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3D PRINTING AS A TOOL IN ANATOMY TEACHING: AN INTEGRATIVE REVIEW

João Erivan Façanha Barreto [1,3], Bruna Sobreira Kubrusly[2], Cezar Nilton Rabelo Lemos Filho[2], Renata Souza e Silva [1], Samuel de Osterno Façanha[3,1], Júlio Cézar Claudino dos Santos [3] , Gilberto Santos Cerqueira[3,1]

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1Postgraduate Program in Morpho functional Sciences, Faculty of Medicine, Department of Morphology, Federal University of Ceará, Fortaleza, Brazil

2 Faculty of Medicine, Federal University of Ceará, Fortaleza, Brazil

[3] Medicine Course, Centro Universitário Christus, Fortaleza Brazil

Abstract

Anatomy is essentially a three-dimensional content and learning its structures, through 3D impressions, for example, is of notable importance. In this context, traditional teaching methods, despite being highly effective, still have some limitations. Therefore, 3D printing has been introduced in the teaching of Anatomy, bringing several advantages, such as accuracy, personalized study and easy handling. Based on these premises, the objective of this work was to carry out an integrative review on the use of 3D printing in the teaching of human anatomy. A study was carried out in science direct, PUBMED, Scielo databases between 2010 and 2021 using the following descriptors 3D printing and teaching of anatomy. It was found that among the benefits of using 3D parts, there are: accuracy, durability, ease of production, good cost-benefit ratio and reduction of security risks linked to the fixation of cadaver and plastinated specimens. It was observed that in some studies most students preferred the use of 3D printing to traditional methods. Other studies have shown the importance of the use of 3D printing as a complementary tool to traditional methods of teaching anatomy. It was found that the use of 3D printing as a teaching tool may reduce the demand for bodies and overcome some of the governmental legal and ethical problems in the cadaver study, further studies should be carried out to assess the long-term impact of using 3D printing.

Keywords: Anatomy. Print 3 D, Education, Morphology, Teaching.

1. INTRODUCTION

Modern medical education has a wealth of educational resources as one of the key elements in the development of students' clinical skills and abilities. The acquisition of these teaching resources represents a considerable challenge for many medical schools, not only for financial reasons, but also for a variety of other reasons, including ethical, legal, cultural and pedagogical innovation [1].

3D printing represents the different forms of low-cost manifestations that characterize morphological structures and disease, and can be used as a possible teaching-learning tool for anatomical education [2].

In studies carried out in Brazil, a critical analysis of contents for teaching topographic anatomy, intends to implement new teaching technologies with the possibility of adaptations which meet the expectations of students and the real needs of the course and the job market. It is important to mention that the morphological characteristics of an organic anatomical structure, in a synthetic object, in the construction of 3D didactic models involves virtual and physical steps [3], [4].

Also, 3D printing has, in the last two decades, been used successfully in different medical fields, including education. In anatomy, high-quality 3D-printed replicas of cadaveric material have recently been produced for teaching purposes [5], [6].

Furthermore, according to Soares-Neto (2021) [7], to incorporate technologies, such as 3D printing in the teaching of anatomy, it is necessary to dare, overcome challenges, articulate and innovate knowledge, creating and untying the knots that relate to the inclusion of different digital technologies, educational theories, student learning, teacher practice and change in their practice, at the university and in society.

For many universities, it is neither easy nor quick to demonstrate certain anatomical structures in cadaveric pieces, given the scarcity of bodies for anatomical study and research. Still, there is financial difficulty in acquiring a 3D printer, including the process of training and rapid prototyping of 3D models for teaching anatomy [5].

3D printing in anatomy education in Brazil is a relatively new technology, mainly in an integrated and multimodal way in the interdisciplinary modules of anatomy, histology, embryology and physiology. Based on these premises, the objective of this work was to carry out an integral review on the teaching of anatomy using 3D printing as a tool.

2 METHODLOGY

Therefore, the terms 3D printing and anatomy learning were searched in the PubMed, Scielo and Science Direct databases from January 2010 to July 2021.

From a total of 499 articles identified, 03 were excluded because they were duplicates. Subsequently, the process of selection of articles began with the application of screening tests, which were initially applied to 496 studies. After analyzing the titles and abstracts of each of the articles that were candidates for exclusion at this stage of the screening, 466 articles were excluded according to the criteria. Of this total, there were 30 eligible articles, which were read in full, and the respective criteria previously defined for this review were analyzed, which did not allow for the additional exclusion of other works. Therefore, the

articles included in the qualitative synthesis to be worked on the theme of this study were represented in a number of 30 articles. There were no restrictions regarding the study gender.

For the elaboration of the Prism Flow diagram using as reference the work of Carmo et al., 2020 with some adaptations (Figure 1).

Figure 1. Methodology of the literature review Prisma Flow
Keywords: “3D Printing”, “Anatomy”, “Learning” and “Teaching”. Sources: (PUBMED, Science Direct and SciELO).

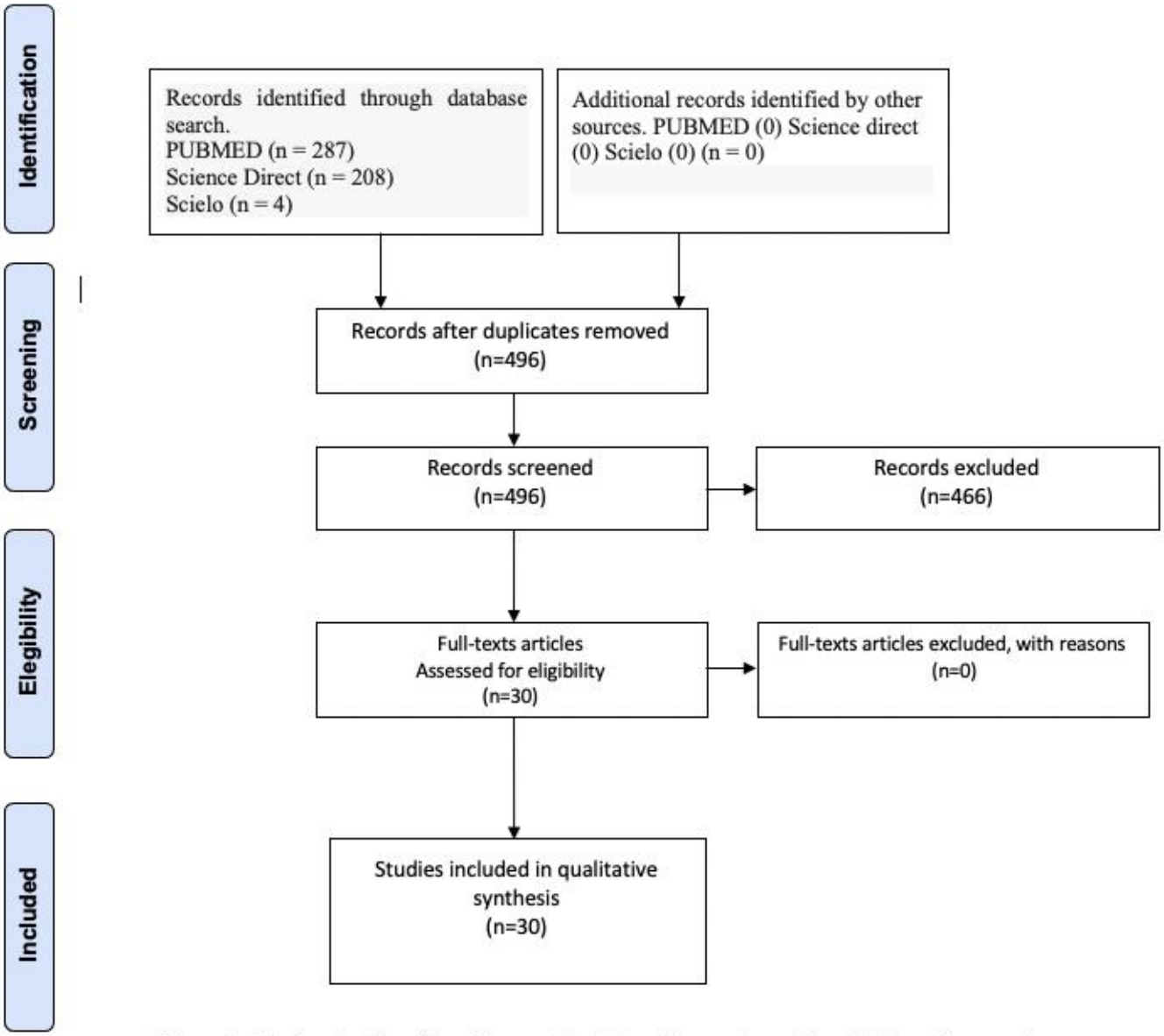

Figure 1. Study selection flow diagram for integrative review. Adapted from Carmo et al., (2020).

3. RESULTS

At this point, the main results of the integrative review on 3D printing are presented. The texts were systematized and detailed for better understanding.

After the Characteristics of the eligible studies, we searched the relevant databases and read the abstracts and full texts of articles found during this search. Thus, thirty studies were included in the analyses.

Table 1 demonstrates the articles selected for inclusion, deeper comprehension and summarization in this integrative review.

Table 1. Main articles used in the integrative review between 2010 to 2021.

AUTOR/ANO	OBJETIVO	RESULTADOS	CONCLUSÃO	PERIÓDICO	BASE DE DADOS
Erolin, 2019	Discuss the use of interactive 3D tools in anatomy and medical education.	They discussed the history, creation, distribution and use of 3D tools.	Adding 3D tools to traditional anatomy teaching is extremely helpful.	Advances in Experimental Medicine and Biology	PubMed
AbouHashem et al., 2015	Talk about the effective use of 3D printing in anatomy education.	They described the resources used, 3D printing and its application based on two Australian medical schools.	The use of 3D bone printing was a success and, probably, its use will expand to other anatomical structures, as it was very useful.	Medical Education Online	PubMed
Backhouse, Taylor e Armitage, 2019	Assess students' perception of the impact of using 3D orbit printing on the learning process.	Most students preferred the use of 3D printing to traditional methods.	The use of 3D printing was well received as a form of multimodal teaching, for its availability and positive impact on learning.	Anat. Scienc. Education	PubMed
Fasel et al., 2016	Introduce an innovative method in anatomy teaching: 3D printing.	A qualitative comparison was made between 3D printing and the traditional method. Satisfaction with the 3D models was 5.8 on a scale of 1-6.	The innovative method can be applied in authentic teaching of anatomical structures.	Surgical and Radiologic Anatomy	PubMed
Garas et al., 2018	Investigate the use of 3D printing as an anatomy learning tool and secondarily assess the effectiveness of	Most students (85%) got more questions right with the use of 3D models, 74% considered 3D	The study showed the use of 3D printing as a complement to	Annals of Anatomy	PubMed

	different specimens and the method students prefer.	printing more useful for identifying structures and 45% preferred the 3D method over the traditional one.	traditional methods in teaching anatomy.		
Kong et al., 2016	Develop a 3D model of the liver segments as an anatomical teaching tool for these structures.	3 types were developed using quizzes, with differences between them depending on the chosen aspects.	The type with segmented partitions has been shown to improve teaching about liver segments.	World Journal of Surgery	PubMed
McMenamin et al., 2014	Detail how the fabrication of 3D printing based on specimens and anatomical parts works.	The application of 3D prints is illustrated and compared to plastination and cadavers.	3D printing has been shown to have several advantages compared to traditional methods: effective reproducibility, accuracy, ease of implementation and reduction of ethical-legal issues.	Anatomical Sciences Education	PubMed
Smith et al., 2018	Assess different methods of teaching anatomy.	The use of 3D models has increased knowledge compared to 2D images.	CT-based 3D printing of a donated body was performed effectively. 3D models have proven to be a useful tool either when used alone or in addition to traditional methods.	Anatomical Sciences Education	PubMed
Thomas et al., 2016	Present the fabrication of models based on the cartilage of a fish and a frog.	The result of the prints was quite true to reality, although some details are not expressed in the models.	Minimal preparation and equipment are required for the fabrication of the models, being a great tool for teaching anatomy.	Journal of Anatomy	PubMed
Young et al., 2019	Introduce the use of 3D printing, such as replicas of real humans, for practical lessons and exposure on human development.	Several replicas of different stages of human development were produced and used in a large teaching group.	The use of this technology has enormous potential for teaching embryology with international replications and different gestational ages.	Anatomical Sciences Education	PubMed

Chytas et al., 2020	Investigate the evidence supporting the effectiveness of using 3D prints in teaching human anatomy.	3D printing was statistically significantly superior to two-dimensional images. Comparison between 3D printing and cadaver dissection did not occur in any study.	The implementation of 3D printing in the teaching of anatomy shows promising results. There is a lack of studies comparing 3D tools and cadaver dissection.	Surgical and Radiologic Anatomy	PubMed
Lim et al., 2016	Evaluate the effectiveness of 3D printing in relation to cadaveric materials in teaching external cardiac anatomy.	Post-test scores were significantly higher for the group of students who used 3D impressions compared to those who used cadaveric materials or combined materials.	The use of 3D prints does not harm students in relation to cadaveric materials. The results suggest that 3D may confer certain benefits on learning anatomy and support its use and ongoing assessment as supplements to cadaver-based curricula.	Anatomical Sciences Education	PubMed
Chen et al., 2017	Compare the learning effectiveness of 3D printed skulls with that of cadaver skulls and cadaver atlases.	Students who used the 3D printed models had better results in the post-test.	3D printing facilitates basic cranial education, aiding in structure recognition, compared to cadaver skulls and atlases. It also has advantages related to ethics, cost, hygiene and repair of fragile structures.	Scientific Reports	PubMed
Wilk et al., 2020	Determine knowledge about the use of 3D printing in medicine in medical school students.	Students appreciated the value of 3D printing for accurate anatomical models useful in learning. However, they do not consider the possibility of totally abandoning human corpses in anatomy classes.	Medical education should be extended to include issues related to using 3D printing for medical applications	PLOS ONE	PubMed

Mogali et al., 2017	Examine the educational value of the 3D printing model from the student's perspective.	The 3D printed anatomical features were rated as accurate by all students. However, students reported that anatomical features in 3D models are less realistic compared to plastinated specimens.	3D models are a valuable resource for anatomical education and an excellent complement to cadaveric, wet or plastinated parts.	Anatomical Sciences Education	PubMed
Clifton et al., 2020	Compare static and flexible 3D models in teaching kinematic and physiological concepts beyond surface anatomy.	The flexible 3D model was more successful in teaching the physiological concepts of spinal canal changes during flexion and extension than the static 3D model to a cohort of students.	Dynamic 3D models provide educators with a good innovative and cost-effective educational tool for not only instruction in surface anatomy but also in case-specific physiological and pathological conditions.	Clinical Anatomy	PubMed
Low et al., 2019	Describe the technology and process required to create 3D printed models of the frontal sinus.	Seven unique exams from unidentified patients were selected as the basis for the models so that all frontal cell types described in the International Frontal Sinus Classification (IFAC) scheme are represented among all 3D printed models.	This document describes the technology and process required to create these models.	The Neuroradiology Journal	PubMed
Hochman et al., 2015	Compare isomorphic and cadaveric 3D models in temporal bone education.	The physical characteristics of the 3D model were quite similar to those of the cadaveric model, with cortical and trabecular bone bur quality highly rated, in addition to having respectable air cell reproduction and having	The isomorphic 3D model proved to be a valuable adjuvant training tool with a realistic mechanical and visual character.	The Laryngoscope	PubMed

		internal constructions rated as satisfactory.			
Fleming et al., 2020	Evaluate the effect of 3D printed models in relation to traditional 2D methods for teaching anatomy.	3D models were associated with higher anatomy exam scores for medical students ($P < 0.0001$), but for resident physicians they were not statistically significant ($P = 0.53$).	3D models have been shown to have a positive impact on medical students.	Journal of the American Collegue of Radiology	PubMed
Tripodi et al., 2020	Evaluate the implementation of a set of anatomy learning activities centered on 3D models of upper limb bones.	Students felt strongly that using the models inspired greater academic confidence and better overall performance in their assessments.	Overall, the models were an effective way to increase engagement and learning, and they reinforced previous research findings in medical education.	Anatomical Sciences Education	PubMed
Coles-Black et al., 2017	Describe the technology and process required to create printed models, as well as their applications.	They explained about the advantages, applications and limitations of implementing 3D tools.	3D printing is booming in the medical field, where new approaches to complex anatomical relationships have helped in therapeutic interventions.	The Medical Journal of Australia	PubMed
Drake e Pawlina, 2014	Show how anatomy teaching resources through 3D printing can be used.	In some places there are no cadavers available to carry out the anatomical study directly on them, requiring other technologies or tools to make this study possible, such as body painting exercises, image exams or 3D printed anatomical replicas.	In cases of unavailability of cadavers or when their use is not possible, 3D prints may be an accurate and effective substitute for teaching Anatomy.	Anatomical Sciences Education	PUBMED

Casciato, Builes e Singh, 2018	Show in detail the production of 3D-printed cross-sections of the lower limbs, highlighting its usefulness and advantages in teaching anatomy in this region and its low cost compared to traditional methods.	In addition to being relatively inexpensive, 3D printing for cross-sectional studies of the lower limbs proved to be safe and reproducible.	The cost-effective inclusion of 3D printing in Anatomy classes can help students understand the spatial structures of the lower limbs, as well as enhance their clinical skills, through better interpretation of imaging and surgical exams.	Journal of the American Podiatric Medical Association	PUBMED
O'Reilly et al., 2016	Describe the fabrication of anatomically accurate blood vessels (femoral vessel) and lower limbs, showing their application for teaching anatomy.	There was no statistical difference between the number of correct answers between students who had practiced on cadavers and those who used three-dimensionally printed models.	Printable templates have increased anatomy teaching capabilities. Furthermore, the printed lower limbs models were not inferior to the cadaveric models, which was seen through standardized tests of anatomical knowledge.	Anatomical Sciences Education	PUBMED
Wu et al., 2018	Compare the use of 3D printed models with radiographic images as teaching techniques for medical students about bone spatial anatomy and fractures.	There was no significant difference between both methods for upper and lower limbs, either in score or time, however, there was a difference in the pelvis and spine tests, with the traditional method having significantly lower results and even longer time to perform the test.	Students' understanding of the spatial anatomy of bones and fractures, particularly in complex locations, can be improved with the use of 3D printed models.	Annals of Translational Medicine	PUBMED
Jones, 2019	Evaluate the ethical dimensions of using three-dimensional pieces for teaching anatomy.	The dynamics presented by digital technology raise questions about the nature of the body donor's consent, the reasons for 3D printing, the extent to which it will be commercialized and	It is concluded that the scientific content of 3D processes represents a distancing from the human person, so that efforts are needed to avoid the accentuation of depersonalization and	Anatomical Sciences Education	PUBMED

		its comparative advantages over other available teaching resources.	commodification of data for 3D printing based on these people.		
Chen et al., 2020	Investigate the effects of 3D printing on interns' understanding of the celiac trunk compared to two-dimensional images.	There was an improvement in the scores of both groups, being higher in the 3D printing group compared to the 2D group. Participants also reported an improvement in satisfaction with the three-dimensional methods, but less interaction between them and the teacher, as well as less teaching time with the 3D model.	The 3D model of the trunk of Henle or celiac is a very effective tool for internal students to understand the anatomy of this structure. Thus, the use of 3D technology proves to be of great value for teaching the anatomy of complex vascular structures, deserving to be popularized in university hospitals.	Journal of Surgical Education	PUBMED
Skrzat et al., 2019	Detail the production of a durable physical replica of the adult human temporal bone, manufactured using 3D printing technology.	Virtual and physical 3D models accurately reproduced the external anatomy of the temporal bone in all its parts: squamous, tympanic, petrous and mastoid.	Temporal bone 3D prototypes can be used for educational purposes in order to supplant the use of damaged or fragile human temporal bones.	Folia Medica Cracoviensia	PUBMED

4. Discussion

Anatomy education is facing challenges mainly due to reduced curriculum time and lack of cadavers [8]. Thus, active methodologies, gamification and 3D printing can be an important teaching strategy alongside 3D printing.

3D printing has become more popular in medical education in recent years in northern hemisphere countries. In Brazil, the spread of use is in its infancy due to lack of financial resources and academic training [9]. Despite the limited number of studies comparing the use of three-dimensionally printed pieces with the classical methodology for teaching Anatomy, the use of such tools has shown to be promising [10]. As an example of anatomical structures that have already been used in scientific studies for comparative purposes of the aforementioned methods, we find bone structures such as skulls [11] and

neurocranial bones [12], internal organs, such as hepatic segments [13] and even vascular structures such as the gastrocolic trunk of Henle and aortic segments [14].

Another example of a study evaluating the efficiency of 3D impressions in relation to cadaver studies, conducted by Lim et al., (2016), divided first-year medical school students into three groups: studies on three-dimensional models, cadavers and both combined. The object of study used in this experimental model with robust methodology was the external cardiac anatomy, showing surprising results: the group of students who used only 3D models had a statistically significant superior performance in the post-test than the group who used cadavers and, also, than the group that used the combined material. Thus, it was concluded that, in addition to being innovative in the teaching of anatomy, 3D printed models can, even when there is no need for replacement due to lack of cadavers, be an important supplement in the teaching of cadaver-based curricula, bringing good results and benefits in relation to cadaveric material [15].

According to Fleming et al. (2020) [16], 3D impressions also showed better results in post-tests carried out with medical students, corroborating the experimental model described above, this difference, however, was not statistically significant in a group of resident physicians.

3D printing, however, does not have its benefits restricted to teaching surface anatomy. Using dynamic models, this teaching methodology provides teachers with innovative and cost-effective teaching apparatus for case-specific physiological and pathological kinematic conditions [17].

Regarding the advantages of using 3D printing over traditional methods, firstly, the use of such methodologies does not compromise student learning in relation to the traditional way of teaching [15]. Added to this, the results found in comparative studies suggest other benefits of using 3D printing, such as: efficiency in the reproducibility of models, accuracy of these materials and fidelity to original anatomical structures, whether static or dynamic, possibility of representations of common pathologies of a location to another through the availability of files containing the spatial content of these changes, which can be obtained through CT scans and surface scanning, ease of deployment and reduction of ethical-legal issues [6], [15], [17]–[19].

Thus, using 3D printers suitable for rapid prototyping, in addition to the aforementioned benefits, the cost can be increasingly reduced through the production of multiple structurally identical anatomical models, fractionating the amounts spent with conventional printing. This makes it even possible to produce personalized and individual study accessories for students, enabling them to study in a location and time flexible to the needs and availability of academics [20].

The use of 3D printing has taken promising directions and progress has been made in the area of teaching not only anatomy, but also other morphofunctional sciences. The production of three-dimensional real human models used during embryology classes with accurate replicas of different gestational ages showed significant potential for the study of this other discipline, in addition to reducing the adverse reactions of the student when faced with embryonic models of more advanced ages, as well as reducing the loss of original data [21].

It is worth emphasizing here that the association of 3D technologies with Fedathi Sequence allows for a better qualification in the teaching in question, in addition to emphasizing the importance of as a methodological resource to be incorporated in the health area [22].

Therefore, this study aims to evaluate the impact of 3D impressions on the teaching-learning process of the anatomy, as a way to meet the need for studies on this topic.

5. Final Considerations

The results of the aforementioned studies support the hypothesis that the implementation of 3D printed models in the teaching of human anatomy improves the effectiveness of the learning process of morphological structures. The 3D printing technique has proven to be a powerful pedagogical tool in medical education and future studies will be able to further investigate the impact of its use. More studies are needed to deepen the learning mechanisms using 3D printing as a tool.

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Conflict of interests

The researchers declare that there is no conflict of interest between the research members.

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