Article

Application of 3D Reconstruction-Based Stereoscopic Visualization Combined With a Flipped Classroom Teaching Model in Undergraduate Clinical Medicine Education in Thoracic Surgery

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Gang Lan[1,†], Ye Ye[2,†], Xiaofeng Li[1], Youcai Zhu[1], Huafei Chen[1], Lichao Huang[1], Yong Gao[1], Puen Chen[1], Yonghua Min[1], Zhanqiang Zhai[1]

[1]Department of Thoracic Disease Center, The Third Affiliated Hospital of Jiaxing University (Zhejiang Rongjun Hospital), 314000 Jiaxing, Zhejiang, China
[2]Internal Medicine, The Third Affiliated Hospital of Jiaxing University (Zhejiang Rongjun Hospital), 314000 Jiaxing, Zhejiang, China

AIM: This study aimed to investigate the application effect of a stereoscopic visualization teaching method combined with a flipped classroom model in the clinical internship of thoracic surgery for undergraduate clinical medicine students.
METHODS: Based on teaching methods documented in instructional records, students were retrospectively assigned to a control group (n = 59) and an experimental group (n = 53). The control group employed the flipped classroom teaching model, while the experimental group utilized a three-dimensional visualization approach integrated with the flipped classroom model. Three-dimensional (3D) reconstructed anatomical models of the chest were exclusively used for clinical instruction within the experimental group. Theoretical examinations, case analyses, and clinical practice assessments were adopted to evaluate teaching effectiveness. Teaching satisfaction was measured through a questionnaire survey.
RESULTS: The theoretical scores, case analysis scores, and clinical practice scores of the experimental group were significantly higher than those of the control group ($p < 0.001$). Satisfaction with teaching content in the experimental group was higher than in the control group, although the difference was not statistically significant ($p = 0.347$). Satisfaction with teaching methods, teaching effectiveness, learning experience, and overall evaluation in the experimental group was significantly improved compared with the control group ($p < 0.001$).
CONCLUSIONS: Stereoscopic visualization, based on 3D reconstruction combined with a flipped classroom teaching model, has the potential to improve theoretical knowledge, case analysis skills, and clinical practical skills among undergraduate clinical medicine students during thoracic surgery internships. Compared with the flipped classroom alone, the combined teaching model results in higher teaching satisfaction.

Keywords: three-dimensional reconstruction; undergraduate medical education; thoracic surgery

Introduction

Thoracic surgery is an essential branch of surgical medicine. It involves the diagnosis and treatment of various thoracic diseases, such as rib fractures, pneumothorax, pulmonary infection, lung cancer, mediastinal tumors, and esophageal cancer. Thoracic surgeons need to master a wide range of professional knowledge and clinical skills, including anatomical and imaging expertise, thoracoscopic techniques, and clinical surgical operations [1]. Currently, the educational pathway for clinical medical students involves completing theoretical courses in university classrooms and subsequently entering hospitals for clinical internships. Overall, theoretical education and clinical practice are separated in time and space for clinical medical students [2], making it challenging for them to effectively apply and expand their theoretical knowledge in clinical settings. Students face numerous challenges during thoracic surgery internships, including the complex and variable anatomical structures of the chest, difficulties in interpreting imaging results, and insufficient proficiency in essential clinical techniques [3,4]. As a result, it is challenging for students to improve their skills in thoracic surgery within a short period. This places higher demands on clinical medical education in thoracic surgery.

The flipped classroom teaching model has been shown to enhance student interest in learning and teaching effectiveness. In clinical teaching, flipped classrooms may improve clinical thinking and operational skills of students [5]. However, this teaching model requires students to study course materials independently before class. Some stu-

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Correspondence to: Zhanqiang Zhai, Department of Thoracic Disease Center, The Third Affiliated Hospital of Jiaxing University (Zhejiang Rongjun Hospital), 314000 Jiaxing, Zhejiang, China (e-mail: 307509567@163.com).
† These authors contributed equally.
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dents have reported that the preparation required for flipped classrooms is burdensome [6]. For students who struggle with autonomous learning, it is challenging to complete pre-class preparation effectively [7,8]. Notably, thoracic surgery education involves a large volume of knowledge, complex anatomical relationships, and stringent clinical requirements, further exacerbating the difficulties students face during pre-class study. Therefore, it is necessary to further optimize teaching methods in clinical medical education.

Due to the shortage of cadaveric specimens and the limitations of teaching with organ models and anatomical atlases, students often fail to gain a deep understanding of chest anatomy through traditional teaching methods [9,10]. Furthermore, students must have a certain degree of spatial imagination to understand the anatomical structure of the chest. Traditional diagnostic approaches rely primarily on two-dimensional (2D) images, such as computed tomography (CT) scans and X-rays [11,12], which do not clearly display specific chest structures, including blood vessels and bronchi. This makes the identification of lesions and microlesions challenging. Three-dimensional (3D) reconstruction technology can generate 3D anatomical models through the extraction, segmentation, rendering, and fusion of various processes applied to 2D medical images [13]. These 3D reconstruction models can clearly and stereoscopically display anatomical structures. In cases involving complex or highly variable, 3D reconstruction technology enables detailed analysis and accurate measurement of lesion areas [14]. The clinical application of 3D reconstruction technology has received increasing attention, including its use in thoracoscopic segmentectomy [15] and preoperative evaluation of tumor diseases [16]. In knee arthroplasty, 3D multimodality imaging provides accurate registration of cartilage surfaces in affected areas [17]. An international survey reported that in urological surgery, 3D models were widely applied in partial nephrectomy, radical nephrectomy, and radical prostatectomy, with more than half of the respondents recognizing significant improvements in surgical outcomes [18].

Three-dimensional reconstruction technology is also increasingly applied as an educational resource in medical training. It greatly assists students in understanding complex anatomical structures and has been incorporated into clinical teaching. For example, its use improved students' theoretical knowledge, clinical thinking, and comprehensive abilities in hepatocellular carcinoma education [19]. Similarly, multimodality 3D reconstruction enhanced postgraduate learners' understanding of basic pelvic anatomy, image interpretation skills, learning efficiency, clinical reasoning, and learning interest [20]. However, the impact of 3D reconstruction technology on medical education in thoracic surgery has not yet been explored. Therefore, this study aimed to investigate the application effect of stereoscopic visualization teaching combined with a flipped classroom teaching model in the thoracic surgery internship for undergraduate clinical medicine students. These findings may serve as a reference for improving the quality of medical education.

Methods

General Information

This is a retrospective study. All students (n = 112) were collected from those who received internship training in the Department of Thoracic Disease Center, Zhejiang Rongjun Hospital between June 2024 and December 2024. According to the teaching method recorded in the teaching records, students were retrospectively divided into a control group (n = 59; flipped classroom teaching model) and an experimental group (n = 53; stereoscopic visualization combined with a flipped classroom teaching model). The inclusion criteria were: (1) fourth-year undergraduate students majoring in clinical medicine; (2) completion and passing of theoretical professional courses; and (3) complete data available. Exclusion criteria were: (1) previous internships in thoracic or other surgical departments; (2) inability to understand or cooperate with the teaching content or format. The flowchart of student selection is presented in Fig. 1. This study was approved by the Zhejiang Rongjun Hospital ethics committee (Approval Number: 2025-092) and complied with the principles outlined in the Declaration of Helsinki. All participants were informed and provided consent to participate in the study.

Construction of Stereoscopic Visualization Models

Clinical information from patients treated in the Department of Thoracic Disease Center, Zhejiang Rongjun Hospital was collected. These cases covered the diagnoses, anatomical sites, and clinical management of thoracic surgical diseases. The content included rib fractures, pulmonary tuberculosis, bronchiectasis, pneumothorax, tumors (lung cancer, mediastinal tumor, esophageal cancer), and clinical procedures (thoracentesis, closed drainage, and thoracoscopic surgery). The collected clinical information focused on thoracic anatomy, lesion characteristics, imaging data analysis, treatment approaches, and surgical procedures.

Stereoscopic visualization teaching materials were developed using 3D reconstruction technology. Two-dimensional imaging data, including CT and magnetic resonance imaging (MRI) scans, were obtained from patients. These data were imported into Mimics 2.0 software (Materialise Corp., Leuven, Belgium) for 3D reconstruction. Specifically, the process included the following steps: (1) Pre-processing of images, such as smoothing or contrast adjustment, to identify thoracic tissues; (2) Unifying the coordinate system using the "Landmark Registration" function; (3) Segmenting thoracic tissues from the background using "threshold segmentation" and "region growing" functions, including the esophagus, lungs, ribs, mediastinum, blood vessels, and nerves; (4) Applying "Calculate 3D" function

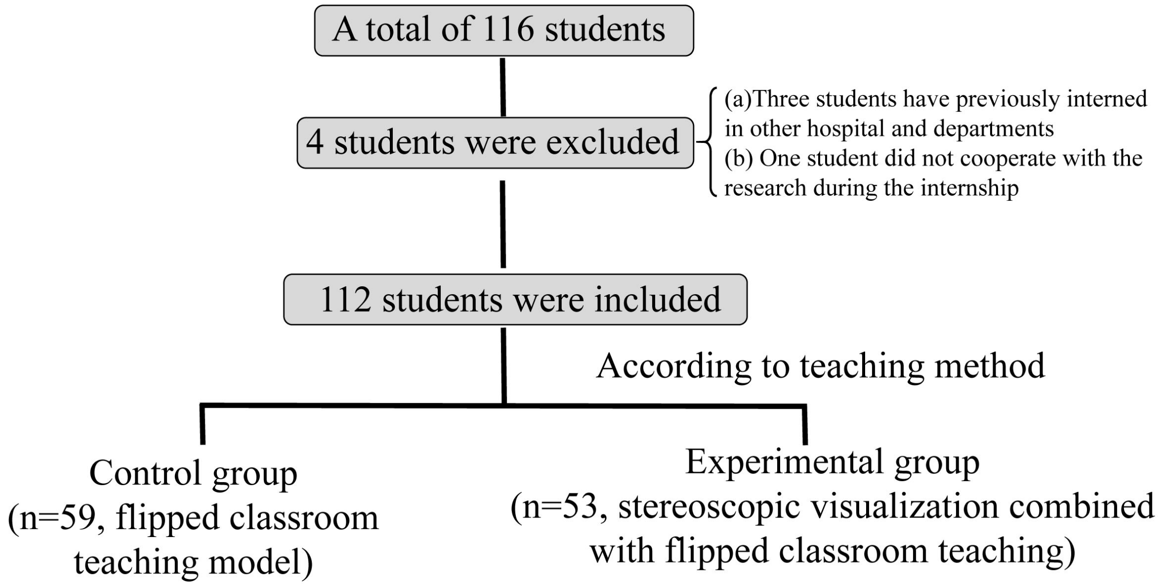

Fig. 1. Flowchart of student selection.

to convert 2D contours into 3D models based on segmentation results; and (5) Adjusting the 3D models to improve visualization quality through smoothing, filling, and adjusting transparency. Fig. 2 shows the 3D models used for teaching. All teachers and an imaging engineer jointly participated in the construction of the 3D models. All clinical imaging data were anonymized and met the ethical requirements approved by the ethics committee. The 3D models were used for clinical teaching in the experimental group. Teaching resources for the control group did not include 3D models.

Teaching Methods

The clinical cases used for teaching were identical in both groups. Students in the control group received clinical data, including general clinical information, 2D imaging data, and surgical videos. Students in the experimental group received the same clinical data, along with stereoscopic visualization data constructed from these clinical materials. Students in the experimental group accessed these resources using digital devices.

The control group adopted the flipped classroom method. Teachers sent the clinical information to students one week before the internships. Students reviewed the patient's clinical data in advance and searched for relevant information (including literature, textbooks, or online resources). Teachers provided academic support to address difficulties encountered during self-study through the internet and phone. In the classroom, teachers first presented the clinical information of patients and then guided students to summarize the primary symptoms. Students provided diagnostic rationale and preliminary treatment plans after discussing and analyzing the clinical data. Next, teachers addressed students' questions, corrected misunderstandings, and demonstrated standardized diagnostic procedures and treatment protocols. Before simulation training, surgical videos were sent to the students. During simulation training, students performed surgical operations using simulation equipment under the supervision and guidance of teachers. After the simulation training, the teacher summarized and analyzed the issues that had been encountered. Finally, teachers demonstrated the surgical procedures using simulation equipment, while students observed and evaluated the entire process.

The experimental group adopted stereoscopic visualization combined with the flipped classroom teaching model. The stereoscopic visualization models and clinical materials were sent to the students one week before the internships. Following the flipped classroom teaching approach, students studied relevant thoracic surgery knowledge before the classroom teaching sessions. At the same time, teachers provided guidance on how to use the 3D models. During the teaching session, students described pathological mechanisms and diagnostic bases, and proposed preliminary treatment plans in combination with the 3D models. Teachers encouraged students to actively utilize the 3D software for basic operations (such as scaling, rotating, moving, and adjusting transparency) and to conduct comprehensive analyses together with 2D images. Teachers corrected student errors, answered relevant questions and difficulties, and demonstrated standardized diagnostic and treatment procedures. Before simulation training, students familiarized themselves with surgical principles and operations by viewing surgical videos and stereoscopic visualization materials. During simulation training, students performed simulated surgical procedures under the supervision and guidance of their teachers. Finally, teachers analyzed and summarized the difficulties and mistakes in surgical operations

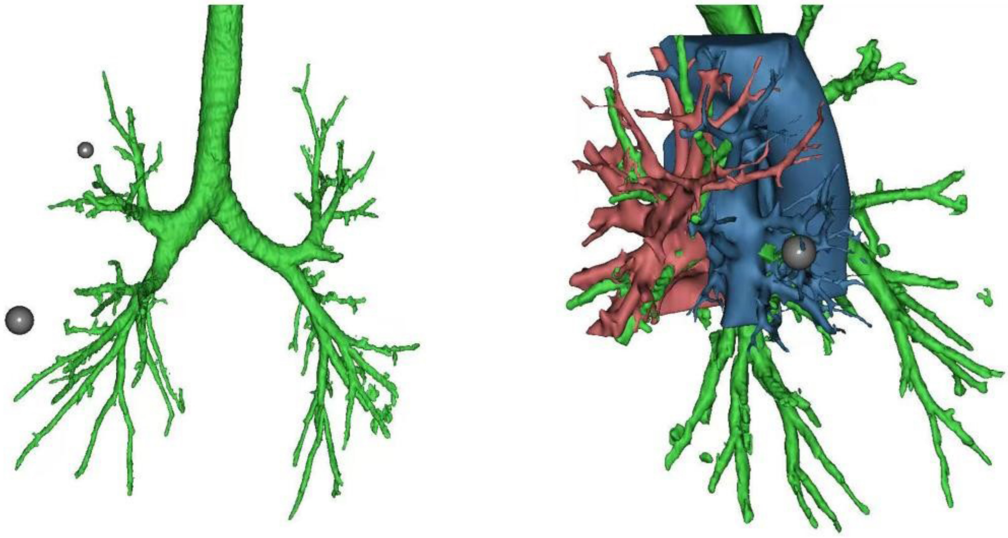

Fig. 2. Three-dimensional reconstruction images.

in conjunction with the 3D models and demonstrated standardized surgical techniques using simulation equipment. Throughout the teaching process, students performed only basic operations (such as scaling, rotating, moving, and adjusting transparency) on the 3D models. Complex models and professional procedures were completed by the teachers.

General Information Collection of Students

General information about the students was collected, including age, sex, and grades in their professional courses. The grades of professional courses closely related to clinical skills in thoracic surgery were obtained, including anatomy, surgery, pathology, diagnostic medicine, medical imaging, and clinical skills.

Teaching Achievement Evaluation

After completing the internships, all students participated in a unified assessment administered by the Department of Thoracic Disease Center, Zhejiang Rongjun Hospital. The assessment consisted of three parts: a theoretical test, a case analysis, and a clinical practice component, each with a total score of 50 points. A higher score indicates greater proficiency in skills or better mastery of knowledge. All assessments were graded by three thoracic surgeons (each with more than 3 years of work experience) who did not participate in teaching. All students were evaluated using the same scoring criteria. The examiners were blinded to the allocation of students to groups.

The theoretical test covered pathogenesis, clinical characteristics, disease diagnosis and treatment, and key technical points of surgical procedures. For the care analysis test, examiners selected one case from six patients, including rib fracture, traumatic pneumothorax, tuberculosis, lung cancer, mediastinal tumor, and esophageal cancer. These patients were not used in teaching. Based on the patient's clinical information and imaging data, students were required to describe the disease diagnosis, pathogenesis, feasible treatment plan, postoperative rehabilitation, and potential risks. The clinical practice test included three procedures: closed thoracic drainage, thoracentesis, and thoracoscopy. The thoracoscopic operation examination was performed using a simulation model. The clinical practice test assessed aseptic technique, operational standardization and accuracy, safety, and procedural proficiency. For both case analysis and clinical practice assessments, the mean score from three examiners was used as the final student score.

Teaching Satisfaction

Teaching satisfaction was evaluated through a questionnaire survey completed by students. The questionnaire included four areas: teaching content, teaching method, teaching effectiveness, and learning feeling [21,22]. Each field contained three questions, with each question scored from 0 to 3 points (0: Dissatisfied; 1: Average; 2: Satisfied; 3: Highly satisfied). The total possible score ranged from 0 to 36 points. Questions in the teaching content section evaluated satisfaction with the richness, clinical practicality, and rationality of the teaching content. In the teaching method section, questions evaluated satisfaction with the diversity, interactivity, and attractiveness of the teaching method. In the teaching effectiveness section, items assessed satisfaction with learning outcomes, whether the course significantly improved clinical skills, and whether it enhanced clinical thinking and diagnostic abilities. In the learning feeling section, questions evaluated whether the course increased interest in further learning thoracic surgery skills, willingness to recommend the course, and overall satisfaction with the learning experience.

Table 1. Baseline characteristics of students.

General information	Control group (n = 59)	Experimental group (n = 53)	$z/t/\chi^2$	p-value
Age (year)	21 (20, 22)	21 (20, 22)	0.286	0.775
Sex (n, %)			0.075	0.785
Male	33 (55.93%)	31 (58.49%)		
Female	26 (44.07%)	22 (41.51%)		
Professional course grades (points)				
Anatomy	80.39 ± 8.78	79.13 ± 9.26	0.739	0.462
Surgery	78.85 ± 8.87	79.11 ± 8.69	0.156	0.876
Pathology	82.73 ± 6.31	84.09 ± 4.64	1.287	0.201
Diagnostic medicine	80.42 ± 7.27	81.15 ± 8.07	0.504	0.616
Medical imaging	77.41 ± 8.08	76.36 ± 7.83	0.697	0.487
Clinical skills	80.85 ± 5.94	80.17 ± 7.45	0.537	0.593

Table 2. Comparison of test scores between the two groups.

Test scores (points)	Control group (n = 59)	Experimental group (n = 53)	t	p-value
Theoretical score (points)	38.49 ± 5.64	44.36 ± 3.47	6.544	<0.001
Case analysis score (points)	30.49 ± 7.80	42.06 ± 4.23	9.602	<0.001
Clinical practice score (points)	31.08 ± 7.74	42.43 ± 4.04	9.566	<0.001

Note: After Bonferroni correction, statistical significance was set at $p < 0.017$ for multiple comparisons.

Statistical Analysis

SPSS 27.0 (IBM, Armonk, NY, USA) was adopted for statistical analysis. The Shapiro-Wilk test was applied to assess the normality of measurement data. Normally distributed data were presented as mean ± standard deviation (SD), and an independent samples t-test was used for comparison. Non-normally distributed data were expressed as medians with interquartile ranges, and the Mann-Whitney U test was used for between-group comparisons. Categorical variables were expressed as numbers and frequencies, and the chi-square test was used for inter-group comparisons. A $p < 0.05$ was considered statistically significant. To reduce the risk of false positives (Type I errors), the Bonferroni correction (p-value = 0.05/n tests) was applied for multiple comparisons.

Results

General Information About Students

There were no significant differences between the control group and the experimental group in age or sex ($p > 0.05$). No significant differences were observed in professional course grades between the two groups ($p > 0.05$) (Table 1).

Comparison of Test Scores Between the Two Groups

The theoretical score, case analysis score, and clinical practice score of the experimental group were significantly higher than those of the control group ($p < 0.001$) (Table 2).

Comparison of Teaching Satisfaction Between the Two Groups

Satisfaction with teaching content in the experimental group was higher than in the control group, although the difference was not statistically significant ($p = 0.347$). Satisfaction with teaching methods, teaching effectiveness, learning feeling, and overall satisfaction in the experimental group were significantly higher than in the control group ($p < 0.001$) (Table 3).

Discussion

With the development of clinical medicine, the demand for professional clinicians continues to expand. Shortening the transition period from medical student to doctor and improving the quality of clinical medical teaching have received increasing attention. Traditional education, which centers on teachers imparting knowledge, offers the advantages of centralized instruction and a structured knowledge system. However, this approach is not conducive to cultivating students' clinical thinking and practical skills [23]. Clinical teaching in thoracic surgery encompasses a complex knowledge system and numerous practical operations [24]. It involves multiple organs, including the esophagus, lungs, mediastinum, and chest wall. It addresses diverse conditions such as trauma, tumors, and infections. Additionally, it intersects with disciplines such as anatomy, pathology, and radiology. Furthermore, thoracic surgery encompasses various surgical procedures, including thoracoscopic surgery, drainage, thoracentesis, and rib fixation. A single teaching model is insufficient to enable students to systematically master thoracic surgery knowledge during a short-term internship. Therefore, innovating the clinical teaching model in thoracic surgery is essential.

In this study, a combination of stereoscopic visualization and a flipped classroom teaching model was applied during the thoracic surgery internship for undergraduate clinical medicine students. Before the internship, no significant dif-

Table 3. Comparison of teaching satisfaction between the two groups.

Teaching satisfaction	Control group (n = 59)	Experimental group (n = 53)	t	p-value
Teaching content (point)	7.59 ± 0.83	7.76 ± 1.07	0.945	0.347
Teaching method (point)	6.93 ± 1.17	8.11 ± 0.58	6.643	<0.001
Teaching effectiveness (point)	7.02 ± 1.14	8.08 ± 0.47	6.303	<0.001
Learning feeling (point)	7.05 ± 0.99	8.06 ± 0.46	6.795	<0.001
Total score (point)	28.59 ± 2.07	32.00 ± 1.40	10.095	<0.001

Note: After Bonferroni correction, statistical significance was set at $p < 0.01$ for multiple comparisons.

ferences were observed in age, sex, or professional course grades between the two groups, indicating their comparability. Compared with the control group, students in the experimental group demonstrated higher theoretical scores, case analysis scores, and clinical practice performance. This finding suggests that combining stereoscopic visualization with a flipped classroom teaching model enhances students' clinical competencies during the thoracic surgery internship. Furthermore, students expressed high satisfaction with the integrated teaching approach. This study was the first to investigate the effects of stereoscopic visualization combined with a flipped classroom teaching model in clinical thoracic surgery education.

Previous studies have also reported the benefits of the flipped classroom in thoracic surgery. Liang *et al*. [25] reported that a flipped classroom combined with scientific research expansion stimulated enthusiasm for learning thoracic surgery and improved clinical thinking. However, flipped classrooms also have certain limitations. For students with insufficient professional knowledge reserves, weak self-learning ability, or limited learning interest and motivation, the flipped classroom exerts only a limited impact on their professional knowledge and skills [8]. Thoracic surgery, in particular, involves complex anatomical structures and variations. Some students have struggled to construct a complete 3D mental image of the chest, leading to difficulties in interpreting imaging data, diagnosing lesion areas, and understanding surgical principles. Therefore, we introduced stereoscopic visualization into the flipped classroom in the hope of improving students' professional skills during thoracic surgery internships.

3D reconstruction technology can accurately determine the lung segment in which pulmonary nodules are located and can establish volumetric models of mediastinal tumors, esophageal cancer, and ribs. It can also identify the status and variation of the target segment bronchi and lesion-associated vessels [26–28]. This technology has significant application value in formulating surgical plans and guiding lesion identification during surgery [28,29]. Mimics software is a commonly used tool for building 3D models. It has powerful functions, including measurement, analysis, segmentation, fusion, and simulation [30]. Mimics software has also been applied in clinical teaching [19]. Through rotation, scaling, filtering, and transparency adjustments, students can observe tissue morphology, anatomical structures, and the distribution of blood vessels, nerves, and lesion areas from multiple dimensions. By integrating 3D models with imaging data, such as CT or MRI, students can gain a more intuitive understanding of the pathological information contained in 2D images, thereby improving their imaging analysis abilities. Additionally, students can simulate surgical procedures to determine surgical approaches and steps, and observe pathological changes before and after surgery, which increases their clinical skills and interest [20].

In this study, Mimics software was applied to construct 3D reconstruction models of patients. The test scores and teaching satisfaction of the experimental group were higher than those of the control group. In the experimental group, students were able to understand complex anatomical structures, pathological mechanisms, and surgical treatments more easily through visualized 3D materials. Meanwhile, the 3D models enhanced students' comprehension of 2D images, thereby improving learning efficiency. These advantages of 3D models were reflected in the improvement in theoretical scores, case analysis scores, and clinical practice scores observed in the experimental group. Additionally, the 3D model-based teaching method improved learning efficacy and reduced the difficulty of understanding chest anatomy and 2D image interpretation. These effects further enhanced students' enthusiasm and initiative during clinical internships and strengthened their interest in thoracic surgery. This was reflected in the high satisfaction reported by the experimental group in teaching methods, teaching effectiveness, and learning experience. A previous study has reported similar findings in the clinical teaching of pelvic tumors [20]. 3D reconstruction technology significantly enhanced theoretical knowledge of pelvic anatomy, imaging analysis ability, learning efficiency, and learning interest [20].

In this study, we observed that there were no significant differences in teaching content satisfaction between the two groups. A possible reason is that according to the teaching guidelines, the teaching content for both groups was identical. The differences between the two groups were limited to the teaching format. This resulted in no significant difference in teaching content satisfaction between the two groups. This may be related to the scope of assessment for the teaching content dimension in the satisfaction scale. The teaching content satisfaction focuses on the adequacy, clinical practicality and rationality, but does not assess students' understanding depth and mastery of knowledge. This resulted in no significant difference in satisfaction with the teaching content between the two groups. Future research can further optimize evaluation tools and increase satisfaction assessments of knowledge understanding and mastery.

This study has several limitations. First, it was a retrospective study with a relatively small sample size. This may have led to biased conclusions due to insufficient control of potential confounding factors, such as differences in students' interests in thoracic surgery. Prospective studies with larger sample sizes and better control of confounders should be conducted in the future. Moreover, our study was conducted in a single center. Subsequent research in multiple centers is needed to improve the generalizability of the findings.

Additionally, the duration of this study was relatively short, and we did not assess the long-term effects of the teaching model on students. Longitudinal studies with extended follow-up are necessary to evaluate the sustained impact of the teaching model on students' knowledge acquisition and motivation in thoracic surgery. Another concern to acknowledge is that the teaching satisfaction survey used in our study has not been validated for its efficacy and reliability. This is due to the absence of a universally accepted standard clinical teaching satisfaction instrument in China. Our teaching satisfaction survey was developed with reference to previous studies. The Clinical Learning Evaluation Questionnaire (CLEQ) was developed to assess teaching satisfaction [31]. However, due to language and cultural barriers, the application of the CLEQ in China has been limited, and only recently has its cross-cultural applicability been reported [32]. Future studies could evaluate teaching satisfaction for the combined teaching model using a validated clinical teaching satisfaction scale.

Finally, we explored only the teaching effects of stereoscopic visualization in thoracic surgery. The effectiveness of this teaching model in other disciplines requires further investigation.

Conclusions

Overall, this study utilized 3D reconstruction technology to construct stereoscopic models of the anatomical structure of the chest. These models enable intuitive observation of tissue morphology, pathological changes, and surgical processes in thoracic surgery teaching. The stereoscopic visualization based on 3D reconstruction combined with a flipped classroom teaching model demonstrates potential to improve the theoretical knowledge, case analysis ability, and clinical practical skills of undergraduate clinical medicine students during their thoracic surgery internships. Compared with the flipped classroom alone, the combined teaching model achieves higher teaching satisfaction. This study may provide a basis for the application of 3D reconstruction technology in clinical teaching of thoracic surgery and offer a reference for the innovation of clinical teaching models.

Availability of Data and Materials

The data used and analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions

ZZ, GL and YY designed the research study and wrote the first draft. YY, XL, YZ, and HC performed the research. LH, YG, PC, and YM analyzed the data. All authors contributed to the critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study was approved by the Zhejiang Rongjun Hospital ethics committee (Approval Number: 2025-092) and complied with the principles outlined in the Declaration of Helsinki. All participants were informed and provided consent to participate in the study.

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Conflict of Interest

The authors declare no conflict of interest.

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