications. Polymers (Basel) 2021;13:1499.
19. Salazar D, Thompson M, Rosen A, Zuniga J. Using 3D printing to improve student education of complex anatomy: a systematic review and meta-analysis. Med Sci Educ 2022;32:1209–18.
20. Maeda Y, Yoon SY. A meta-analysis on gender differences in mental rotation ability measured by the Purdue spatial visualization tests: visualization of rotations (PSVT:R). Educational Psychology Review 2013;25:69–94.
21. Voyer D. On the reliability and validity of noninvasive laterality measures. Brain Cogn 1998;36:209–36.
22. Guillot A, Champely S, Batier C, Thiriet P, Collet C. Relationship between spatial abilities, mental rotation and functional anatomy learning. Adv Health Sci Educ Theory Pract 2007;12:491–507.
23. Terlecki MS, Newcombe NS, Little M. Durable and generalized effects of spatial experience on mental rotation: gender differences in growth patterns. Applied Cognitive Psychology 2008;22:996–1013.
24. Fasel JH, Aguiar D, Kiss-Bodolay D, Montet X, Kalangos A, Stimec BV, Ratib O. Adapting anatomy teaching to surgical trends: a combination of classical dissection, medical imaging, and 3D-printing technologies. Surg Radiol Anat 2016;38:361–7.
25. O'Reilly MK, Reese S, Herlihy T, Geoghegan T, Cantwell CP, Feeney RN, Jones JFX. Fabrication and assessment of 3 D printed anatomical models of the lower limb for anatomical teaching and femoral vessel access training in medicine. Anat Sci Educ 2016;9:71–9.
26. Mogali SR, Yeong WY, Tan HKJ, Tan GJS, Abrahams PH, Zary N, Low-Beer N, Ferenczi MA. Evaluation by medical students of the educational value of multi-material and multi-colored three-dimensional printed models of the upper limb for anatomical education. Anat Sci Educ 2018;11:54–64.
27. Young J, Van Merrienboer J, During S, Ten Cate O. Cognitive load theory: implications for medical education: AMEE guide no.86. Med Teach 2014;36:371–84.
28. Chen S, Pan Z, Wu Y, Gu Z, Li M, Liang Z, Zhu H, Yao Y, Shui W, Shen Z, Zhao J, Pan H. The role of three-dimensional printed models of skull in anatomy education: a randomized controlled trail. Sci Rep 2017;7:575.
29. Smith CF, Tollemache N, Covill D, Johnston M. Take away body parts! An investigation into the use of 3D-printed anatomical models in undergraduate anatomy education. Anat Sci Educ 2018;11:44–53.
30. Garas M, Vaccarezza M, Newland G, McVay-Doornbusch K, Hasani J. 3D-Printed specimens as a valuable tool in anatomy education: a pilot study. Ann Anat 2018;219:57–64.
31. Boeckers A, Brinkmann A, Jerg-Bretzke L, Lamp C, Traue HC, Boeckers TM. How can we deal with mental distress in the dissection room?-An evaluation of the need for psychological support. Ann Anat 2010;192:366–72.
32. Singh K, Gaur U, Hall K, Mascoll K, Cohall D, Majumder MAA. Teaching anatomy and dissection in an era of social distancing and remote learning. Advances in Human Biology 2020;10:90.

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Conflict of interest statement: No conflicts declared.

 How to cite this article: Kurul R, Dıramalı M, Özdemir D, Erdoğan KE. Can high resolution 3D resin printed models be used in anatomy education? A randomized controlled trial. Anatomy 2022;16(3):179–184.