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A Practical Study on Enhancing Cardiac Ultrasound Diagnostic Ability of Residents in Standardized Residency Training Based on the BOPPPS Teaching Model

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Abstract: *This study aimed to evaluate the application effect of the BOPPPS (Bridge-in, Objective, Pre-assessment, Participatory Learning, Post-assessment, Summary) teaching model in cardiac ultrasound education during standardized residency training. A total of 60 residents rotating through the Department of Ultrasound Medicine and Department of Cardiovascular Medicine at Jiangsu Provincial People's Hospital from March 2024 to September 2024 were enrolled and randomly assigned to a traditional teaching group (n=30) and a BOPPPS teaching group (n=30). The traditional group received lecture-based combined with apprenticeship teaching, while the BOPPPS group underwent systematic instructional design incorporating the six core components. After the teaching sessions, comprehensive evaluations were conducted through theoretical examinations, technical operation assessments, cardiac ultrasound image interpretation and diagnostic accuracy tests, and teaching effectiveness questionnaires. Results showed that the BOPPPS group scored significantly higher than the traditional group in both theoretical examinations and technical operations ($P<0.05$). In terms of core diagnostic competence, the BOPPPS group significantly outperformed the traditional group in standard view identification, pathological ultrasound feature interpretation, diagnostic report completeness, and overall diagnostic ability scores (all $P<0.001$). Furthermore, the BOPPPS group exhibited significantly higher scores across all dimensions of the teaching effectiveness questionnaire (all $P<0.001$). The findings indicate that the BOPPPS teaching model effectively improves residents' cardiac ultrasound diagnostic ability, with particularly notable advantages in image interpretation and diagnostic accuracy, while also enhancing learning interest and teaching participation, making it worthy of broader application in ultrasound medical education.*

Keywords: *BOPPPS teaching model; Standardized residency training; Cardiac ultrasound; Diagnostic ability; Medical education*

1. Introduction

Cardiac ultrasound, as a core non-invasive diagnostic technique for cardiovascular diseases, holds an irreplaceable role in clinical decision-making [1]. With the continuous increase in the global burden of cardiovascular diseases, the cardiac ultrasound diagnostic competence of clinicians has become a critical factor affecting patient prognosis [2]. Standardized residency training, as a key component of postgraduate medical education, shoulders the mission of cultivating physicians with independent clinical working capabilities. However, systematic teaching of point-of-care ultrasound (POCUS) in current internal medicine residency programs remains significantly inadequate [3]. Surveys indicate that cardiac ultrasound teaching in most training bases is predominantly conducted in a fragmented, non-structured manner, with residents having limited hands-on opportunities and insufficient systematic feedback [4]. Most residents have not received standardized ultrasound operation or image interpretation instruction before entering clinical rotations, and the teaching time during rotations is also very limited [5]. Traditional teaching models, which are teacher-centered and focus on one-way knowledge transmission, fail to adequately consider individual learner differences, are less effective in stimulating residents' learning initiative, and, combined with the lack of real-time feedback mechanisms, are detrimental to the cultivation of clinical reasoning and independent diagnostic skills [6].

The BOPPPS (Bridge-in, Objective, Pre-assessment, Participatory Learning, Post-assessment,

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Summary) teaching model originated from the Instructional Skills Workshop in Canada and is a student-centered, closed-loop instructional model emphasizing participatory learning and immediate feedback. This model systematically divides the teaching process into six core components: Bridge-in, Objective, Pre-assessment, Participatory Learning, Post-assessment, and Summary [7]. Its core concept is to understand learners' knowledge baseline through pre-assessment, promote deep cognitive processing through participatory learning, and form a teaching closed loop through post-assessment and summary, thereby achieving precise attainment of teaching objectives.

In recent years, the BOPPPS teaching model has gained increasing attention and application in medical education both domestically and internationally. A systematic review and meta-analysis by Zhu et al., including 16 studies with a total of 2,320 learners, demonstrated that the BOPPPS model significantly improved learners' final examination scores (SMD=1.14, 95%CI 0.84-1.43, P<0.001), and also showed significant advantages in student satisfaction (SMD=0.94, 95%CI 0.63-1.26), classroom interaction (SMD=0.83), and learning initiative (SMD=0.73) [7]. Another meta-analysis by Li et al., including 13 RCTs with a total of 2,991 nursing students, confirmed that the BOPPPS model significantly improved theoretical scores (MD=3.35), practical scores (MD=4.50), and self-directed learning ability (MD=6.76) [8]. In otolaryngology education, the BOPPPS model significantly improved students' final examination scores (87.7±6.7 vs. 84.0±7.7, P<0.01) as well as problem-solving and teamwork abilities [9]. In intensive care clinical training, BOPPPS combined with situational teaching was proven to effectively enhance residents' comprehensive clinical abilities and training quality [10]. In nephrology residency training, the BOPPPS model also significantly improved residents' theoretical and practical scores as well as teaching satisfaction [11]. In nursing standardized training, the BOPPPS model similarly showed superior effects compared to traditional teaching [12]. Moreover, the combination of BOPPPS and case-based learning (CBL) was confirmed to effectively improve students' clinical critical thinking ability in oral and maxillofacial surgery teaching [13].

However, high-quality randomized controlled studies systematically applying the BOPPPS teaching model to cardiac ultrasound teaching in standardized residency training are still relatively limited. Cardiac ultrasound teaching, characterized by strong theoretical foundations, high operational dependence, and considerable subjectivity in image interpretation, places higher demands on the systematic and interactive nature of teaching models [14]. The pre-assessment, participatory learning, and immediate feedback emphasized by the BOPPPS model are highly compatible with the intrinsic needs of cardiac ultrasound diagnostic competence development. Therefore, this study intends to introduce the BOPPPS teaching model into cardiac ultrasound residency teaching and, through a randomized controlled trial design, systematically evaluate its effect on improving residents' cardiac ultrasound diagnostic ability, so as to provide evidence-based references for ultrasound medical education reform.

2. Materials and Methods

2.1. Study Subjects

A total of 60 residents rotating through the Department of Ultrasound Medicine and Department of Cardiovascular Medicine at Jiangsu Provincial People's Hospital (the First Affiliated Hospital of Nanjing Medical University) from January 2023 to January 2026 were enrolled as study subjects. All residents had completed basic medical education and entered the residency training base, with no prior specialized experience in cardiac ultrasound operation or independent diagnosis. They were randomly divided into a traditional teaching group and a BOPPPS group using a random number table, with 30 residents in each group. Inclusion criteria: (1) residents entering cardiac ultrasound rotation for the first time; (2) voluntary participation with good compliance. Exclusion criteria: (1) prior experience in cardiac ultrasound operation or diagnosis; (2) absence exceeding 10% of total teaching hours due to personal reasons during the rotation; (3) refusal to cooperate with teaching or assessment.

2.2. Teaching Models

The control group received traditional lecture-based combined with apprenticeship teaching, as follows: (1) Theoretical lectures (4 credit hours): Teachers used multimedia PPT to deliver concentrated lectures on basic cardiac ultrasound theory, including cardiac anatomy and standard views (parasternal long-axis view, parasternal short-axis view, apical four-chamber view, subcostal view, etc.), M-mode and two-dimensional ultrasound measurement methods, and ultrasound findings and diagnostic points

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of common cardiac diseases (mitral stenosis, mitral regurgitation, aortic valve diseases, ventricular septal defect, ejection fraction assessment, etc.). The lectures were mainly teacher-directed one-way instruction, with students allowed to ask questions at any time but without dedicated interactive discussion sessions. (2) Demonstration and self-practice (4 credit hours): Teachers first demonstrated standard view scanning and measurements on real patients or ultrasound simulators; then residents, in groups of 2-3, practiced on real patients under the teacher's circulating guidance. During practice, students could consult teachers when encountering problems, but teachers did not actively set up case discussions or systematic problem-guided sessions; students mainly relied on personal observation and repeated practice to comprehend diagnostic points.

The experimental group received BOPPPS teaching, with the 8 credit hours systematically designed according to the six core components, as follows: (1) Bridge-in (0.5 credit hour): Teachers introduced the topic with a real clinical case, e.g., a outpatient case of "chest tightness and shortness of breath after activity for 3 years, aggravated for 1 week," providing physical examination (diastolic rumbling murmur on cardiac auscultation) and transthoracic echocardiography report (mitral valve area 1.2 cm^2). By asking "What is the most likely ultrasound diagnosis for this patient? Which views help clarify the diagnosis?" teachers stimulated residents' learning interest and inquiry motivation, naturally transitioning to the teaching objectives. (2) Objective (0.25 credit hour): Teachers clearly and specifically presented the learning objectives of the unit, ensuring that students understood the direction: to independently acquire three standard views (parasternal long-axis, apical four-chamber, and short-axis); to correctly identify typical ultrasound signs of mitral stenosis, mitral regurgitation, and reduced left ventricular ejection fraction; and to complete a structurally sound cardiac ultrasound report. (3) Pre-assessment (0.25 credit hour): Before formal teaching, students completed a quick 5-8 question test on basic cardiac ultrasound knowledge (cardiac anatomical landmarks, standard view nomenclature, ultrasound features of common diseases) via an ultrasound education platform or paper questionnaire. Pre-assessment scores were not included in final assessments but were used to help teachers understand students' knowledge baseline and dynamically adjust teaching focus. (4) Participatory Learning (5 credit hours): This adopted a "problem-guided + group practice + case discussion" three-in-one participatory teaching strategy, embodying the core spirit of the BOPPPS model: ① Problem-oriented group practice: Students still worked in groups of 2-3, but before each practice session, teachers posed a clinical question (e.g., "How to accurately measure left ventricular ejection fraction using M-mode ultrasound? Where should the sampling line be placed?"), and each group independently explored view acquisition and measurement methods on real patients or simulators. ② Peer assessment and immediate feedback: Within each group, students took turns as "operator" and "observer/evaluator." After the operator completed view scanning, the observer pointed out deficiencies immediately using a standard view scoring sheet, while teachers circulated among groups, correcting technique errors and guiding students to observe key anatomical structures. ③ Small-group case discussion: After completing practice for each standard view, a 10-15 minute group case discussion was held. Teachers provided 3-5 dynamic ultrasound images of different diseases, and groups discussed questions such as "What are the image features?" "What is the diagnostic basis?" "What differential diagnoses should be considered?" Representatives from each group presented, and teachers provided immediate comments and supplements. (5) Post-assessment (1 credit hour): Before the end of teaching, students independently completed a comprehensive cardiac ultrasound image interpretation test of comparable difficulty to the bridge-in case, including standard view identification, sign interpretation, and brief diagnostic report writing. Post-assessment scores were directly included in the summative evaluation of the teaching unit; teachers graded on the spot and recorded scores while giving concentrated feedback on common problems. (6) Summary (1 credit hour): Teachers and students jointly reviewed core knowledge and operational key points, using a "students summarize first, teachers supplement" format: students orally outlined the main gains, operational difficulties, and common mistakes; then teachers systematically summarized the standardized process of cardiac ultrasound diagnosis ("view acquisition → image optimization → standard measurement → sign recognition → comprehensive diagnosis") using a mind map, and assigned post-class extended learning tasks (e.g., reading one cardiac ultrasound guideline or watching one video of a challenging case).

2.3. Teaching Effect Evaluation

2.3.1. Theoretical Examination and Technical Operation Assessment

After completing the teaching module, both groups of residents underwent a unified end-of-rotation examination, using the same test papers and scoring rubrics; the teachers who set the questions did not participate in the teaching for that rotation.

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(1) The theoretical examination was a closed-book written test lasting 60 minutes, with a full score of 100. Questions covered basic cardiac ultrasound theory, standard view anatomical identification, diagnostic criteria for common diseases, and differential diagnostic points. Question types included 30 single-choice questions, 10 multiple-choice questions, and 2 case analysis questions. Papers were independently graded by two teachers with associate senior or above titles using a double-blind method, and the average score was taken as the final result.

(2) The technical operation assessment adopted an objective structured clinical examination (OSCE) format, with students operating on standardized patients using real ultrasound equipment. Each assessment lasted 20 minutes, with a full score of 100. Assessment contents included: pre-examination preparation and humanistic communication, equipment adjustment and image optimization, standard view acquisition (parasternal long-axis, short-axis, apical four-chamber), and standard measurement parameter acquisition (left ventricular ejection fraction, left atrial diameter, interventricular septal and posterior wall thickness). Two senior teachers used a unified Direct Observation of Procedural Skills (DOPS) scoring form for on-site independent scoring, and the average score was taken as the final result.

2.3.2. Cardiac Ultrasound Image Interpretation and Diagnostic Accuracy Assessment

A computer-assisted static ultrasound image interpretation test was employed, lasting 30 minutes, with a full score of 100. The test consisted of three modules: (1) Standard view identification (30 points): 10 static cardiac ultrasound images were randomly presented, requiring students to identify the view name and key anatomical structures. (2) Pathological ultrasound sign interpretation (40 points): 8 typical images of common cardiac diseases (mitral stenosis, mitral regurgitation, aortic stenosis, ventricular septal defect, dilated cardiomyopathy, hypertrophic cardiomyopathy, pericardial effusion, reduced ejection fraction, etc.) were randomly presented; students were required to write down the abnormal signs and the most likely ultrasound diagnosis. (3) Diagnostic report completeness (30 points): Two complete clinical case histories (including history, physical examination, and 4-6 key ultrasound images) were provided; students were asked to simulate writing a structurally complete cardiac ultrasound diagnostic report, including ultrasound findings, measured values, and comprehensive diagnostic conclusions.

Two teachers with associate senior or above titles independently graded the tests using a double-blind method, and the average score was taken as the final result. The sum of scores from the three modules constituted the total diagnostic ability score (full score 100).

2.3.3. Teaching Effectiveness Questionnaire

After the teaching sessions, an anonymous survey was conducted using a self-designed "Cardiac Ultrasound Teaching Effectiveness Satisfaction Questionnaire." The questionnaire was designed based on literature review and expert consultation (two senior cardiac ultrasound physicians and one medical education expert), and revised after a pilot test with 15 non-participating respondents. Cronbach's α coefficient was 0.874, indicating good internal consistency. The questionnaire comprised 5 dimensions, each with one item: learning interest, learning efficiency, comprehension of theoretical knowledge, comprehension of technical operations, and teaching participation. Each item used a 10-point Likert scale (1-10), with higher scores indicating higher recognition or satisfaction. The survey was distributed and immediately collected by non-teaching teachers; students completed it independently and anonymously to ensure authenticity.

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 Data Between the Two Groups

There were no statistically significant differences between the traditional teaching group and the BOPPPS group in terms of gender, age, or educational background ($P>0.05$), indicating comparability

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(see Table 1).

Table 1: Comparison of general data between the two groups

Group	n	Gender (n)		Age (years)	Education (n)		
		Male	Female		Bachelor	Master	Doctor
Traditional group	30	13	16	25.36±2.21	15	11	4
BOPPPS group	30	17	14	25.49±2.33	17	8	5
t/χ^2		0.601		0.222	0.710		
P		0.438		0.825	0.701		

3.2. Comparison of Examination Scores Between the Two Groups

The BOPPPS group scored significantly higher than the traditional group in both theoretical and technical operation examinations (P<0.05, see Table 2).

Table 2: Comparison of examination scores between the two groups (points)

Group	n	Theoretical score	Technical operation score
Traditional group	30	79.65±8.42	83.28±7.91
BOPPPS group	30	84.76±9.13	89.14±7.53
t		2.254	2.939
P		0.028	0.005

3.3. Comparison of Cardiac Ultrasound Image Interpretation and Diagnostic Accuracy Between the Two Groups

The BOPPPS group significantly outperformed the traditional group in standard view identification, pathological sign interpretation, diagnostic report completeness, and total diagnostic ability score (all P<0.001, see Table 3).

Table 3: Comparison of cardiac ultrasound image interpretation and diagnostic accuracy between the two groups (points)

Item	Traditional group (n=30)	BOPPPS group (n=30)	t	P
Standard view identification	18.34±3.21	21.56±2.98	4.027	<0.001
Pathological sign interpretation	16.78±4.12	22.45±3.56	5.704	<0.001
Diagnostic report completeness	17.22±3.89	21.78±3.12	5.009	<0.001
Total diagnostic ability score	52.34±9.22	65.79±8.66	5.824	<0.001

3.4 Comparison of Teaching Effectiveness Scores Between the Two Groups

Compared with the traditional teaching group, the BOPPPS group showed significantly higher scores in learning interest, learning efficiency, comprehension of theoretical knowledge, comprehension of technical operations, and teaching participation (all P<0.001, see Table 4).

Table 4: Comparison of teaching effectiveness scores between the two groups (points)

Item	Traditional group (n=30)	BOPPPS group (n=30)	t	P
Learning interest	7.52±0.78	9.21±0.64	9.174	<0.001
Learning efficiency	7.86±0.69	9.35±0.56	9.184	<0.001
Comprehension of theoretical knowledge	8.12±0.73	9.29±0.67	6.467	<0.001
Comprehension of technical operations	7.78±0.76	9.40±0.59	9.222	<0.001
Teaching participation	7.82±0.85	9.18±0.62	7.080	<0.001

4. Discussion

This study systematically evaluated the application effect of the BOPPPS teaching model in cardiac

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ultrasound education during standardized residency training through a randomized controlled trial design. The results demonstrated that residents in the BOPPPS group significantly outperformed those in the traditional teaching group in theoretical examinations, technical operations, and core diagnostic abilities, while also showing clear advantages in subjective teaching effectiveness evaluations across all dimensions. These findings suggest that the BOPPPS teaching model can effectively improve residents' cardiac ultrasound diagnostic ability, and its systematic instructional design has important value for dissemination in medical education practice.

In this study, the theoretical examination scores of the BOPPPS group were significantly higher than those of the traditional group, consistent with previous findings from multiple studies. Zhang et al., in urology clinical teaching, reported that the BOPPPS group was significantly superior to the traditional group in both theoretical knowledge assessment and clinical practical skills [15]. In gynecology clinical internships, Xu et al. applied a hybrid BOPPPS teaching model and similarly found that the experimental group scored significantly higher on final examinations ($P<0.05$), with 93.4% of students believing the model helped improve case analysis ability [16]. In thoracic surgery teaching, Hu et al. also confirmed that the BOPPPS model better stimulated students' learning enthusiasm and enhanced comprehensive abilities [17]. Notably, the technical operation scores of the BOPPPS group in our study were also significantly higher than those of the control group, suggesting that the "problem-guided + group practice + peer assessment" strategy within the participatory learning component, through structured problem-driving and immediate feedback, strengthened students' grasp of technical key points. A comprehensive systematic review and meta-analysis including 44 studies also confirmed that blended BOPPPS teaching effectively improved medical students' practical skills (SMD=1.246, 95% CI: 0.799-1.693) [18]. In ultrasound simulation training, de Oliveira Filho et al. showed that high-frequency, structured expert feedback significantly shortened the learning curve and reduced technical errors, indicating that structured feedback plays a critical role in skill acquisition [19].

The core finding of our study lies in the cardiac ultrasound image interpretation and diagnostic accuracy domain. The BOPPPS group significantly outperformed the traditional group in standard view identification, pathological sign interpretation, diagnostic report completeness, and total diagnostic ability score (all $P<0.001$). This result may be closely related to the design of the "Participatory Learning" component in the BOPPPS model. In traditional teaching, image interpretation ability cultivation mainly relies on students' individual observation and comprehension, lacking systematic interpretive framework training and immediate error-correction mechanisms. In contrast, the BOPPPS model, through small-group case discussions, requires students to actively extract signs, propose diagnostic bases, and perform differential analyses in front of real case images—a process that essentially simulates the cognitive pathway of clinical diagnosis. Wachsman et al. confirmed in radiology teaching that after converting traditional lecture-based teaching to interactive, clinically-based learning, students' total scores significantly improved (65.1 ± 21.5 vs. 40.8 ± 19.1, $P<0.001$), with pneumothorax recognition rates increasing from 4.2% to 61.8% ($P<0.001$), demonstrating that case-driven participatory learning substantially promotes image interpretation ability [20]. In the field of ultrasound medical education, a study on cardiac ultrasound virtual simulation technology showed that virtual simulation teaching significantly improved students' ultrasound operation skills and clinical reasoning ability in diagnosing structural heart diseases ($P<0.05$) [21]. Additionally, Lu et al. applied BOPPPS combined with CBL in pediatric dentistry clinical clerkships and found that the experimental group showed significant improvement in clinical critical thinking and knowledge integration ability compared with the control group [22].

In terms of subjective teaching effectiveness evaluation, the BOPPPS group scored significantly higher than the traditional group in all five dimensions: learning interest, learning efficiency, comprehension of theoretical knowledge, comprehension of technical operations, and teaching participation (all $P<0.001$). Xu et al. in gynecology clinical internships similarly found that the hybrid BOPPPS teaching model effectively improved residents' learning environment, stimulated interest and initiative, and increased teaching satisfaction [16]. Jia et al., applying BOPPPS-CBL in emergency chest pain management teaching, also reported that the BOPPPS-CBL group showed significantly higher teaching satisfaction and self-adjustment ability compared with the traditional group (both $P<0.05$) [23]. Self-determination theory posits that when learners' autonomy, competence, and relatedness are satisfied, their intrinsic motivation is significantly enhanced [24]. The particularly notable difference in teaching participation scores in our study may be attributed to the closed-loop design of "pre-assessment → participatory learning → post-assessment → summary" in the BOPPPS model, which requires students to actively invest cognitive resources at each step rather than passively receiving information.

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It is worth noting that the advantage of the BOPPPS model in cardiac ultrasound teaching may also relate to its precise deconstruction of "diagnostic ability" as a composite competency. Cardiac ultrasound diagnostic ability can be broken down into multiple components: view acquisition, image optimization, standard measurement, sign recognition, and comprehensive diagnosis—each with different cognitive processing demands. Deliberate practice theory states that mastering complex skills requires decomposing the task into manageable sub-skills and obtaining timely, specific feedback on each [25]. The six components of the BOPPPS model correspond exactly to the teaching needs of this competency chain: bridge-in stimulates diagnostic motivation, objectives clarify the learning direction, pre-assessment evaluates baseline levels, participatory learning trains each sub-skill, post-assessment tests comprehensive application, and summary facilitates knowledge systematization. This "interlocking, step-by-step feedback" design philosophy is highly congruent with the inherent patterns of ultrasound diagnostic competence formation.

This study has some limitations. First, the sample size was relatively small (n=60), and only a single-center population was included, so the generalizability of the findings requires validation through multicenter, larger-sample studies. Second, the long-term retention of teaching effects was not assessed, and the long-term impact of the BOPPPS model on residents' diagnostic ability remains unclear. Third, image interpretation assessment used static images, which do not fully replicate the complex context of dynamic scanning and real-time diagnosis in actual clinical practice; future studies could incorporate dynamic video interpretation and real-patient diagnostic report quality evaluation as supplementary measures. In addition, although having the same group of teachers for both models eliminated instructor-related bias, the teachers' familiarity with the BOPPPS model may have changed over the course of teaching; future research could include a longer adaptation period to mitigate this potential influence.

5. Conclusion

In summary, the BOPPPS teaching model can effectively enhance the cardiac ultrasound diagnostic ability of residents in standardized residency training, with significant advantages particularly in image interpretation and diagnostic accuracy, while also improving learners' experience and engagement. The model has a clear operational process and strong replicability, making it worthy of wider application in ultrasound medicine and other clinical skills training.

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