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Competency-based ultrasound curriculum for standardized training resident: a pre- and post-training evaluation

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Abstract

Background Ultrasound training is crucial for residents across specialties but presents challenges for residents that are not specializing in ultrasound. Investigating the effectiveness of competency-based ultrasound curricula for a wider range of medical specialties is imperative.

Methods A total of 250 residents who attended the ultrasound curriculum between June 2023 and June 2024 were included in the analysis. The competency-based curriculum combined theoretical and practical training. The evaluations were taken both before the residents participated in the ultrasound curriculum (pre-training) and after completing the training (post-training). Resident feedback was also collected.

Results Post-training, all the grades improved interpretation scores and reduced answer times, resulting in knowledge homogenization. Imaging specialty residents initially scored higher, but non-imaging-related residents showed greater improvements post-training; feedback highlighted the need for an expanded training scope, more hands-on practice, and optimized schedules, emphasizing the importance of comprehensive ultrasound training.

Conclusions The competency-based ultrasound curriculum enhances theoretical and practical skills, standardizing knowledge across grades and benefiting non-imaging-related residents the most. This study supports the integration of structured ultrasound training in residency programs to improve clinical competencies.

Keywords Ultrasound, Standardized training resident, Teaching, Training, Ultrasound curriculum, Ultrasound education

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Background

The standardized training system for residents in China, instituted in 2014 through a collaborative effort led by the Chinese Ministry of Education and involving six additional departments, including the National Health and Family Planning Commission and the State Administration of Traditional Chinese Medicine, aims to increase the quality and consistency of medical education nationwide [1]. This system mandates a three-year residency program, during which residents undergo rigorous training across various clinical disciplines. The training includes both formative and summative assessments, ensuring that residents achieve the necessary competencies before becoming licensed practitioners [2]. Regular assessments are conducted throughout the program to ensure residents' proficiency, and the curriculum is designed to meet international standards of postgraduate medical education.

Among the competencies that a resident should acquire, proficiency in ultrasound is paramount in contemporary medical practice. Ultrasound is not only a powerful diagnostic tool but also plays an essential role in guiding clinical and interventional treatment procedures across multiple medical specialties. In specialties such as emergency medicine [3], internal medicine [4], surgery [5], and obstetrics and gynecology [4], the ability to perform and interpret ultrasound is increasingly becoming a critical skill. The quality of ultrasound images is contingent upon the operator's foundational knowledge of ultrasound physics, proficiency with the control panel of the ultrasound equipment, and skills and competency in conducting the examination [6].

The incorporation of ultrasound training into residency programs worldwide has been widely recognized as necessary, yet it presents several challenges [7, 8]. One primary concern is patient safety, which limits opportunities for residents, especially those from non-ultrasound specialties, to practice on real patients [9]. Traditional residency training models, in which residents learn under direct supervision while managing patients, can present ethical dilemmas, particularly regarding junior residents performing the procedures [10]. Furthermore, non-ultrasound specialty residents often have sporadic and unstructured exposure to ultrasound procedures, limiting their ability to develop consistent and comprehensive skills [11]. To address these challenges, some medical specialties have implemented training programs using simulators and phantoms, providing a safe and controlled environment for residents to practice and refine their skills [12, 13]. International societies, such as the European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB), and the American College of Emergency Physicians (ACEP), have developed competency frameworks to guide ultrasound training across a range of specialties [14]. Despite these advances, comprehensive evaluation studies assessing the effectiveness of ultrasound training programs for residents in non-ultrasound specialties—referring to residents from medical specialties other than ultrasound, who receive ultrasound training as a supplementary skill rather than a core component of their specialty training—remain sparse [13, 15, 16].

There are no published studies that have conducted a comparative analysis of the efficiency of ultrasound curricula before and after training for standardized training residents. Our study aims to address this gap by evaluating a competency-based ultrasound curriculum specifically designed for residents from diverse non-ultrasound specialties, focusing on their accuracy and confidence in ultrasound interpretation. The findings from this research will offer valuable insights into the educational effectiveness of the curriculum and provide recommendations for future curriculum development.

Methods

Study population

This is a retrospective observational study. We provided a competency-based ultrasound curriculum for residents who had completed their undergraduate medical education and had undergone a minimum of six months of training at our hospital. The residents specializing in ultrasound would not be invited to participant in this curriculum, as they participated in a more comprehensive and systematic training program in ultrasound medicine. Residents who attended the ultrasound curriculum between June 2023 and June 2024 were included in the analysis. Residents who lacked theoretical or practical test scores related to the ultrasound curriculum were excluded from the study. The flowchart of the subject selection was presented in Supplementary Figure S1. Ethical approval for the study was obtained from the Ethics Committee of Shaoxing People's Hospital (NO. 2024-Y075-01).

Teaching and assessment methods

At the beginning of the curriculum, each resident was required to complete an online questionnaire about ultrasound image interpretation to clarify their knowledge of ultrasound images. The content of the questionnaire is mainly about the typical ultrasound images of the diseases. The details of the questionnaire are available in Supplementary Appendix S1.

The theoretical component of the curriculum comprised four classes, each lasting one hour, covering foundational knowledge of ultrasound and the interpretation of typical ultrasound images related to common diseases of liver, cardiovascular system, thyroid, and breast—diseases that most frequently encountered in clinical practice. Immediately after the theoretical training, residents were re-evaluated using the same ultrasound image interpretation questionnaire to assess their progress.

The practical component included two one-hour sessions focused on ultrasound scanning techniques. The first session involved a demonstration of liver and abdominal blood vessel scanning methods, while the second session provided residents with hands-on practice using an ultrasound phantom, under the guidance of experienced teachers.

Following the practical training, an evaluation was conducted by two radiologists specializing in ultrasound, each with over a decade of professional experience. The assessment encompasses the adjustment of ultrasound equipment and the scanning of fundamental sections of the liver as well as the major abdominal blood vessels. The average of the scores given by the two ultrasound radiologists was taken as the scan score of the residents. The details of the scan scoring sheet are available in Supplementary Appendix S2.

Additionally, an investigation of satisfaction with the ultrasound curriculum was conducted through the analysis of a feedback questionnaire. Comprehensive details of the questionnaire are available in Supplementary Appendix S3.

Study outcomes

Primary outcome of the study was the improvement in ultrasound image interpretation scores post-training. Secondary outcomes were the reduction in image interpretation time, differences in ultrasound scan skills, and resident feedback on the curriculum's effectiveness.

Table 1 Baseline information of the residents

Characteristic	Total (*n*=250)	ST1 (*n*=124)	ST2 (*n*=28)	ST3 (*n*=98)	*P*
Gender, **n (%)**					0.696
Female	100 (40.0)	52 (41.9)	12 (42.9)	36 (36.7)	
Male	150 (60.0)	72 (58.1)	16 (57.1)	62 (63.3)	
Specialties, **n (%)**					
Internal Medicine	76 (30.4)	21 (16.9)	1 (3.6)	54 (55.1)	<0.001**
Surgery	43 (17.2)	13 (10.5)	12 (42.9)	18 (18.4)	
Pediatrics	9 (3.6)	4 (3.2)	0 (0.0)	5 (5.1)	
General Practice	47 (18.8)	35 (28.2)	1 (3.6)	11 (11.2)	
Emergency	11 (4.4)	9 (7.3)	0 (0.0)	2 (2.0)	
Anesthesiology	18 (7.6)	16 (12.9)	0 (0.0)	3 (3.1)	
Imaging Specialties	37 (14.8)	21 (16.9)	14 (50.0)	2 (2.0)	
Others	8 (3.21)	5 (4.0)	0 (0.0)	3 (3.1)	

Note: ST, stage. Data are presented as number (%)

* indicate $P<0.01$; ** indicate $P<0.001$

Statistical analysis

The data analysis was conducted via SPSS 26.0. The Kolmogorov‒Smirnov test was employed to assess the normality of the data distribution. Descriptive statistics for normally distributed data are presented as the means ± standard deviations, whereas nonnormally distributed data are presented as medians (P25-P75). The categorical variables are presented as percentages. Intergroup comparisons were performed via the independent samples t test or Mann‒Whitney U test for continuous data and the chi‒square test for categorical data. To evaluate individual differences before and after training, the Wilcoxon signed-rank test was used for paired analysis. Additionally, a comparative analysis of residents' image interpretation evaluations before and after training was conducted using linear regression. A *P* value of less than 0.01 was considered indicative of statistical significance.

Results

Baseline information of the study population

Baseline information of the study population was present in Table 1. The analysis included 250 residents divided into three training stages: ST1 (49.6%, 124/250), ST2 (11.2%, 28/250), and ST3 (39.2%, 98/250), with no significant sex distribution difference ($P=0.696$). In the ST1 group, the majority were residents of general medicine (28.2%, 35/124), internal medicine (16.9%, 21/124), and imaging-related specialties (16.9%, 21/124). The ST2 group primarily comprised imaging-related specialty residents (50.0%, 14/28) and surgical residents (42.9%, 12/28). In the ST3 group, the predominant specialties were internal medicine (55.1%, 54/98) and surgery (18.4%, 18/98) ($P<0.001$).

Primary outcome: improvement in image interpretation scores post-training

Overall improvement: Post-training, there was a significant increase in the interpretation scores for all residents, with an average improvement of 20.92 points (95% CI: 19.05–22.80) over the pre-training scores (Table 2).

Comparison by training stage: Before training, image interpretation scores differed among ST1, ST2, and ST3 residents [72.00 (64.00–76.00) vs. 80.00 (72.00–88.00) vs. 72.00 (64.00–76.00), $P=0.002$]. However, post-training scores showed no significant differences among these stages [92.00 (88.00–96.00) vs. 96.00 (92.00-100.00) vs. 92.00 (88.00–96.00), $P=0.043$] (Table 3).

Comparison by specialty: After training, both non-imaging and imaging specialties improved in image interpretation accuracy (Table 4; Fig. 1). Non-imaging residents showed greater score improvement than

Table 2 Comparison of score and time of residents pre- and post-training using linear regression

Predictors	Estimates	95% CI	*P*
Score			
(Intercept)	70.23	68.90-71.55	< 0.001**
Post-evaluation	20.92	19.05–22.80	< 0.001**
R^2/adjusted R^2	0.492/0.491		
Time			
(Intercept)	516.70	494.78-538.63	< 0.001**
Post-evaluation	-155.29	-186.29-124.29	< 0.001**
R^2/adjusted R^2	0.163/0.161		

Note: CI, Confidence interval

** indicate $P<0.001$

imaging residents [(21.55, 95% CI: 19.53–23.58) vs. (17.30, 95% CI: 13.61–20.99), $P<0.001$] (Supplementary Table S1).

Secondary outcome: reduction in image interpretation time

Overall reduction: Across all residents, the training resulted in a significant decrease in image interpretation time, with a mean reduction of 155.29 s (95% CI: -186.29 to -124.29) (Table 2).

Comparison by training stage: Pre-training, times were comparable among ST1, ST2, and ST3 residents [469.50 (392.50-659.75) vs. 405.50 (334.75-479.75) vs. 480.50 (376.50-605.50), $P=0.022$]; post-training, times differed significantly [345.00 (290.00-484.50) vs. 275.00 (231.75-327.25) vs. 327.50 (265.75–420.00), $P<0.001$] (Table 3).

Comparison by specialty: After training, both non-imaging and imaging specialties reduced image interpretation time (Table 4; Fig. 1). The interpretation times showed greater improvement for imaging-specialized residents compared to non-imaging residents [(-378.30, 95% CI: -465.25 to -291.35) vs. (-116.55, 95% CI: -148.27 to -84.84), $P<0.001$] (Supplementary Table S2).

Secondary outcome: differences in ultrasound scan skills

Comparison by training stage: No significant differences were noted in scan scores across the training stages [87.60 (84.30–90.80) vs. 88.00 (85.88-90.00) vs. 86.15 (83.93-88.00), $P=0.011$] (Table 3).

Comparison by specialty: Residents from imaging-related specialties scored higher on practical scans compared to their non-imaging counterparts [(89.71 ± 3.80) vs. (86.36 ± 3.75), $P<0.001$] (Table 4).

Secondary outcome: residents' feedback toward the ultrasound curriculum

A total of 223 feedbacks were collected through a structured questionnaire, addressing aspects such as content setting, instructor guidance, practical relevance, and suggestions for improvement. Among the feedback received, 56.95% (127/223) rated the curriculum as "very good" without providing any suggestions for improvement; these responses were categorized as "no special recommendations". Of the remaining 43.05% (96/223) of feedback, 20.83% (20/96) recommended expanding the scope of training. This was followed by requests for

Table 3 Comparison of score and time for residents from different stages

Evaluation	ST1 (*n* = 124)	ST2 (*n* = 28)	ST3 (*n* = 98)	*P*
Image Interpretation Score, points				
Score $_{pre-}$	72.00 (64.00–76.00)	80.00 (72.00–88.00)	72.00 (64.00–76.00)	0.002*
Score $_{post-}$	92.00 (88.00–96.00)	96.00 (92.00-100.00)	92.00 (88.00–96.00)	0.043
Image Interpretation Time, s				
Time $_{pre-}$	469.50 (392.50-659.75)	405.50 (334.75-479.75)	480.50 (376.50-605.50)	0.022
Time $_{post-}$	345.00 (290.00-484.50)	275.00 (231.75-327.25)	327.50 (265.75–420.00)	< 0.001**
Scan Score	87.60 (84.30–90.80)	88.00 (85.88-90.00)	86.15 (83.93-88.00)	0.011

Note: ST, stage. Data are presented as number (%) and median (P25-P75)

* indicate $P<0.01$; ** indicate $P<0.001$

Table 4 Comparison of score and time for residents from different specialties

Evaluation	Non-imaging-related Specialties (*n* = 212)	Imaging-related Specialties (*n* = 37)	*P*
Image Interpretation Score, points			
Score $_{pre-}$	69.00 (64.00–76.00)	80.00 (72.00–88.00)	< 0.001**
Score $_{post-}$	92.00 (88.00–96.00)	96.00 (92.00-100.00)	< 0.001**
Image Interpretation Time, s			
Time $_{pre-}$	486.00 (390.00-628.00)	414.00 (340.00-469.00)	0.002*
Time $_{post-}$	338.00 (287.00-444.00)	271.00 (221.00-357.00)	< 0.001**
Scan Score	86.36 ± 3.75	89.71 ± 3.80	< 0.001**

Note: Data are presented as median (P25-P75) or means ± SD

* indicate $P<0.01$; ** indicate $P<0.001$

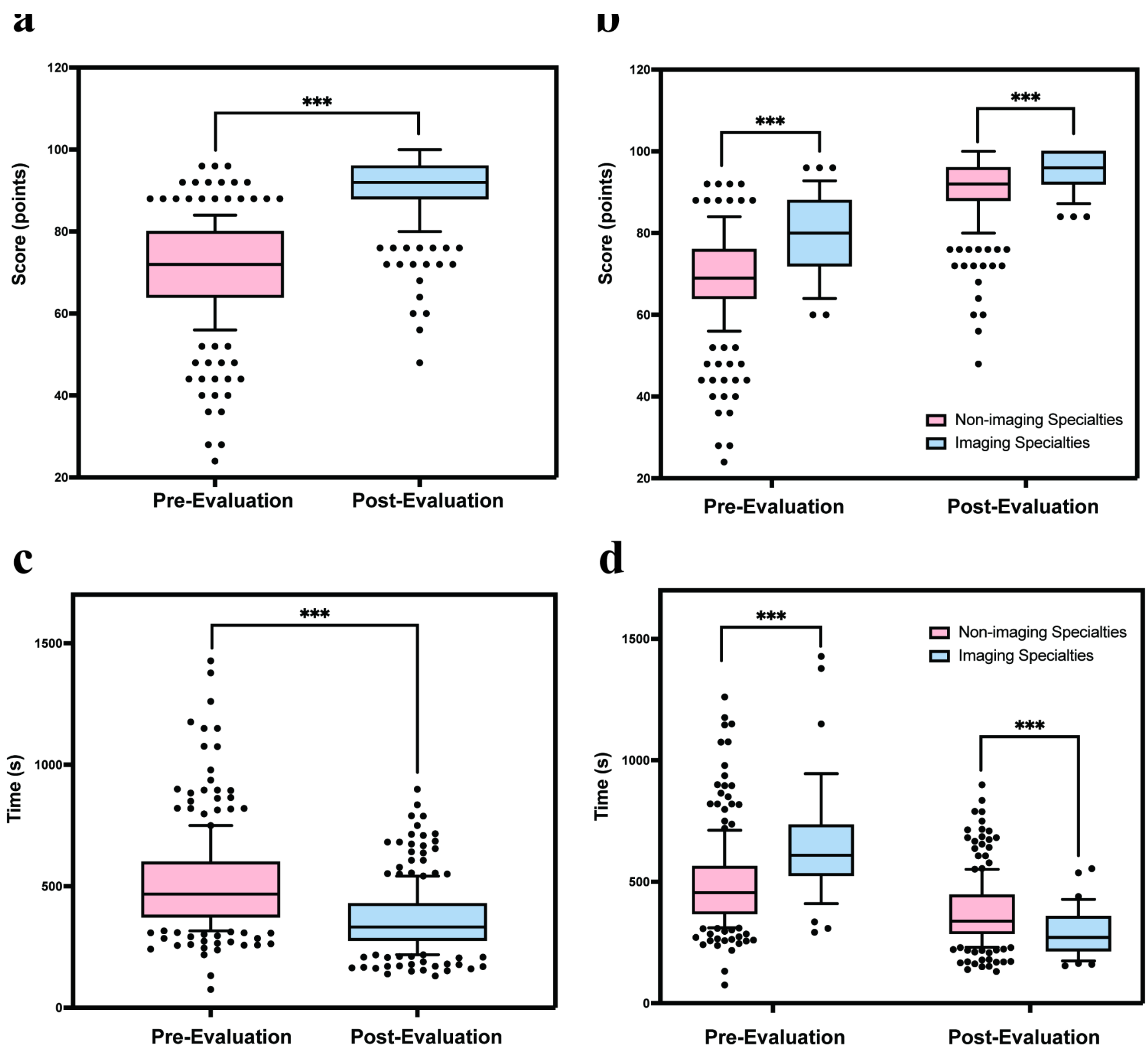

Fig. 1 Boxplots that present the standardized training residents' performance pre- and post-training. (**a**) Boxplots of the image interpretation score for all the residents pre- and post-training; (**b**) Boxplots of the image interpretation score for non-imaging-related specialized and imaging specialized residents pre- and post-training; (**c**) Boxplots of the image interpretation time for all the residents pre- and post-training; (**d**) Boxplots of the image interpretation time for non-imaging-related specialized and imaging specialized residents pre- and post-training

more practice time (16.67%, 16/96) and more effective scheduling (12.50%, 12/96). Additionally, residents recommended optimizing training materials and increasing training frequency, each at 11.46% (11/96) (Fig. 2). All feedbacks are presented in Supplementary Figure S2.

Discussion

This study demonstrates the effectiveness of a competency-based ultrasound curriculum for non-ultrasound specialty residents. First, the curriculum markedly improved the image interpretation scores across all three training levels, shortened image interpretation times, and standardized both theoretical knowledge and practical ultrasound skills post-training. These results indicate that structured ultrasound education can harmonize knowledge and skills among residents at different stages of training. Second, while residents from imaging-related specialties displayed an initial advantage due to their background, non-imaging specialty residents showed more substantial improvements in post-training scores. This highlights the importance of incorporating ultrasound training across all specialties, ensuring comprehensive skill development regardless of prior exposure to the image. Third, the residents' feedback revealed

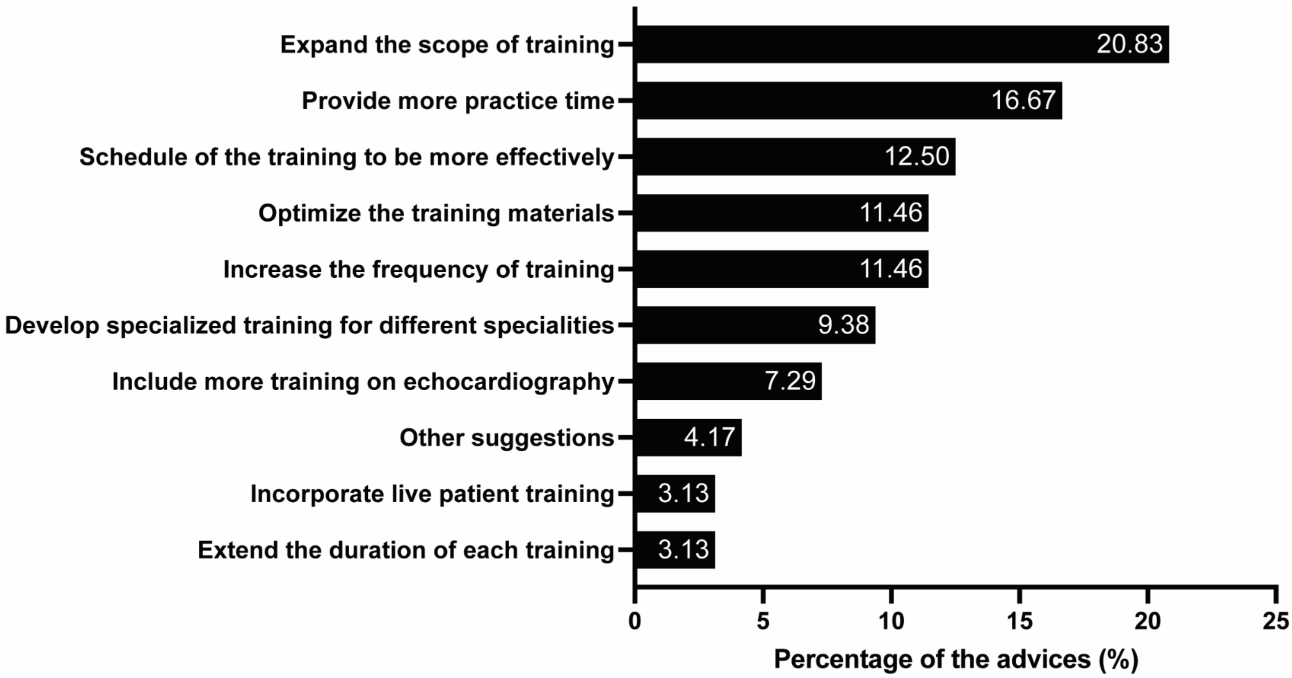

Fig. 2 Analysis of the substantive feedbacks from the standardized training residents who participated in the competency-based ultrasound curriculum

a strong demand for expanding the training's scope, increasing hands-on practice time, and optimizing training schedules. These insights underscore the need for widespread, application-oriented ultrasound training that can accommodate the specific requirements of different medical fields.

Our findings align with the growing recognition globally of the importance of ultrasound training in residency programs across various specialties [17, 18]. Internationally, ultrasound training programs have expanded beyond radiology and emergency medicine to include other specialties in response to the increasing need for point-of-care ultrasound proficiency [19, 20]. However, there is still limited research on ultrasound training integration across a broader range of specialties [21, 22]. Our study addresses this gap by assessing the effectiveness of ultrasound training among residents from various medical disciplines, including internal medicine, surgery, and anesthesia. This reflects the international trend towards diversifying ultrasound training and expanding its application beyond traditional imaging-focused fields.

In this study, residents were divided into three groups according to their training stages. The group sizes were not pre-planned but reflected the residency program's enrollment, as the study was conducted in a real-world educational setting. The smaller number of ST2 residents in our ultrasound curriculum may be attributed to the structured progression of the training program. In our training program, residents in the first year (ST1) often participate in foundational courses, including introductory ultrasound training, to develop essential skills early on. By the third year (ST3), residents typically revisit ultrasound training to prepare for more independent practice, leading to a larger number of participants in the two stages. In contrast, ST2 residents are generally in a transitional phase of their training, during which they are often focused on rotations in other specialties or developing competencies specific to their chosen field, which may reduce their availability for ultrasound training. Additionally, the observed differences in the composition of specialties across the three training stages reflect recent policy shifts prioritizing general medicine, emergency medicine, and anesthesia. These fields have experienced a relatively high influx of first-year residents, likely due to national efforts to address shortages in these essential areas [23].

Analysis of the pre- and post-training results revealed substantial improvements in both the image interpretation scores and the time taken for image interpretation across all three training stages. Pre-training, no significant differences were noted in image interpretation times, whereas ST2 residents scored higher, possibly because a greater proportion of residents from surgery and imaging-related specialties, who may have had better foundational knowledge of anatomy and imaging principles [24]. Post-training, the homogenization of scores across all grades indicates the effectiveness of the training program in enhancing the knowledge and skills of residents, irrespective of their initial specialty. The shorter image interpretation times observed among ST2 residents post-training may reflect their intermediate level of experience, balancing foundational knowledge with increased clinical exposure compared with that of ST1 residents.

Furthermore, to assess the performance of the competency-based ultrasound curriculum across specialties, residents were categorized into non-imaging-related specialties and imaging-related specialties. The imaging-related specialties in our study include radiology and nuclear medicine. It was found that residents in imaging-related specialties outperformed their non-imaging-related counterparts in both accuracy and time taken for image interpretation. This finding is consistent with the literature, which suggests that residents in imaging fields benefit from greater internal exchange of knowledge and familiarity with imaging modalities, even if they have not received formal ultrasound training [25, 26]. Interestingly, although imaging-specialized residents improved interpretation time more, non-imaging-related residents showed greater score improvements. This suggests that the competency-based ultrasound curriculum provided significant educational value and filled the knowledge gap for non-imaging-related residents, underscoring the importance of imaging-related education [24].

Feedback from residents further supports the necessity of the competency-based ultrasound curriculum. The primary demands for expanding the scope of training, increasing practice time, and optimizing the schedule highlight residents' recognition of the value of ultrasound skills in their practice and their desire for more comprehensive training [27]. These findings are in line with those of other studies, which emphasize the importance of hands-on practice and structured training schedules in medical education [28, 29].

We acknowledged some limitations in the current study. First, the study focuses primarily on the training processes specific to China. Integrating more comprehensive international training concepts in the future could improve the generalizability and applicability of the study. Second, the evaluation instruments used in this study were developed based on preliminary research and have not undergone formal validation, which may affect the reliability. Future studies could focus on validating these evaluation tools to ensure their accuracy and consistency across diverse training settings.

Conclusion

In conclusion, this study provides evidence for the efficacy of competency-based ultrasound curricula in enhancing skills for standardized training residents of non-ultrasound specialties. The improvements observed in both theoretical knowledge and practical application underscore the importance of integrating such training into standardized residency programs. Future research may focus on long-term outcomes and the integration of advanced ultrasound training modules to improve residents' ultrasound diagnostic capabilities across various medical fields.

Abbreviations

ST Stage
CI Confidence interval

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Not applicable.

Author contributions

All the authors were involved in writing the above article. ZZJ was responsible for conceptualization, investigation, statistical data analysis, and writing of the original draft. JW was responsible for organizing the training. YJL and JBZ contributed to the data collection. XMC, HMS, and QZ contributed to theory teaching and examination. DJN, YYT, and LXQ were responsible for skill teaching. TW, HZ, YJD, and YPB contributed teaching assistants. YYZ and XTL contributed to teaching theory and critically revised the manuscript. The authors read and approved the final manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Shaoxing People's Hospital (NO. 2024-Y075-01). All methods were performed in accordance with the relevant guidelines and regulations. Informed consent was obtained from the subjects.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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