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Application of Flipped Classroom Combined with Case-Based Learning in Cardiac Ultrasound Teaching for Standardized Residency Training

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Abstract: *The flipped classroom and case-based learning (CBL) are both novel teaching models that have garnered considerable attention in medical education. However, the effectiveness of their combined application in cardiac ultrasound teaching for standardized residency training remains to be further validated in cardiac ultrasound training. This study enrolled 60 residents who participated in cardiac ultrasound standardized training at Jiangsu Provincial Hospital (the First Affiliated Hospital of Nanjing Medical University) from January to December 2025. Participants were randomly assigned to a control group (n=30, receiving traditional lecture-based instruction) and an observation group (n=30, receiving flipped classroom combined with CBL). Both groups underwent a 4-week training period with the same group of instructors. At the conclusion of the training, learning outcomes were assessed across four dimensions: theoretical written examination, practical operation, multimedia image interpretation, and OSCE-based humanistic literacy assessment. Additionally, a Likert 5-point scale was employed to survey residents' self-reported teaching satisfaction. The results demonstrated that the observation group significantly outperformed the control group in all four assessment domains (all P<0.05), and also exhibited significantly higher scores across all six dimensions of teaching satisfaction, including learning interest, communication ability, self-learning capability, operational skills, clinical thinking, and overall satisfaction (all P<0.05). These findings indicate that the flipped classroom combined with CBL teaching model effectively enhances residents' mastery of cardiac ultrasound theoretical knowledge, operational proficiency, and clinical image interpretation skills, while simultaneously improving their learning initiative and comprehensive clinical thinking abilities. This model demonstrates favorable feasibility and promotional value in cardiac ultrasound standardized training, providing a reference for reforms in ultrasound medical education.*

Keywords: *Flipped classroom; Case-based learning; Standardized residency training; Cardiac ultrasound*

1. Introduction

Standardized residency training constitutes a critical transitional phase during which medical graduates develop into competent clinical physicians. The quality of this training directly influences the professional competence and practical capabilities of practicing physicians. As an indispensable non-invasive imaging modality in the diagnosis and management of cardiovascular diseases, cardiac ultrasound enables real-time assessment of cardiac structure and function, playing an increasingly vital role in bedside evaluation of critically ill patients, hemodynamic monitoring, and precision therapeutic decision-making [1]. Nevertheless, current cardiac ultrasound standardized residency training in China remains predominantly reliant on traditional lecture-based instruction, characterized by relatively monolithic teaching approaches, insufficient hands-on operating time for residents, and considerable challenges in translating theoretical knowledge into clinical practical competence [2]. How to efficiently enhance residents' theoretical understanding, operational skills, and clinical image interpretation capabilities within a limited training period has emerged as a critical issue in ultrasound medical education reform.

The flipped classroom, as a learner-centered active learning pedagogical model, transfers the knowledge transmission phase to the pre-class period (through micro-lecture videos and self-study materials), thereby reserving classroom time for discussion, interaction, and hands-on practice, which effectively stimulates learners' initiative [3]. In recent years, the flipped classroom has demonstrated favorable educational outcomes across multiple domains of medical education. In emergency medicine

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residency training, the flipped classroom model has shown potential in improving residents' knowledge acquisition [4]. Within ultrasound medical residency training, the combination of random flipped classroom and simulation-based skills training has been confirmed to effectively enhance residents' theoretical and operational assessment scores [2]. Case-based learning, by recreating authentic clinical scenarios and guiding residents to engage in problem analysis and clinical decision-making around specific cases, facilitates the development of clinical reasoning and comprehensive knowledge application skills [5]. Systematic reviews have indicated that CBL is more effective than traditional lecture-based instruction in improving academic performance and case analysis capabilities among medical and pharmacy students [6]. In cardiology residency training, case-based pedagogical approaches have also been validated to effectively enhance teaching outcomes [7].

Given the complementary advantages of the flipped classroom and CBL in promoting active learning and cultivating clinical reasoning, researchers have recently attempted to integrate these two approaches in medical education. McDaniel et al., in a study of flipped classroom combined with CBL in neurosurgery residency, found that this innovative educational model improved residents' perceptions of the learning environment and enhanced educational outcomes [8]. In anesthesiology residency training, the flipped classroom model has similarly been confirmed to improve learning outcomes and engagement [9]. Research on flipped teaching for internal medicine residents has demonstrated that video conference-based flipped instruction is generally effective in infectious disease training and can serve as a valuable supplement to traditional teaching methods [10]. Additionally, Sierra-Fernández et al. confirmed in a cardiology residency program that the flipped learning model achieved high levels of acceptance among both residents and faculty, while significantly improving academic performance [11]. He et al. implemented case-based collaborative learning through webinars in internal medicine residency training, demonstrating favorable effectiveness in cardiovascular topic knowledge transmission [12]. However, research on the application of flipped classroom combined with CBL in cardiac ultrasound standardized residency training remains relatively limited both domestically and internationally, with insufficient empirical evidence regarding its educational effectiveness. Against this background, the present study aims to introduce the flipped classroom combined with CBL teaching model into cardiac ultrasound standardized residency training, systematically evaluate its effectiveness in improving residents' assessment scores and teaching satisfaction compared with traditional teaching methods, and provide a reference for ultrasound medical education reform.

2. Materials and Methods

2.1. Study Subjects

A total of 60 residents participating in cardiac ultrasound standardized residency training at Jiangsu Provincial Hospital (the First Affiliated Hospital of Nanjing Medical University) from January to December 2025 were enrolled as study participants. Using a random number table method, participants were assigned to a control group and an observation group, with 30 residents in each group. The control group received traditional teaching methods, while the observation group received flipped classroom combined with CBL instruction. Inclusion criteria were: (1) possession of a valid Practicing Physician Qualification Certificate; (2) first-time participation in cardiac ultrasound standardized training; and (3) voluntary consent to participate in this study. Exclusion criteria were: (1) prior systematic training experience in cardiac ultrasound; (2) interruption of training or leave exceeding 3 days during the training period; and (3) refusal to comply with teaching arrangements or assessment procedures. All residents underwent a pre-training comprehensive ultrasound knowledge assessment (100-point scale, covering foundational cardiac ultrasound theory) to evaluate baseline levels and ensure comparability between the two groups.

2.2. Teaching Methods

The control group received traditional lecture-based instruction. Instructors delivered centralized classroom lectures using multimedia presentations, systematically covering foundational cardiac ultrasound theory, standardized scanning techniques, ultrasonographic manifestations of common diseases, and diagnostic key points. Following lectures, instructors performed procedural demonstrations, and residents engaged in ultrasound equipment operation practice and typical case image interpretation under instructor guidance. Throughout the training period, instruction was predominantly instructor-led, with residents primarily learning through listening, observation, and imitative practice.

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The observation group received flipped classroom combined with CBL instruction, implemented as follows: (1) Pre-class preparation phase: One week prior to training, instructors released micro-lecture videos on foundational cardiac ultrasound knowledge (each lasting 15–20 minutes, covering cardiac anatomy, ultrasound physics fundamentals, and standardized view identification), typical case materials, and pre-class self-study task sheets through the departmental teaching platform (WeChat group or online learning system). Residents were required to complete video viewing and relevant textbook chapter reading before class, and conduct preliminary case discussions in small groups (5-6 members per group), documenting challenging questions encountered. (2) In-class implementation phase (core component, accounting for three-quarters of each session): Classroom sessions centered on case discussions. Instructors selected typical cases encompassing common cardiac ultrasound pathologies including valvular heart disease, cardiomyopathy, congenital heart disease, and pericardial disease (with case themes rotating every 1–2 weeks). The specific procedure was: ① Residents presented pre-class self-study outcomes and case analysis approaches in small groups (10 minutes); ② Cross-group questioning and discussion among groups (15 minutes); ③ Instructors served as facilitators, posing follow-up questions, correcting misconceptions, and providing in-depth explanations regarding controversial points and knowledge gaps identified during discussions, with emphasis on elucidating the intrinsic relationship between ultrasonographic findings and pathophysiological mechanisms, and demonstrating standardized image interpretation logic (20 minutes); ④ Residents took turns performing hands-on operations, with instructors providing on-site guidance on standard view acquisition and common artifact recognition (15 minutes). The classroom fully embodied the teaching philosophy of "learner-centered, case-driven, and problem-oriented." (3) Post-class consolidation phase: Instructors assigned extended case analysis homework, requiring residents to independently complete ultrasound report writing and differential diagnosis formulation, with submissions due before the next class. Instructors reviewed assignments and provided collective feedback, addressing common issues in subsequent classroom sessions.

Both groups underwent a 4-week training period totaling 32 credit hours, with instruction delivered by the same group of faculty members holding attending physician or higher professional titles with over 5 years of cardiac ultrasound teaching experience, using unified textbooks and teaching syllabi.

2.3. Teaching Effectiveness Evaluation

2.3.1. Assessment Score Evaluation

At the conclusion of training, both groups underwent unified assessments to evaluate teaching effectiveness. The assessment comprised four dimensions, each with a maximum score of 50 points, as detailed below. (1) Theoretical assessment: A closed-book written examination consisting of 20 single-choice questions (1 point each), 10 multiple-choice questions (2 points each), and 1 case analysis question (10 points), totaling 50 points. Content covered cardiac anatomy and physiological foundations, ultrasound physics principles, standardized view identification, ultrasonographic diagnostic criteria and differential diagnostic key points for common cardiac diseases (valvular heart disease, cardiomyopathy, congenital heart disease, pericardial disease, etc.), with emphasis on assessing residents' mastery of foundational cardiac ultrasound theoretical knowledge. (2) Operational assessment: A hands-on practical examination in which each resident completed cardiac ultrasound standard view scanning within a specified time frame (15 minutes), including parasternal long-axis view, parasternal short-axis view at the aortic valve level, apical four-chamber view, apical two-chamber view, and subcostal four-chamber view. Scoring criteria included: probe handling standardization (10 points), standard view acquisition success rate (15 points), equipment adjustment and image optimization capability (10 points), examination procedural rationality (10 points), and operational proficiency (5 points), totaling 50 points. (3) Image interpretation assessment: A multimedia-based image interpretation examination in which residents randomly drew 5 cardiac ultrasound case images (10 points per case, totaling 50 points) and were required to complete the following tasks within a specified time (20 minutes): ① Describe the primary abnormal findings observed in the ultrasound images (4 points per case); ② Formulate a preliminary diagnosis with supporting diagnostic evidence (3 points per case); ③ List differential diagnoses requiring consideration and briefly describe the distinguishing features (3 points per case). This assessment focused on evaluating residents' image recognition capability, diagnostic reasoning skills, and comprehensive knowledge application abilities. (4) Humanistic literacy assessment: An OSCE-based physician-patient communication station employing standardized patient scenarios, with each resident completing an 8-minute simulated consultation. Scoring criteria included: physician-patient communication skills and empathy (15 points), medical documentation standardization (10 points),

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medical ethical awareness (10 points), teamwork awareness (5 points), and professional attitude (10 points), totaling 50 points.

All assessments were independently scored by two ultrasound medicine teaching faculty members holding associate chief physician or higher professional titles, with the average score serving as the final grade. In cases where the score discrepancy between the two evaluators exceeded 5 points, a third faculty member with a higher professional title performed adjudication. The assessment process employed a double-blind method, meaning that evaluating faculty were unaware of the participants' group assignments, ensuring objectivity and impartiality of the evaluation results.

2.3.2. Teaching Satisfaction Evaluation

Following training, a self-designed teaching satisfaction questionnaire was administered anonymously to both groups. The questionnaire encompassed six dimensions: learning interest, communication ability, self-learning capability, operational skills, clinical thinking, and overall teaching satisfaction. Each dimension employed a Likert 5-point scale, with 1 representing very dissatisfied/very inconsistent, 2 dissatisfied/inconsistent, 3 neutral, 4 satisfied/consistent, and 5 very satisfied/very consistent. All questionnaires were distributed and collected on-site, achieving a 100% effective response rate.

2.4. Statistical Methods

Data analysis was performed using SPSS 22.0 software. Normally distributed continuous data were expressed as mean ± standard deviation, and group comparisons were made using independent samples t-tests. Categorical data were expressed as frequencies, and group comparisons were made using the chi-square test. A P-value <0.05 was considered statistically significant.

3. Results

3.1. Comparison of General Characteristics Between Groups

There were no statistically significant differences between the two groups in terms of gender, age, educational background, or pre-training comprehensive ultrasound knowledge assessment scores (P>0.05), indicating comparability, as shown in Table 1.

Table 1: Comparison of General Characteristics Between Groups

Parameter	Control Group (n=30)	Observation Group (n=30)	t/χ^2	P
Gender (n)			0.606	0.436
Male	12	15		
Female	18	15		
Age (years)	26.02±2.39	25.89±2.41	0.210	0.835
Education (n)			0.305	0.859
Bachelor's	12	14		
Master's	13	12		
Doctoral	5	4		
Pre-training ultrasound knowledge score	81.54±4.39	81.16±4.28	0.339	0.735

3.2. Comparison of Assessment Scores Between Groups

Following training, the observation group demonstrated significantly higher scores than the control group in humanistic literacy, theoretical knowledge, operational skills, and image interpretation assessments, with statistically significant differences (P<0.05), as shown in Table 2.

Table 2: Comparison of Assessment Scores Between Groups (points)

Dimension	Control Group (n=30)	Observation Group (n=30)	t	P
Humanistic Literacy	43.26±2.48	41.45±2.32	2.919	0.005
Theoretical Knowledge	42.89±1.92	41.63±2.01	2.483	0.016
Operational Skills	44.18±2.13	42.76±2.42	2.413	0.019
Image Interpretation	43.15±2.05	41.57±2.21	2.871	0.006

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3.3. Comparison of Teaching Satisfaction Evaluation Results Between Groups

Following training, the observation group exhibited significantly higher scores than the control group in learning interest, communication ability, self-learning capability, operational skills, clinical thinking, and overall teaching satisfaction, with statistically significant differences ($P<0.05$), as shown in Table 3.

Table 3: Comparison of Teaching Satisfaction Evaluation Results Between Groups (points)

Dimension	Control Group (n=30)	Observation Group (n=30)	t	P
Learning Interest	2.81±0.89	4.38±0.61	7.970	<0.001
Communication Ability	3.06±0.81	3.95±0.69	4.581	<0.001
Self-learning Capability	3.45±0.85	4.22±0.73	3.764	<0.001
Operational Skills	3.64±0.55	4.58±0.49	6.990	<0.001
Clinical Thinking	3.21±0.76	3.95±0.91	3.419	0.001
Teaching Satisfaction	3.52±0.84	4.31±0.67	4.027	<0.001

4. Discussion

This study introduced the flipped classroom combined with CBL teaching model into cardiac ultrasound standardized residency training. The results demonstrated that the observation group significantly outperformed the control group across all four assessment dimensions, including theoretical knowledge, operational skills, image interpretation, and humanistic literacy, and similarly exhibited superior performance in all six dimensions of teaching satisfaction evaluation. These findings suggest that this combined teaching model confers significant advantages in enhancing residents' comprehensive competencies, which is generally consistent with the findings of recent related studies [13,14].

In the present study, the observation group achieved significantly higher theoretical assessment scores compared with the control group. This finding aligns with the systematic review and meta-analysis conducted by Shi et al., which incorporated multiple randomized controlled trials and found that the flipped classroom combined with CBL teaching approach yielded significantly superior outcomes in both theoretical scores and clinical analytical capability compared with traditional lecture-based instruction [15]. Furthermore, research on flipped classroom implementation in internal medicine residency demonstrated that the flipped group achieved significantly higher scores on the Internal Medicine In-Training Examination and demonstrated superior first-time pass rates on the American Board of Internal Medicine certification examination compared with the traditional teaching group [16]. With respect to operational skills and image interpretation capability, the observation group similarly exhibited notable advantages. Wang et al., in ultrasound medical residency training, combined random flipped classroom with simulation-based skills training, confirming the model's effectiveness in enhancing residents' theoretical and operational assessment performance [17]. Liu et al. integrated paper-based pulmonary function test case group discussions into flipped classroom instruction, finding that the intervention group demonstrated significantly superior comprehensive assessment scores and professional self-efficacy compared with the control group [18]. Wang et al. applied flipped classroom combined with Peyton's four-step approach to thyroid and cervical lymph node zoning training for ultrasound residents, similarly confirming the model's capacity to significantly improve residents' procedural skills and clinical case analysis performance [19]. The cumulative evidence suggests that the flipped classroom, by front-loading knowledge transmission, liberates valuable classroom time for hands-on practice and in-depth discussion, while CBL facilitates the translation of theoretical knowledge into clinical competence through authentic case scenarios. Together, these approaches generate a synergistic effect in cardiac ultrasound training [20,21].

Regarding satisfaction evaluation, the observation group exhibited significantly higher scores in learning interest, self-learning capability, clinical thinking, and other dimensions compared with the control group. This finding is consistent with the results reported by Hu et al. in nephrology bedside teaching, which demonstrated that the CBL combined with flipped classroom group yielded more positive self-evaluations in clinical reasoning ability, history-taking, physical examination, and medical documentation [22]. Wei et al. applied the BOPPPS model combined with flipped classroom to obstetrics and gynecology residency training, confirming the model's effectiveness in improving residents' assessment scores, clinical thinking, and self-learning capability [13]. Yueyang et al. validated the effectiveness of flipped classroom combined with the One-Minute Preceptor model in general practice

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residency training, showing that the experimental group significantly outperformed the control group in theoretical assessment, initial course note writing, comprehensive medical record documentation, and clinical reasoning [23]. The mechanisms by which flipped classroom combined with CBL enhances learners' self-learning capability and learning interest may include the following: first, pre-class micro-lecture videos and self-study tasks require residents to actively acquire knowledge, cultivating independent learning habits; second, with case discussions and group interactions at the core of classroom sessions, residents transition from passive recipients to active participants, with substantially increased classroom engagement; third, CBL, by recreating authentic clinical decision-making scenarios, establishes meaningful connections between learning content and future professional practice, thereby enhancing intrinsic motivation for learning [24].

This study has several limitations. First, the relatively small sample size may affect statistical power and the generalizability of conclusions. Second, the single-center design means that teaching effectiveness may be influenced by specific teaching teams, educational resources, and participant characteristics, limiting external validity. Third, this study only assessed short-term teaching effectiveness at the conclusion of training, without follow-up tracking of residents' long-term knowledge retention and clinical practice competency. Additionally, the teaching satisfaction evaluation employed a self-designed questionnaire that has not undergone large-scale, multi-center external validation. Future research should consider expanding sample sizes, conducting multi-center randomized controlled trials, and incorporating longitudinal follow-up to evaluate the sustainability of educational outcomes.

5. Conclusion

In summary, the application of the flipped classroom combined with CBL teaching model in cardiac ultrasound standardized residency training demonstrates superiority over traditional lecture-based instruction in improving residents' theoretical knowledge, operational skills, image interpretation capability, and humanistic literacy, while simultaneously significantly enhancing learning interest, self-learning capability, and clinical thinking skills. Through the integrated orchestration of pre-class knowledge acquisition, in-class case discussions and hands-on practice, and post-class consolidation and extension, this model effectively facilitates the translation of theoretical knowledge into clinical practical competence, addresses the limitations of traditional teaching characterized by passive learning and insufficient hands-on opportunities, and demonstrates favorable feasibility and promotional value in residency training. Although this study has limitations including a modest sample size, single-center design, and lack of longitudinal follow-up, the findings provide preliminary empirical evidence for the application of flipped classroom combined with CBL in ultrasound medical education. Future research should further pursue multi-center, large-sample randomized controlled studies to validate the generalizability and long-term effectiveness of this model, thereby advancing continuous quality improvement in cardiac ultrasound education.

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