

Application of 3D printing technology combined with PBL teaching method in clinical teaching of cerebrovascular disease

An observational study

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Abstract

Traditional clinical teaching does not allow medical students to combine theoretical knowledge with practical knowledge. As such, we aimed to determine the effectiveness of three dimensional (3D) printing technology combined with problem-based learning (PBL) in the clinical teaching of cerebrovascular diseases. Medical interns were randomly divided into an experimental group (n = 136) that was taught using 3D printing technology + PBL method and a control group (n = 133) that was taught using traditional methods. We compared assessment results of theoretical and clinical practice skills and the subjective evaluation of teaching methods between the 2 groups. The assessment results of the experimental group were significantly higher than those in the control group ($P < .05$). The survey assessing the evaluation of teaching methods showed higher satisfaction with teaching methods, increased learning interest, and improvement in the spatial thinking ability of interns in the experimental group compared to the control group ($P < .05$). There was no significant difference when assessing which teaching method better improved the interns' understanding of cerebrovascular diseases ($P < .05$). The application of 3D printing technology combined with the PBL teaching method in neurosurgery clinical teaching can stimulate interest in learning and significantly improve academic performance and problem-analysis and solving skills.

Abbreviations: 3D = three dimensional, DSA = digital subtraction angiography, PBL = problem-based learning.

Keywords: 3D printing, cerebrovascular disease, clinical teaching, PBL teaching method

1. Introduction

Cerebrovascular disease is a complex and intricate condition. Therefore, it is particularly important that learners have in-depth knowledge and understanding of anatomy before learning to treat cerebrovascular disease. We found that residents and medical students, herein referred to as interns, have limited anatomical knowledge of the cerebrovascular system and face difficulties in learning. Traditional clinical teaching does not allow medical students to combine theoretical knowledge with practical knowledge. Three-dimensional (3D) printing technology originated in the 1990s and was applied in various fields.^[1,2] Owing to continuous advancements in science and technology, 3D printing technology

has gradually been applied in clinical teaching and assisted surgery.^[3–5] Tan et al reported positive results of 3D printing technology application when teaching congenital heart surgery.^[6] 3D printing technology transformed from simple vision to a visual-tactile model, facilitating clinical training of neurosurgeons.

Problem-based learning (PBL) method is a teaching method in which students are the main body and teachers play an assistive role. The PBL teaching method advocates for students to solve problems through self-study and small group discussions. Consequently, the PBL teaching method cultivates autonomous learning abilities and develops comprehensive thinking. Compared to traditional teaching methods, the PBL method shifts the focus from teaching to learning. Several

This work was supported by Clinical Medical Science and Technology Development Foundation of Jiangsu University (JLY2021019, JLY2021020, JLY2021025), Changzhou Sci & Tech Program (CJ20210016), Young Talent Development Plan of Changzhou Health Commission (CZQM2020119), and Open Project of Jiangsu Province Key Laboratory of Encephalopathy biological information, Xuzhou Medical University (XZYSKF2021021).

The authors have no conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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How to cite this article: Jiang W, Jiang W, Jin P, Zhang J, Xia J, Wei W, Qing B. Application of 3D printing technology combined with PBL teaching method in clinical teaching of cerebrovascular disease: An observational study. *Medicine* 2022;101:47(e31970).

Received: 30 April 2022 / Received in final form: 31 October 2022 / Accepted: 1 November 2022

<http://dx.doi.org/10.1097/MD.00000000000031970>

recent studies have found that the PBL method is effective in enhancing clinical practice and analytical skills of medical students compared to traditional lectures.^[7-9] Zhao et al found that the PBL method might be effective in improving performance and enhancing clinical skills of interns.^[10] Moreover, the same study reported that students in PBL programs had higher satisfaction levels.

In this study, we combined 3D printing technology with the PBL teaching method for clinical teaching of cerebrovascular disease. We assessed whether the PBL method can compensate for the inadequacy of traditional teaching by improving learning interest and enhancing understanding of cerebrovascular disease.

2. Methods

2.1. Research participants

The study included interns who studied neurosurgery at Wujin Hospital Affiliated to Jiangsu University from September 2020 to December 2021. The interns were randomly divided into 2 groups, the 3D printing technology + PBL group and the traditional group. All teachers were qualified senior neurosurgery professors.

The ethics committee at Wujin Hospital Affiliated with Jiangsu University approved this study (NO.2020-08). All interns participating in the experiment signed informed consent and the names and contact information of patients and interns that did not take part in the experiment were not recorded.

2.2. Study design

Participants in the traditional group were taught using the traditional teaching methods. Firstly, participants attended lectures on epidemiology, pathogenesis, clinical manifestations, relevant examinations, differential diagnosis, treatment methods, and prognosis of cerebrovascular diseases; thereafter, clinical practice training was carried out. Secondly, professors taught the anatomical and surgical scheme of cerebrovascular diseases through medical history collection, physical examination, and imaging data such as computerized tomography, Magnetic Resonance Imaging, and Digital Subtraction Angiography (DSA).

The 3D printing technology + PBL group was taught using 3D printing technology combined with the PBL teaching method. Clinical cases were selected according to the teaching plan, and complete clinical and imaging data of the selected cases were presented. The DSA data of typical cases selected in the current teaching were collected and saved in DICOM format. The intracranial artery was reconstructed using Mimics software 17.0 (Materialise, Belgium) and the stereolithography format file was exported. The intracranial vascular model with a ratio of 1:1 was printed using a 3D printer (Chuangxiang 3D, Shenzhen, China) and 2 chief professors from the cerebrovascular disease group determined whether the model conformed to the real-life representation of intracranial arteries and related lesions (Fig. 1). The lecturer taught a lesson on typical clinical manifestations of cerebrovascular disease and posed questions based on the characteristics of the disease. Participants were involved in the 3D printing of an intracranial vascular model, as required in clinical cases. Thereafter, group discussions were held in which they listed clinical characteristics and proposed treatment methods. During the discussion, participants could consult books or other materials and communicate with one another about the problems they found. Both groups received theoretical and practical examinations after the lessons.

2.3. Evaluation of teaching effects

Professors assessed the theoretical and clinical practice skills of all participants according to the contents of the standardized training program, before and after clinical lessons. The theoretical examination contents included clinical symptoms, imaging characteristics, and perioperative treatment of cerebrovascular disease. The assessment of clinical practice skills involved diagnosis and differential diagnosis of cerebrovascular diseases, image reading, and surgical procedures selection. Both assessments were presented as 10 single-choice questions, with 1 point for each question.

An anonymous survey was conducted among all participants. The survey comprised questions on motivation, understanding, student-teacher interaction, the final examination, communication skills, clinical thinking skills, self-learning skills, teamwork skills, and knowledge absorption.^[6,10] The evaluation criteria were based on a previous study. Based on the degree of improvement, the scores were divided into 5 grades, from 1 (poor) to 5 (excellent)^[10].

2.4. Statistical analysis

SPSS 22.0 (SPSS Inc., Chicago, IL) was used to perform statistical analyses. Normally distributed data were expressed as mean \pm standard deviation and enumeration data were presented as percentages. The differences between the groups were statistically analyzed using the *t* test or χ^2 test, depending on the variables. *P* < .05 was regarded as statistically significant.

3. Results

3.1. Basic characteristics

A total of 269 participants were enrolled in the study and were randomly divided into traditional group (*n* = 133) and 3D printing + PBL group (*n* = 136). The average age of the traditional and 3D printing + PBL groups were 23.3 \pm 2.3 years and 23.5 \pm 1.9 years, respectively. There were 65 (51.13%) and 72 (52.94%) male participants in the traditional and 3D printing + PBL groups, respectively. Furthermore, the traditional and 3D printing + PBL groups had 86 (64.66%) and 90 (66.18%) residents, respectively. There was no significant difference between the 2 groups in age, sex, and grade (*P* > .05, Table 1).

3.2. Comparison of quiz scores between the groups

We compared the pre- and post-class quiz scores between the 2 groups (Table 2). The mean pre-class theoretical and clinical practice scores in the traditional versus 3D printing + PBL groups were 3.81 \pm 1.56 and 4.12 \pm 1.38 versus 4.15 \pm 2.04, 3.97 \pm 1.51, respectively, whilst the post-class theoretical and clinical practice scores in the traditional versus 3D printing + PBL groups were 7.06 \pm 1.64 and 7.01 \pm 1.52 versus 8.33 \pm 1.33 and 7.97 \pm 1.30, respectively. There was no significant difference in pre-class theoretical and clinical practice scores between the 2 groups (*P* > .05). The post-class theoretical score and clinical practice score in both groups were improved compared to pre-class scores (*P* < .05). The post-class theoretical and clinical practice scores in the 3D printing + PBL group were significantly higher than that in the traditional group (*P* < .001, Table 2, Fig. 2).

3.3. Comparison of survey scores between the traditional and 3D printing + PBL groups

We analyzed the post-class survey scores to compare interns' perspectives and self-perceived competence between the groups. The results showed significantly higher scores in the 3D printing + PBL group when assessing learning motivation, understanding,

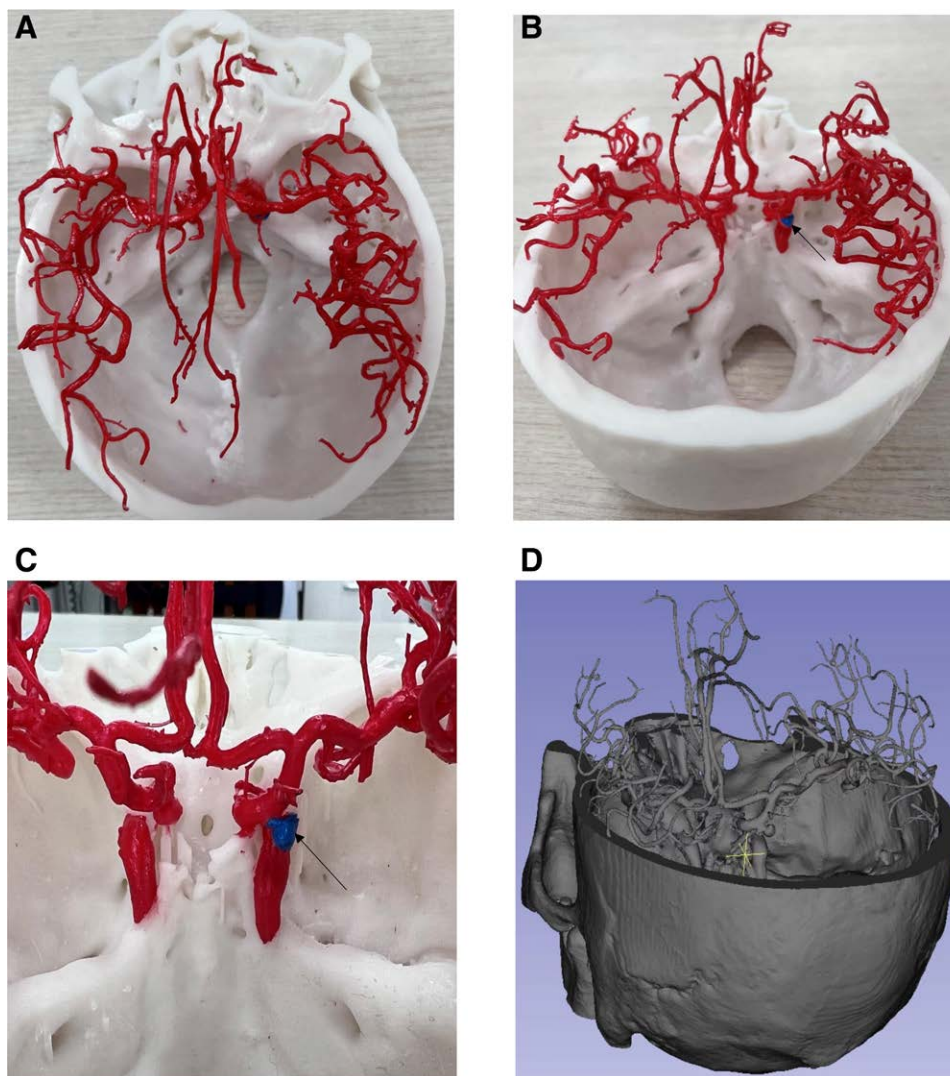


Figure 1. The 3D model of intracranial arteries. The intracranial artery was reconstructed by MIMICS 17.0, and the STL format file was exported (D). The intracranial vascular model with aneurysm (black arrow) was printed by 3D printer (A–C). 3D = three dimensional, STL = stereolithography.

Table 1
Demographics of all subjects.

Item	Traditional group (n = 133)	3D printing + PBL group (n = 136)	t or χ^2	P
Age (yr)	23.3 ± 2.3	23.5 ± 1.9	-0.121	.904
Gender (n)			0.089	.766
Male	68 (51.13%)	72 (52.94%)		
Female	65 (48.87%)	64 (47.06%)		
Grade (n)			0.068	.794
Residents	86 (64.66%)	90 (66.18%)		
Fourth-year students	47 (35.34%)	46 (33.82%)		

3D = three dimensional, PBL = problem-based learning.

student-teacher interaction, the final examination, communication skills, clinical thinking skills, self-learning skills, teamwork skills, and knowledge absorption ($P < .001$, Table 3).

4. Discussion

The relationship between intracranial arteries and veins is complex because of characteristics of dual arterial blood supply and

many communicating branches. Consequently, it is difficult for medical students to understand and master cerebrovascular disease in a short period. A complete understanding of cerebrovascular anatomy is necessary when performing craniotomy or vascular intervention. Medical students have a short clinical learning cycle, a long interval between theoretical classes, and limited clinical reasoning ability. Simultaneously, traditional teaching methods are focused on teachers and conveying theoretical knowledge, thus disregarding the cultivation of clinical thinking. Consequently, many medical students are less prepared upon entering neurosurgery clinical practice.

Based on different technical principles and raw materials, 3D printing technology can be divided into the following categories: stereolithography apparatus, selective laser sintering, fused deposition modeling, laminated object manufacturing and inkjet printing.^[11,12] The printing technology used in this study is based on fused deposition modeling, which has the following advantages: small land occupation, affordable, and high printing accuracy.^[13] In our study, the printing time of each vascular model was 4 to 5 hours, and the printed intracranial vessels with cerebrovascular diseases were highly consistent with the DSA 3D reconstruction image approved by the 2 senior neurosurgery professors. The 3D printing technology is a good development prospect in clinical teaching since 3D printed models can more intuitively demonstrate the complex anatomical structures and

Table 2
Comparison of examination time and score between 2 groups.

Item	Traditional group (n = 133)	3D printing + PBL group (n = 136)	t	P
Pre-class				
Theoretical score	3.81 ± 1.56	4.15 ± 2.04	-1.533	.126
Clinical practice score	4.12 ± 1.38	3.97 ± 1.51	0.849	.396
Post-class				
Theoretical score	7.06 ± 1.64	8.33 ± 1.33	-6.983	<.001
Clinical practice score	7.01 ± 1.52	7.97 ± 1.30	-5.571	<.001

3D = three dimensional, PBL = problem-based learning.

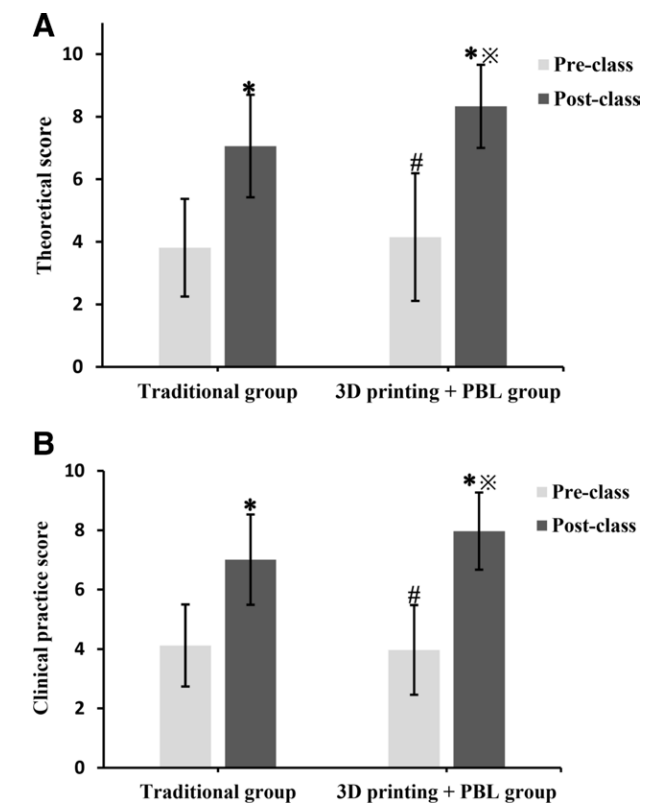


Figure 2. The comparison of theoretical score and clinical practice score in 2 groups. There was no significant difference in pre-class theoretical score and clinical practice score between 2 groups (A and B). The post-class theoretical score and clinical practice score in both groups were improved than pre-class. Meanwhile, the post-class theoretical score and clinical practice score in the 3D printing + PBL group were significantly higher than that in the traditional group (A and B). # $P > .05$ of pre-class theoretical score and clinical practice score in 2 groups. * $P < .05$ of the post-class theoretical score and clinical practice score in the 3D printing + PBL group comparison of that in the traditional group. * $P < .05$ of post-class theoretical score and clinical practice score in both groups than pre-class. 3D = three dimensional, PBL = problem-based learning.

relative positioning of lesions, and enable handling and observation of anatomical parts from different angles. Consequently, 3D printing technology has been used more frequently in clinical teaching of orthopedics, stomatology, maxillofacial surgery, urology, and gynecology.^[14-16]

Currently, 3D printing technology is increasingly applied in neurosurgery teaching. Many studies showed that 3D printing technology has great advantages over traditional teaching

methods. The Beijing Union Medical College Hospital conducted a randomized controlled study on 79 medical students.^[17] The students were randomly divided into 3 different teaching groups: 3D printing, general skull, and atlas teaching. This study found significantly higher examination scores in the 3D printing group compared to those of the other 2 groups. Bairamian divided 10 neurosurgical students from Australia and New Zealand into 3D printing and traditional groups.^[18] The results showed that the 3D printing technology was immensely helpful in increasing 3D depth perception of the complex cerebrovascular anatomy.

If 3D printing technology was applied solely in clinical teaching, medical students would not comprehend and master vascular anatomy, the relationship between adjacent lesions, and real-life surgical approach of pathological conditions.^[19] However, when combined with the PBL teaching method, 3D printing technology would be more effective in improving clinical understanding in medical students. PBL teaching method was introduced in 1969 by Barrows,^[20] who was a professor of neurology at McMaster University Medicine School. Compared to traditional teaching methods, the PBL method can stimulate learning enthusiasm and improve practical skills. In this study, the teacher selected typical cases according to the requirements of the neurosurgery syllabus and printed 3D models of cerebrovascular disease using DSA data. The models displayed cerebrovascular disease characteristics under pathological conditions enabling cultivation of complete understanding and mastery of cerebrovascular disease.

5. Conclusion

This study showed that compared to the traditional teaching methods, 3D printing technology combined with PBL teaching method can assist in stimulating learning interest and improve logical thinking, problem-analysis, and problem-solving.

6. Limitation

The main limitation of the current study was that a double-blind study design could not be used. Furthermore, this study also had instrumentation limitations, such as subjective method to evaluate the effects of teaching methods and the inability of the 3D printing technology to reconstruct small blood vessels, skull base nerve, and other important brain tissue structures simultaneously. As 3D printing technology continues to develop, future studies should use more detailed models and conduct multidisciplinary studies to further elucidate the effects of 3D printing technology combined with the PBL method.

Author contributions

Wenqing JIANG, Jing ZHANG, and Junjie XIA conducted the study and drafted the manuscript. Peng JIN, Wenfeng WEI, Qing BAO, and Wei JIANG were involved in the study design and statistical analysis. All the authors read and approved the final manuscript.

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Table 3
Comparison of questionnaire survey results between 2 groups.

Item	Traditional group (n = 133)	3D printing + PBL group (n = 136)	t	P
Learning motivation (point)	3.01 ± 0.65	4.12 ± 0.78	12.691	<.001
Understanding (point)	3.03 ± 0.71	4.02 ± 0.82	10.593	<.001
Student-teacher interaction (point)	2.94 ± 0.82	3.99 ± 0.82	10.501	<.001
Final examination (point)	2.85 ± 0.76	3.89 ± 0.79	11.004	<.001
Communication skills (point)	2.93 ± 0.77	4.13 ± 0.81	12.455	<.001
Clinical thinking skills (point)	2.75 ± 0.81	3.78 ± 0.83	10.301	<.001
Self-learning skills (point)	2.48 ± 0.68	4.05 ± 0.79	17.482	<.001
Teamwork skills (point)	2.49 ± 0.79	3.95 ± 0.83	14.780	<.001
Knowledge absorption (point)	2.51 ± 0.69	4.08 ± 0.81	17.126	<.01

3D = three dimensional, PBL = problem-based learning.

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