JOURNAL OF Surgical Simulation

Journal of Surgical Simulation (2022) **9**, 49–56
DOI: https://doi.org/10.1102/2051-7726.2022.0007

ORIGINAL ARTICLE

Utilizing a 3D printed model of the mediastinum to teach thoracic anatomy and its visual-spatial relationships to medical trainees

Deven C. Patel,[a] Ingrid Schmiederer,[b] Tiffany Anderson,[b] Prasha Bhandari,[a] Kyle Gifford,[c] Dana Lin,[b] H. Henry Guo[c] and Natalie S. Lui[a,]*

[a]*Department of Cardiothoracic Surgery, Division of Thoracic Surgery, Stanford University, Stanford, CA, USA;* [b]*Department of Surgery, Stanford University, Stanford, CA, USA;* [c]*Department of Radiology, Stanford University, Stanford, CA, USA*

Corresponding author at: 300 Pasteur Drive, Falk Cardiovascular Research Institute, Stanford, CA 94305, USA. Email: natalielui@stanford.edu

Date accepted for publication: 15 February 2022

Abstract

Background: Three-dimensional (3D) printed anatomic models are increasingly being developed for medical education, however, their efficacy as a study tool is unclear, particularly in the context of thoracic anatomy. **Methods:** Premedical and medical students were randomly assigned to either a lecture using a standard anatomy textbook or the same lecture along with a 3D printed model of the mediastinum. Participants took a timed pre-test and post-test, identifying 12 mediastinal structures on a prosected human cadaver. Independent and dependent t tests were used to compare individual and group improvements, respectively. A subjective assessment was also performed. **Results:** A total of ten medical trainees participated, five in the textbook cohort and five in the 3D model cohort. Overall, there was a significant improvement in test scores from the pre-test to the post-test (4.4 to 6.8, $P < 0.01$), and within both the textbook cohort (3.7 to 5.9, $P < 0.01$) and the 3D model cohort (5.0 to 7.6, $P < 0.01$). There was no difference in time to test completion overall or within the two cohorts. There were greater improvements in the 3D model cohort compared with the textbook cohort in terms of test scores (2.2 vs. 2.6, $P = 0.53$) and time to test completion (−0.8 vs. −1.6 min, $P = 0.54$), however, these differences were not statistically significant. Subjectively, all five of the trainees using the 3D model acknowledged a perceived benefit in their mediastinal anatomy education. Positive feedback from trainees in both cohorts included the visual-spatial relationships and haptics afforded by the model that standardized textbooks failed to provide, as well as general excitement in using an innovative 3D model to learn human anatomy. **Conclusions:** The 3D printed model of the mediastinum did not demonstrate a quantitative improvement in identifying anatomic structures on a cadaver compared with standard textbook education in a small cohort of medical trainees. However, there was strong perceived benefit and enjoyment in the use of the 3D model.

Keywords: *3D printing; mediastinum; medical education; anatomy; cadaver; visual-spatial*

Introduction

Anatomy education has long been a cornerstone in medical training, classically taught through didactic lectures, and supplemented by textbooks and cadaveric dissection.[1] The latter is widely considered the gold standard for learning and testing anatomy, secondary to the three-dimensional (3D) interaction and tactile manipulation of tissues using this educational tool.[2,3] However, pressures on the curriculum and increasing ethical issues have forced medical schools to reduce the amount of time and resources available to trainees regarding cadaveric specimens.[2,4,5] Consequently, some have reported that the baseline knowledge of anatomy among medical graduates is substandard and may be unsafe for medical practice.[6–8] In this context, there has been increasing educational demand to provide medical trainees with accurate, realistic, and innovative supplements to cadaveric resources.[4,5,9]

3D printing technology has evolved rapidly in the last decade and has garnered considerable traction within the medical community for applications such as surgical planning, implant fabrication, and medical education.[10–15] The popularity of this technology is largely a result of readily available high-resolution medical tomographic radiologic imaging, enabling patient-specific 3D models with substantial structural and anatomic fidelity.[16] The visual-spatial relationships and tactile interaction afforded by 3D printed models has naturally led to the adoption of this innovative tool to enhance medical trainee education. Advantages of using 3D printed models for anatomy education are the patient-specific anatomic fidelity and the ability to develop these models quickly and in house by educational staff. Alternatively, plastic educational anatomy models are often expensive, mass-produced, and have been criticized as "idealized caricatures lacking anatomical accuracy".[9,17]

The introduction and development of 3D printed models for anatomy education and surgical simulation have been published by a few groups for various medical and veterinary applications.[2,9,10,18] These novel approaches have certainly demonstrated promising results; however, our group became curious about the usefulness of testing the efficacy of these innovative 3D models using two-dimensional (2D) testing (multiple choice and structure identification using images).[2,9] Medical trainees are often relegated to using 2D resources (textbooks and didactic lectures) to study anatomy, because access to and hours of operation of cadaver labs are limited. Accordingly, a randomized controlled trial was designed to delineate whether a 3D printed model of the thoracic mediastinum had any advantage compared with the existing 2D resources in teaching anatomy to medical trainees based on an anatomy test using a prosected cadaver. The primary aim of this study was to evaluate the efficacy of a 3D printed model as a viable resource that can be used to aid in a medical trainee's ability to identify key thoracic anatomy. As a secondary aim, we sought to assess the subjective responses of our study participants to the 3D printed model. We hypothesized that the 3D printed model would objectively improve a trainee's ability to identify key mediastinal anatomy.

Material and methods

Development of the 3D mediastinal model

The anatomy of interest was segmented from computed tomography images of the mediastinum from a selected patient using Materialise Mimics (Materialise NV, Ghent, Belgium) and then exported as mesh (.stl) files. These files were assembled in Autodesk Maya (Autodesk, San Rafael, CA) for further manipulation, repair, and rendering. The completed files were printed on the Stratasys J735 printer (Stratasys, Edina, MN), an industrial level full color printer that utilizes polyjet technology. The print includes various colors blended with the Agilus30 Clear material to give the printed anatomic vasculature flexibility. To increase visibility of the posterior mediastinal structures within our model, the sternum was printed so that it could be removed and reattached using small magnets that were inserted after printing (Fig. 1).

Testing anatomic knowledge using a human cadaver

With the support of our medical school anatomy lab, we prosected a cadaver, isolating and carefully labeling 12 mediastinal anatomic structures of varying difficulty: aorta, right lung, left innominate vein, right innominate artery, trachea, station seven lymph node, left recurrent laryngeal nerve, right pulmonary artery, main pulmonary artery, superior vena cava, station 5 (aortopulmonary window) lymph node, left common carotid artery (Fig. 2). The structures selected were based on the existing medical school clinical curriculum as well as expert opinion from a panel of multidisciplinary academic physicians involved in medical education.

Study randomization

Medical trainees within our institution were asked to participate in our study through medical student interest group outreach, as well as flyers and email advertisements. The trainee level of education ranged from pre-medical to medical student. Participants in the study were randomized to either a lecture from an attending thoracic surgeon (N.S.L.) using images from a standard anatomy textbook (control) or the same lecture as well as a review of anatomic structures using our 3D printed model of the mediastinum (intervention) (Fig. 3). Block randomization was carried out by a member of the institution's surgical education program.

Study protocol

Once assigned to a cohort, all participants completed a pretest to record gender, training level, interest in thoracic surgery, and self-reported confidence in ability to identify mediastinal structures. They were then asked to identify 12 prosected mediastinal structures within a single cadaver, thus testing baseline knowledge. Trainees were given unlimited time, and the time to test completion was documented by the proctor supervising the trainees. Participants were given a study identification number, so that their pre- and post-test scores could be compared.

After the pre-test was completed, all trainees underwent a 10-min lecture using 2D images of the mediastinum selected from standard textbook resources. The lecture carefully reviewed the mediastinal anatomy reflected in the prosected cadaver and provided a variety of 2D axial, coronal, and sagittal images. On completion of the didactic session, the textbook cohort was asked to leave the room, and the 3D

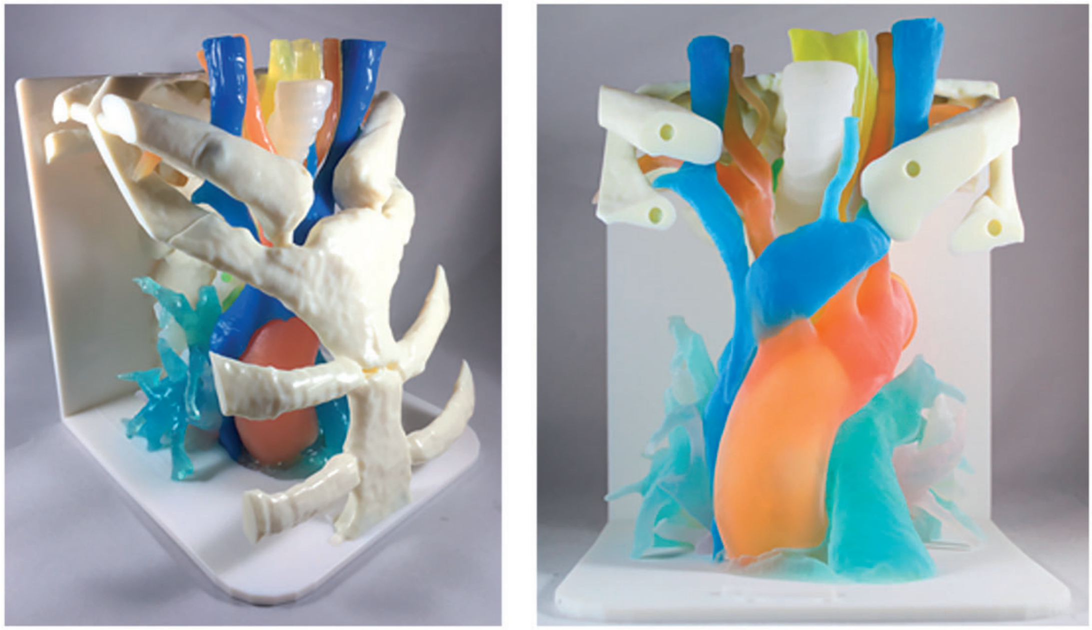

Figure 1. 3D printed mediastinal model developed within our institution.

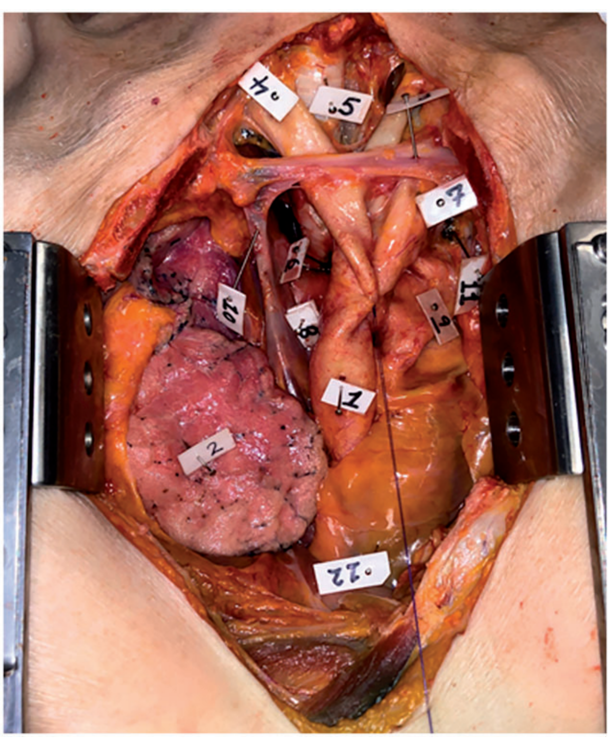

Figure 2. Test to identify 12 mediastinal structures on a prosected human cadaver.

model cohort was provided with an additional 10-min interactive lecture reviewing the same focused mediastinal anatomic structures using the 3D model. Trainees were given the opportunity to self-study after the textbook lecture and/or 3D model lecture using the resources from their respective cohorts.

Once all participants completed their self-study period (for approximately 10 min after the lecture), all participants returned to the cadaver model for a post-test to identify the same 12 structures assessed on the pre-test. Again, time to test completion was recorded. The post-test included additional questions on the trainee's primary anatomy educational resource and reassessing interest in thoracic surgery and confidence in ability to identify mediastinal structures. Further, the intervention cohort was asked to self-report whether the 3D printed model of the mediastinum improved the participant's ability to identify key mediastinal structures, and assessed participant enjoyment using the model to learn anatomy. All subjective questions utilized a 5-point Likert scale (strongly agree, agree, neither agree or disagree, disagree, or strongly disagree). At the end of the study, the control cohort was given the same lecture that the intervention cohort received using the 3D model. Ultimately, all participants were asked to provide anonymous feedback and comments using a free response question on their experience with the model. This study was assessed by the Institutional Review Board, and deemed to present minimal risk of harm to all study participants; accordingly a notice of exemption for full review was obtained.

Test scoring and statistical analysis

A blinded grader scored all tests out of a possible 12 points. A full point was given for correct laterality and structure. A

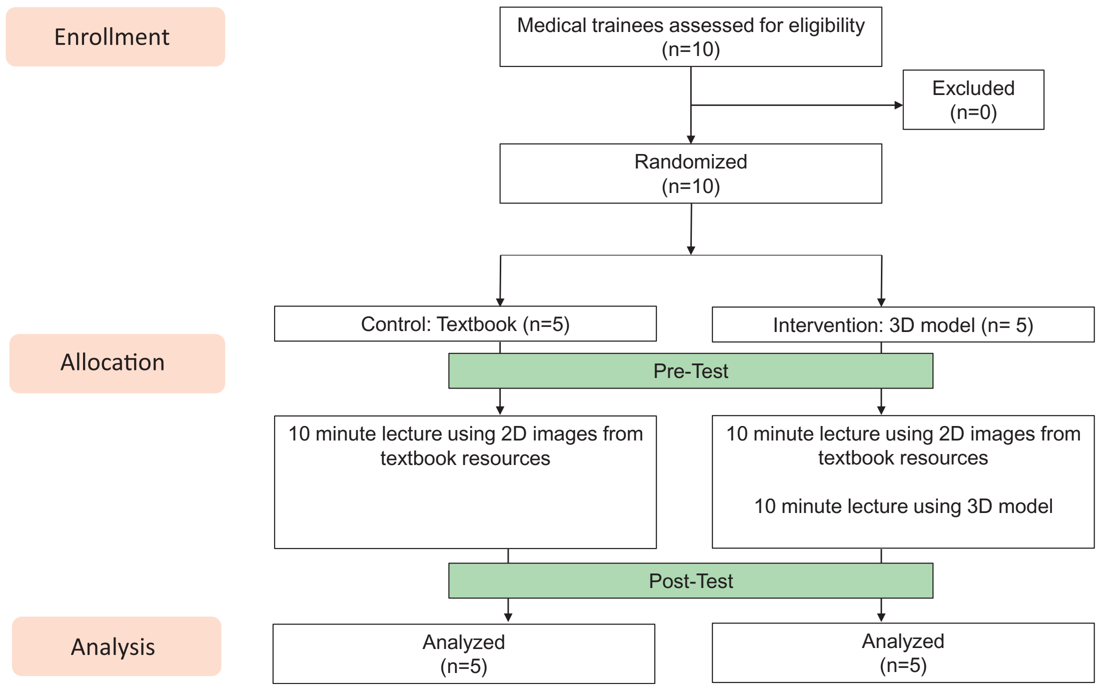

Figure 3. CONSORT diagram for the study.

half point was given for the correct structure but incorrect laterality. Test scores and times to test completion for each participant were compared using paired t tests. Further, the differences in the mean score and time to completion between pre- and post-test were compared between the two cohorts using independent sample t tests. Categorical variables were compared using Fisher exact and chi-squared tests. A P value <0.05 was considered statistically significant. All analyses were performed in IBM SPSS Statistics, Version 25 (IBM, Armonk, NY).

Results

Cadaver anatomy test results

A total of ten medical trainees participated in the study. After randomization, five participants were assigned to the textbook cohort and five participants to the 3D model cohort. There was no difference between the groups in terms of gender (male: 60% vs. 60%, $P > 0.99$). The textbook group (pre-medical students, 2; medical students, 3) and 3D model group (pre-medical student, 1; medical students, 4) were of similar educational level ($P = 0.67$), as shown in Table 1. There were significant improvements in test scores between pre-test and post-test for the textbook cohort (3.7 $\pm$ 1.9 to 5.9 $\pm$ 2.5, $P = 0.003$) and 3D model cohort (5.0 $\pm$ 2.2 to 7.6 $\pm$ 1.9, $P = 0.007$), as well as the overall cohort (4.4 $\pm$ 2.1 to 6.8 $\pm$ 2.3, $P < 0.01$). However, there were no statistical differences in the time to test completion for either cohort or the overall cohort (6.9 $\pm$ 1.4 to 5.7 $\pm$ 1.7 min, $P = 0.08$) (Table 2). Comparing the two cohorts with one another, greater improvements were observed in the 3D model cohort compared with the textbook cohort in terms of test scores (2.6 $\pm$ 1.2 vs. 2.2 $\pm$ 0.8, $P = 0.53$) and time to test completion (-1.6 ± 2.1 vs. -0.8 ± 1.9 min, $P = 0.54$), but these differences were not statistically significant (Fig. 4).

Subjective outcomes and student feedback

Among all participants, 70% listed using textbooks as the primary resource used to study anatomy, and the remaining 30% utilized textbooks in combination with either online virtual anatomy or video resources. A single trainee within the 3D model cohort responded with an increased interest in thoracic surgery between pre-test and post-test. Similarly, between testing, three trainees in each cohort reported increased levels of confidence in identifying mediastinal anatomy. All five of the trainees using the 3D model acknowledged a perceived benefit in their ability to identify key mediastinal structures (agree, 80%; strongly agree, 20%) and in enjoyment (agree, 20%; strongly agree, 80%). Positive feedback from trainees in both cohorts included the visual-spatial relationships and haptics afforded by the model that standardized textbooks failed to provide, as well as general excitement in using an innovative 3D model to learn human anatomy. Student comments included: "[the 3D model was] very helpful distinguishing between anterior and posterior

Table 1. Baseline characteristics and subjective assessment after the post-test

	Textbook (n = 5)	3D model (n = 5)	*P* value
Sex			
Male	3	3	>0.99
Female	2	2	
Trainee education level			
Pre-medical undergraduate	2	1	0.67
Medical student year 1	1	2*	
Medical student year 2	1	2	
Medical student year 4	1	0	
Increased confidence in anatomic knowledge	3	3	>0.99
Increased interest in thoracic surgery	0	1	0.37

* One participant was a first year physician assistant student.

Table 2. Medical trainee cadaver test results

	Pre-test	Post-test	*P* value
Cadaver test scores (out of 12 points)			
Textbook	3.7 ± 1.9	5.9 ± 2.5	0.003
3D model	5.0 ± 2.2	7.6 ± 1.9	0.007
Time to test completion (minutes)			
Textbook	7.2 ± 1.8	6.4 ± 1.8	0.41
3D model	6.6 ± 0.9	5.0 ± 1.4	0.16

Values are reported as the mean ± standard deviation. Compared using paired t tests.

structures, not as apparent in 2D images found in textbooks"; "the ability to manipulate the [3D] model was stimulating and provided me with a greater appreciation for the proximity of important mediastinal structures".

Discussion

Once utilized for niche industrial prototyping, 3D printing is becoming an affordable resource with increasing ubiquity in a variety of medical applications.[12] Utilizing this technology for medical education has several advantages and addresses concerns that the existing anatomy education landscape may be in decline.[4,19,20] Namely, 3D models give medical trainees the ability to manipulate and interact with the 3D aspects of human anatomy. Given the increasing financial, ethical, and logistical barriers associated with cadaveric resources, educators have turned to innovative alternatives to supplement existing 2D resources outside of the cadaver lab.[4,9,21]

Our findings in this study did not support our hypothesis because we did not find any objective differences in ability to identify mediastinal anatomy between trainees using standard 2D didactics and textbooks with those also exposed to our internally developed 3D printed model. In a randomized controlled trial from Australia, 3D printed models were compared with cadaveric materials for learning cardiac anatomy. The trainees using the 3D models alone demonstrated significant improvements in test scores.[9] Similarly, in a veterinary medicine study from the United Kingdom, students utilizing a 3D printed model of an equine foot demonstrated significantly higher test scores than those using textbooks or 3D computer models. In both of these studies, trainees' knowledge of anatomy was tested using short-answer questions using labeled images to test identification of structures, highlighting our concern in testing the efficacy of a 3D resource using 2D materials. In our study, we identified an increase in test scores for trainees using the supplemental 3D model compared with those using 2D resources alone, however, our findings were not statistically significant. Given the positive findings seen when testing 2D anatomy knowledge testing in the previously mentioned studies, it was unexpected to find that the 3D model did not demonstrate the same efficacy when students were asked to identify structures using a 3D test resource (prosected cadaver). This may be attributed to the small sample size, limiting the power to detect differences between our cohorts. Further, previous studies have suggested novice trainees exhibit substantial stress, apprehension, and anxiety during their initial encounter with a cadaver. This may in part have affected some of our pre-medical participants who have never been exposed to a cadaver.[22,23]

Although there were no clear objective benefits with the use of the 3D printed mediastinal model, there was certainly a unanimous perceived benefit by all participants using the model. Other studies have illustrated similar self-reported findings, suggesting students using 3D printed models are more likely to demonstrate increased engagement, and may be more likely to embrace private study using these models.[2,9] It is possible that the novelty of introducing a new resource, shifting away from the monotony of historically established resources, may artificially enhance the self-perceived benefits of the 3D printed model.[4] Nonetheless, any opportunity to stimulate medical trainee education is certainly worth considering.

The positive subjective feedback regarding the visual-spatial benefits received by our participants is certainly reassuring and aligns with previous literature demonstrating the value

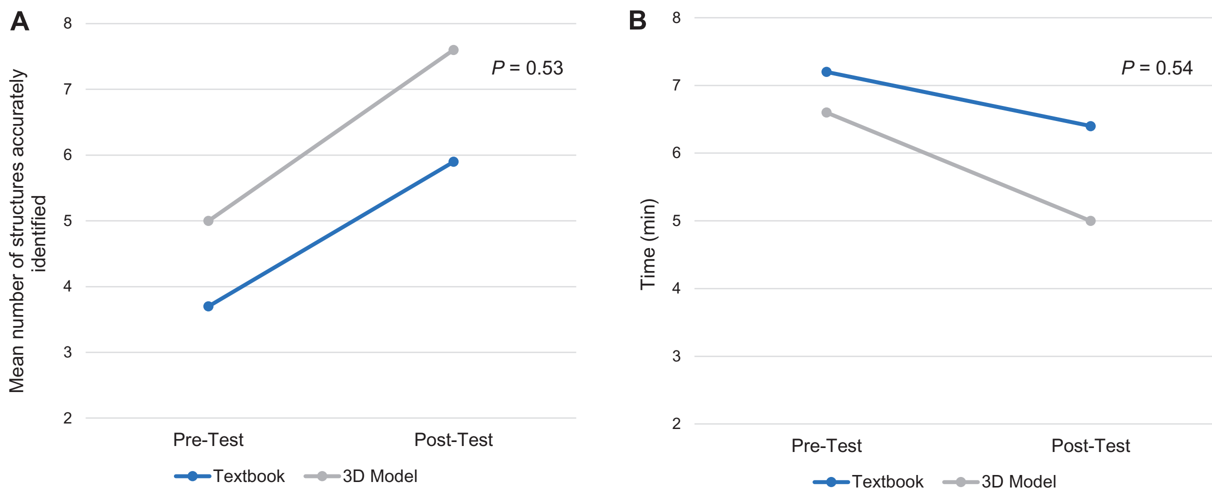

Figure 4. Comparison of pre-test and post-test (A) test score and (B) time to completion of test for the textbook cohort (control) and the 3D model cohort (intervention).

of using a physical model for anatomy education.[24–26] These perceived benefits were expected, because the mediastinum is a clinically important anatomic area with an abundance of key visual-spatial relationships between major vasculature, nerves, airways, and the esophageal tract. Tactile manipulation with a 3D model is often an undervalued learning interaction, however, it has been shown to provide a significant advantage in trainee understanding and retention of anatomic spatial information and relationships.[2,25] For this reason, cadaver educational resources have remained the mainstay of medical trainee education.[27] Unique innovative attempts to develop alternatives to cadaver resources for trainees while maintaining tactile manipulation have included clay molding,[24,28,29] plastination,[30,31] and body painting.[32]

Collectively, all medical trainees participating in our study demonstrated marked improvements in scores between pre-test and post-test. As our study design aggregated traditional 2D resources (textbook images with a didactic lecture), it is not possible to identify an individual study resource that may have benefited the participants. The didactic teaching process and teacher may have contributed to the overall positive change in score for the medical trainees. The teaching process itself has been identified as a confounding variable in educational comparative analyses, particularly when an investigator is directly involved in the teaching process.[33]

Although out of the scope of this study, there is a possibility that educators may be better teachers when a 3D anatomic model is available to facilitate their didactic process. In particular, new teachers having difficulty explaining anatomic relationships to their students may benefit the most from having tangible models available. One of the unique features of 3D printing of educational anatomic models is the relative scalability and affordability of fabricating several models for a class group, a cheaper alternative to purchasing generic plastic models.[32] Further, as 3D printing technology continues to evolve, it may be possible in the future to develop patient-specific anatomic models to coalesce with problem-based learning strategies, particularly in scenarios with anatomic variation in patients.[4]

There are several limitations to our study. We expected the 3D printed model to provide substantial benefits compared with traditional resources, however, the small sample size of our study limits our group comparisons and prevents us from drawing definitive conclusions. Although no significant differences in education level were identified between the two cohorts, the varying educational levels of the medical students who participated in this small randomized study may introduce selection bias. However, the subjective benefits identified certainly offer insight into the potential benefits of incorporating 3D models into medical education, especially because access to cadaver labs may be limited for some students. As previously discussed, our study may have benefited from a blinded instructor not associated with our study. However, both groups participating in our study were given the same impartial lecture and 2D textbook anatomic images. Given the varied study patterns of medical trainees, it is difficult to determine the ideal length of a lecture, accordingly the 10-min lectures provided to the participants in this study may not have been long enough for some. In addition, both groups were given the opportunity to self-study using the resources from their respective cohorts; this study period may have confounded the outcomes of this study based on the trainee's motivation to utilize this time. A unique aspect to this study is the testing of anatomic knowledge using a 3D resource. Previous studies have used 2D testing resources, which may fail to capture the true utility of using 3D models. There are a few limitations to the use of 3D printing for developing anatomic models for medical education, including the restricted build size depending on the dimensions of the print chamber, and the costs associated with materials and post-print processing. Moreover, further larger scale studies using 3D testing resources are needed to validate the use of 3D printed models.

Conclusions

3D printed anatomic models offer an innovative solution to enhance the current standard of anatomy education. This educational tool is not a substitute for cadaveric resources, instead it should be considered a supplement that can be used by medical trainees to improve anatomic retention and knowledge. The principal advantage of utilizing 3D printed models may be the visual-spatial relationships appreciated by medical trainees, a particularly important facet for mediastinal anatomy. As 3D printed models continue to be developed, future studies are needed to validate this potentially beneficial educational resource.

Conflict of interest

The authors have no financial disclosures or conflicts of interest associated with this study.

Funding

The study was supported by the Western Thoracic Surgical Association 2019 Donald B. Doty Educational Award.

References

1. Winkelmann A. Anatomical dissection as a teaching method in medical school: a review of the evidence. Med Educ 2007; 41(1): 15–22. https://doi.org/10.1111/j.1365-2929.2006.02625.x.
2. Preece D, Williams SB, Lam R, Weller R. "Let's get physical": advantages of a physical model over 3D computer models and textbooks in learning imaging anatomy. Anat Sci Educ 2013; 6(4): 216–224. https://doi.org/10.1002/ase.1345.
3. Tazelaar HD, Schneiderman H, Yaremko L, Weinstein RS. Medical students' attitudes toward the autopsy as an educational tool. Acad Med 1987; 62(1): 66–68. https://doi.org/10.1097/00001888-198701000-00013.
4. Turney BW. Anatomy in a modern medical curriculum. Ann R Coll Surg Engl 2007; 89(2): 104–107. https://doi.org/10.1308/003588407X168244.
5. Lewis T, Burnett B, Tunstall R, Abrahams P. Complementing anatomy education using three-dimensional anatomy mobile software applications on tablet computers. Clin Anat 2014; 27(3): 313–320. https://doi.org/10.1002/ca.22256.
6. Waterston SW, Stewart IJ. Survey of clinicians' attitudes to the anatomical teaching and knowledge of medical students. Clin Anat 2005; 18(5): 380–384. https://doi.org/10.1002/ca.20101.
7. Older J. Anatomy: a must for teaching the next generation. Surgeon 2004; 2(2): 79–90. https://doi.org/10.1016/S1479-666X(04)80050-7.
8. Cottam WW. Adequacy of medical school gross anatomy education as perceived by certain postgraduate residency programs and anatomy course directors. Clin Anat 1999; 12(1): 55–65. https://doi.org/10.1002/(SICI)1098-2353(1999)12:1<55::AID-CA8>3.0.CO;2-O.
9. 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(3): 213–221. https://doi.org/10.1002/ase.1573.
10. O'Reilly MK, Reese S, Herlihy T, Geoghegan T, Cantwell CP, Feeney RN, et al. 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(1): 71–79. https://doi.org/10.1002/ase.1538.
11. Tuomi J, Paloheimo K-S, Vehviläinen J, Björkstrand R, Salmi M, Huotilainen E, et al. A novel classification and online platform for planning and documentation of medical applications of additive manufacturing. Surg Innov 2014; 21(6): 553–559. https://doi.org/10.1177/1553350614524838.
12. Michalski MH, Ross JS. The shape of things to come: 3D printing in medicine. JAMA 2014; 312(21): 2213–2214. https://doi.org/10.1001/jama.2014.9542.
13. Youssef RF, Spradling K, Yoon R, Dolan B, Chamberlin J, Okhunov Z, et al. Applications of three-dimensional printing technology in urological practice. BJU Int 2015; 116(5): 697–702. https://doi.org/10.1111/bju.13183.
14. Cheung CL, Looi T, Lendvay TS, Drake JM, Farhat WA. Use of 3-dimensional printing technology and silicone modeling in surgical simulation: development and face validation in pediatric laparoscopic pyeloplasty. J Surg Educ 2014; 71(5): 762–767. https://doi.org/10.1016/j.jsurg.2014.03.001.
15. Waran V, Narayanan V, Karuppiah R, Pancharatnam D, Chandran H, Raman R, et al. Injecting realism in surgical training-initial simulation experience with custom 3D models. J Surg Educ 2014; 71(2): 193–197. https://doi.org/10.1016/j.jsurg.2013.08.010.
16. Garcia J, Yang Z, Mongrain R, Leask RL, Lachapelle K. 3D printing materials and their use in medical education: a review of current technology and trends for the future. BMJ Simul Technol Enhanc Learn 2018; 4(1): 27–40. https://doi.org/10.1136/bmjstel-2017-000234.

17. Hagens GV. Impregnation of soft biological specimens with thermosetting resins and elastomers. Anat Rec 1979; 194(2): 247–255. https://doi.org/10.1002/ar.1091940206.
18. Monfared A, Mitteramskogler G, Gruber S, Salisbury Jr JK, Stampfl J, Blevins NH. High-fidelity, inexpensive surgical middle ear simulator. Otol Neurotol 2012; 33(9): 1573–1577. https://doi.org/10.1097/MAO.0b013e31826dbca5.
19. Kaufman M. Anatomy training for surgeons - a personal viewpoint. J R Coll Surg Edinb 1997; 42(4): 215. PMID: 9276550.
20. Heylings D. Anatomy 1999-2000: The curriculum, who teaches it and how? Med Educ 2002; 36(8): 702–710. https://doi.org/10.1046/j.1365-2923.2002.01272.x.
21. Crossingham JL, Jenkinson J, Woolridge N, Gallinger S, Tait GA, Moulton CAE. Interpreting three-dimensional structures from two-dimensional images: a web-based interactive 3D teaching model of surgical liver anatomy. HPB 2009; 11(6): 523–528. https://doi.org/10.1111/j.1477-2574.2009.00097.x.
22. 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(6): 366–372. https://doi.org/10.1016/j.aanat.2010.08.002.
23. Arráez-Aybar LA, Casado-Morales MI, Castaño-Collado G. Anxiety and dissection of the human cadaver: an unsolvable relationship? Anat Rec B New Anat 2004; 279(1): 16–23. https://doi.org/10.1002/ar.b.20022.
24. Krontiris-Litowitz J. Using manipulatives to improve learning in the undergraduate neurophysiology curriculum. Adv Physiol Educ 2003; 27(3): 109–119. https://doi.org/10.1152/advan.00042.2002.
25. Estevez ME, Lindgren KA, Bergethon PR. A novel three-dimensional tool for teaching human neuroanatomy. Anat Sci Educ 2010; 3(6): 309–317. https://doi.org/10.1002/ase.186.
26. DeHoff ME, Clark KL, Meganathan K. Learning outcomes and student-perceived value of clay modeling and cat dissection in undergraduate human anatomy and physiology. Adv Physiol Educ 2011; 35(1): 68–75. https://doi.org/10.1152/advan.00094.2010.
27. Rizzolo LJ, Stewart WB. Should we continue teaching anatomy by dissection when . . .? Anat Rec B New Anat 2006; 289(6): 215–218. https://doi.org/10.1002/ar.b.20117.
28. Motoike HK, O'Kane RL, Lenchner E, Haspel C. Clay modeling as a method to learn human muscles: A community college study. Anat Sci Educ 2009; 2(1): 19–23. https://doi.org/10.1002/ase.61.
29. Oh CS, Kim JY, Choe YH. Learning of cross-sectional anatomy using clay models. Anat Sci Educ 2009; 2(4): 156–159. https://doi.org/10.1002/ase.92.
30. Von Hagens G, Tiedemann K, Kriz W. The current potential of plastination. Anat Embryol 1987; 175(4): 411–421. https://doi.org/10.1007/BF00309677.
31. Dhingra R, Taranikanti V, Kumar R. Plastination: teaching aids in anatomy revisited. Natl Med J India 2006; 19(3): 171. PMID: 16838416.
32. 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(6): 479–486. https://doi.org/10.1002/ase.1475.
33. Cook TD. Randomized experiments in education: assessing the objections to doing them. Econ Innov New Technol 2007; 16(5): 331–455. https://doi.org/10.1080/10438590600982335.