



Digital clinical teaching of cardiovascular surgery supported by precision imaging and 3D printing technology

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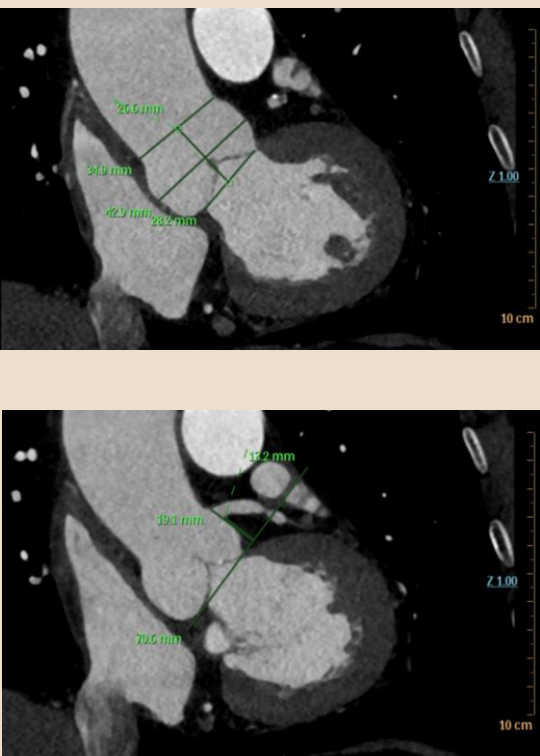
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Abstract

Cardiovascular surgery necessitates advanced three-dimensional spatial skills, which are frequently insufficiently cultivated by conventional pedagogical approaches. A study was conducted comparing two cohorts of medical students: one group utilized digital tools incorporating precision imaging and three-dimensional printing, while the other employed a hybrid approach combining Case-Based Learning (CBL), Problem-Based Learning (PBL), and Team-Based Learning (TBL). The cohort utilizing digital teaching methodologies demonstrated superior performance relative to the CBL-PBL-TBL group in terms of theoretical knowledge, clinical competencies, and overall assessment outcomes. Additionally, students in the digital cohort reported enhanced abilities in self-directed learning, spatial visualization, and problem-solving. The integration of digital technologies with traditional educational methodologies significantly augments both the quality of medical education and student satisfaction.

Introduction

Cardiovascular surgery necessitates a comprehensive understanding of the three-dimensional anatomy of the heart and its spatial interrelationships. There has been a pedagogical shift from conventional lecture-based instruction to active learning methodologies, such as CBL, PBL, and TBL, aimed at enhancing clinical reasoning and collaborative skills. In contemporary medical education, precision imaging and three-dimensional printing technologies are being incorporated to augment spatial visualization capabilities. This paper examines the integration of digital tools in the pedagogy of cardiovascular surgery, proposing an innovative model that combines Case-Problem-Team-Based Learning (C-P-TBL) with advanced imaging and three-dimensional printing technologies.

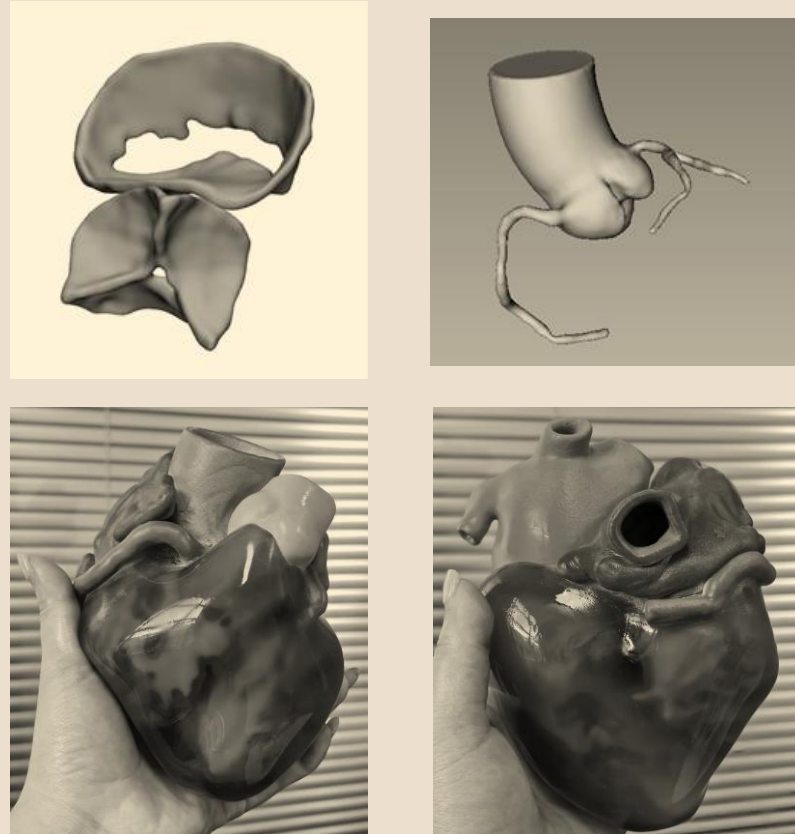


These two images are CTA images of the aortic root, primarily depicting the anatomy of the aortic sinuses and coronary arteries.

Methods

A study was conducted with a cohort of 80 medical students to compare the efficacy of two pedagogical approaches: Case-Problem-Team-Based Learning (C-P-TBL) and digital instruction. The C-P-TBL cohort engaged in collaborative problem-solving of clinical cases using a combination of case-based, problem-based, and team-based learning strategies. Conversely, the digital instruction cohort employed 3D reconstructions and 3D-printed heart models derived from CT scans, building upon the C-P-TBL framework to enhance spatial visualization and anatomical comprehension. Both cohorts were assessed through objective measures, including theoretical and practical examinations, as well as subjective evaluations via a teaching quality questionnaire.

The objective evaluation comprised theoretical examinations, which constituted 60% of the total weight and included 100 multiple-choice questions, alongside practical examinations, accounting for 40% of the weight, which assessed surgical competencies such as history taking, case analysis, and cardiac examinations. The subjective evaluation employed a questionnaire designed to assess various dimensions, including self-directed learning capability, comprehension of theoretical concepts, problem-solving proficiency, teamwork, communication skills, spatial imagination, clinical competencies, and overall self-comprehensive ability. Levels of satisfaction were classified into four categories: dissatisfied, general, satisfied, and very satisfied.



These four diagrams demonstrate the three-dimensional reconstructions of the aortic valve, mitral valve, and aortic root, and exhibit the 3D printed appearance of the cardiac image of a patient with aortic insufficiency.

Score	Digital Teaching Group	C-P-TBL Teaching Group	Z/t	P
Self-learning ability	16.93±2.464	14.18±1.534	-4.686	0.000
Ability to understand and apply theoretical knowledge	16.05±2.882	14.80±2.472	-2.046	0.041
Ability to identify and analyze problems	17.02±2.486	14.95±2.698	-3.293	0.001
Teamwork skills	15.78±2.759	14.98±1.954	-1.334	0.182
Communication and presentation skills	16.73±2.491	15.88±2.420	-1.553	0.120
Spatial imagination ability	17.25±2.351	15.55±2.581	-2.878	0.004
Clinical skills	16.58±2.707	16.05±2.230	-1.109	0.267
Self comprehensive ability	16.58±2.707	15.05±1.518	-2.714	0.007

Results

In this study, a total of 80 electronic questionnaires were collected, all of which were deemed valid. Statistical analysis revealed that students in the digital teaching group outperformed those in the C-P-TBL teaching group regarding self-learning ability, comprehension and application of theoretical knowledge, problem identification and analytical skills, spatial imagination, and overall self-comprehensive ability ($P < 0.05$). Nonetheless, no significant differences were observed between the two groups in terms of teamwork ability, communication and expression skills, and clinical skills training.

Score	Digital Teaching Group	C-P-TBL Teaching Group	Z/t	P	95%CI
Theoretical examination	86.28±10.756	80.25±9.440	-2.862	0.004	3.0-11.0
Skills Assessment	87.90±7.530	83.05±7.473	-2.755	0.006	1.0-9.0
Total score	86.93±8.131	81.37±7.716	-3.147	0.002	2.4-9.6

Results

The students in the digital teaching group demonstrated significantly higher scores in theoretical knowledge assessment, clinical skills assessment, and overall performance compared to those in the C-P-TBL teaching group, with the differences reaching statistical significance ($P < 0.05$).

Groups	n	Very satisfied	Satisfied	Fair	Dissatisfied	Satisfaction (%)
Digital Teaching Group	40	21	18	1	0	97.5%
C-P-TBL Teaching Group	40	17	18	5	0	87.5%
Chi-square value						1.622
P						0.203

Results

The findings from the questionnaire indicated that student satisfaction in the digital teaching cohort was 97.5%, while that in the C-P-TBL teaching cohort was 87.5%. The difference between these satisfaction levels was not statistically significant ($P > 0.05$).

Conclusion

In conclusion, we sought to incorporate precision imaging and 3D printing technology into CBL, PBL, and TBL, and conducted evaluations focusing on knowledge acquisition, theoretical understanding, and clinical skill development. This initiative led to the preliminary optimization of a digital clinical teaching model for cardiovascular surgery, alongside the formulation of a personalized surgical clinical teaching plan aimed at enhancing students' theoretical and practical competencies. Particular emphasis was placed on addressing clinical practical challenges and fostering improved spatial reasoning abilities. The initial investment required for a single 3D model, typically ranging from approximately \$200 to \$500, can be efficiently amortized through high rates of reuse, resource sharing, and the long-term educational advantages it provides. Furthermore, the model's capacity to deliver personalized and real-world scenario-based instruction is invaluable in augmenting clinical reasoning and practical skills. Meanwhile, it is essential to acknowledge the limitations in teamwork collaboration and teacher training. Multimodal assessment approaches, such as behavioral observation, can be employed in the future to guarantee the sustained enhancement of educational achievements.