Focused echocardiography: Dyad versus individual training in an authentic clinical context☆

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ABSTRACT

Purpose: Echocardiography is increasingly being taught to intensive care unit residents. Current training methods require teachers to closely supervise trainees individually, and are time-intensive. To reduce the time burden, dyad training (training in pairs) under simulation conditions has been shown to be non-inferior to individual training. We aimed to validate these preliminary results for focused subcostal echocardiography (FSE), in an authentic clinical context.
Materials and methods: We conducted a quasi-experimental study within a 20-bed medical intensive care unit from June 2016 to March 2017. For supervised practice, residents were divided into individual versus dyad training groups. Residents then performed at least five FSE examinations, which were remotely scored by a blinded observer for image quality and correct interpretation. The main outcome measure was the mean composite image quality and interpretation score for the first five echoes done under indirect supervision (composite score range 1–8).
Results: 16 residents received individual training and 17 residents received dyad training. The mean composite score did not differ between the individual and dyad training groups (6.0 ± 0.4 versus 5.9 ± 0.4, 95% CI of difference − 0.2 to 0.4).
Conclusions: Assuming a 1-point non-inferiority threshold for the mean composite score, dyad training for FSE was non-inferior to individual training.

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1. Introduction

The spread of critical care echocardiography technology and expertise has allowed intensive care unit (ICU) physicians to incorporate echocardiography into routine clinical practice. Given its utility, echocardiography has been proposed as a core skill for intensive care medicine physicians by several expert groups [1-6]. For learning complex procedures like echocardiography, skill acquisition requires both a theoretical foundation and hands-on (procedural) practice. During hands-on practice, teachers need to spend substantial time supervising novice trainees, which has led to efforts to improve training efficiency within time-constrained learning environments. One of these methods that is particularly suited for procedural tasks is dyad training [7-9], as opposed to individual training. During dyad training, two participants collaborate and interact to learn echocardiography, though they would eventually perform echocardiography independently.

The rationale for dyad training is that, firstly, it harnesses collaborative learning, allowing participants to observe one another [8,10]. Observation could then activate the same neural structures for practice (the mirror neuron effect) [11]. Secondly, dyad training leads to participants comparing themselves against one another. According to social comparison theory, such comparison with a peer can allow a learner to be more aware of one's shortcomings and strengths, the latter reinforcing learner confidence and motivation [12,13]. Thirdly, the cognitive load required for learning complex tasks could potentially be shared

between two participants, facilitating learning [14]. Fourthly, dyad training, compared to individual training, effectively halves the instructor time required to train two trainees. Dyad training has been applied to bronchoscopy training [7], to coronary angiography training [15], to lumbar puncture training [16], to clinical skills training [17], and to obstetric ultrasound training [18]. However, these applications were studied in simulation scenarios, which may not be generalizable to the real world [15].

In our experience, a single subcostal echocardiographic view is sufficient to detect major abnormalities that would affect acute management of a critically ill patient (i.e. moderate/severe left ventricular dysfunction, dilated right ventricle, pericardial effusion >20 mm in thickness) [19]. To demonstrate generalizability of dyad training to echocardiography in the real world [20], we therefore aimed to investigate if dyad training would be non-inferior to individual training for focused subcostal echocardiography (FSE), among ICU residents learning and performing the procedure within an authentic clinical context.

2. Materials and methods

2.1. Study design, setting and participants

A quasi-experimental study was conducted within a 20-bed medical ICU of a 1250-bed university hospital (National University Hospital, Singapore) from June 2016 to March 2017. This study design took advantage of the training schedule of the residents. The residents had three one-hour training slots within any week, with one slot earlier in the afternoon from 1400 to 1500 h (allowing two residents to train together as work would be less busy then), and two slots on separate days later in the afternoon from 1500 to 1600 h (allowing one resident to train at any one time as work would be more busy then). Each resident was required to attend one training slot only and this would effectively allocate residents to dyad versus individualized training in a 1:1 ratio. Furthermore, the sessions were tightly controlled for time, and could not exceed one hour each due to residents' work commitments. The allocation of residents was not fixed; rather, we fixed the training slots, and the residents who had the least duties during those slots were trained. Residents did not have influence over which training slot to attend.

Internal Medicine junior residents rotating into the medical ICU were included in the study. Residents who had prior echocardiography training in any form, or who did fewer than five cases after directly supervised training were excluded. As FSE training was a standard part of the ICU curriculum, written informed consent was not required. Ethical approval for the study was obtained from the National Healthcare Group Domain-Specific Review Board (2017/00119).

2.2. Training phase

FSE training was delivered by one trainer (Physician A, KCS) with five years of critical care echocardiography experience. From our prior experience with echocardiography, the vast majority of patients in our ICU are not excessively obese and satisfactory images would be possible [19]. Ultrasound scanning was done using the Sparq Ultrasound System (Philips Healthcare, Andover, MA) equipped with a 2–4 MHz broadband sector phased array transducer.

Training was done using a protocol involving self-directed learning from a standard slide deck, theoretical testing, practical demonstration, hands-on practice, and just-in-time feedback. Learning slides were sent to the participants 2–3 days before the theory test. The theory test (paper-based, 10 questions, 1 mark per question, 5 min) (Supplementary Appendix 1), followed by the trainer giving a 5-min debrief, was done just before the practical training session. The practical training session with demonstration, hands-on practice, and just-in-time feedback, lasted a total of 50 min (with 2–4 patients being scanned). During dyad training, both trainees performed the ultrasound scan, one after another

without a fixed order. The practical training duration did not differ for dyad and for individual training. Given the very narrow scope of basic echocardiography in our study (only one view and three interpretation points), approximately one hour of training should be sufficient to create an educational impact. Other studies have also designed similarly short periods of hands-on training for critical care ultrasound in general [21,22], and for other focused techniques in ultrasonography [23,24].

2.3. Evaluation phase

Residents were expected to perform at least five subsequent FSE examinations, to save the cine images in the hard drive of the echocardiography machine, and to record their findings in the ICU electronic documentation system. Depending on clinical need, each patient could be scanned multiple times, and each time was considered as a separate case for the analysis. The echocardiographic cine images and documentation were then reviewed by an independent observer with two years of critical care echocardiography experience (Physician B, JWC) for image quality and accuracy of image interpretation [25]. To ensure reliability of assessment, Physicians A and B independently evaluated the image quality and interpretation of 10 FSE examinations done by residents excluded from the study, and achieved 100% agreement. Physician B did not know the training status (dyad versus independent) of each resident.

Image acquisition quality was scored by Physician B on 5-point Likert scale according to the American College of Emergency Physicians' recommendation [26] (Table 1). A "3" of the American College of Emergency Physicians' grading scale was the minimum grade required for an adequate image. For images graded "2" or below, the observer would provide feedback to improve image acquisition, and the observer's image interpretation would be based upon supplementary information gathering by the independent observer.

Image interpretation accuracy was scored by Physician B as correct or incorrect for each of three individual features. Firstly, pericardial effusion, which can be none, small-moderate (1–20 mm in thickness) or large (>20 mm in thickness) [27]. Secondly, left ventricular function, which can be normal (visual ejection fraction ≥50%) or depressed (visual ejection fraction <50%). Thirdly, right ventricular size, which can be normal-mildly dilated (visual right ventricle to left ventricle end-diastolic area < 1) or severely dilated (visual right ventricle to left ventricle end-diastolic area ≥ 1) [28].

Evaluation was based upon cases done under indirect supervision only. The overall score of each case (range 1–8 points) was taken as the sum of image acquisition quality (range 1–5 points) and image interpretation accuracy (range 0–3 points). We gave more weight to image quality as a good image is key to accurate interpretation. We reasoned that the minimum clinically important difference would be 1 point, since a 1-point increase in composite score would be the minimum needed for either better image quality or an additional feature that was correctly interpreted.

To ensure patient safety, Physician B provided indirect supervision daily during office hours and gave telephonic feedback when errors of image acquisition or interpretation were detected. Residents were taught to link findings to management in the following way:

Table 1
Assessment scale for image quality.

Grade	Definition
1	No recognizable structures. No objective data can be gathered
2	Minimally recognizable structures. Image quality insufficient for diagnosis
3	Recognizable structures but with some technical or other flaws (e.g. certain failures in the image's position, gain or depth). Image quality minimally sufficient for diagnosis
4	All structures imaged well. Diagnosis easily supported
5	All structures imaged with excellent image quality. Diagnosis completely supported

(1) large pericardial effusion triggered cardiology consultation; (2) left ventricular dysfunction triggered consideration of acute myocardial infarction and septic cardiomyopathy; (3) severe right ventricular dilatation triggered consideration of pulmonary embolism, fluid overload, and acute cor pulmonale. Patient safety was further assured by oversight of all clinical decisions by the ICU senior resident or consultant at all times.

2.4. Statistical analysis and power consideration

The main outcome measure was the mean composite score (range 1–8 points) for image quality and image interpretation, averaged across the first five cases done under indirect supervision by each participant. Assuming a significance level of 0.05, an anticipated difference of zero, a non-inferiority limit of one-point, a population standard deviation of 0.75, and a 1:1 allocation ratio, with 90% power, 20 residents were required. To demonstrate that using the first five cases done under indirect supervision would be fair reflection of longer term training outcomes, we investigated the score trajectory in incremental blocks of five echoes, using Cuzick's nonparametric test for trend [29].

3. Results

Out of 43 junior residents who received FSE training, 8 had prior echocardiography training and 2 did fewer than five cases after directly supervised training, leaving 33 participants (age 28.2 ± 3.0, 19 or 57.6% female) for analysis (Table 2). A total of 403 cases were completed and the patient characteristics are shown in Table 3.

Training outcomes were nearly identical for the individual and dyad training groups, with regard to theoretical test performance, number of echoes done, image quality and image interpretation (Table 4). For the main outcome measure, which was the mean composite score for the first five echoes done under indirect supervision, individual and dyad training had similar results (6.0 ± 0.4 versus 5.9 ± 0.4, 95% CI of difference − 0.2 to 0.4). This fulfilled the condition of non-inferiority, assuming a non-inferiority threshold of 1-point. Furthermore, when we considered all the echoes each individual performed, the similarity of the mean composite score persisted (6.2 ± 0.5 versus 6.1 ± 0.3, P = .498).

Adjustment of the main outcome measure (mean composite score for image quality and image interpretation) for participant characteristics (age, gender, years after graduation from medical school, year of residency, and prior ultrasound (non-echocardiography) experience) also yielded a result nearly identical to the unadjusted one: 95% CI of difference of individual training versus dyad training

Table 2
Participant characteristics.

Characteristics	All participants (N = 33)	Individual training (N = 16)	Dyad training (N = 17)	P-value
Age, mean (SD)	28.2 (3.0)	28.1 (2.4)	28.4 (3.5)	0.742
Gender				
Male (%)	14 (42.4)	6 (37.5)	8 (47.1)	0.728
Female (%)	19 (57.6)	10 (62.5)	9 (52.9)	
Years after graduation from medical school, median (IQR)	3 (2–5)	3 (2–5.5)	4 (3–5)	0.449
Year of residency				
1st year (%)	1 (3.0)	0 (0.0)	1 (5.9)	0.305
2nd year (%)	25 (75.8)	14 (87.5)	11 (64.7)	
3rd year (%)	7 (21.2)	2 (12.5)	5 (29.4)	
Prior ultrasound (non-echocardiography) experience	13 (39.4)	6 (37.5)	7 (41.2)	1.000

IQR: Interquartile range, SD: Standard deviation.

Table 3
Case characteristics.

Characteristics	All cases (N = 403)	Individual training cases (N = 198)	Dyad training cases (N = 205)	P-value
Age (years), mean (SD)	62.7 (16.0)	60.9 (17.3)	64.4 (14.5)	0.028
Gender				0.918
Male (%)	252 (62.5)	123 (62.1)	129 (62.9)	
Female (%)	151 (37.5)	75 (37.9)	76 (37.1)	
Height (m), mean (SD)	1.60 (0.10)	1.61 (0.10)	1.60 (0.10)	0.222
Weight (kg), mean (SD)	62.5 (14.8)	62.5 (15.2)	62.5 (14.6)	0.996
Body-mass index (kg/m^2), mean (SD)	24.6 (6.6)	24.3 (6.2)	24.8 (6.9)	0.459
Primary diagnosis				
Pneumonia (%)	151 (37.5)	79 (39.9)	72 (35.1)	0.618
Urosepsis (%)	16 (4.0)	6 (3.0)	19 (4.9)	
Intraabdominal sepsis (%)	41 (10.2)	16 (8.1)	25 (12.2)	
Asthma/COPD (%)	31 (7.7)	17 (8.6)	14 (6.8)	
Acute myocardial infarction (%)	27 (6.7)	10 (5.1)	17 (8.3)	
Fluid overload	26 (6.5)	11 (5.6)	15 (7.3)	
Stroke (%)	27 (6.7)	15 (7.6)	12 (5.9)	
Intestinal tract bleeding (%)	28 (7.0)	13 (6.6)	15 (7.3)	
Seizure (%)	13 (3.2)	8 (4.0)	5 (2.4)	
Other[a] (%)	43 (10.7)	23 (11.6)	20 (9.8)	
Mechanical ventilation at time of scanning				
Yes (%)	153 (38.0)	82 (41.4)	71 (34.6)	0.182
No (%)	250 (62.0)	116 (58.6)	134 (65.4)	
Pericardial effusion[b]				
None (%)	264 (65.5)	133 (67.2)	131 (63.9)	0.724
Small (<2 cm thickness) (%)	134 (33.3)	63 (31.8)	71 (34.6)	
Large (2 cm or greater) (%)	5 (1.2)	2 (1.0)	3 (1.5)	
Left ventricular function[b]				
Normal (%)	323 (80.1)	157 (79.3)	166 (81.0)	0.709
Depressed (%)	80 (19.9)	41 (20.7)	39 (19.0)	
Ratio of right-to-left ventricle size[b]				
<1 (%)	389 (96.5)	193 (97.5)	196 (95.6)	0.417
1 or greater (%)	14 (3.5)	5 (2.5)	9 (4.4)	
Any echocardiographic finding				
Absent[c]	201 (49.9)	97 (49.0)	104 (50.7)	0.765
Present	202 (50.1)	101 (51.0)	101 (49.3)	

NB. A patient could be scanned several times, and each time was considered as a separate case for the analysis. For the individual training group 128 patients were scanned 198 times; for the dyad training group 149 were scanned 205 times; in total 277 patients were scanned 403 times.
COPD: Chronic obstructive pulmonary disease.
SD: Standard deviation.
[a] E.g. meningitis, septic arthritis, liver failure, lung cancer, lymphoma, pulmonary embolism, diabetic ketoacidosi.
[b] Based on characteristics determined by the faculty (Physician B), rather than by the trainee (participant).
[c] Defined as presence of any pericardial effusion or depressed left ventricular function or ratio of right-to-left ventricle size of 1 or greater. These characteristics are as determined by the faculty (Physician B), rather than by the trainee (participant).

−0.1 to 0.5. As more echoes were done, the composite image quality and interpretation score had a statistically significant increase (6.0 to 6.2 to 6.3 to 6.4) (Table 5). Participants however demonstrated no significant improvement of mean composite scores from the first to the fifth echo (Table 6).

Table 4
Training outcomes.

	Individual training (N = 16)	Dyad training (N = 17)	P-value
Theoretical test performance			
Theoretical test score			
Mean (SD)	7.3 (2.1)	7.3 (1.1)	0.975
Number of echoes done			
Number of echoes done under indirect supervision			
Mean (SD)	12.2 (6.6)	12.1 (5.7)	0.953
Median (IQR)	10.5 (7.5–16)	12 (7–14)	0.899
Minimum	5	5	
Maximum	27	24	
Mean score for first five echoes, done under indirect supervision			
Composite score[a]			
Mean (SD)	6.0 (0.4)	5.9 (0.4)	0.445
	Mean I-D (95% CI) = 0.1 (−0.2 to 0.4)		
Image quality score			
Mean (SD)	3.4 (0.3)	3.2 (0.4)	0.241
	Mean I-D (95% CI) = 0.2 (−0.2 to 0.4)		
Image interpretation score			
Mean (SD)	2.7 (0.2)	2.7 (0.2)	0.599
	Mean I-D (95% CI) = 0.0 (−0.2 to 0.1)		
Mean score for all echoes, done under indirect supervision[b]			
Composite score[a]			
Mean (SD)	6.2 (0.5)	6.1 (0.3)	0.498
	Mean I-D (95% CI) = 0.1 (−0.2 to 0.4)		
Image quality score			
Mean (SD)	3.4 (0.3)	3.3 (0.3)	0.351
	Mean I-D (95% CI) = 0.1 (−0.1 to 0.3)		
Image interpretation score			
Mean (SD)	2.8 (0.3)	2.8 (0.1)	0.928
	Mean I-D (95% CI) = 0.0 (−0.2 to 0.2)		

CI; Confidence interval.
I-D: Individual training score minus dyad training score.
IQR: Interquartile range.
SD: Standard deviation.
[a] Composite score (score range 1–8) is the sum of image quality score (score range 1–5) and image interpretation score (score range 0–3).
[b] Scores for each participant were averaged across all the echoes by each participant under indirect supervision.

Table 6
Trajectory of scores for the first 5 echoes performed under indirect supervision.

Test scores	1st echo	2nd echo	3rd echo	4th echo	5th echo
Number of cases	33	33	33	33	33
Number of participants performing the echoes	33	33	33	33	33
Composite score[a]					
Mean (SD)	5.8 (0.9)	6.1 (0.7)	5.8 (0.7)	6.1 (0.9)	6.1 (0.9)
Image quality score					
Mean (SD)	3.1 (0.6)	3.4 (0.7)	3.1 (0.5)	3.5 (0.8)	3.4 (0.7)
Image interpretation score					
Mean (SD)	2.7 (0.5)	2.8 (0.4)	2.7 (0.5)	2.7 (0.5)	2.7 (0.5)
P-value[b]	NA	0.088	0.756	0.127	0.178

NA: Not applicable.
SD: Standard deviation.
[a] Composite score (score range 1–8) is the sum of image quality score (score range 1–5) and image interpretation score (score range 0–3).
[b] P-value for the composite score, taking the composite score for the 1st echo as the reference value.

4. Discussion

Satisfactory balance of participant and patient characteristics between the individual and dyad training groups for FSE was observed in this quasi-experimental study. Compared to individual training, dyad training resulted in non-inferior mean composite score, mean image quality score, and mean image interpretation score.

The training outcomes were satisfactory, as the image quality scores exceeded three, which was the American College of Emergency Physicians' minimum grade required for an adequate image. The mean image interpretation scores were nearly three, which meant that participants usually identified all the key abnormalities correctly. As participants did more echoes, the mean composite and image quality scores increased, though the increments were very small (maximal increment <7% of the baseline score) and were clinically not significant. This relatively flat trajectory of score increments demonstrated that using the first five cases done under indirect supervision may be a fair reflection of longer term training outcomes. At the same time, a spread of composite scores were achieved by participants (see Fig. 1 for the density histogram), suggesting the absence of floor or ceiling effects, and that our chosen outcome measure was able to detect differences in trainee performance.

In line with theoretical expectations, dyad training was not inferior to individual training. Although each participant had less hands-on practice during dyad training compared to individual training, this was compensated adequately by collaborative learning. During dyad training, we observed that participants did not interact much, but rather
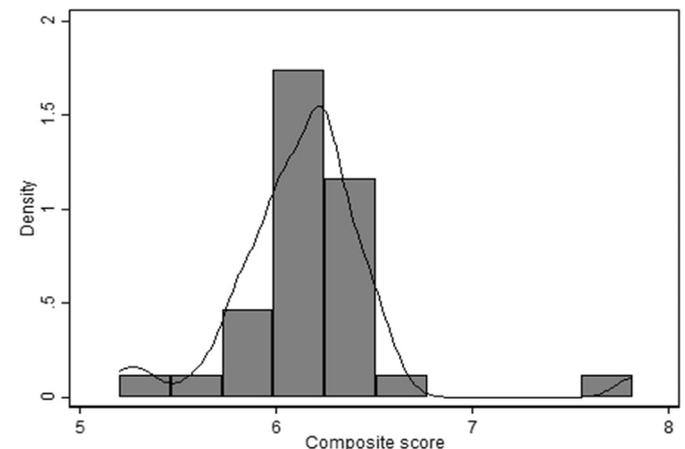
Table 5
Trajectory of scores for cases performed under indirect supervision.

Test scores	1–5 echoes	6–10 echoes	11–15 echoes	16+ echoes	P-value[b]
Number of cases	165	121	71	46	NA
Number of participants performing the echoes	33	28	18	8	NA
Composite score[a]					
Mean (SD)	6.0 (0.8)	6.2 (0.8)	6.3 (1.0)	6.4 (0.8)	<0.001
Image quality score					
Mean (SD)	3.3 (0.7)	3.4 (0.6)	3.6 (0.7)	3.6 (0.7)	<0.001
Image interpretation score					
Mean (SD)	2.7 (0.5)	2.8 (0.5)	2.7 (0.7)	2.8 (0.4)	0.139

NA: Not applicable.
SD: Standard deviation.
[a] Composite score (score range 1–8) is the sum of image quality score (score range 1–5) and image interpretation score (score range 0–3).
[b] Using Cuzick's nonparametric test for trend.

Fig. 1. Density histogram of the mean composite score for all echoes, done under indirect supervision.

learnt from both correct and incorrect actions made by their partners. This can be explained by social comparison theory, whereby peer learners tend to relate information about others to oneself [13]. If their partners did something right, participants would reproduce that action, so as to enhance their own ability. If their partners did something wrong while they did it right, participants would then feel more confident and motivated to do well.

Logically, the results of this study could be extrapolated to the learning of skills other than echocardiography, as long as the learning process involved is similar. The process would include initial theoretical training and testing, directly supervised hands-on performance, and indirectly supervised self-performance of a focused skill. Skill complexity should not matter, since complex tasks can be broken down into simpler subroutines, and dyad training could be applied to each of these subroutines. Therefore, apart from FSE training, it is possible that dyad training would also be non-inferior to individual training for other components of point-of-care ultrasound and other procedures, and more real-world studies in other fields should be done.

Our study had several strengths. We had the opportunity to compare the training outcomes of dyad versus individual training for FSE in the real world setting, rather than in simulation. This real world application bolsters the generalizability of dyad training in the learning of practical skills [20]. We also managed to blind our outcome assessor (Physician B) to the training group, as scoring took place off-line using saved images and electronic documentation only. This method eliminated the bias inherent in direct supervisor-trainee interactions. Moreover, we effectively used the quasi-experimental study design to attain satisfactory balance of baseline characteristics between the dyad and individual training groups. Such a quasi-experimental design involving all ICU residents would have three advantages over prior studies. Firstly, compared to simulation studies, it more accurately reflects real world learning outcomes. Secondly, when compared to a trial which would inevitably recruit only motivated participants, it may more accurately reflect the range of learning outcomes from a trainees of both lower and higher motivation levels. Thirdly, compared to a randomized controlled trial, using a quasi-experimental study will not require the underlying hypothesis of the study to be revealed, reducing both participant-related and observer-related bias.

We acknowledge that several limitations exist. Firstly, the study design is quasi-experimental and does not involve true randomization. Nonetheless, from Table 1, the known baseline characteristics were well-balanced, and it appears that the quasi-experimental model was successful in simulating true randomization. Secondly, most participants were not ultrasound-naïve, though they were echocardiography-naïve. Prior knowledge about ultrasound could accelerate their learning. This is unavoidable as ultrasound is widely available in contemporary medicine, especially to improve the safety of vascular and pleural procedures. In any case, prior experience with non-echocardiography ultrasound techniques was well-balanced between the dyad and individual training groups, and would likely not have biased the test scores. Thirdly, our dyad training could only happen earlier in the afternoon as the ICU would be less busy then. While it is possible that dyad training participants could be less fatigued than individual training participants, the time difference between the dyad and individual training slots was only one hour. This short period of time was unlikely to have produced significant differences in learning aptitude. Fourthly, we only allowed a maximum of two participants per group. As such, our results may not apply to group training where more than two participants learnt together. Fifthly, we trained participants in only one subcostal view, and extrapolation of our results to other echocardiographic views requires further validation. Sixthly, although imaging difficulty would be variable in different patients, we believe that on aggregate, given similar body-mass indices (Table 3), imaging difficulty would be similar between the dyad and individual training groups. Seventhly, indirect supervision after directly-supervised training could complement learning of ultrasound skills. But the former's influence would be minor,

given the similarity of scores between the individual and dyad training groups for the first five cases, and the relatively flat trajectory of score improvement after the first five cases. Finally, we were not able to test the ability of participants to integrate their echocardiography findings into actual clinical scenarios, as all clinical decisions would have been vetted by senior ICU team members to ensure patient safety.

After considering the limitations above, the findings of this study can perhaps stimulate echocardiography training programs to use dyad training methods, which can help save faculty time by 50%. Such savings would help overcome the time constraints when spreading echocardiography training to areas beyond critical care, such as general internal medicine [30] and undergraduate medical curricula [31]. To further improve the sustainability of echocardiography teaching, indirect supervision done by Physician B can be replaced by workplace-based supervision by senior residents and staff. Similar to what was done for indirect supervision, junior residents would have to get at least five echoes endorsed by the senior members of their team before the former obtained a certificate of completion of training.

In conclusion, this study demonstrated that dyad training was non-inferior to individual training for FSE in an authentic clinical context, in terms of image acquisition quality and image interpretation accuracy. If dyad training were to be adopted, faculty time would be reduced by 50%, lessening the time-related cost of education and improving longer-term sustainability of FSE training.

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Declaration of interest

Declarations of interest: none.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcrc.2018.10.009.

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