

# Analysis of the Effectiveness of Inferior Vena Cava and Lung Ultrasound Training for ICU Specialist Nurses

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## Abstract

**Hypothesis:** An integrated training model incorporating theory, case-based discussion and hands-on practice can significantly improve the theoretical knowledge of Intensive Care Unit (ICU) specialist nurses in inferior vena cava (IVC) and lung ultrasound (LUS), with a statistically significant increase in their post-training theoretical assessment scores compared with pre-training scores. **Primary Outcome:** The median pre-training theoretical score of ICU specialist nurses in IVC and LUS was 30 points (Interquartile Range [IQR]: 15 - 44), which increased significantly to 65.5 points (IQR: 49.5 - 73.5) after training ( $Z = -6.214$ ,  $P < 0.001$ ), with the pass rate rising from 6.4% to 95.7%. **Background:** As bedside techniques for volume management in critically ill patients, IVC and LUS offer the advantages of non-invasiveness, convenience and real-time monitoring, and are recommended in multiple clinical guidelines for disease assessment and treatment decision-making. The application of ultrasound technology in the nursing field is expanding, and in particular, the participation of ICU specialist nurses in point-of-care ultrasound (POCUS) has become a development trend. However, most ICU nurses in China lack systematic specialized training, resulting in inadequate theoretical knowledge and operational skills to meet clinical demands. **Objective:** To evaluate the effectiveness of an integrated training model of theory, case-based discussion and hands-on practice in improving ICU specialist nurses' proficiency in IVC and LUS, and to provide evidence-based evidence for optimizing the ultrasound training system for specialist nurses. **Methods:** A self-controlled before-and-after study design was adopted with convenience sampling. A total of 47 ICU specialist nurses from 45 hospitals in 29 cities across 15 provinces in China were enrolled to receive a 2-day intensive training program. Theoretical knowledge was assessed via closed-book examinations before and after the training. Post-training assessments included basic ultrasound operation, LUS

operation and IVC ultrasound operation on human models in accordance with standardized operating procedures. Statistical analysis was performed using SPSS 26.0 software. **Results:** The median pre-training theoretical score was 30 points (IQR: 15 - 44), with only 3 participants (6.4%) scoring over 60 points; the median post-training theoretical score reached 65.5 points (IQR: 49.5 - 73.5), with a pass rate of 95.7% ( $Z = -6.214$ ,  $P < 0.001$ ). The mean post-training scores for basic ultrasound operation, LUS operation and IVC operation were  $78.3 \pm 4.2$ ,  $76.5 \pm 3.8$  and  $77.2 \pm 3.5$ , respectively. The pass rate ( $\geq 60$  points) for all three operational assessments exceeded 95%, while the excellent rate ( $\geq 80$  points) was 29.3%, 24.4% and 26.8%, respectively. **Conclusion:** Targeted specialized ultrasound training can significantly improve the theoretical knowledge and operational skills of ICU specialist nurses, and this training model has strong feasibility and promotional value. It is recommended to establish a long-term mechanism combining basic training, clinical practice and regular retraining, integrated with simulation teaching and clinical supervision, to continuously improve the standardization and proficiency of nurses' ultrasound operations.

## Keywords

ICU Specialist Nurse, Point-of-Care Ultrasound, Inferior Vena Cava Ultrasound, Lung Ultrasound, Training Effectiveness

## 1. Introduction

Precise volume management in critically ill patients is a key link in reducing mortality and improving prognosis (Longino et al., 2024). IVC ultrasound indirectly reflects changes in central venous pressure by assessing vessel diameter and collapsibility index, while LUS rapidly determines lung water content and ventilation status by identifying characteristic images such as A-lines, B-lines and lung sliding. The combined application of the two techniques enables comprehensive and dynamic assessment of patients' volume status (Arvig et al., 2022; Elgenidy et al., 2024). A systematic review by Arvig et al. (2022) showed that the accuracy of combined IVC and LUS monitoring for etiological differentiation in patients with acute dyspnea reached 89%, which was significantly higher than that of traditional physical examination (62%). A meta-analysis by Elgenidy et al. (2024) confirmed that LUS is superior to chest X-ray in sensitivity (0.87 vs 0.72) and specificity (0.83 vs 0.68) for evaluating extravascular lung water in hemodialysis patients.

The European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) Clinical Practice Guidelines for Point-of-Care Ultrasound clearly state that nurses can act as practitioners of bedside ultrasound (Jarman et al., 2023), and the participation of ICU specialist nurses in ultrasound application has become an important measure to improve nursing quality (Vives et al., 2022). As direct caregivers of critically ill patients, nurses can detect changes in patients' conditions in a timely manner via ultrasound, provide real-time assessment data

for physicians and support the optimization of volume management decisions (Greenstein & Guevarra, 2022). However, there are obvious shortcomings in the current clinical situation in China. Baseline data of this study showed that only 19.1% of the enrolled ICU nurses had received ultrasound-related training; although 89.4% of ICUs were equipped with ultrasound devices, and the proportions of physicians who performed LUS and IVC ultrasound occasionally or frequently were 65.9% and 58.5%, respectively, the utilization rate of ultrasound by nurses was less than 10% (Chinese Medical Association Society of Critical Care Medicine, 2021). This phenomenon is in sharp contrast to the international trend, as relevant studies have shown that systematically trained ICU nurses can achieve an ultrasound operation pass rate of more than 85% and independently complete ultrasound assessment of common diseases (Berikashvili et al., 2025; Burgos et al., 2024).

Existing ultrasound training research has mainly focused on physicians, and specialized training programs for nurses are still inadequate (Ghosh et al., 2024; Kim et al., 2025). Some studies have adopted a simple theory + practice training model, lacking case-based discussion and clinical application transformation links, leading to unsustainable training effects (Burgos et al., 2022; Dana et al., 2024). Based on this, the present study designed a tripartite training model integrating theory, case-based discussion and hands-on practice. Through a rigorous self-controlled before-and-after study, we systematically evaluated the improvement in theoretical knowledge and operational skills of ICU specialist nurses, so as to provide practical support for promoting nurse-led bedside ultrasound application and evidence-based evidence for optimizing the national ultrasound training program for specialist nurses.

## 2. Methods

### 2.1. Study Participants

By convenience sampling, 47 nurses who participated in the 2025 National ICU Specialist Nurse Training Course were selected as the study subjects.

Inclusion criteria: ① Currently engaged in ICU specialist nursing work with at least 3 years of clinical work experience; ② Voluntarily participate in the study; ③ Complete the entire training program and all assessments. Exclusion criteria: ① Cumulative absence of more than 4 academic hours during the training period; ② Failure to complete any of the pre-training or post-training assessment indicators.

### 2.2. Training Protocol

The training adopted a modular design, including theoretical learning (6 academic hours), hands-on training (6 academic hours) and assessment (4 academic hours), with a total duration of 2 days (16 academic hours) (Jarman et al., 2023; Vives et al., 2022). The detailed contents are as follows:

Theoretical learning (6 academic hours): The courses were jointly delivered by

ICU physicians with more than 5 years of clinical ultrasound and teaching experience and senior nurses with ultrasound certification. The content covered basic ultrasound principles, IVC anatomical structure and volume assessment standards (collapsibility index, diameter measurement), LUS image recognition (A-lines, B-lines, lung sliding, pleural effusion), clinical application scenarios (heart failure, septic shock, acute respiratory distress syndrome) and operational safety specifications.

Hands-on training (6 academic hours): Human models (volunteered by male trainee nurses) were used for simulated operations. The training focused on probe operation skills, IVC localization and measurement methods, and acquisition of standard LUS views. Clinical images were used for result analysis and interpretation training, with four senior trainers providing on-site personalized guidance and real-time error correction.

Assessment (4 academic hours): Theoretical knowledge tests were conducted before and after the training; in view of the fact that most nurses had no ultrasound operation foundation, skills assessments for basic ultrasound, IVC and LUS were only conducted after the hands-on training.

### **2.3. Evaluation Indicators**

Theoretical knowledge (Primary Outcome): Assessed via online closed-book tests (scanning QR code to access the test). The test consisted of 25 single-choice questions with a total score of 100 points, covering basic ultrasound principles (24 points), IVC ultrasound (36 points) and LUS (40 points).

Operational skills (Secondary Outcome): The assessment was conducted on the day after the hands-on training. Participants were divided into two groups, and each participant was assessed by two standardized trained evaluators on human models. The assessment included: Basic operation (probe control, view acquisition, image adjustment; 100 points), LUS operation (view standardization, image recognition, result judgment; 100 points), and IVC operation (localization accuracy, measurement standardization, result interpretation; 100 points).

Baseline data: Collected via online questionnaires, including gender, age, clinical working years, highest educational background, professional title, ultrasound equipment configuration in the affiliated department, and previous ultrasound training experience.

### **2.4. Quality Control**

All trainers had at least 5 years of relevant clinical and teaching experience; objective single-choice questions were used in theoretical tests to ensure assessment objectivity; all evaluators received standardized training before skill assessments to unify assessment criteria; all research data were double-entered into Microsoft Excel spreadsheets with strict logical verification to ensure data accuracy.

### **2.5. Statistical Analysis**

SPSS 26.0 software was used for data processing. Quantitative data conforming to

normal distribution were expressed as Mean  $\pm$  Standard Deviation (SD); non-normal data were expressed as Median (IQR). Categorical data were analyzed using the Chi-square ( $\chi^2$ ) test. A two-tailed P value  $< 0.05$  was considered statistically significant.

### 3. Results

#### 3.1. Baseline Characteristics of Study Participants

Among the 47 nurses, 38 were female (80.9%) and 9 were male (19.1%); the mean age was  $31.7 \pm 3.7$  years, and the mean clinical working years was  $9.7 \pm 3.8$  years; 41 nurses (87.2%) held a bachelor's degree, which was the main educational background; in terms of professional titles, 16 were senior nurses (34.0%) and 28 were nurses (59.6%). 89.4% of the medical institutions affiliated to the study participants were equipped with ultrasound devices, but only 19.1% of the nurses had previous ultrasound training experience, and only 14.9% had received specialized training in LUS or IVC ultrasound. The frequency of clinical ultrasound application by physicians in the same institution was significantly higher than that by nurses (LUS: 65.9% vs 8.5%; IVC ultrasound: 58.5% vs 6.4%). Detailed baseline characteristics of the participants are presented in **Table 1**.

**Table 1.** Baseline characteristics of study participants (N = 47).

Characteristics	Distribution
Gender	Female: 38 (80.9%); Male: 9 (19.1%)
Age (years)	$31.7 \pm 3.7$
Working years (years)	$9.7 \pm 3.8$
Highest educational background	Junior college: 4 (8.5%); Bachelor: 41 (87.2%); Master: 2 (4.3%)
Professional title	Nurse: 1 (2.1%); Senior nurse: 16 (34.0%); Nurse Supervisor: 28 (59.6%); Associate chief nurse: 2 (4.3%)
Administrative position	No: 42 (89.4%); Yes: 5 (10.6%)
Ultrasound equipment in the department	Yes: 42 (89.4%); No: 5 (10.6%)
Previous ultrasound training	Yes: 9 (19.1%); No: 38 (80.9%)
Previous training in lung/inferior vena cava ultrasound	Yes: 7 (14.9%); No: 40 (85.1%)
Physicians performing lung ultrasound occasionally or more	31 (65.9%)
Physicians performing IVC ultrasound occasionally or more	28 (58.5%)
Nurses performing lung ultrasound occasionally or more	4 (8.5%)
Nurses performing IVC ultrasound occasionally or more	3 (6.4%)

### 3.2. Comparison of Theoretical Knowledge Scores

The pre-training theoretical scores of nurses were generally low, with a median of 30 points (IQR: 15 - 44), and only 3 participants (6.4%) reached the passing score ( $\geq 60$  points); the post-training theoretical scores increased significantly, with a median of 65.5 points (IQR: 49.5 - 73.5) and a pass rate of 95.7% ( $Z = -6.214$ ,  $P < 0.001$ ). Scores in all theoretical knowledge dimensions showed a statistically significant increase (all  $P < 0.001$ ), among which the LUS-related knowledge dimension had the most significant improvement, with the median score increasing from 6 points to 23 points. Specific comparisons of theoretical knowledge scores before and after training are shown in **Table 2**.

**Table 2.** Comparison of theoretical knowledge scores before and after training (N = 47).

Theoretical knowledge dimensions	Before training, Median (IQR)	After training, Median (IQR)	Z value	P value
Basic ultrasound principles	8 (4 - 12)	16 (14 - 18)	-5.892	<0.001
Inferior vena cava ultrasound	7 (3 - 11)	22 (18 - 25)	-6.015	<0.001
Lung ultrasound	6 (2 - 10)	23 (19 - 26)	-6.103	<0.001
Clinical application guidelines	5 (2 - 8)	14 (12 - 16)	-5.987	<0.001
Total score	30 (15 - 44)	65.5 (49.5 - 73.5)	-6.214	<0.001

### 3.3. Post-Training Operational Skill Assessment Results

The performance of all three operational skills after training met the basic requirements for clinical application. The mean scores were  $78.3 \pm 4.2$  for basic ultrasound operation,  $76.5 \pm 3.8$  for LUS operation and  $77.2 \pm 3.5$  for IVC operation; the pass rate ( $\geq 60$  points) for all three operations exceeded 95%, and the excellent rate ( $\geq 80$  points) ranged from 24.4% to 29.3%. Nurses with previous ultrasound training experience had a higher excellent rate (41.7%) than those without (23.5%), but the difference was not statistically significant ( $P > 0.05$ ). The distribution of post-training operational skill scores is detailed in **Table 3**.

**Table 3.** Distribution of post-training operational skill scores (N = 47).

Operational items	Mean $\pm$ SD (score)	60 - 79 points, n (%)	80 - 100 points, n (%)
Basic ultrasound operation	$78.3 \pm 4.2$	33 (70.7)	14 (29.3)
Lung ultrasound operation	$76.5 \pm 3.8$	36 (75.6)	11 (24.4)
Inferior vena cava ultrasound operation	$77.2 \pm 3.5$	34 (73.2)	13 (26.8)
Mean operational score	$77.3 \pm 3.6$	35 (74.5)	12 (25.5)

## 4. Discussion

### 4.1. Effectiveness and Mechanism of the Training Model

The results of this study verified the preset hypothesis: the integrated theory-case-practice training model can significantly improve the theoretical knowledge of ICU specialist nurses in IVC and LUS, with the median theoretical score increas-

ing by 35.5 points and the pass rate increasing by 89.3 percentage points ( $P < 0.001$ ). This significant improvement is attributed to the rigorous design of training content: abandoning complex theoretical knowledge and setting training content oriented to clinical needs; adopting a progressive teaching method of theory-clinical images-real cases to help participants establish cognitive associations between theoretical knowledge and clinical application scenarios (Jarman et al., 2023; Lockstone et al., 2024; Vives et al., 2022; Zachariah et al., 2024).

For simulated operational skills, hands-on training on human models not only reduces the risk of clinical operations, but also provides nurses with opportunities for repeated practice of operational skills (Asmara et al., 2022; Martínez et al., 2025). Joint teaching by senior ICU physicians and certified nurses ensures both the standardization of operational techniques and the clinical relevance of training content (Greenstein & Guevarra, 2022; Jarman et al., 2023); meanwhile, the case-based discussion session in theoretical courses further strengthens nurses' ability to apply the learned theoretical knowledge and simulated operational skills to clinical problem-solving thinking, forming a closed loop of learning-practice-application (Yuan et al., 2021).

#### 4.2. Comparison with Established Nurse-Led POCUS Training/Competency Frameworks

Established international nurse-led POCUS training and competency frameworks (e.g., the EFSUMB Nurse-led POCUS Framework (Jarman et al., 2023), the Diploma in Basic Echocardiography Training for Critical Care Nurses by the Spanish Society of Anesthesiology and Critical Care/ Spanish Society of Emergency Medicine (Vives et al., 2022)) focus on competency development and emphasize the integration of theoretical foundation, operational proficiency and clinical decision-making ability. Such frameworks mostly adopt a phased training model with a long training cycle (3 - 6 months) and focus on multi-scenario clinical practice, but have the limitations of high resource input and slow promotion in regions with uneven distribution of medical resources.

In contrast, the tripartite theory-case-practice training model designed in this study is a short-term intensive training model tailored to the current situation of ICU nursing in China, which complements the existing domestic and international nurse-led POCUS training frameworks in the following aspects:

Simplified and efficient training for low-baseline groups: Aiming at the characteristic that most ICU nurses in China lack systematic ultrasound training (80.9% in this study), the model compresses the theoretical and practical content of bedside ultrasound into 2 days (16 academic hours), abandons redundant theories, and focuses on IVC and LUS skills closely related to critical care volume management, realizing the efficient improvement of theoretical knowledge and basic operational skills of low-baseline nurses.

Integration of clinical case transformation in short-term training: Different from the simple theory + practice model, this model embeds case-based discus-

sion throughout the training process, connecting theoretical learning and simulated operations with real clinical scenarios, which solves the problem of separation of learning and application in short-term training and lays a foundation for the clinical application of nurses' acquired skills.

Matching training content with grassroots clinical needs: The model focuses on IVC and LUS, the most needed ultrasound techniques for ICU volume management in China, which is more in line with the clinical needs of grassroots medical institutions and has stronger practicality and promotional value.

### 4.3. Comparison with Domestic and International Studies

The significant improvement in nurses' theoretical scores (46.7% increase in median score) and the high pass rate of simulated operational skills (mean score  $\geq 75$  points) in this study are consistent with the conclusions of international studies by Burgos et al. (2024) and Vives et al. (2022), verifying the universality of the effectiveness of integrated POCUS training for nurses. The unique advantages of this study are that the research sample covers 45 hospitals nationwide with strong representativeness, and it focuses on the volume management field combining IVC and LUS, directly addressing the clinical characteristic in China of available equipment, frequent use by physicians and rare use by nurses (Elgenidy et al., 2024).

However, the excellent rate of simulated operational skills of nurses in this study ( $<30\%$ ) was lower than that in some international studies (40% - 50%) (Berikashvili et al., 2025; Burgos et al., 2024). This result may be related to the limited training duration (16 academic hours), weak ultrasound foundation of the participants, and the inherent gap between simulated assessment and complex real clinical scenarios (Dana et al., 2024; Jobs et al., 2025; Kotevska Angjushev et al., 2025; Squizzato et al., 2021). International studies with higher excellent rates generally have longer training cycles and more in-depth clinical practice links, which also suggests that short-term intensive training can achieve the goal of cultivating nurses' basic ultrasound ability, but long-term clinical practice and regular re-training are needed to improve the proficiency of nurses' ultrasound operations.

### 4.4. Clinical Reality and Necessity of Training

The baseline data of this study reveal three major clinical problems in the field of ICU nursing in China: low coverage of specialized ultrasound skill training ( $<15\%$ ), low clinical application frequency by nurses ( $<10\%$ ), and high configuration rate of ultrasound hardware (89.4%). This phenomenon of available hardware but low utilization efficiency highlights the urgency of carrying out systematic and efficient specialized training in IVC and LUS for ICU specialist nurses. This study found that there was no significant correlation between training effects and demographic factors such as gender, age, educational background and professional title, indicating that this theory-case-practice training model has wide applicability and is suitable for promotion among ICU nurses with different back-

grounds in China.

#### 4.5. Clinical Evidence, Inferences and Study Limitations

The direct clinical evidence obtained in this study is limited to the improvement of ICU nurses' theoretical knowledge and simulated operational skills in IVC and LUS: after training, nurses have a solid theoretical foundation in ultrasound image recognition, mastery of volume assessment standards and judgment of clinical application scenarios, and can complete standardized simulated IVC and LUS operations on human models. This evidence confirms that the theory-case-practice model is an effective short-term training method to improve the basic POCUS ability of low-baseline ICU nurses.

Based on the above measured evidence, the following reasonable clinical inferences can be made: ① Nurses with improved theoretical knowledge and simulated operational skills can collect ultrasound-related clinical data for critically ill patients more accurately, providing more reliable real-time information for physicians' volume management decisions; ② The promotion of this training model can increase the proportion of nurses participating in bedside ultrasound application, make full use of the existing ultrasound hardware resources in ICUs, and improve the efficiency of bedside assessment for critically ill patients; ③ Nurse-led bedside IVC and LUS assessment can shorten the time of clinical data collection, which is expected to provide more timely clinical decision support for volume management. It should be emphasized that this study did not measure the actual clinical outcomes of patients, and the above inferences have not been verified by clinical outcome data such as mortality, duration of mechanical ventilation and readmission rate.

This study has the following limitations: ① A self-controlled before-and-after design was adopted without a control group, which may lead to the Hawthorne effect and affect the objectivity of training effect evaluation; ② There is a lack of long-term follow-up assessment, and the retention time of nurses' ultrasound theoretical knowledge and simulated operational skills is not clear, so the persistence of training effects remains to be verified; ③ Skill assessments were based on simulated scenarios, without operational assessments on real clinical patients, and the actual clinical application effect of nurses' ultrasound skills and related patient outcomes were not measured; ④ The sample size is relatively small, and the research results need to be further verified by large-sample and multi-center studies.

Future research directions: Adopt a randomized controlled trial design to compare the effectiveness of the theory-case-practice model with the traditional training model; extend the follow-up period to 6 - 12 months to evaluate the skill retention and long-term clinical application effect of trained nurses; carry out clinical outcome studies to verify whether nurse-led IVC and LUS assessment can improve the volume management effect and prognosis of critically ill patients; expand the training sample size and carry out multi-center research to further optimize the training model.

## 5. Conclusion

With the change in theoretical assessment scores as the primary outcome, this study verifies the preset hypothesis: the specialized IVC and LUS ultrasound training integrating theory, case-based discussion and hands-on practice can effectively improve the professional theoretical knowledge and simulated operational skills of ICU specialist nurses. Compared with established international nurse-led POCUS training/competency frameworks, this short-term intensive training model complements the simplified and efficient training for low-baseline groups and has strong promotional value and applicability in China.

In view of the current situation in China where the configuration rate of ultrasound hardware in ICUs is high but the clinical utilization rate of IVC and LUS by nurses is low, it is urgent to promote such systematic and efficient specialized ultrasound training. It is recommended that medical institutions incorporate this integrated theory-case-practice training model into the compulsory training curriculum for ICU specialist nurses, and establish a long-term training mechanism of basic intensive training-clinical practice application-regular retraining and assessment to continuously improve the standardization and proficiency of nurses' ultrasound operations, make full use of existing ultrasound resources, and provide more professional nursing support for the precise volume management of critically ill patients.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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