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Original Article

Role of 2-day critical ultrasound training curriculum in guiding clinical activities in China

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Abstract: Background: The effectiveness of critical care ultrasound has been demonstrated and training for it is urgent. Critical Care Ultrasound Study Group (CCUSG) has been dedicated to ultrasound training. The aim of the study was to evaluate course structure and training effect and provide improvement suggestions for future training. Methods: A multicenter retrospective study was conducted. All participants went through a 2-day training curriculum based on the critical care ultrasonic examination (CCUE) protocol. Pre- and post-class evaluation were applied and data were collected. Non-parametric tests were adopted for the comparison, and a Generalized Linear Model (GLM) was used for further analysis. Results: A total number of 792 trainees, with a mean age of 35.8, participated in the study. There were more males in the study population. Most of the trainees were attendings, and most of them had bachelor's degrees, worked at tertiary hospitals and had a mean working experience of 6.9 years. The scores of all trainees were improved to various degrees after the course. An increase from 50% to 72% ($P \leq 0.001$) was seen in theory test scores. All the competency assessment scores, including IAS (34% to 50% for cardiac images and 30% to 60% for pulmonary images), IPS (30% to 50%) and AAS (31% to 44%), were improved. A questionnaire after class suggested that 88.0% of the participants found the training course very useful. Conclusion: 2-day training course can improve the ability of physicians to assess critically ill patients with the help of the ultrasound.

Keywords: Critical ultrasound, training curriculum, CCUE protocol, hemodynamic state, training effect

Introduction

In recent years, critical ultrasound has become the first choice among imaging techniques to integrate both clinical and laboratory information of critically ill patients [1]. Point-of-care (POC) ultrasound provides effective help for bedside monitoring and assessment of complex clinical situations [2]. Differential diagnosis can also be effectively carried out in most cases, such as for hemodynamic instability and acute respiratory failure [3-5]. Since the beginning of 2020, the coronavirus disease 2019 (COVID-19) pandemic has led to unprecedented pressure on healthcare services, especially for critically ill patients [6], and POC ultrasound has been an effective weapon for doctors to maximize patient access to appropriate clinical evaluation, and plays a decisive role in decision making and surveillance [7].

Although evidence exists to support the clinical value of POC ultrasound [8], the steep learning curves for ultrasound suggest that the learning period should be very long. However, studies showed that it can be significantly shortened under the guidance of the tutor [9, 10]. In the past few years, many curricula have sprung up in order to give effective training [11-14]. In China, there has been no mature training sys-

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tem for the intensivists. Since 2013, Critical Ultrasound Study Group (CCUSG) has been dedicated to the construction of a proper training system and the popularization of critical ultrasound, and thousands of doctors have been trained (Supplementary Material). In order to improve the quality of training continuously, research started focusing on training effect as well as the problems in the training process. The aim of this study was to evaluate course structure and training effect, at the same time, to provide improvement suggestions for future training.

Methods

Participants

A multicenter retrospective study was conducted nationwide in China from July 2019 to December 2020, and 19 centers were involved including Beijing, Changsha, Chengdu, Chongqing, Fuzhou, Guangzhou, Guiyang, Jinan, Kunming, Nanning, Shanghai, Shenyang, Shenzhen, Shijiazhuang, Tianjin, Wuhan, Xining, Xuzhou and Yantai. This study was approved by the ethics committee of Peking Union Medical College Hospital. Ethics board review was waived as the training is part of the normal practice, which was confirmed by the local committee. Trainees were all invited to this program and written informed consent were obtained.

Training course setting

Trainees, including intensive care specialists, anesthetists and other physicians, with different backgrounds (time for critical work, hospital level, gender, age, professional rank and education background) were all in a two-day critical ultrasound training curriculum, no matter whether they had undergone any ultrasound training.

A pre-class test was applied before starting the course including a theory test and a competence assessment which composed of image acquisition score (IAS), image interpretation score (IPS) and application ability score (AAS). The training curriculum was based on the critical care ultrasonic examination (CCUE) protocol, and was composed of three sections, which were imaging acquisition, imaging interpretation, and clinical application [15] (Supplementary Material).

Imaging acquisition

The imaging acquisition section, including five cardiac views and ten pulmonary views, and a combination of eFATE and BLUE-plus protocols [15, 16], was taught by the trainers through a "hand to hand teaching" method. In critically ill conditions, we need to assess the cardiopulmonary function at the same time. CCUE protocol was selected because eFATE protocol focused on cardiac function while BLUE-plus protocol only assessed morphology and function of the lung. Every trainer was responsible for about 8 trainees who were trained at the same time in the same place.

Image interpretation

The image interpretation section included more than 100 dynamic images carefully selected from the database of CCUSG and was divided into the echocardiography (ECHO) part and the lung ultrasound (LUS) part. In the ECHO part, the trainees were taught to recognize the normal and abnormal structure and function of the heart by the sequence of "cavity-wall-valve-flow", and in the LUS part, the trainees were taught to recognize the typical patterns including A lines, B lines, consolidation (including shred sign, and tissue-like sign), pleural effusion, and lung point. Clinical application section included the integration of ultrasound imaging and the clinical information, also known as "6 steps of hemodynamic assessment", and a typical case would also be used to fully illustrate this method. A post-class test which was the same as the pre-class test was repeated after the whole training program. All the trainers were authorized by CCUSG, with more than five years of experience in critical care ultrasound practice and three years of training experience. The flow chart is seen in **Figure 1**. Details of the curriculum and CCUSG are shown in Supplementary Material.

Feedback questionnaire survey

A questionnaire was used to survey participants' satisfaction with the course. The questionnaires were designed to be short, and were distributed through the WeChat QR code, and participants attending the course were invited to fill them out after each session and informed that real-time teaching improvements would be made based on the results of the question-

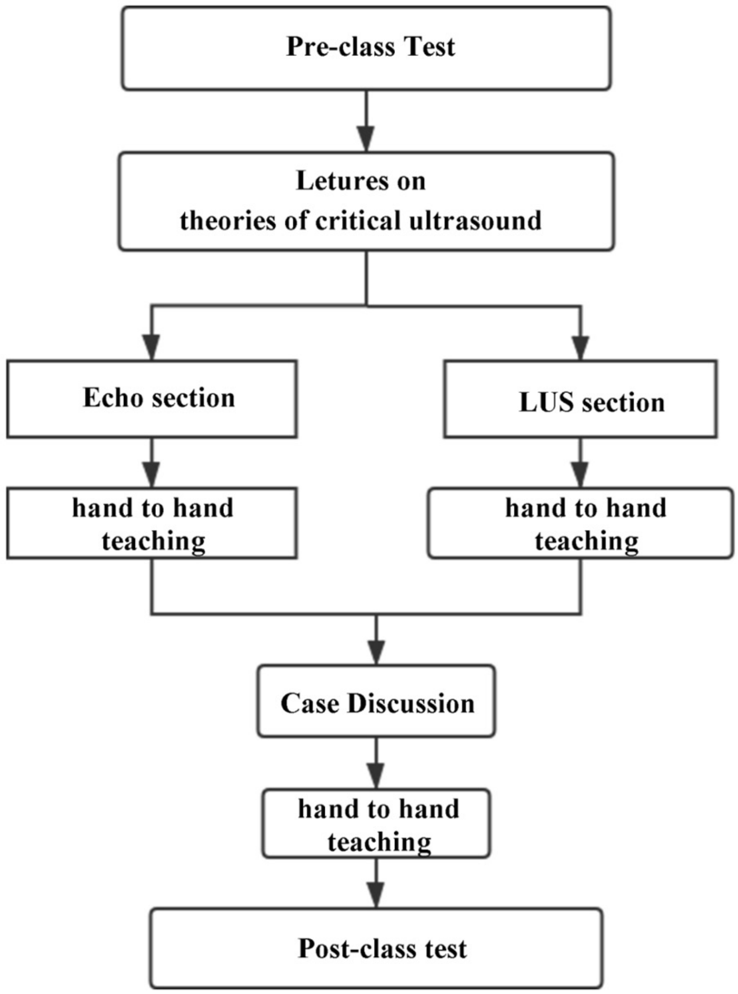

Figure 1. Flow chart of the curriculum. LUS: Lung Ultrasound.

naires, which ensured the authenticity and reliability of the survey results as well as a high response rate.

Statistical methods

All the data were collected from CCUSG database, including personal information, scores of theory tests and scales both pre- and after-class. Personal information included gender, age, time for critical care work, professional rank, hospital level [17], education background, and training city. Continuous variables were described as mean ± standard deviation (SD) or median value with 25th and 75th percentiles. Categorical variables were presented as numbers and percentages. Gender, hospital level, education background, professional rank and training city were used as categorical variables. Comparison of scores of trainees before and after the training course were conducted with non-parametric tests, since the data were not in a Gaussian distribution.

Subgroup analyses were stratified by gender, hospital level, education background, professional rank, and training city to assess the factors influencing the training effect. If P<0.05, Generalized Linear Model (GLM) was adopted to determine the predictors of various characters for each intensivist. β-values and their confidence intervals (CIs) were estimated to quantify them. In the first step, a basic model was constructed without the inclusion of the confounding factors. To adjust for confounding effects, personal information was incorporated into the model in the second step. In multivariate regression analysis, a situation may occur where the predictor variables are highly correlated with each other as well as with the response variable, and this is referred to as "collinearity". As age and time for critical work was highly correlated, we only took the latter into the final model. We set the bachelor degree group and Beijing as reference groups, separately. Statistical significance was set as P<0.05. All analyses were conducted using Statistical Product and Service Solutions (SPSS) software Version 25.0.

Results

A totalof 792 trainees participated in the study. Distribution of trainees are shown in **Figure 2**. The mean age of the trainees was (35.8±6.3). The trainees included more males (N=438), taking up 55.3% of the total population. 46.6% of the trainees were attendings, and 58.4% of them had bachelor's degree. Among the 19 training cities, Changsha trained the most intensivists (N=123, 15.5%). 78.2% of the trainees worked at the tertiary hospitals. The mean working experience was 6.9±4.9 years (**Table 1**).

Figure 2. Distribution of training locations and number of trainees in China.

Non-parametric test showed that after the training course, the theory scores and the assessment scale of all trainees were improved to various degrees (**Table 2**). The median score for the theory test improved significantly from 50% to 72% (P<0.0001). Competence assessment scale, including IAS, IPS and AAS, was also improved. Acquisition scores on the cardiac images went up from 34% to 50% and 30% to 60% for pulmonary images (P<0.0001). IPS also increased, from 30% to 50% (P<0.0001). Also, we were pleased to find the training course was helpful to the clinical work, as AAS improved from 31% to 44% (P<0.0001). A 38% improvement was seen from the feedback of the trainees. The results of the questionnaire suggested that 88.0% of the participants felt it very useful after the training course.

As shown in **Table 3**, *P* values were different among various subgroups. Non-parametric test showed that educational background and training place affect the quality of training, with *P* values less than 0.05 (**Table 3**). Educational background affect the improvement in theory test, IPS and AAS. Then, an analysis of covariance (ANCOVA) with educational background as the independent variable, pre-training scores as the covariate, and score differences across scores as the dependent variable showed that there was no interaction between educational background and pre-training score, and the slope homogeneity assumption was met; the ANCOVA results showed that there was a significant difference in the score difference comparisons across educational backgrounds after removing confounders from pre-training scores (**Table 4**). When we did further analysis in GLM, only theory test scores were affected. In the single-factor model, taking the bachelor's degree group as the reference group, the β-value for master's group was 1.95 (95% CI: 0.17-3.73). For the doctor's group, β-value was 3.86 (95% CI: 0.22-7.05). In the multi-factor model, no statistical significance was found in the master's group, while the doctor's group showed statistical significance: β-value was 4.11 (95% CI: 0.31-7.91) (**Table 5**). Training location also affected efficacy. Taking Beijing as the reference group, improvement of pulmonary IAS and AAS were lower in Yantai and higher in Fuzhou. In Yantai, β-value for pulmonary IAS was -18.2 (95% CI, -33.12 and -3.29). For AAS, the value was -14.28 (95% CI, -23.48 and -5.07). In Fuzhou, the values were 27.16 (95% CI, 13.82 and 43.51) and 14.57 (95% CI, 6.03 and 23.12), separately. No statistically significance was seen among other cities (**Table 6**).

Discussion

To the best of our knowledge, this is the first study ever conducted nationwide in China to improve the ability of all physicians to rapidly assess critical illness. It is also the largest multi-center study on critical ultrasound training in the world. After the 2-day training course, trainees can grasp the basic skills in critical ultrasound, and the method of evaluating hemodynamics can be mastered in a short time. Ultrasonography can be effectively used to help doctors evaluate the patients' hemodynamic state. In the past, point-of-care ultrasound was mainly used to guide operations and other procedures but it is now generally recognized as an indispensable tool in intensive care units (ICUs) [18]. In the last few decades, ultra-

Table 1. Demographics of all trainees in the curriculum

Demographics (N=792)	Mean ± SD/N%
Age	35.8±6.3
Time for Critical Work	6.9±4.9
Gender	
Male	438 (55.3%)
Female	354 (44.7%)
Professional rank	
Residents	213 (26.9%)
Attendings	369 (46.6%)
Associate chief physician	163 (20.6%)
Chief physician	47 (5.9%)
Hospital Level	
Level 1	11 (1.4%)
Level 2	162 (20.5%)
Level 3	619 (78.2%)
City	
Beijing	22 (2.8%)
Changsha	123 (15.5%)
Chengdu	61 (7.7%)
Chongqing	37 (4.7%)
Fuzhou	46 (5.8%)
Guangzhou	60 (7.6%)
Jinan	24 (3%)
Kunming	31 (3.9%)
Nanning	33 (4.2%)
Shanghai	39 (4.9%)
Shenyang	16 (2%)
Shenzhen	30 (3.8%)
Shijiazhuang	65 (8.2%)
Tianjin	27 (3.4%)
Wuhan	32 (4%)
Xining	50 (6.3%)
Xuzhou	34 (4.3%)
Yantai	31 (39%)
Guiyang	31 (39%)

Note: SD: Standard deviation.

Table 2. Non-parametric tests before and after the training curriculum

	Before Class	After Class	*P* value
Theory Test	48.3±9.9	69.5±12.3	P<0.0001
Image Acquisition			
Cardiac Image	18.7±12.4	24.5±12.1	P<0.0001
Pulmonary Image	18.7±13.3	29.0±13.2	P<0.0001
Image Interpretation	16.9±11.3	24.2±11.9	P<0.0001
Application Ability	15.9±10.5	22.0±11.4	P<0.0001

sound has gradually become the most important imaging technique at the bedside to integrate clinical assessment of the critically ill patients [1]. Its application in ICUs includes differential diagnosis and therapeutic management for most critical situations such as hemodynamic instability [3], acute respiratory failure [4], or cardiac arrest [5]. Early, goal-directed therapy (EGDT) is recommended for the resuscitation of critical patients, especially those presenting with early septic shock [19].

Ultrasound played a vital role in clinical decision-making during the COVID-19 pandemic. Under heavy protective clothing, doctors' visual diagnosis, palpation, percussion and auscultation are restricted to various degrees [6]. It has rapidly become the main assessment methods in diagnosis and treatment during the process of disease. Critically ill patients benefit from ultrasound exam due to its advantages such as convenience, speed, non-invasiveness, and saving of medical resources. There is already much evidence to support the clinical value of lung ultrasound [8]. As for other areas, examinations should also be conducted focusing on a main clinical question [20]. Problem-oriented assessment of critically ill patients are of maximum benefit to patients. Many doctors think it is imperative to master critical ultrasound, especially after COVID-19.

CCUSG, which was established in 2013, launched a series of ultrasound training courses at the beginning, aiming at getting every critical care physician to master critical ultrasound. We have focused on the critical care ultrasound for a long time, and established a series of procedures [9]. The curriculum integrates the concept of visual management of critically ill patients based on critical ultrasound to provide early and correct therapy to the maximum extent. After constant exploration and trials, we finally set the course duration as 2 days. In the course, we choose the CCUE process for detailed introduction, because it provided assess-

Table 3. Subgroup analysis: non-parametric test of subgroup differences on score-improvement

No.	Item	Gender	Professional rank	Hospital Level	Educational Background	City	Professional background
n=788	Theory Test	0.464	0.143	0.682	0.035	0.324	0.682
n=785	Image Acquisition	0.637	0.611	0.784	0.265	0.128	0.676
n=784	Cardiac Image	0.461	0.794	0.671	0.413	0.418	0.744
n=787	Pulmonary Image	0.676	0.453	0.804	0.21	**0.037**	0.696
n=788	Image Interpretation	0.524	0.692	0.969	**0.031**	0.902	0.705
n=780	Application Ability	0.189	0.994	0.432	**0.049**	**0.042**	0.584

All results were expressed as *p* values. The bolded ones were significant.

Table 4. ANCOVA results of the groups' score improvement corrected for pre-training score

	Source of variance	Type III sum of squares	Df	Mean square	F	Significant
Theory Test	Corrected Model	21243.776[a]	3	7081.259	59.327	0.000
	Intercept	65569.880	1	65569.880	549.346	0.000
	Pre-training score	20155.442	1	20155.442	168.863	0.000
	Education background	2233.613	2	1116.806	9.357	0.000
	Error	93578.096	784	119.360	-	-
	Total	473293.000	788	-	-	-
	Corrected Total	114821.872	787	-	-	-
	a. R Squared =0.185 (Adjusted R Squared =0.182).					
Image Interpretation	Corrected Model	2604.966[a]	3	7868.322	62.022	0.000
	Intercept	69864.847	1	69864.847	550.713	0.000
	Pre-training score	22419.585	1	22419.585	176.723	0.000
	Education background	2521.135	2	1260.567	9.936	0.000
	Error	99079.684	781	126.863	-	
	Total	478810.000	785	-	-	
	Corrected Total	12264.650	784	-	-	
	a. R Squared =0.192 (Adjusted R Squared =0.189).					
Application Ability	Corrected Model	22268.362[a]	3	7422.787	59.222	0.000
	Intercept	67459.508	1	67459.508	538.219	0.000
	Pre-training score	21254.499	1	21254.499	169.577	0.000
	Educational background	2204.057	2	1102.029	8.792	0.000
	Error	97262.576	776	125.338	-	-
	Total	473111.000	780	-	-	-
	Corrected Total	119530.937	779	-	-	-
	a. R Squared =0.186 (Adjusted R Squared =0.183).					

ment for heart and lung function at the same time and was performed according to the patients' clinical problems. The ultrasonographic findings provided strong evidence for clinical diagnosis, and treatment was rapidly applied. In terms of research programs, the study showed that the CCUE group had a shorter time to diagnosis, treatment response and a higher diagnostic accuracy rate [15]. During the course, the trainees learned the basic knowledge of ultrasound and the key points of ultrasound evaluation. Through hands-on and case discussion, they could apply this knowledge to the clinical practice to guide diagnosis and treatment. In general, practice is underpinned through education, competency and associated governance procedures [10]. Our study showed that all the scores including theory

Table 5. Effect of different educational background on score improvement

	Single-factor model	Multi-factor model
Theory Test		
Master	1.95 (0.17, 3.73)*	1.82 (-0.53, 3.69)
Doctor	3.86 (0.22, 7.05)*	4.11 (0.31, 7.91)*
Image Interpretation		
Master	-0.01 (-3.60, 3.59)	0.40 (-3.40, 4.20)
Doctor	6.13 (-1.23, 13.49)	7.16 (-0.55, 14.86)
Application Ability		
Master	1.30 (-1.28, 3.87)	1.71 (-1.01, 4.43)
Doctor	5.24 (-0.06, 10.54)	5.44 (-0.10, 10.98)

*: Significant difference. The reference group: bachelor's group.

test, image acquisition, image interpretation, and application ability were improved markedly through the 2-day training. The feedback indicated 88.0% of the participants felt the training course was very useful. This result proved that the course was set reasonably, and that students can master the relevant knowledge easily, which was gratifying to the training team.

As a training course for peers across the country, we found that the training effect was little affected by gender, age, or professional title. In the study, we found that improvements in theoretical performance was the most significant. Sensitivity analysis showed that theoretical score for those with high academic qualifications improved to a larger extent. This indicated that most trainees could master the theoretical knowledge. Different education background led to different learning abilities. Therefore, setting different courses for different groups was added to the course-improvement plan. The grades on practical courses were generally lower, which indicates that we should lengthen the hands-on part within the time limit. For IAS, pulmonary ultrasound improved to a larger extent. Pulmonary images were easily mastered, which was consistent with the learning curve of cardiac and pulmonary ultrasound.

Although we spent a lot of time on echocardiography, cardiac IAS was still lower. Studies have shown that echocardiography was the hardest to learn compared to other parts of the body. Meanwhile, pulmonary ultrasound was easier to obtain [21]. Practice makes perfect. All the trainees needed repeated practice, because even after a few examinations, image quality was not as well as for experienced sonographers [21, 22]. A study showed that ultrasound technique improved even after 200 examinations [21, 23]. Students need 37-109 ultrasound-guided procedures to gain competency even for ultrasound-guided interventions, a relatively easier procedure [24]. So, it is not possible to enable students to reach the level of experienced sonographers within two days of training.

We found the improvements in IPS and AAS were relatively slower, which is reasonable. The number of abnormal images was limited, and the models were healthy adults without cardiopulmonary diseases. In the past, we did not spend much time on image interpretation. Instead, we only focused on the way to get the image. Gradually, we improved the course by adding more abnormal slides and images to improve interpretation ability. A case-discussion part was also added to the course to combine critical ultrasound with clinical cases. According to the Canadian recommendations for critical care ultrasound training and competency, taking the difference in difficulty of cardiopulmonary ultrasound into consideration, a minimum number of 30 supervised studies for echocardiography should be performed by the learner in the training course while only 20 should be needed for lung and pleural ultrasound [9]. As the number of trainees increased rapidly, we could not meet the requirement in a limited time, so we assigned homework. The assignment included both image acquisition and interpretation, so that we can evaluate the students' learning effect comprehensively. Repeated practice was needed before handing in the final images, because we needed a video clip not only of images, but also of the evaluation process.

A difference existed in the training effect among different training cities. No statistical significance was found among other classifications, including gender, professional rank, or hospital level. That is to say, except for training location, all the other factors such as gender, professional rank, and hospital levels did not affect the students' learning curves. Our curriculum should reach more cities across the country. In terms of the training places, the training effect was better in provincial capitals than in remote

Table 6. Effect of different training city on score improvement (Reference city: Beijing)

City	Pulmonary IAS		AAS	
	β and 95% CI	*P* value	β and 95% CI	*P* value
Guiyang	-11.22 (-25.52, 3.08)	0.12	-10.74 (-19.78, -1.70)	0.02
Yantai	-18.20 (-33.11, -3.27)	0.02	-14.28 (-23.48, -5.07)	P<0.0001
Xuzhou	3.84 (-10.14, 17.82)	0.59	-3.57 (-12.40, 5.27)	0.43
Xining	10.77 (-2.61, 24.15)	0.15	-4.90 (-13.35, 3.56)	0.26
Wuhan	10.45 (-3.65, 24.56)	0.15	-1.22 (-10.13, 7.69)	0.79
Tianjin	3.16 (-11.50, 17.82)	0.67	-1.91 (-11.26, 7.44)	0.69
Shijiazhuang	9.56 (-3.08, 22.20)	0.14	3.29 (-4.70, 11.28)	0.42
Shenzhen	-11.58 (-25.92, 2.75)	0.11	-6.17 (-15.22, 2.89)	0.18
Shenyang	3.59 (-13.16, 20.34)	0.67	-1.89 (-12.48, 8.70)	0.73
Shanghai	-6.29 (-19.88, 7.30)	0.36	-3.63 (-12.21, 4.96)	0.41
Nanning	10.88 (-3.39, 25.15)	0.14	1.35 (-7.73, 10.42)	0.77
Kunming	0.62 (-13.90, 15.14)	0.93	-5.11 (-14.29, 4.07)	0.27
Jinan	-10.60 (-25.72, 4.52)	0.17	0.51 (-9.36, 10.38)	0.92
Guangzhou	-4.86 (-17.59, 7.87)	0.45	-5.10 (-13.14, 2.94)	0.21
Fuzhou	27.16 (13.82, 40.51)	P<0.0001	14.57 (6.03, 23.11)	0
Chongqing	10.18 (-3.78, 24.15)	0.15	4.10 (-4.77, 12.97)	0.36
Chengdu	-11.15 (-24.03, 1.72)	0.09	-7.87 (-16.00, 0.25)	0.06
Changsha	-11.77 (-23.67, 0.14)	0.06	-3.50 (-11.03, 4.03)	0.36

AAS: Application Ability Score; IAS: Image Acquisition Score.

cities. One reason may be that the number of trainers was smaller in remote cities. At the same time, as the use of critical ultrasound has expanded from provincial capitals to remote cities, the training experience in remote cities was relatively less. The results suggested that we should put more energy into training in remote areas. A unified arrangement of trainers nationwide will help to improve the quality of training.

There are several limitations to the study. First, the scores may exaggerate the training effect. In the training course, the models we used were healthy. Though they could contribute to increased hands-on competencies, they were most suitable for adapting with the ultrasound devices, learning differences of various probes, and improving hand-eye coordination. We should use different models to enable the trainees to identify more exceptions, because different models could contribute to different aspects of the learning process [10]. Dinh et al., however, found it was difficult to standardize patient with specific diseases and sonographic patterns [25]. Meanwhile, critical ultrasound test differed from other ultrasound examinations because image interpretation and pathologic recognition were based on the patient's hemodynamics instead of directly imaging diagnostics such as thickening of the gallbladder wall. Therefore, there is a great need for a standardized tool for assessing image acquisition and image interpretation. We added more image test on basic abnormalities to lay a solid foundation to achieve the purpose of reminding students to carefully analyze them in various circumstances. The evaluation system upgraded to coexistence of both subjective and objective scores. Second, our training system lacks long-term evaluation. As mentioned above, practice makes perfect. We ensure only a minimum level of competency and experience during the curriculum. Students need to continuously improve their skills and abilities in clinical practice. It is a challenge to evaluate long-term outcomes after training. We asked the trainees to hand in homework on cases they evaluated and treated with the help of critical ultrasound. We graded the assignments to assess the long-term effects of the course. The results will be presented in future articles. Third, we only set Beijing as the reference group in terms of the training effect, which may not be appropriate. Although Beijing is the birthplace of critical ultrasound in China, it might not be appropriate to set it as the only reference group. We should compare cities in pairs in our future work.

Conclusion

Physicians' abilities to assess critical ill patients with the help of the ultrasound improved after the 2-day training course. Through the curriculum, we proved that the method of evaluating hemodynamics can be mastered in a short time. After the training course, the students' theoretical and practical abilities were greatly improved. Prompt feedback showed ultrasonography could be effectively used to help doctors evaluate the patients' hemodynamic state. In the following courses, we will improve evaluation system and adjust the course structure to meet more needs.

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Disclosure of conflict of interest

None.

Abbreviations

AAS, Application Ability Score; CCUE, Critical Care Ultrasonic Examination; CCUSG, Chinese Critical Ultrasound Study Group; CI, Confidence Interval; COVID-19, the Coronavirus Disease 2019; ECHO, Echocardiography; EGDT, Early, Goal-Directed Therapy; GLM, Generalized Linear Model; IAS, Image Acquisition Score; ICU, Intensive Care Unit; IPS, Image Interpretation Score; LUS, Lung Ultrasound; SD, Standard Deviation; SPSS, Statistical Product and Service Solutions; POC, Point-Of-Care.

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References

[1] Zieleskiewicz L, Muller L, Lakhal K, Meresse Z, Arbelot C, Bertrand PM, Bouhemad B, Cholley B, Demory D, Duperret S, Duranteau J, Guervilly C, Hammad E, Ichai C, Jaber S, Langeron O, Lefrant JY, Mahjoub Y, Maury E, Meaudre E, Michel F, Muller M, Nafati C, Perbet S, Quintard H, Riu B, Vigne C, Chaumoitre K, Antonini F, Allaouchiche B, Martin C, Constantin JM, De Backer D and Leone M; CAR'Echo and AzuRea Collaborative Networks. Point-of-care ultrasound in intensive care units: assessment of 1073 procedures in a multicentric, prospective, observational study. Intensive Care Med 2015; 41: 1638-1647.

[2] Lamperti M, Bodenham AR, Pittiruti M, Blaivas M, Augoustides JG, Elbarbary M, Pirotte T, Karakitsos D, Ledonne J, Doniger S, Scoppettuolo G, Feller-Kopman D, Schummer W, Biffi R, Desruennes E, Melniker LA and Verghese ST. International evidence-based recommendations on ultrasound-guided vascular access. Intensive Care Med 2012; 38: 1105-1117.

[3] Volpicelli G, Lamorte A, Tullio M, Cardinale L, Giraudo M, Stefanone V, Boero E, Nazerian P, Pozzi R and Frascisco MF. Point-of-care multiorgan ultrasonography for the evaluation of undifferentiated hypotension in the emergency department. Intensive Care Med 2013; 39: 1290-1298.

[4] Lichtenstein DA and Meziere GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. Chest 2008; 134: 117-125.

[5] Lien WC, Hsu SH, Chong KM, Sim SS, Wu MC, Chang WT, Fang CC, Ma MH, Chen SC and Chen WJ. US-CAB protocol for ultrasonographic evaluation during cardiopulmonary resuscitation: validation and potential impact. Resuscitation 2018; 127: 125-131.

[6] Buonsenso D, Pata D and Chiaretti A. COVID-19 outbreak: less stethoscope, more ultrasound. Lancet Respir Med 2020; 8: e27.

[7] Peng QY, Wang XT and Zhang LN; Chinese Critical Care Ultrasound Study Group (CCUSG). Findings of lung ultrasonography of novel corona virus pneumonia during the 2019-2020 epidemic. Intensive Care Med 2020; 46: 849-850.

[8] Winkler MH, Touw HR, van de Ven PM, Twisk J and Tuinman PR. Diagnostic accuracy of chest radiograph, and when concomitantly studied lung ultrasound, in critically ill patients with respiratory symptoms: a systematic review and meta-analysis. Crit Care Med 2018; 46: e707-e714.

[9] Arntfield R, Millington S, Ainsworth C, Arora R, Boyd J, Finlayson G, Gallagher W, Gebhardt C, Goffi A, Hockman E, Kirkpatrick A, McDermid R, Waechter J, Wong N, Zavalkoff S and Beaulieu Y. Canadian recommendations for critical

care ultrasound training and competency. Can Respir J 2014; 21: 341-345.
[10] Pietersen PI, Madsen KR, Graumann O, Konge L, Nielsen BU and Laursen CB. Lung ultrasound training: a systematic review of published literature in clinical lung ultrasound training. Crit Ultrasound J 2018; 10: 23.
[11] Tarique U, Tang B, Singh M, Kulasegaram KM and Ailon J. Ultrasound curricula in undergraduate medical education: a scoping review. J Ultrasound Med 2018; 37: 69-82.
[12] So S, Patel RM and Orebaugh SL. Ultrasound imaging in medical student education: impact on learning anatomy and physical diagnosis. Anat Sci Educ 2017; 10: 176-189.
[13] Dietrich CF. Ultrasound student education. Med Ultrason 2017; 19: 131-133.
[14] Feilchenfeld Z, Dornan T, Whitehead C and Kuper A. Ultrasound in undergraduate medical education: a systematic and critical review. Med Educ 2017; 51: 366-378.
[15] Wang XT, Liu DW, Zhang HM, Chai WZ, Du W, He HW and Liu Y. Impact of extended focus assessed transthoracic echocardiography protocol in septic shock patients. Zhonghua Yi Xue Za Zhi 2011; 91: 1879-1883.
[16] Wang XT, Liu DW, Zhang HM, He HW, Liu Y, Chai WZ and Du W. The value of bedside lung ultrasound in emergency-plus protocol for the assessment of lung consolidation and atelectasis in critical patients. Zhonghua Nei Ke Za Zhi 2012; 51: 948-951.
[17] Liu X, Kong D, Lian H, Zhao X, Zhao Y, Xu Q, Peng B, Wang H, Fang Q, Zhang S, Jin X, Cheng K and Fan Z. Distribution and predictors of hospital charges for haemorrhagic stroke patients in Beijing, China, March 2012 to February 2015: a retrospective study. BMJ Open 2018; 8: e017693.
[18] Blaivas M. Update on point of care ultrasound in the care of the critically ill patient. World J Crit Care Med 2012; 1: 102-105.
[19] Mouncey PR, Osborn TM, Power GS, Harrison DA, Sadique MZ, Grieve RD, Jahan R, Harvey SE, Bell D, Bion JF, Coats TJ, Singer M, Young JD and Rowan KM; ProMISe Trial Investigators. Trial of early, goal-directed resuscitation for septic shock. N Engl J Med 2015; 372: 1301-1311.
[20] Dietrich CF, Goudie A, Chiorean L, Cui XW, Gilja OH, Dong Y, Abramowicz JS, Vinayak S, Westerway SC, Nolsoe CP, Chou YH and Blaivas M. Point of care ultrasound: a WFUMB position paper. Ultrasound Med Biol 2017; 43: 49-58.
[21] Blehar DJ, Barton B and Gaspari RJ. Learning curves in emergency ultrasound education. Acad Emerg Med 2015; 22: 574-582.
[22] Martin LD, Howell EE, Ziegelstein RC, Martire C, Shapiro EP and Hellmann DB. Hospitalist performance of cardiac hand-carried ultrasound after focused training. Am J Med 2007; 120: 1000-1004.
[23] Jang T, Kryder G, Sineff S, Naunheim R, Aubin C and Kaji AH. The technical errors of physicians learning to perform focused assessment with sonography in trauma. Acad Emerg Med 2012; 19: 98-101.
[24] de Oliveira Filho GR, Helayel PE, da Conceicao DB, Garzel IS, Pavei P and Ceccon MS. Learning curves and mathematical models for interventional ultrasound basic skills. Anesth Analg 2008; 106: 568-573, table of contents.
[25] Dinh VA, Giri PC, Rathinavel I, Nguyen E, Hecht D, Dorotta I, Nguyen HB and Chrissian AA. Impact of a 2-day critical care ultrasound course during fellowship training: a pilot study. Crit Care Res Pract 2015; 2015: 675041.

Supplementary Material

Introduction of CCUSG (Chinese Critical Ultrasound Study Group) and Professor Xiaoting Wang

The Chinese Critical Ultrasound Study Group (CCUSG) is the largest non-profit medical academic organization in the field of critical ultrasound in China. It has been committed to the research, training, and promotion of critical ultrasound. CCUSG first established the basic ultrasound training system in China, and then created the critical ultrasound-based intensive course, forming a comprehensive critical ultrasound training system including 15 course series. Since its establishment in 2013, it has successfully held nearly 200 critical ultrasound training courses, training more than 10,000 trainees, all over the provinces, municipalities and autonomous regions of the country, becoming an important force to promote the development of critical ultrasound in China. CCUSG has always been committed to promoting the standardized development of critical ultrasound. It has formulated China's first "Consensus for Critical Ultrasound Experts" and the first "Technical Specifications for Clinical Application of Critical Ultrasound". CCUSG first recognized that critical ultrasound is a sub-specialty of critical medicine and an important force to promote the development of critical medicine. Based on the promotion of critical ultrasound, it has made an important contribution to the flattening of critical levels in the region or field. CCUSG is the forerunner of big data for critical ultrasound in China. Starting from the establishment of a training database in 2016, CCUSG has built a training and examination database for more than 6,000 students and has conducted several national multi-center studies based on the database.

Professor Xiaoting Wang, chairman of CCUSG, who is also the deputy director of Department of Critical Care Medicine, Peking Union Medical College Hospital, has been specialized in critical care medicine for 20 years. Professor Xiaoting Wang and his colleagues developed the clinical and scientific research work of critical ultrasonography in China since 2007. He received relevant training and certification at Harvard Medical College in the United States In 2009. After that, he carried out relevant international and domestic exchanges and cooperation and participated in the compilation of international guidelines for the application of critical care echocardiography. It is worth mentioning that, he introduced the training course of WINFOCUS(World Interactive Network Focus on Critical Ultrasound) into China and conducted several training courses of point-of-care ultrasound, and the trained a group of backbone talents for the development of critical ultrasound in China. In 2013, he and his colleagues established CCUSG, established and improved a complete training system of critical ultrasonography according with China's national conditions. He then established CCUSG working committee in 2015, led the completion of "Chinese Experts Consensus on critical ultrasonography", and "Technical specification for clinical application of critical ultrasonography". In 2016, He and his CCUSG colleagues held the first Chinese Academic Conference on Critical Ultrasonography in Chengdu. After that, four annual conferences on Critical Ultrasonography were organized. He has published several papers on the field of critical ultrasound and participated in the development of international expert consensus on this field, such as the Multi-organ point-of-care ultrasound for COVID-19 (PoCUS4COVID).

About the CCUE protocol

The CCUE (critical care chest ultrasonic examination) protocol is a combination of eFATE and BLUE-plus protocols in order to avoid the shortcomings and the highlight the strengths of each individual protocol [1]. The eFATE protocol adds rapid ultrasonographic examination of the inferior vena cava, which allows for evaluation of the volume status and fluid responsiveness [2], and the BLUE-plus protocol adds the posterior BLUE point (the scapular line area) to increase the sensitivity and specificity in the diagnosis of lung consolidation and atelectasis [3]. And our research showed that, application of the CCUE protocol in emergent consultation for patients with respiratory and cardiovascular failures can effectively improve the bedside treatment, help to rapidly establish the preliminary diagnosis, and suggest treatment regimens. The CCUE protocol can improve the preliminary diagnostic accuracy and significantly reduce the time to final diagnosis, time to X-ray/CT examinations, delay in ICU transfer and ICU stay [1]. The flow chart is in Figure S1.

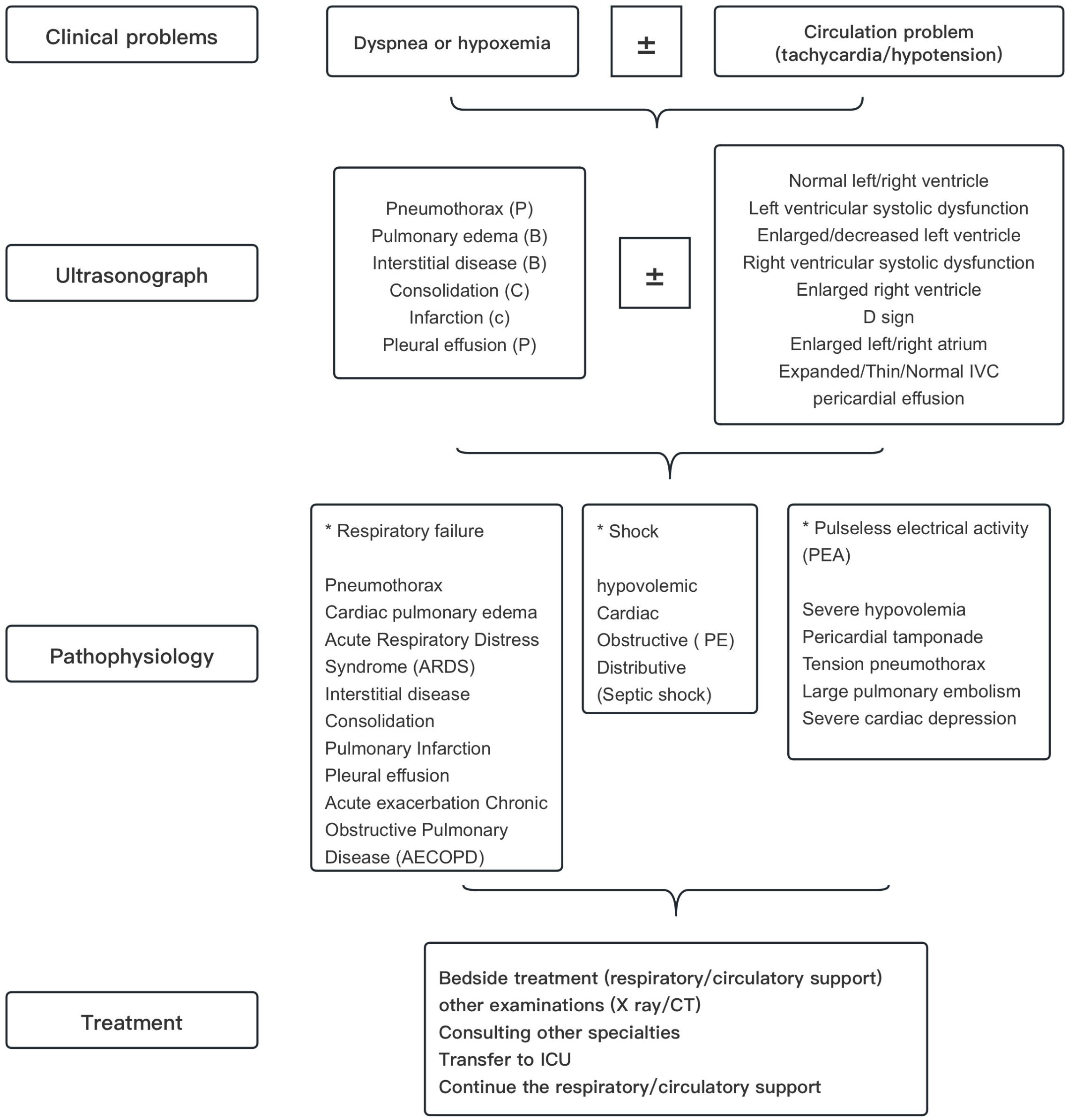

Figure S1. Flow chart of the critical care chest ultrasound examination for emergency consultation.

The CCUE protocol includes five cardiac views and ten pulmonary views (Figure S2). The cardiac views are parasternal long axis view, parasternal short axis view, apical four chambers view, subcostal four chambers view and inferior vena cava view; the pulmonary views are composed of five points of each lung, which are upper BLUE point, lower BLUE point, phrenic point, PLAPS point and posterior point.

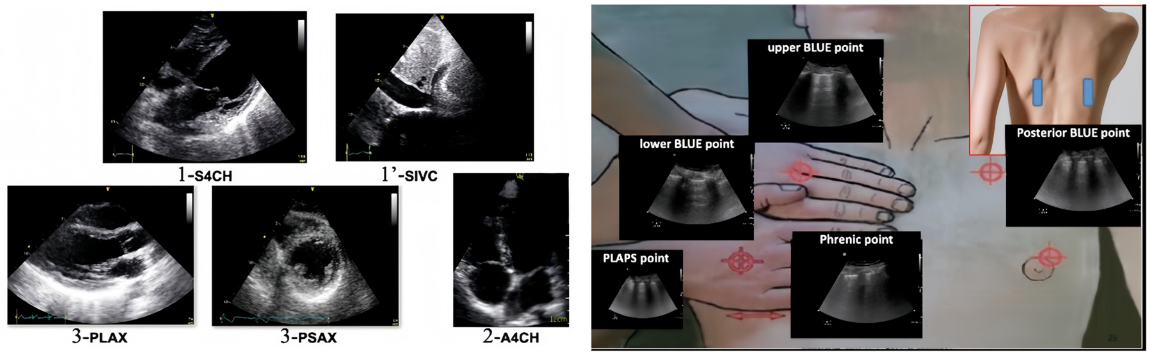

Figure S2. Views of the CCUE protocol.

About the training curriculum based on CCUE protocol

The training curriculum mentioned in our article is based on the CCUE protocol, and the purpose is to improve the trainees' abilities of ultrasound image acquisition, image interpretation and clinical application. The detail curriculum is as follows (Table S1):

Table S1. Curriculum of the 2-day critical ultrasound training program

Day 1 AM		
Test	Pre course test	
Lecture	Critical care ultrasound & Critical care	30 min
Lecture	Basic knowledge and technology of CCUS	30 min
Lecture	Basic knowledge of Cardiac ultrasound	30 min
Lecture	Basic knowledge of Lung ultrasound Hongmin Zhang	30 min
Practice	Imaging acquisition by hands on: cardiac views	120 min
Day 1 PM		
Lecture	Assessment of the Pericardium and right ventricular function	30 min
Lecture	The CCUE Protocol	30 min
Lecture	Application of CCUS in hemodynamic therapy	30 min
Lecture	Application of CCUS in ARDS	30 min
Practice	Imaging acquisition by hands on: pulmonary views	120 min
Day 2 AM		
Lecture	Interpretation of typical images	30 min
Lecture	Pitfalls and Limitations of CCUS	30 min
Discussion	Case discussion	60 min
Practice	Imaging acquisition by hands on: the CCUE protocol	120 min
Day 2 PM		
Test	Post course test	120 min
Discussion	Questions and answer	60 min

About the Trainers

Since 2011, Professor Xiaoting Wang and Professor Yangong Chao, the founders of CCUSG introduced the training course of WINFOCUS (World Interactive Network Focus on Critical Ultrasound) into China and conducted several training courses of point-of-care ultrasound. Dozens of doctors from different hospitals of China participated in the training and passed the certification as providers, Dr Xiaoting Wang and Dr Yangong Chao also passed the certification as trainers (Figure S3). Later, most of these doctors became the first trainers of critical ultrasound in China after passing a "training the trainer" program. After the establishment of CCUSG, a strict system of trainer certification was set up to make sure all the trainers were qualified. After being selected and completing training courses and periodic examinations, which is about 2 years, doctors grow to become trainers.

Figure S3. Certificates of competences of Dr Xiaoting Wang and Yangong Chao.

[1] Wang X, Liu D, He H, Du W, Zhang H, Liu Y, Chai W, Zhang Q and Zhou X. Using critical care chest ultrasonic examination in emergency consultation: a pilot study. Ultrasound Med Biol 2015; 41: 401-406.

[2] Wang XT, Liu DW, Zhang HM, Chai WZ, Du W, He HW and Liu Y. Impact of extended focus assessed transthoracic echocardiography protocol in septic shock patients. Zhonghua Yi Xue Za Zhi 2011; 91: 1879-1883.

[3] Wang XT, Liu DW, Zhang HM, He HW, Liu Y, Chai WZ and Du W. The value of bedside lung ultrasound in emergency-plus protocol for the assessment of lung consolidation and atelectasis in critical patients. Zhonghua Nei Ke Za Zhi 2012; 51: 948-951.