Performance of emergency physicians in point-of-care echocardiography following limited training

Aida Bustam,1 Muhaimin Noor Azhar,1 Ramesh Singh Veriah,2 Kulenthran Arumugam,3 Alexander Loch4

ABSTRACT

Objectives The aim of this study was to evaluate if emergency medicine trainees with a short duration of training in echocardiography could perform and interpret bedside-focused echocardiography reliably on emergency department patients.

Methods Following a web-based learning module and 3 h of proctored practical training, emergency medicine trainees were evaluated in technical and interpretative skills in estimating left ventricular function, detection of pericardial effusion and inferior vena cava (IVC) diameter measurements using bedside-focused echocardiography on emergency department patients. An inter-rater agreement analysis was performed between the trainees and a board-certified cardiologist.

Results 100 focused echocardiography examinations were performed by nine emergency medicine trainees. Agreement between the trainees and the cardiologist was 93% (K=0.79, 95% CI 0.773 to 0.842) for visual estimation of left ventricular function, 92.9% (K=0.80, 95% CI 0.636 to 0.882) for quantitative left ventricular ejection fraction by M-mode measurements, 98% (K=0.74, 95% CI 0.396 to 1.00) for the detection of pericardial effusion, and 64.2% (K=0.45, 95% CI 0.383 to 0.467) for IVC diameter assessment. The Bland–Altman limits of agreement for left ventricular function was −9.5% to 13.7%, and a Pearson’s correlation yielded a value of 0.82 (p<0.0001, 95% CI 0.734 to 0.881). The trainees detected pericardial effusion with a sensitivity of 60%, specificity of 100%, positive predictive value of 100% and negative predictive value of 97.9%.

Conclusions Emergency medicine trainees were found to be able to perform and interpret focused echocardiography reliably after a short duration of training.

INTRODUCTION

While comprehensive training and experience have traditionally been the prerequisite to be certified as fully competent in performing and interpreting echocardiography, the role of point-of-care echocardiography in emergency medicine has expanded. Bedside emergency department echocardiography has been shown to help emergency physicians make the correct diagnosis, treatment and enhanced disposition decision, and significantly improve patient care.1 2

Bedside emergency department echocardiography is a brief and rapid usage of cardiovascular ultrasound focusing on specific goal-directed indications, such as assessing cardiac function and contractility, to help differentiate the causes of shock, chest pain or dyspnoea in patients,1 4 or to look for reversible causes during cardiac arrest; ruling out pericardial effusion causing haemodynamic compromise; and estimating the central venous pressure (CVP) non-invasively by measuring the inferior vena cava (IVC) diameter to help guide fluid management.7 Training of emergency physicians in emergency echocardiography can be focused on these applications, specifically, and be of much shorter duration.

It is important to appreciate the limitations of bedside echocardiography in the hands of the minimally trained emergency physicians. If emergency physicians were to incorporate bedside emergency echocardiography into emergency medical practice, then training and assessment are therefore crucial. This study was aimed to design a simple and short training on bedside-focused emergency echocardiography, and to evaluate the skills of minimally experienced emergency medicine trainees after such training.

METHODS

Setting This study was conducted at the trauma and emergency department of University of Malaya Medical Centre, Kuala Lumpur. The department sees more than 100 000 patients annually.

Subjects All study subjects were postgraduate trainees in emergency medicine at the University of Malaya. The residency programme is a 4-year postgraduate training. At the point of entry into this study, depending on their postgraduate year, the study subjects had varying limited experience and skills in echocardiography from no experience to non-structured and informal learning from rounds and instructions from senior emergency physicians. This study involved the postgraduate year 1 and year 2 trainees with the least experience and skills in echocardiography.

Study design This was a prospective observational study comprising training and assessment. Training consisted of the delivery of a standardised theoretical and practical teaching to the study subjects based on a focused curriculum for echocardiography in emergency medicine. In the assessment phase, the study subjects were evaluated in their ability to perform and interpret focused echocardiography on emergency department patients compared with a cardiologist as the reference standard. This study received approval from the institutional medical ethics committee.
Training and curriculum
The curriculum objectives developed for this study are as outlined in the box and are based on the echocardiography curriculum guidelines for emergency medicine. The theory learning was delivered as a web-based learning module using Moodle and served as an ‘instructions manual’ which included images and videos. Practical training was delivered at the bedside by a cardiologist. Each trainee received a total of 3 h of practical training to perform focused echocardiography on patients in a systematic and focused approach according to the curriculum objectives in this study. The ultrasound machine used in this study was the departmental portable ultrasound machine Logiq-e (General Electronics) with a 2–3.6 MHz phased array cardiac transducer.

Assessment
After the completion of training, all the trainees underwent an assessment to evaluate their skills in performing focused echocardiography on patients in the emergency department. Patient subjects included were adult patients with or without underlying cardiac disease. Whenever possible, consecutive patients in the department were examined. Consent was obtained from every patient. Patients were excluded if they were unstable or were still receiving acute treatment.

**Box Emergency echocardiography curriculum objectives**

<table>
<thead>
<tr>
<th>Basic ultrasound physics</th>
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<tr>
<td>1. Basic physics</td>
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<tr>
<td>2. Ultrasound and tissue</td>
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<tr>
<td>3. Components of ultrasound machine</td>
</tr>
<tr>
<td>4. Transducers</td>
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<tr>
<td>5. Image artefacts</td>
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<tr>
<td>6. Ultrasound settings and image zones</td>
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<tr>
<td>7. A-mode, B-mode and M-mode</td>
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<td>8. Image resolution</td>
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</table>

**Technical skills**

1. Technique for obtaining the four standard cardiac ultrasound windows
   - A. Parasternal long-axis view
   - B. Parasternal short-axis view
   - C. Apical four-chamber view
   - D. Subcostal four-chamber view

2. Identification of cardiac anatomy on ultrasound
   - A. Cardiac chambers
   - B. Valves
   - C. Pericardium
   - D. Aorta

3. Quantitative measurement of left ventricular ejection fraction (LVEF) using M-mode

4. Technique for visualising the IVC for assessment of central venous volume status and measurement of maximum and minimum diameter using M-mode

**Interpretative skills**

1. Estimation of global cardiac systolic function by visual and correlation with quantitative measurement of LVEF using M-mode
2. Assessment of the presence or absence of pericardial effusion
3. Estimation of central venous pressure from IVC diameter and collapsibility

The cardiologist first performed a focused echocardiography protocol and obtained three parameters: global left ventricular (LV) systolic function using visual estimation, and then left ventricular ejection fraction (LVEF) using M-mode quantitative measurements, presence or absence of pericardial effusion, and inferior vena cava (IVC) diameter and collapsibility. Trainees then performed the same focused echocardiography protocol on the same patients. Both cardiologist and trainees used the same ultrasound machine and both were blinded to the clinical diagnosis of the patients they examined.

**Data collection and measurements**

Global LV systolic function estimation was performed by visual inspection of gross ventricular wall contraction and wall thickening during systole and diastole assessed in all the four cardiac windows. The gross LV contractility was differentiated into three categorical functions: normal, moderate dysfunction and severe dysfunction.

Quantitative measurement of LVEF by M-mode was performed at the level of the tips of the mitral valve either in the long axis or the short axis. LV internal diameters, intraventricular septal wall thickness and posterior LV wall thickness were measured at end-diastole and end-systole. The ejection fraction (EF) was calculated using Teichholz method. The measured EF was recorded as the actual percentage and also categorised into normal (EF>50%), moderately depressed, (EF 30–50%) or severely depressed (EF<30%).

Pericardial effusion was identified by the presence of an anechoic stripe within the pericardium surrounding the heart, and was categorically assessed as either absent or present.

IVC diameter assessment was performed using image obtained through the subcostal long-axis view. The IVC diameter was measured at about 2 cm from the junction with the right atrium, and measurement made perpendicular to the IVC long axis. The maximum and minimum diameter of the IVC were measured to evaluate the percentage collapsibility and categorised into: <1.5 cm (CVP of 0–5 mm Hg), 1.5–2.5 cm with >50% collapse (CVP of 5–10 mm Hg), 1.5–2.5 cm with <50% collapse (CVP of 10–15 mm Hg) or >2.5 cm with very little respiratory phasicity (CVP of 15–20 mm Hg).

**Data analysis**

An inter-rater reliability analysis using the x statistics with 95% CI was performed to determine the degree of agreement between the trainees and the cardiologist for each echocardiographic parameter. The kappa statistics were performed using the Stata Statistical Software Release 11. In order to analyse with clinical relevance the percentage LVEF by M-mode data obtained by the trainees and the cardiologist, the Bland–Altman method was chosen. For the pericardial effusion data, the sensitivity, specificity, positive predictive value and negative predictive value were calculated for the trainees using the cardiologist as the reference standard.

**RESULTS**

The study was conducted from July 2011 to November 2011. Nine emergency medicine trainees participated in this study. Five were from year 2 and four from year 1 of the postgraduate programme, all of whom had less than 10 numbers of informal echocardiography examinations prior to entry into this study. The trainees performed an average of five proctored echocardiography examinations during training and an average of 11 examinations during assessment. A total of 100 paired
Echocardiography examinations were performed by the nine trainees on 50 emergency department patients.

**LV systolic function**

The comparison of LV function categorisation using visual estimation between the cardiologist and the trainees is shown in Table 1. The $\kappa$ statistic yielded a value of 0.79 (95% CI 0.773 to 0.842) with a raw agreement of 93%.

Quantitative LVEF by M-mode measurements were available for 92 paired examinations due to technical difficulties in obtaining optimal images for measurements in the remaining paired examinations. The mean LVEF obtained using M-mode measurements by the cardiologist and trainees were 58.9% ±20% (range 10–85%) and 54.6%±19% (range 10–86%) respectively. The scatterplot of correlation between the cardiologist and trainees is shown in figure 1. The Pearson’s correlation $r$ yielded a value of 0.82 ($p<0.0001$, 95% CI 0.734 to 0.881).

The quantitative LVEF measurements comparison plotted using the Bland–Altman method is shown in figure 2 to show the degree of agreement between the LVEF measurements by the trainees and the average LVEF values between the cardiologist and trainees. The plot shows that the 95% upper and lower agreement limits of LVEF are 13.7% and –9.5%, respectively, and the mean difference (systematic error) is 2.1%. It also shows that there was a better agreement in the lower LVEF range (LVEF<30%) than in the higher LVEF range (LVEF>50%).

When the quantitative LVEF percentages obtained by the trainees were also categorised into the three categorical functions: normal (EF>50%), moderate dysfunction (EF 30–50%) and severe dysfunction (EF<30%), these were compared with the visual LV function categorisation by the cardiologist (table 2). The cardiologist’s visual estimation of LV function was taken as the reference since visual estimation of LV function is a widely accepted method, and it has been shown to have the best correlation with radionuclide angiography and contrast ventriculography, compared with two-dimensional echocardiographic measurements.12 13 The $\kappa$ statistics based on table 2 was 0.80 (95% CI 0.636 to 0.882) and 92.9% raw agreement.

**Pericardial effusion**

The cardiologist detected five out of 100 paired examinations to have pericardial effusion. All were small effusions and without haemodynamic instability. The trainees identified the presence of pericardial effusion with 60% sensitivity, 100% specificity, 100% positive predictive value and 97.9% negative predictive value.

**IVC diameter**

IVC diameter measurements were available for 95 paired examinations due to technical difficulties in obtaining optimal images for measurements in the remaining paired examinations. The

<table>
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<th>Cardiologist</th>
<th>Normal n (%)</th>
<th>Moderate n (%)</th>
<th>Severe n (%)</th>
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<tr>
<td>Normal n (%)</td>
<td>77 (77)</td>
<td>5 (5)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Moderate n (%)</td>
<td>1 (1)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Severe n (%)</td>
<td>0 (0)</td>
<td>1 (1)</td>
<td>16 (16)</td>
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**DISCUSSION**

**LV systolic function**

Visual estimation of global LV systolic function by the trainees in this study showed substantial agreement with that made by the cardiologist (93%, $\kappa=0.79$, n=100). This degree of agreement is comparable with those found in previous studies of emergency physician-performed echocardiography.4 14

LVEF estimation using calculated measurements of cardiac walls thickening in systole and diastole at the level of the tip of the mitral valve provides a more objective assessment of the LV systolic function. Even though subjective visual estimation of LV systolic function has been shown to be equal or superior to two-dimensional echocardiographic measurements,12 13 it was presumed that less experienced trainees might rely more on objective measurements than on minimally trained visual acumen to make subjective estimations of LV function. Indeed, the trainees’ M-mode quantitative LVEF measurements correlated well with those of the cardiologist in our study ($r=0.82$, n=84). The scatterplot in figure 2 shows that the trainees in our study were precisely good at ‘grouping’ patients with severe dysfunction into the LVEF <30% range, and patients with normal function into the LVEF >30% range.

However, in real clinical practice, categorical LV function into normal, moderate dysfunction and severe dysfunction should suffice. Knowledge of the LVEF in actual percentage may not change decision making to any significant degree more than knowledge of categorical LV function in the management of patients in the emergency department.

When analysed with the Bland–Altman method (figure 2), the trainees’ quantitative measurement of LVEF showed a 95% limits of agreement of EF of −9.5% to +13.7%. In the context of the patient subjects population in this study, these limits of agreement may be acceptable as there was close to none in the moderate dysfunction group. Moreover, no patient with normal LV function was categorised by the trainees as having severe dysfunction, and vice versa. The mean difference of 2.1% which indicates that the trainees were consistently underestimating LVEF by 2.1% is not considered clinically significant. Further

**Figure 1** Scatterplot comparing quantitative M-mode left ventricular ejection fraction measurements by cardiologist and by trainees.
studies are needed to evaluate whether the limits of agreement in our study are clinically applicable in a bigger subject population of emergency department patients that measure effects of LVEF estimations on intervention and outcome as well. When the trainees’ quantitative M-mode LVEF data were assigned to categorical LV functions: normal (LVEF>50%), moderate dysfunction (LVEF 30–50%) and severe dysfunction (LVEF<30%), the trainees’ accuracy is close to that of their LV function categorisation by visual estimation (K=0.80 vs K=0.79). This study suggests that, even with limited training, emergency medicine trainees were able to use visual estimation for global LV function with reliable accuracy. Using the more time-consuming method of M-mode measurements for LVEF did not add to significant increase in the trainees’ accuracy. Therefore, this study suggests that, in the busy emergency department, the use of one method rather than both methods for LV function estimation is reliable enough and can save time and costs. The visual technique to estimate LV function by emergency medicine trainees is not only accurate but also quicker to perform.

Our study directly compared echocardiography examinations performed by the trainees and the cardiologist immediately after one another. This provides a more direct and real-time comparison.

Pericardial effusion
The sensitivity of the trainees in this study in the detection of pericardial effusion is low compared with other studies which reported sensitivities of emergency physicians-performed focused echocardiography in detecting pericardial effusion of between 88% and 100%.

This may be due to the low prevalence of the disease in our patients-subjects population compared with that in other studies, and also all pericardial effusions in our study were small effusions which may be more difficult to detect.

The prevalence of pericardial effusion in our patients-subjects population was 5%, and all were small effusions without haemodynamic compromise. In a similarly low prevalence study by Alexander et al, internal medical house staff with limited training in echocardiography detected the presence or absence of pericardial effusion with a sensitivity of 54%, specificity of 99%, positive predictive value of 50% and negative predictive value of 99%, which are comparable with the findings in our study.

Blavas found that even though the frequency of pericardial effusion was low in their study, with most effusions not clinically significant, it was still an important cause of dyspnoea in patients presenting to the emergency department. It is also important for emergency physicians to be able to accurately diagnose the absence of pericardial effusion, as it can be mistaken for pericardial fat, other pericardial abnormalities or the more common pleural effusion.

False positive findings of pericardial effusion might lead to inadvertent pericardiocentesis.

IVC assessment for fluid volume status
IVC assessment in this study involved measuring the changes in diameter of IVC during inspiration and expiration. The degree of collapsibility of the inferior vena cava provides information regarding the central venous filling volume and the right atrial pressure represented by the CVP. IVC diameter and collapsibility assessment by the trainees in our study showed only moderate agreement with that made by the cardiologist (64.2%, K=0.45, n=95). This degree of agreement is comparable with that found in Randazzo et al study which demonstrated an agreement of 68.1% (K=0.41, n=94). There may be several possible reasons for this moderate agreement. Assessment of IVC diameter in our study had employed the use of calliper measurements. Accurate calliper measurements rely upon orientation of the IVC view along the centre of its long axis. Off-axis measurements would yield falsely smaller diameter measurements. IVC size may also be affected by the variation in shape influenced by respiratory rate and the degree of inspiration. Variability in the placement of caliper on the IVC from its junction with the right atrial junction can also contribute to variation in percentage of collapse.
Minimal training in echocardiography for emergency physicians

This study supports the findings of previous studies that showed that emergency physicians could reliably perform and interpret focused echocardiography after minimal amount of training.15 16 In our study, the trainees had far more minimal background experience than the participants in the previous studies.

Our study is also unique in that it incorporated a web-based learning module. Few studies have evaluated the effectiveness of web-based teaching on ultrasound skills.24 25 No previous studies have evaluated emergency physicians in performing echocardiography after a training method that includes web-based learning. This study shows that web-based learning in emergency echocardiography is feasible and can support practical training. Web-based learning has the advantages of being easily accessible, reproducible and has very low maintenance. We believe that online learning can enhance skills learning by providing the necessary background reading for learners to be able to apply their knowledge and focus more on using the classroom for hands-on training.

Limitations

Competency in emergency echocardiography requires emergency physicians to be (A) knowledgeable in the indications, (B) competent in the technical skills of image acquisition and in the interpretation of the images and (C) be able to integrate the echocardiographic findings into the clinical management of patients.6 This study evaluated (B), but not (A) and (C).

As this study focused more on the technical and interpretative skills of the trainees, the patient subjects were convenient consecutive subjects and not particularly chosen from a symptomatic or high-risk population. Therefore, this study did not provide enough data to make associations between the findings of severe LV dysfunction with cardiogenic cause or between the IVC data with hypotensive patients. This study also did not compare CVP estimation based on echocardiographic IVC assessment with barometric intravenous CVP measurement, given that there was only moderate agreement in the echocardiographic assessment of IVC diameter and collapsibility between the cardiologist and the trainees.

At least two factors could contribute to bias in the trainees’ performance. First, the selection of stable patients meant lower incidences of pathologies and, therefore, the assessment of interpretative subjects and not particularly chosen from a symptomatic or high-risk population. Therefore, this study did not provide enough data to make associations between the findings of severe LV dysfunction with cardiogenic cause or between the IVC data with hypotensive patients. This study also did not compare CVP estimation based on echocardiographic IVC assessment with barometric intravenous CVP measurement, given that there was only moderate agreement in the echocardiographic assessment of IVC diameter and collapsibility between the cardiologist and the trainees.

The ultimate question will be the impact on patient management. A follow-up study would be to ascertain whether or not those who are trained in bedside emergency echocardiography would be able to identify the correct diagnosis and influence patient management compared with those who are not trained, and whether or not this translates to differences in outcomes, such as mortality and hospital length of stay.

CONCLUSION

This study suggests that with a minimal training consisting of web-based theory learning and 3 h of practical training, emergency medicine trainees are able to perform and interpret focused echocardiography with reliable accuracy. Web-based learning is a feasible method of training in emergency echocardiography, and can support practical training.

Contributors AB and AL conceived and designed the study. AB developed the study protocol. AB, MNA, RSV and AL supervised data collection. KA advised and supervised data analysis. AB, MNA and AL prepared and approved the manuscript.

Competing interests None.

Ethics approval University of Malaya Medical Ethics Committee.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES