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Others

Is a Three-Dimensional Printing Model Better Than a Traditional Cardiac Model for Medical Education? A Pilot Randomized Controlled Study

Zhongmin Wang, Yuhao Liu, Hongxing Luo, Chuanyu Gao, Jing Zhang and Yuya Dai

Background: Three-dimensional (3D) printing is a newly-emerged technology converting a series of two-dimensional images to a touchable 3D model, but no studies have investigated whether or not a 3D printing model is better than a traditional cardiac model for medical education.

Methods: A 3D printing cardiac model was generated using multi-slice computed tomography datasets. Thirty-four medical students were randomized to either the 3D Printing Group taught with the aid of a 3D printing cardiac model or the Traditional Model Group with a commonly used plastic cardiac model. Questionnaires with 10 medical questions and 3 evaluative questions were filled in by the students.

Results: A 3D printing cardiac model was successfully generated. Students in the 3D Printing Group were slightly quicker to answer all questions when compared with the Traditional Model Group (224.53 ± 44.13 s vs. 238.71 ± 68.46 s, p = 0.09), but the total score was not significantly different (6.24 ± 1.30 vs. 7.18 ± 1.70, p = 0.12). Neither the students'satisfaction (p = 0.48) nor their understanding of cardiac structures (p = 0.24) was significantly different between two groups. More students in the 3D Printing Group believed that they had understood at least 90% of teaching content (6 vs. 1). Both groups had 12 (70.6%) students who preferred a 3D printing model for medical education.

Conclusions: A 3D printing model was not significantly superior to a traditional model in teaching cardiac diseases in our pilot randomized controlled study, yet more studies may be conducted to validate the real effect of 3D printing on medical education.

Key Words: Medical education • Structural heart disease • Three-dimensional printing • Traditional cardiac model

INTRODUCTION

Three-dimensional (3D) printing is an emerged technology that builds up a physical model commonly in a layer-by-layer manner using a 3D computerized model reconstructed from a series of images such as computed tomography or magnetic resonance imaging datasets.[1-3] It has the advantage of presenting 2D images in a manner to enable a more comprehensive study of human anatomical structures, especially complex anatomical structures,[4,5] and it has been widely utilized for preoperative simulation in orthopedics, plastic surgery, and cardiology.[6-8]

Medical education has greatly evolved from traditional 2D presentation techniques such as textbooks, chalkboards and photographic projections to relatively high-tech 3D solutions such as rotatable 3D models displayed on computer screen.[9] 3D presentations have been shown to improve the understanding of complex

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Department of Cardiology, Zhengzhou University People's Hospital (Henan Provincial People's Hospital), Zhengzhou, Henan 450003, China.
Corresponding author: Dr. Hongxing Luo, Department of Cardiology, Zhengzhou University People's Hospital, Zhengzhou, Henan 450003, China. Tel: 86 15290885448; E-mail: 1519782837@qq.com

anatomical structures among medical students and practitioners.[10-13] Previous studies have investigated the use of 3D printing for the medical education of cardiovascular diseases, however no randomized controlled trials have yet compared the effects of a 3D printing cardiac model with a traditional cardiac model for medical education.[14,15] Therefore, we conduct this randomized controlled trial to investigate whether a 3D printing cardiac model is superior to a traditionally made cardiac model in teaching medical students about cardiovascular diseases.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board of Henan Provincial People's Hospital and conformed to the statements in the Declaration of Helsinki.

Manufacture of a 3D printing cardiac model

Due to our previous project on the efficacy of a 3D printing cardiac model for the preoperative and postoperative evaluations of patients with structural cardiac diseases, several 3D printing cardiac models were available for this study.[16,17] In this study, a ventricular septal defect (VSD) model was 3D printed for the purpose of medical education. Briefly, after obtaining written informed consent, a 47-year-old male patient with VSD was scanned using 64-slice multi-detector computed tomography (Siemens AG, Berlin, Germany) to obtain raw data. The raw data were then processed by Mimics 17.0 software (Materialise NV, Leuven, Belgium) for 3D reconstruction, after which a virtual 3D model was saved in stereolithography (.stl) format. It was then loaded to a 3D printer (ZRapid Technologies Co., Ltd., Jiangsu, China) and printed with ZR80 resin (ZRapid Technologies Co., Ltd., Jiangsu, China).

Medical education

Figure 1 illustrates our study design. Briefly, 34 third-year medical students were randomly assigned to either the Traditional Model Group (n = 17) taught with the aid of a traditional cardiac model (AstraZeneca Plc., London, United Kingdom) or the 3D Printing Group (n = 17) taught with the 3D printed model for a 120-minute course about valvular heart diseases. By the end of the class, both groups were required to complete a questionnaire with 10 medical questions and 3 evaluative questions (Table 1).

Statistical analysis

All data were analysed using SPSS software version 12.0 (SPSS Inc., IL, USA), with a significant level defined as $p < 0.05$. Continuous and normally distributed data were expressed as mean ± standard deviation and compared using the *t* test. Categorical data were expressed as median (the first quartile, the third quartile) and compared using the *chi*-squared test. Box plots were also used to illustrate the study results.

RESULTS

Generation of the 3D printing model

The 3D printing model was successfully manufactured, and it could be either viewed as a whole (Figure 2B) or separated to two parts to show the internal structures (Figure 2D). Compared with the traditional cardiac model (Figure 2A), the 3D printing model showed no coronary branches (e.g., left descending artery) on the cardiac surface. The atrioventricular groove and interventricular groove were also deep and large. Although our study aimed to teach the medical students about valvular heart diseases, unfortunately the 3D printing model showed no heart valves. In contrast, the traditional cardiac model (Figure 2C) clearly showed the tricuspid valves, pulmonary valves and mitral valves.

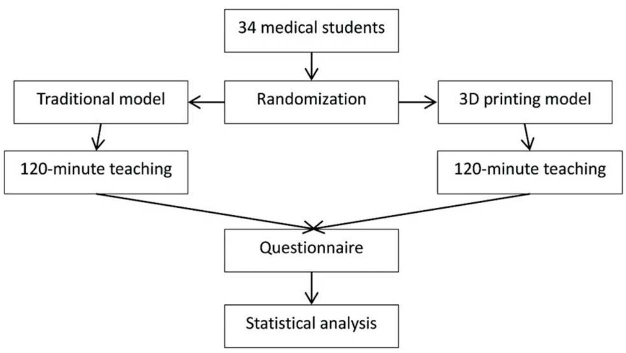

Figure 1. *Flowchart of the study design. A total of 34 medical students were randomized to either the Traditional Model Group (n = 17) or the 3D Printing Model Group (n = 17) for a 120-minute course, after which questionnaires were distributed and filled in by all students.*

Table 1. Ten medical questions and the correct answers

Capabilities	Questions	Answers
Memory	1. Normal mitral valve area is	A 2-4 cm^2 B 3-5 cm^2 C 4-6 cm^2 (✓) D 5-7 cm^2
	2. Moderate mitral stenosis area is	A 1-1.5 cm^2 (✓) B 1-2 cm^2 C 1.5-2.5 cm^2 D 2-3 cm^2
Inference	3. Mitral stenosis causes	A Pear-shaped heart (✓) B Flask-shaped heart C Boot-shaped heart D Generalized enlarged heart
	4. Murmurs of mitral stenosis occur at	A Systole B Diastole (✓) C Systole and diastole D Systole or diastole
	5. Percutaneous balloon mitral valvuloplasty punctures via	A Atrial septum (✓) B Pulmonary vein C Pulmonary artery D Ventricular septum
	6. Left ventricular papillary muscle rupture most probably causes	A Acute left heart failure (✓) B Acute right heart failure C Acute whole heart failure D Arrhythmia
	10. Murmurs of pathological mitral valve posterior cusp radiate to	A Left chest and cardiac base (✓) B Right chest and cardiac base C Left chest and cardiac apex D Right chest and cardiac apex
Space	7. For an upright normal person, pulmonary valve is at the _______ position of aortic valve	A Left higher (✓) B Left lower C Right higher D Right lower
	8. For an upright normal person, the most anterior valve is	A Tricuspid valve B Mitral valve C Aortic valve D Pulmonary valve (✓)
	9. For an upright normal person, the most upper valve is	A Tricuspid valve B Mitral valve C Aortic valve D Pulmonary valve (✓)

Students' basic characteristics and overall performance

Table 2 summarizes the students' basic characteristics and overall performance. Both groups had 17 medical students of similar age (22.18 ± 0.53 years vs. 22.29 ± 0.85 years, p = 0.63) and sex (p = 0.74). Students in the 3D Printing Group completed the questionnaire slightly faster (224.53 ± 44.13 s vs. 238.71 ± 68.46 s, p = 0.09), but the total score was lower compared with the Traditional Model Group (6.24 ± 1.30 vs. 7.18 ± 1.70, p = 0.12).

Students' performance in 10 medical questions

Figure 3 shows the students' performance in each of 10 different questions. There were no significant differences between the groups, however the Traditional Model Group had higher scores on Questions 1 to 8 whereas the 3D Printing Group had higher scores on Questions 9 and 10. Both groups showed their lowest scores on Questions 7 to 9 about spatial capability.

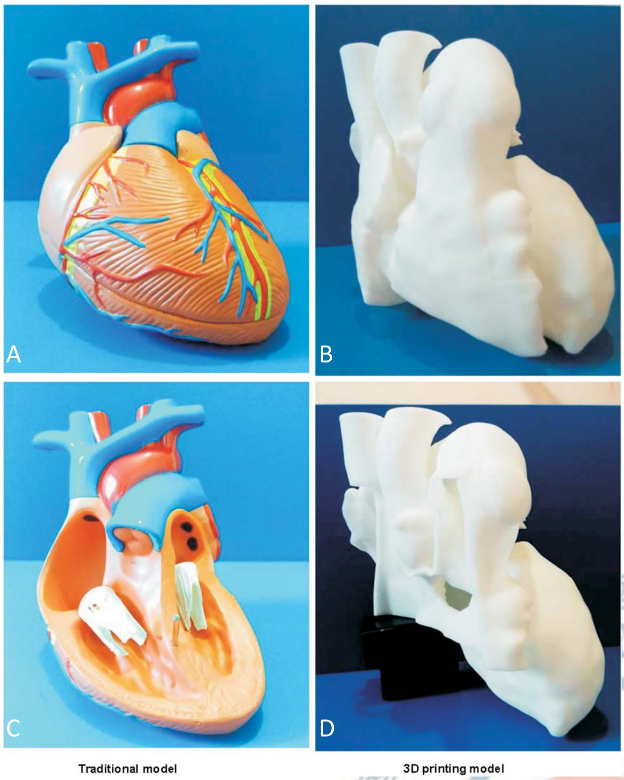

Figure 2. *Comparison of the traditional cardiac model with the 3D printing model.*

Table 2. Age, sex, time and total score in Traditional Model Group and 3D Printing Group

	Traditional Model Group	3D Printing Group
Number of students	17	17
Age (mean ± SD, years)	22.18 ± 0.53	22.29 ± 0.85
Sex (number)		
Male	8	9
Female	9	8
Time (mean ± SD, s)	238.71 ± 68.46	224.53 ± 44.13
Total score (mean ± SD)	7.18 ± 1.70	6.24 ± 1.30

3D, three-dimensional; SD, standard deviation.

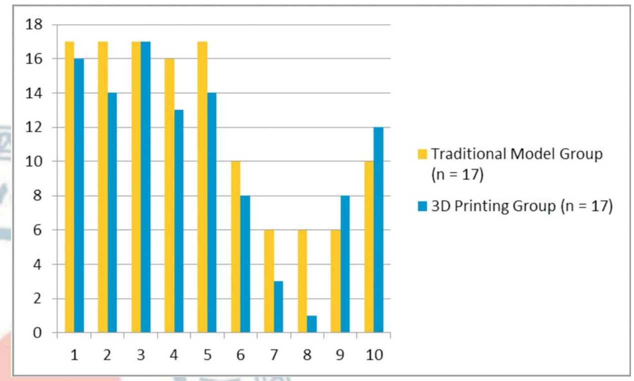

Figure 3. *Number of students giving correct answers to each question.*

Satisfaction, understanding and preferred teaching methods

There were no significant differences in satisfaction [10 (9-10) vs. 10 (9-10), p = 0.48] or understanding of the medical knowledge [80 (72-88) vs. 80 (60-100), p = 0.24] between the two groups. Compared with the Traditional Model Group, more students in the 3D Printing Group marked 9 to 10 points for satisfaction with teaching, however the difference was not significant (17 vs. 14, p = 0.07). Six students in the 3D Printing Group believed that they had understood at least 90% of the teaching content, compared to only 1 student in the Traditional Model Group. Twelve (70.6%) students in each group preferred the 3D printing model as a teaching aid.

DISCUSSION

To the best of our knowledge, this is the first randomized controlled study comparing the effects of a 3D printing cardiac model versus a traditionally made cardiac model on medical education. Our results did not indicate a superior role of the 3D printing model in teaching medical students about valvular heart diseases, although 3D printing technology appears to have revolutionized traditional medical teaching.[18] 3D printing can enable a more effective learning environment by allowing medical teachers and students to develop more disease- and patient-specific models to better understand anatomical structures. In general, complex congenital heart diseases are difficult for medical students to understand from 2D representations in textbooks. The adoption of 3D printing models for medical education is likely to minimize the potential misinterpretations of cardiac anatomy among medical students. Costello[14,15] used 5 VSD subtypes (infundibular, membranous, inlet, muscular, and atrioventricular types) for the education of 52 medical students and pediatric residents, and observed that the students reported a significant improvement in knowledge acquisition. Lim[19] used 1 prosected cardiac model, 2 cardiac models without great vessels and 3 coronary artery models in the education of 52 medical undergraduate students, and found a significant improvement in overall test scores in the 3D printing group. They concluded that 3D printing models did not disadvantage students relative to cadaveric materials. Biglino[20] used 3D printing models of complex structural heart diseases for the education of 65 pediatric nurses and 35 adult nurses, and discovered that 3D models improved the appreciation of overall anatomy, spatial orientation, and anatomical complexity.

Our study showed no significant improvements in the understanding of cardiac structures in the 3D Printing Group compared with the Traditional Model Group. Although the total scores were not significantly different, the students in the 3D Printing Group appeared to be more confident in their studies, as reflected by the higher proportion of students who believed that they had understood at least 90% of the teaching content. This finding indicates that in the long run, 3D printing cardiac models may have a positive effect on the students' learning by stimulating their curiosity to study. With the increasing popularity and development of 3D printing, the price of a 3D printer is likely to go down, and more medical students may have access to the technology, which may greatly improve their understanding of anatomical relationships. Of note, we used a 3D printing cardiac model primarily generated for preoperative evaluations in this study. The 3D printing cardiac model therefore served both clinical and educational needs, thereby increasing the extra values of the 3D printing model. In the future, further as yet unimagined functions of 3D printing may be discovered.

Several factors may have affected our study results. First, the traditional cardiac model was colored and clearly showed heart valves, while the 3D printing model showed neither colors nor valves. In fact, the development of a precise cardiac model to mimic cardiac structures has become a challenge in the field of 3D printing. Most studies have employed computed tomography or magnetic resonance imaging to acquire medical images for 3D printing, however heart valves may not be easily extracted in this way because they have similar Hounsfield units with the adjacent tissues and thus the thresholding process may be challenging.[21] Therefore, Mahmood et al. proposed 3D echocardiography as a tool to obtain raw data for 3D printing.[22-25] Second, although a previous study showed that a minimum of 12 participants per group is required for a pilot study, our sample size may not be large enough to test the real effects of 3D printing on medical education.[26] We recognize that with more researchers starting to investigate 3D printing, a study with larger sample size is possible to help investigate the real impact of 3D printing on medical education.

CONCLUSIONS

Our pilot study indicates that a 3D printing cardiac model is not superior to a traditional model in the medical education of cardiac diseases, and more research is needed to further validate the real effect of a 3D printing model on medical education.

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DECLARATION OF CONFLICTS OF INTEREST

All authors declare no conflicts of interest.

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REFERENCES

1. Silva K, Rand S, Cancel D, et al. Three-dimensional (3-D) printing: a cost-effective solution for improving global accessibility to prostheses. *PM&R* 2015;7:1312-4.
2. Luo H, Meyer-Szary J, Wang Z, et al. Three-dimensional printing in cardiology: current applications and future challenges. *Cardiol J* 2017:[Epub ahead of print].
3. Luo H, Wang Z, Liu Y. Three-dimensional printing in cardiology: current status and future challenges in China. *Journal of Xiangya*

Medicine 2017;2:12-5.

4. Luo H. Three-dimensional printing for cardiology: to be, or not to be? *Cardiology* 2017;137:62-3.
5. Liu J, Wang Z, Gao L, et al. A large institutional study on outcomes and complications after transcatheter closure of a perimembranous-type ventricular septal defect in 890 Cases. *Acta Cardiol Sin* 2013;29:271-6.
6. Yu AW, Duncan JM, Daurka JS, et al. A feasibility study into the use of three-dimensional printer modelling in acetabular fracture surgery. *Advances in Orthopedics* 2015;2015:1-4.
7. Kamali P, Dean D, Skoracki R, et al. The current role of three-dimensional (3D) printing in plastic surgery. *Plast Reconstr Surg* 2016:1.
8. Schmauss D, Schmitz C, Bigdeli AK, et al. Three-dimensional printing of models for preoperative planning and simulation of transcatheter valve replacement. *The Annals of Thoracic Surgery* 2012;93:e31-3.
9. Trelease RB. From chalkboard, slides, and paper to e-learning: how computing technologies have transformed anatomical sciences education. *Anatomical Sciences Education* 2016;9:583-602.
10. Peterson DC, Mlynarczyk GS. Analysis of traditional versus three-dimensional augmented curriculum on anatomical learning outcome measures. *Anat Sci Educ* 2016;9:529-36.
11. Müller-Stich BP, Lob N, Wald D, et al. Regular three-dimensional presentations improve in the identification of surgical liver anatomy – a randomized study. *BMC Med Educ* 2013;13:1-8.
12. Kockro RA, Amaxopoulou C, Killeen T, et al. Stereoscopic neuroanatomy lectures using a three-dimensional virtual reality environment. *Annals of Anatomy - Anatomischer Anzeiger* 2015;201:91-8.
13. Beermann J, Tetzlaff R, Bruckner T, et al. Three-dimensional visualisation improves understanding of surgical liver anatomy. *Med Educ* 2010;44:936-40.
14. Costello JP, Olivieri LJ, Krieger A, et al. Utilizing three-dimensional printing technology to assess the feasibility of high-fidelity synthetic ventricular septal defect models for simulation in medical education. *World J Pediatr Congenit Heart Surg* 2014;5:421-6.
15. Costello JP, Olivieri LJ, Su L, et al. Incorporating three-dimensional printing into a simulation-based congenital heart disease and critical care training curriculum for resident physicians. *Congenit Heart Dis* 2015;10:185-90.
16. Wang Z, Luo H, Gao C, Xu Y. Three-dimensional printing model for the postoperative follow-up of atrial septal defect. *Int J Cardiol* 2016;222:891-2.
17. Wang Z, Liu Y, Xu Y, et al. Three-dimensional printing-guided percutaneous transcatheter closure of secundum atrial septal defect with rim deficiency: first-in-human series. *Cardiol J* 2016;23:599-603.
18. Estai M, Bunt S. Best teaching practices in anatomy education: a critical review. *Annals of Anatomy - Anatomischer Anzeiger* 2016;208:151-7.
19. Lim KH, Loo ZY, Goldie SJ, et al. 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.
20. Biglino G, Capelli C, Koniordou D, et al. Use of 3D models of congenital heart disease as an education tool for cardiac nurses. *Congenit Heart Dis* 2017;12:113-8.
21. Luijnenburg SE, Robbers-Visser D, Moelker A, et al. Intra-observer and interobserver variability of biventricular function, volumes and mass in patients with congenital heart disease measured by CMR imaging. *The International Journal of Cardiovascular Imaging* 2010;26:57-64.
22. Mahmood F, Owais K, Taylor C, et al. Three-dimensional printing of mitral valve using echocardiographic data. *JACC Cardiovasc Imaging* 2015;8:227-9.
23. Binder TM, Moertl D, Mundigler G, et al. Stereolithographic biomodeling to create tangible hard copies of cardiac structures from echocardiographic data: in vitro and in vivo validation. *J Am Coll Cardiol* 2000;35:230-7.
24. Gilon D, Cape EG, Handschumacher MD, et al. Effect of three-dimensional valve shape on the hemodynamics of aortic stenosis: three-dimensional echocardiographic stereolithography and patient studies. *J Am Coll Cardiol* 2002;40:1479-86.
25. Wu VC, Takeuchi M. Three-dimensional echocardiography: current status and real-life applications. *Acta Cardiol Sin* 2017;33:107-18.
26. Julious SA. Sample size of 12 per group rule of thumb for a pilot study. *Pharm Stat* 2005;4:287-91.