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Effectiveness of Lung Ultrasound Training Utilizing a High-Fidelity Simulator

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ABSTRACT

Background: The usefulness of lung ultrasound (LUS) has been demonstrated. However, it is unclear whether diagnostic techniques using LUS are accepted by all physicians. A simple simulation-based educational program may improve the LUS skills of beginners, but it has not been fully assessed.

Objective: This prospective study was conducted to assess the educational outcomes of LUS training using a high-fidelity simulator.

Methods: A simulator-based program for LUS was conducted. All clerkship students at the Department of Respirology at Chiba University Hospital participated in the program from December 2022 to April 2023. The participants watched a 30 minute teaching video on demand before a hands-on session lasting for 1 hour during the first week of the clinical clerkship. The readiness of the participants to learn LUS and the usefulness of the program were assessed using questionnaires administered before and after the program. The LUS skills were assessed using simulator-based tests during Weeks 1 and 4. Data on the accuracy and time required to answer the questions were collected during the tests.

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Results: Forty clerkship students participated in this study. Thirty-three (82.5%) had received other ultrasound education; however, only two (5.0%) had experience with LUS. Based on the questionnaire responses, the participants perceived LUS as useful (preprogram: 4.6 vs. postprogram: 4.8; $P = 0.010$; a 5-point Likert scale was used [1: not useful to 5: useful]). The simulator-based tests showed comparable accuracies at Weeks 1 and 4 for pneumothorax (Week 1: 47.5% vs. Week 4: 52.5%; $P = 0.623$), pulmonary edema (Week 1: 100% vs. Week 4: 100%; $P = 1.000$), and pleural effusion (Week 1: 37.5% vs. Week 4: 40.0%; $P = 0.800$). The time required for scanning was the same for each question. In addition, the test results did not differ with prior learning, previous knowledge, or experience during clinical clerkships on LUS.

Conclusion: A short educational program consisting of on-demand learning and hands-on sessions with a high-fidelity simulator would be effective in equipping clerkship students with basic LUS skills. However, to increase its educational effectiveness to a practical degree, the program should be improved, and more opportunities for training using simulators should be provided.

Keywords:
medical education; simulation training; ultrasonography; point of care

Point-of-care ultrasound (POCUS) is gaining popularity as a rapid and minimally invasive diagnostic technique in acute care. Lung ultrasound (LUS) was developed as a diagnostic tool for respiratory diseases (1, 2). The preparation for clinicians on LUS techniques in clinical practice is already available, with an excellent protocol for the differential diagnosis of acute respiratory failure (3). Furthermore, ultrasonography demonstrated a high diagnostic accuracy for the outbreak of the coronavirus disease (COVID-19) (4). LUS is a useful diagnostic tool for pulmonologists.

The usefulness of LUS has been proven. However, it is unclear whether the diagnostic techniques of LUS are accepted by all physicians. Even in recent years, POCUS has not been implemented in internal medicine training programs (5). In addition, specific studies on educational interventions for learning LUS are limited, and methods for teaching LUS to beginners have not been fully investigated. Lum and colleagues reported the outcomes of LUS simulation training with in-person lectures and bedside practice for undergraduate medical students (6). Although this approach has not been established to be optimal for teaching LUS in nonrespiratory fields, some studies have reported the usefulness of ultrasound simulators for POCUS education (7, 8). Furthermore, it became necessary to establish an educational system that does not rely on bedside practice after the COVID-19 outbreak.

We hypothesized that a simple simulation-based educational program for beginners would effectively equip them with LUS skills. To test our hypothesis, we conducted a prospective study using a new educational program for LUS with an ultrasound simulator for clerkship students with limited experience.

METHODS

Study Design and Participants

This was a single-arm study without a control group. A few studies have recommended incorporating LUS into undergraduate education (9), but this has not been implemented in our university. Thus, we expected a significant difference between the LUS skills of the intervention and nonintervention groups, because the participants had no experience with LUS before our program.

The participant selection flow chart is provided in Figure 1A. Undergraduate medical students (fourth–fifth grade) in a clinical clerkship (CC) at the Department of Respiratory Medicine at Chiba University Hospital from December 2022 to April 2023 participated in the study. Medical schools in Japan offer a 6-year curriculum, and the final 2 years are generally spent on CCs (10). At our university, CC starts in December for the fourth grade, and it is an elective focused on Respiratory Medicine or Thoracic Surgery in the fourth–fifth grades at

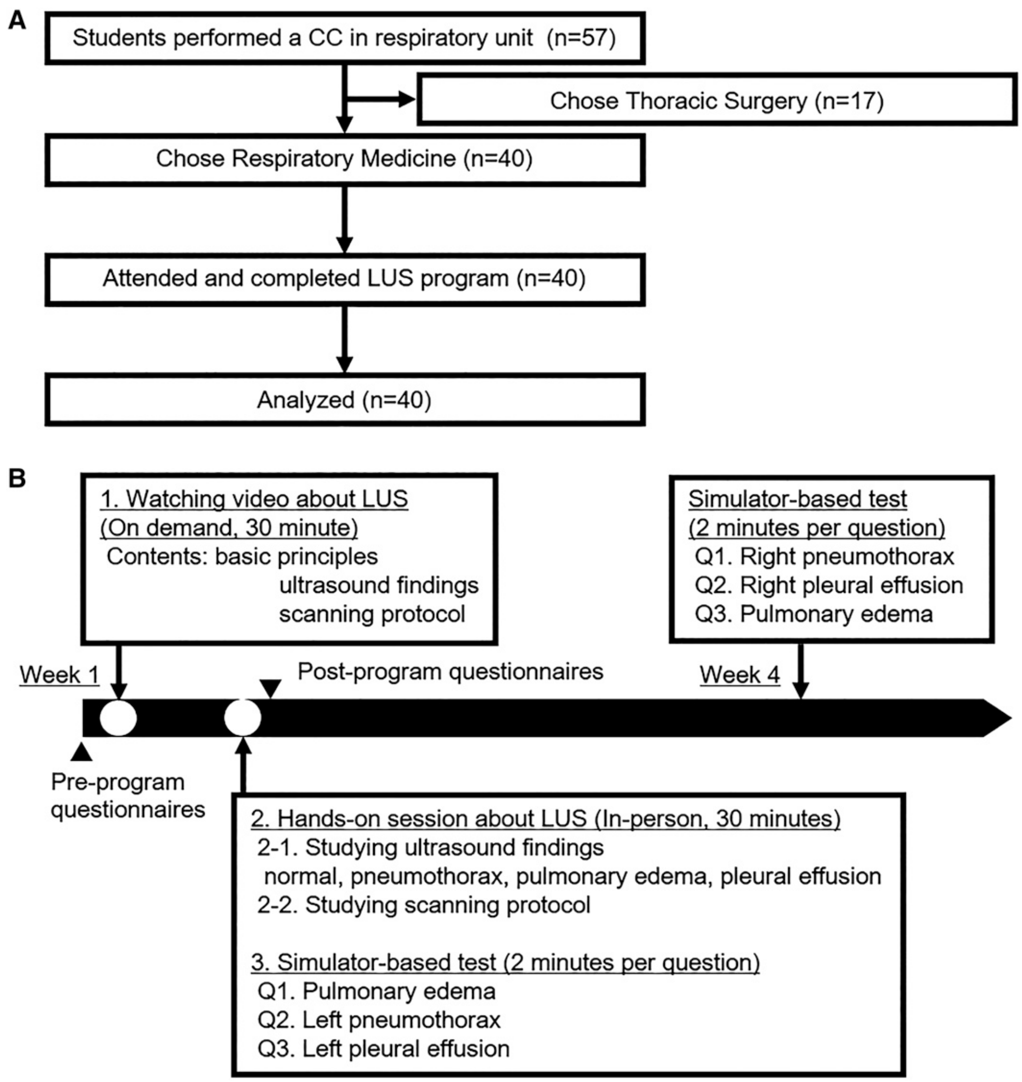

Figure 1. Flow charts for the selection of participants and the program. (*A*) Flow chart for the selection of participants. All 40 medical students who performed CCs in respiratory medicine from December 2022 to April 2023 completed the educational program, and their data were analyzed. (*B*) Flow chart of the educational program and data collection. The demographic data of the participants were collected with preprogram questionnaires. Their needs for LUS were determined based on their pre and postprogram questionnaire responses. CCs = clinical clerkships; LUS = lung ultrasound.

the respiratory unit of our hospital. There are approximately 120 students in each grade at our university.

In this study, the number of participants was based on realistic possibilities, and the sample size was not predetermined. We originally planned to collect data for 1 year (December 2022 to November 2023), and approximately 80 students participated in our study. However, data collection was discontinued in April 2023 because of concerns that the simulator update in May 2023 would affect the interventional results.

Ethical Approval

This study adhered to the principles of the Declaration of Helsinki and was approved by the Research Ethics Committee of Chiba University (approval no. 4106). All adult participants provided written informed consent to participate in this study. We adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist.

Educational Intervention

The flowchart for the educational program is shown in Figure 1B. The participants watched a 30-minute video on demand before the hands-on session. The video explained the theoretical background of ultrasonography, normal imaging, findings of pneumothorax, findings of pulmonary edema, findings of pleural effusion, and the LUS scanning protocol, in that order. The video viewing records of all the participants were verified. In addition, the video was freely available during the CC in our department.

During the first week of CC, a 30-minute hands-on session using the high-fidelity ultrasound simulator (Bodyworks, MedaPhor) was conducted. Each hands-on session involved three to four students. First, the characteristic findings of normal lungs, pneumothorax, pulmonary edema, and pleural effusion, which are diseases primarily diagnosed with LUS, were reviewed. Second, a scanning protocol for acute respiratory failure (bedside lung ultrasound in emergency protocol) (3) was implemented. Immediately after the hands-on session, each participant underwent a simulator-based test. The participants performed LUS for three cases of dyspnea on the simulator within 2 minutes during the test. No specific clinical information was provided during the test. Subsequently, they freely answered questions about the LUS findings and diagnosis for each case. The diagnosis for each question is shown in Figure 1B. Participants received feedback from their supervisor (a pulmonologist proficient in LUS) after the test. The simulated cases used for practice and testing were verified by several physicians (K.T., H.K., and N.H.) skilled in LUS to ensure appropriate answers to the questions.

Data Collection

On the first day of CC, questionnaires were collected to determine the readiness of the participants for LUS. The questionnaire included questions on age, sex, previous knowledge of any ultrasound examination, and understanding of LUS. A 5-point Likert scale was used to determine the perceptions of the participants about the usefulness of LUS (1 = not useful to 5 = useful) and their motivation to learn it (1 = low to 5 = high). Immediately after the hands-on session, the participants responded to similar questionnaires about the perceived usefulness of LUS and the motivation to learn LUS. They also reported their opinions about the educational program and their satisfaction with it.

Simulator-based tests to determine the LUS skill levels were performed during Weeks 1 (immediately after the hands-on session) and 4 of the CC. Data on the accuracy and time required to answer the questions were collected during the tests. On the last day of the CC, the participants indicated whether they had other opportunities to learn LUS during the CC, apart from those enrolled in this educational program.

Data Analysis

Quantitative data are expressed as mean ± standard deviation unless otherwise indicated. The Wilcoxon signed-rank test was used to compare the responses of the questionnaires (pre- and post-program) and the simulator-based test results (Weeks 1 and 4 of the CC). The Mann-Whitney *U* test was also used to determine the effect of the readiness of the participants on the simulator-based test results. *P* value < 0.05 denoted statistical significance. JMP version 15.0 was used for all statistical analyses.

RESULTS

Forty clerkship students participated in the educational program, and all completed it. The demographic characteristics of the participants are shown in Table 1. Thirty-three participants (82.5%) had received other ultrasound education; however, only two (5.0%) had experience with LUS. Thus, as expected, most participants were beginners in LUS. In addition, 27 participants (62.5%) had no prior knowledge of LUS.

The differences between the questionnaire results before and after the program are shown in Table 2. The perceptions of the participants about the usefulness of LUS (5-point Likert scale was used [1: not useful to 5: useful]) were reinforced by our educational intervention (pre-program: 4.6 vs. post-program: 4.8; *P* = 0.010). Meanwhile, their motivation to learn LUS (a 5-point Likert scale was used [1: low to 5: high]) did not change (pre-program: 4.5 vs. post-program: 4.5; *P* = 1.000). The diagnostic accuracies during the simulator-based tests in Weeks 1 and 4 were comparable for pneumothorax (Week 1: 47.5% vs. Week 4: 52.5%; *P* = 0.623), pulmonary edema (Week 1: 100% vs. week 4: 100%; *P* = 1.000), and pleural effusion (Week 1: 37.5% vs. Week 4: 40.0%; *P* = 0.800) (Table 3). In addition, the time required for scanning remained unchanged for each question (*see* Table E1 in the data supplement).

The results of the simulator-based tests did not differ with prior learning or knowledge of LUS (Tables E2 and E3). In addition, four participants (10.0%) had the opportunity to observe LUS at the bedside during CC apart from the opportunities provided by this program. However, the accuracies of these 4 and the other 36 participants in Week 4 did not significantly differ (pneumothorax: 50.0% vs. 52.8%; *P* = 0.938; pulmonary edema: 100% vs. 100%; *P* = 1.000; pleural effusion: 25.0% vs. 41.7%; *P* = 0.541, respectively).

DISCUSSION

In this study, a single educational intervention of approximately 60 minutes, combining on-demand learning and hands-on sessions with a high-fidelity simulator, showed some effectiveness in equipping beginners with LUS skills. To the best of our knowledge, this is the first study to report a combined method for LUS training. Previous studies have reported on educational programs using real patients (11, 12) and simulations (6). Although these methods help in learning

Table 1. Demographics of participants

Participants	*n* (%)
Total	40 (100)
Female sex	12 (30.0)
Prior study of ultrasound (education type)	
Didactic lectures	22 (55.0)
Watching at bedside	23 (57.5)
Simulator	20 (50.0)
Simulated patient or peer students	13 (32.5)
Real patient	12 (30.0)
Prior study of ultrasound (type of ultrasound)	
Cardiac	16 (40.0)
Abdominal	14 (35.0)
Gynecologic	7 (17.5)
Musculoskeletal	5 (12.5)
FAST	4 (10.0)
Lung	2 (5.0)
Previous knowledge of LUS	
Never heard of LUS	8 (20.0)
Not well-informed about LUS	19 (47.5)
LUS can assess pleural effusion	12 (30.0)
In addition to assessing pleural effusion, LUS can diagnose pneumothorax and pulmonary edema	1 (2.5)

Definition of abbreviations: FAST = focused assessment with sonography for trauma; LUS = lung ultrasound.

LUS, there is concern that it may be difficult to recruit live patients to carry out the program consistently. Therefore, the use of simulators as an alternative to live patients is reasonable. In addition, the use of flipped classrooms with on-demand videos may contribute to improvements in educational efficiency (13).

However, the high cost of using a high-fidelity simulator presents an obstacle. Web-based training has also been reported (14, 15) and may be worth incorporating. Gargani and colleagues reported the use of only web-based training. However, their study was specific to the diagnosis of pulmonary edema using ultrasound (15). Hence, it is unclear whether web-based training will have favorable outcomes for the diagnosis of pneumothorax and pleural effusion using LUS.

The differences between the diagnostic accuracies for the diseases in the present study are arguable. No previous studies have reported on the difficulty of each

Table 2. Readiness of the participants for lung ultrasound

Item	Before the Program	After the Program	*P* Value
Perceived usefulness of LUS	4.6	4.8	**0.010**
1 (not useful)	0 (0)	0 (0)	
2	0 (0)	0 (0)	
3	2 (5.0)	0 (0)	
4	12 (30.0)	8 (20.0)	
5 (useful)	26 (65.0)	32 (80.0)	
Motivation to learn LUS	4.5	4.5	1.000
1 (low)	0 (0)	0 (0)	
2	0 (0)	0 (0)	
3	2 (5.0)	2 (5.0)	
4	16 (40.0)	16 (40.0)	
5 (high)	22 (55.0)	22 (55.0)	

Definition of abbreviation: LUS = lung ultrasound.
Data are presented as mean or *n* (%) unless otherwise noted. Each item was answered using a 5-point Likert scale. Bold indicates $P < 0.05$.

LUS finding, but our results suggest that the degree of difficulty varies. For pulmonary edema, abnormal findings are bilateral and diffuse; therefore, it is highly unlikely that all of them will be missed. However, pneumothorax and pleural effusions are more likely to be missed because of their localized distribution. Several studies have reported that LUS has a steep learning curve (16, 17). However, Rouby and colleagues stated that 25 bedside educational interventions are needed to acquire LUS skills (12).

There was no relationship between the degree of prior knowledge and LUS performance in this study. This suggests that interventions to bridge the gap between knowledge ("knows" and "knows how" in Miller's pyramid) and skills ("shows" and "does" in Miller's pyramid), such as simulation training, were inadequate (18). Therefore, modifying the program to help participants who are not fully proficient can improve skill acquisition. In addition, the educational programs were short and easy to repeat

Table 3. Accuracy of simulator-based tests

Question	Week 1	Week 4	*P* Value
Pneumothorax	47.5	52.5	0.623
Pulmonary edema	100	100	100
Pleural effusion	37.5	40.0	0.800
Total number of questions answered correctly	20.0	22.5	0.767

Data are presented as percentages.

for poorly performing students. Meanwhile, the retention of LUS skills was confirmed in this study, although this was based on data obtained during a short period. Previous studies on POCUS for other organs have also reported skill retention (19, 20). The present results suggest that a single LUS educational intervention has a lasting effect.

Limitations

Our study had four limitations. First, it was conducted at a single institution, and the number of participants was less than expected because recruitment had to be discontinued early. Second, part of the evaluation relied on the questionnaire responses of the participants. Third, the participants were undergraduate medical students, and the effectiveness of the educational program was assessed using only simulator-based tests. Therefore, we did not examine whether the skills acquired in this program would be useful in clinical practice. Fourth, although the short-term retention of skills after the program was confirmed, there were no long-term follow-up data.

Conclusions

A short educational program consisting of on-demand learning and hands-on sessions with a high-fidelity simulator would be effective in equipping clerkship students with basic LUS skills. However, more than half of the participants required additional training to accurately diagnose pneumothorax and pleural effusion. To increase its educational effectiveness to a practical level, the program should be improved, and more opportunities for training using simulators should be provided. Further research should extend the target population of participants and conduct longer follow-up.

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