Nurse-delivered focused echocardiography to determine intravascular volume status in a deployed maritime critical care unit

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Abstract

Focused echocardiography is increasingly used by clinicians to guide fluid resuscitation. The UK Defence Medical Services (DMS) have adopted focused echocardiography as a tool to guide flow assessment and resuscitation in deployed critical care. We aimed to explore whether two focused echo techniques, namely Inferior Vena Cava (IVC) and Left Ventricular Outflow Tract Velocity Time integer (LVOT VTi) respiratory variability could be taught to a group of critical care nurses without previous exposure to ultrasound imaging. After a five-week program of training, validation was carried out on healthy volunteers. The mentor, an accredited focused echo trainer, and six nurses performed a total of forty-eight scans on eleven volunteers. The mentor and students acquired subcostal long axis views of the IVC and apical five chamber views using a high frequency linear ultrasound probe. Mean values from three measurements were obtained for IVC diameter and LVOT VTi. Minimum and maximum values were recorded for both variables across a full respiratory cycle. Echo images were saved and at least two images for each student were reviewed offline by an accredited echo-training supervisor. In all cases students were able to obtain adequate echo windows. There was good correlation between values recorded by the mentor and students for both IVC diameter ($r=0.90$, $p<0.001$) and LVOT VTi ($r=0.77$, $p<0.001$). Bland Altman analysis showed good correlation with minimal bias for VTi measurements. There was some increase in bias for IVC measurements below 1.2 cm. In summary, we found that these skills for assessing intravascular volume status could be acquired in a relatively short time by specialist nurses without previous experience, and that results were comparable to those produced by an experienced practitioner.

Introduction

Accurate determination of intravascular volume is a common problem in the management of critically ill patients. Inaccurate estimation of vascular volume can lead to inadequate resuscitation or to deleterious fluid overload, and there is a broad consensus that monitoring volume and flow is vital in critical ill patients (1). There is a plethora of devices available to assist clinicians, but until recently none were available in the deployed military critical care setting (2). We have recently introduced a new capability to this environment, namely focused echocardiography (3). The emphasis of focused echocardiography is not on a detailed diagnostic examination but on the identification of answers to specific questions: for example, is contractility impaired; is there evidence of right ventricular dilatation; what is the intravascular volume status (4,5)? Assessment of intravascular volume status is one of the commonest reasons to use focused echocardiography in critical care practice.

Using focused echo to determine volume status is achieved using two techniques: i) determination of inferior vena cava collapsibility, and ii) left ventricular outflow tract (LVOT) Doppler Velocity Time Integer (VTi) variability.

Changes in the calibre of the inferior vena cava occur during respiration (Figure 1). During normal respiration the reduction in intra-thoracic pressure is transmitted to the IVC and causes a reduction in calibre of the vessel, the degree of collapse being related to the intravascular volume. The reverse effect occurs during mechanical positive pressure ventilation, although the magnitude of change is usually less. Precise data is lacking, but as a general rule IVC collapse of up to 40% during spontaneous breathing and up to 20% during intermittent positive pressure ventilation (IPPV) is taken to be within physiological norms, with values over these limits suggestive of hypovolaemia (6-8).

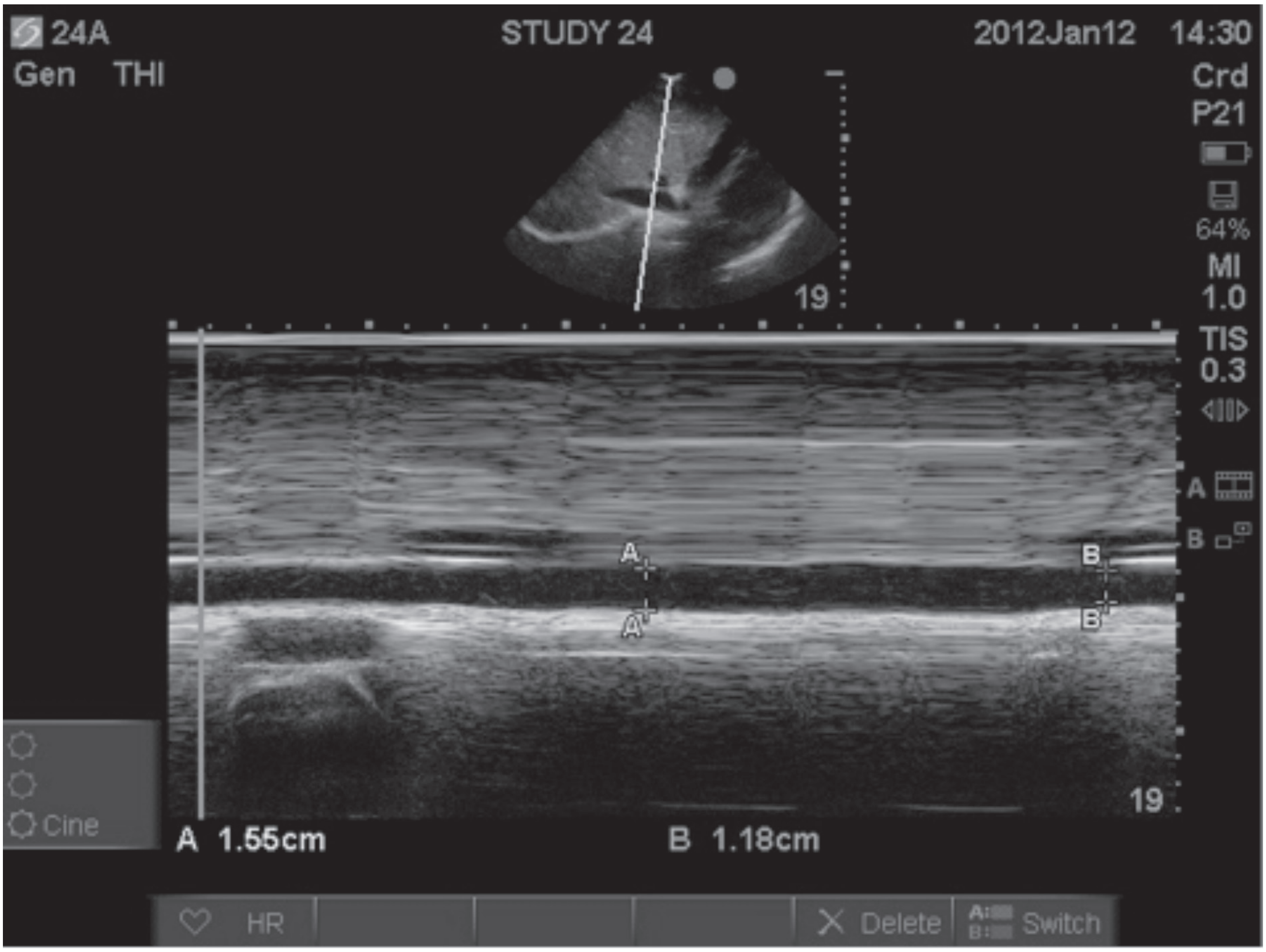

Fig. 1: M Mode view of the IVC in a ventilated patient demonstrating 23% variation in diameter across the respiratory cycle.

Changes in preload occurring as a result of intra-thoracic pressure differences during respiration can cause variation in the ejected stroke volume. The degree of variation is related to the tidal volume and intravascular volume status. Doppler measurement of the velocity time integer (VTi) of blood flow through the left ventricular outflow tract (LVOT) provides an accurate measure of stroke volume (Figure 2). Variation in LVOT VTi of more than 15% is suggestive of hypovolaemia in a patient receiving mandatory ventilation with a fixed tidal volume (9).

An over-arching scheme of competency for focused echocardiography in critical care has been developed by the Faculty of Intensive Care Medicine, the Intensive Care Society and the British Society of Echocardiography (10). This scheme, termed Focused Intensive Care Echocardiography (FICE), is based around a structured training and mentoring program. We have established a training course based on this curriculum and have successfully trained three cohorts of military clinicians from acute specialties. Previous work has suggested that clinicians can assimilate the skills required for focused echo in a relatively short time (11, 12). The aim of this study was to explore whether the technique could also be delivered by critical care nurses.

Methods

This study was classed as a service improvement project by the research office at the Royal Centre for Defence Medicine and ethical approval was not required. The study was conducted during Op GRITROCK within the Primary Casualty Receiving Facility (PCRF) on board RFA ARGUS, and took place between December 2014 and February 2015. Overall conduct of the study was the responsibility of the first author, an accredited mentor, under the FICE scheme. No patients participated in the study and no identifiable information relating to volunteers was held.

Volunteers from within the PCRF were screened by the lead investigator (SH) in order to ascertain the quality of transthoracic echo windows. A total of eleven volunteers participated in the study. All images were acquired using M Turbo base units with P21 51x transducers (Sonosite, UK). Six intensive care nurses, with no previous experience in acquiring or interpreting ultrasound images, were trained in two focused echo techniques by the first author. Training was limited to the specific techniques and did not include acquisition of other echo windows or interpreting images outside of this narrow context. Training consisted of an initial theory lecture followed by practical sessions, which occurred at least weekly for a period of five weeks.

On completion of the training period a validation exercise was conducted in order to assess the ability of the subjects to acquire and interpret images. Each candidate attempted to acquire the following images and information from a series of volunteer models:

i) M Mode long axis subcostal view of the inferior vena cava; maximum and minimum IVC diameter; and respiratory variability.
ii) Apical five chamber view; LVOT VTi calculated using continuous wave Doppler, minimum and maximum VTi and respiratory variability recorded.

The mentor (SH) recorded three measurements for each variable and the mean value was calculated. Each student then acquired three values for each variable and calculated the mean value. No assistance was given to candidates during the validation exercise and image acquisition was carried out by one candidate at a time.

A selection of images was reviewed offline by a consultant cardiologist and accredited FICE supervisor (PR) in order to provide external validity to the results.

Statistical analysis was performed using Prism v.6.0 (GraphPad). Data were assessed for normality using the D'Agostino & Pearson omnibus normality test. Relationships between values obtained by students and mentor were tested using Bland & Altman analysis and Pearson's correlation coefficient; p values of <0.05 were taken as significant.

Results

A total of forty-eight focused echo examinations were conducted on eleven volunteers. In every case, all students were able to obtain good quality images from both echo windows. There was a good correlation between values obtained by the mentor and students for both IVC diameter and LVOT VTi (Figure 3). Bland & Altman analysis of IVC measurements appeared to show a wider degree of

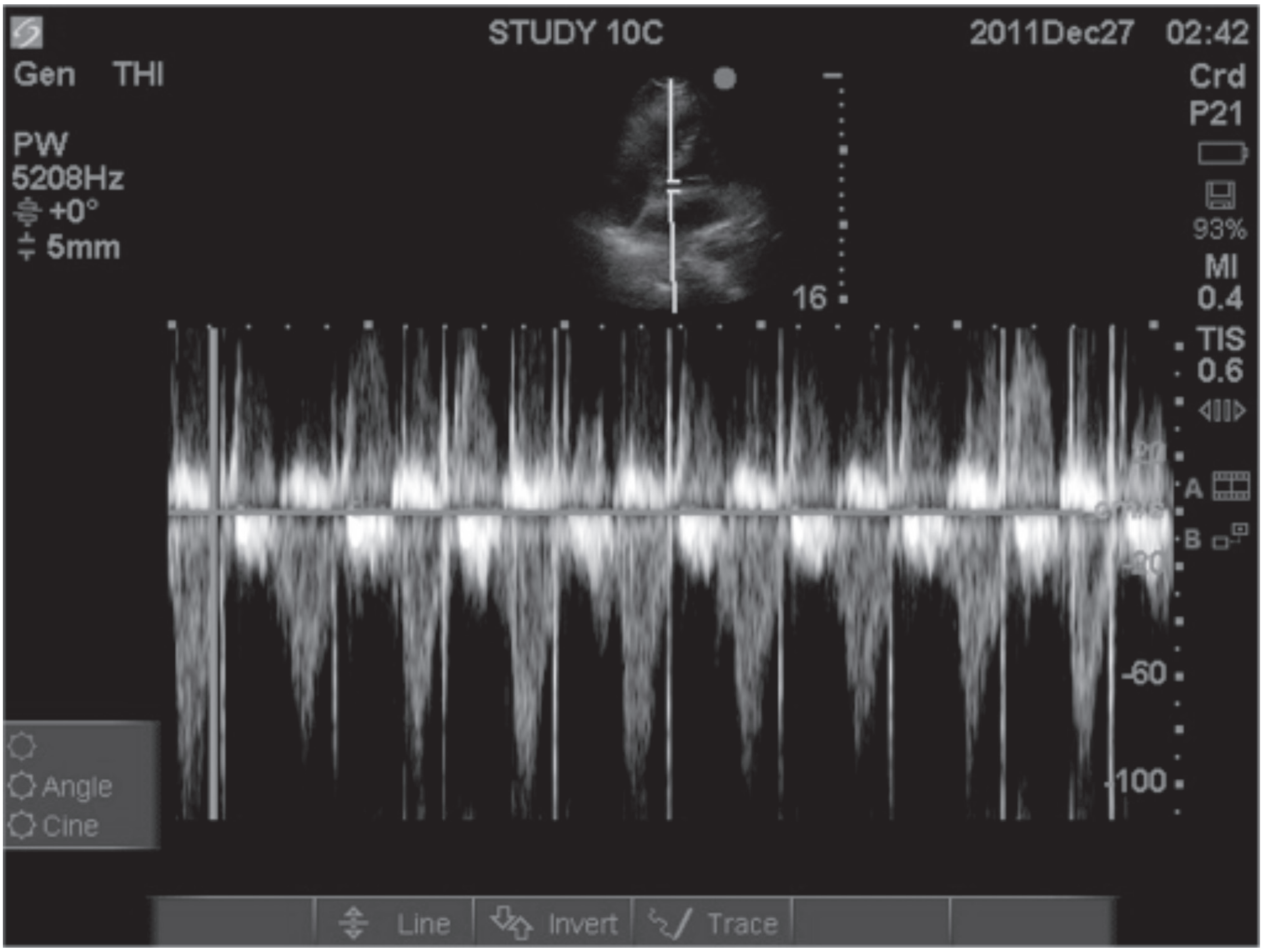

Fig. 2: LVOT VTi Pulse Wave Doppler. Cyclical variation in the VTi signal can be seen during the respiratory cycle.

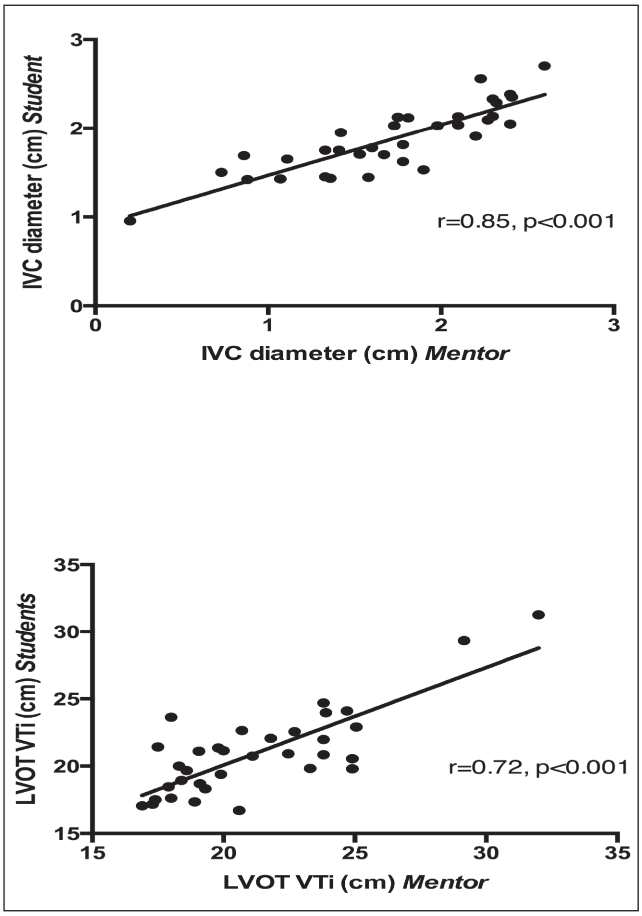

Fig. 3: Correlation between IVC and VTi values obtained by mentor and students in matched subjects.

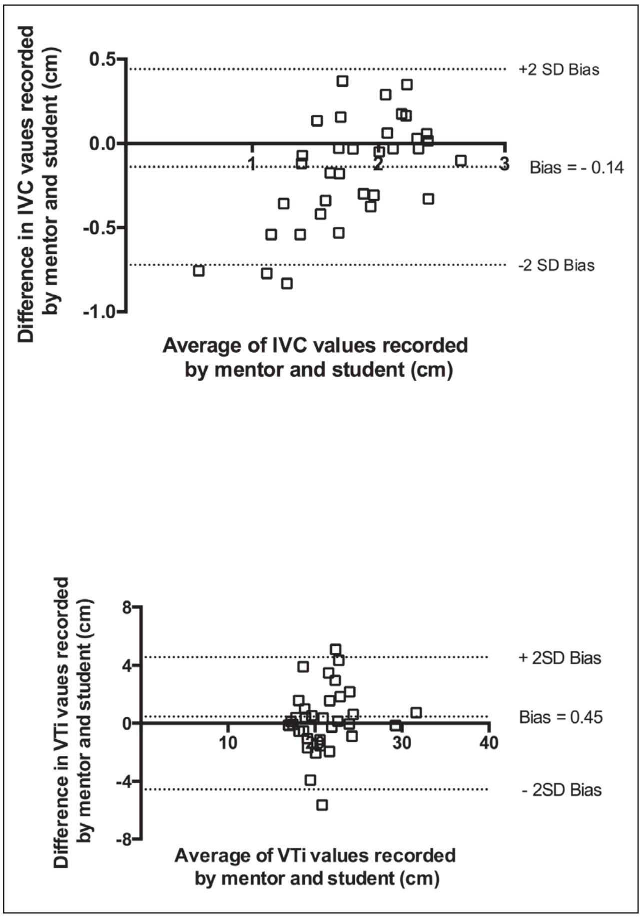

Fig. 4: Bland and Altman plots showing the relationship between IVC and VTi values obtained by mentor and students in matched subjects.

bias for the small number of values where the diameter was less than 1.2cm. There was no demonstrable bias in VTi measurements (Figure 4).

Using pre-determined criteria to identify potential for volume expansion (IVC variability > 40% ± LVOT VTi variability > 15%) we found considerable agreement between mentor and students (86% for IVC variability and 88% for VTi variability).

Discussion

We have successfully demonstrated that following a relatively short program of training, critical care nurses can achieve competency in using focused echocardiography to determine intravascular volume. Good correlation of values between relative novices and an experienced mentor was observed for both IVC and VTi measurements. The wider variation seen in IVC measurements at smaller diameters is noteworthy. Minimum IVC values during spontaneous respiration occur during inspiration and hence the acoustic window is often impaired by the presence of not only an increased amount of interposed air but also movement artifacts. This deterioration in image quality can lead to a blurring of the IVC vessel wall margin and thence to a reduction in the precision of measurements. These factors tend to be minimised with increasing experience, but should be a focus for those teaching focused echo techniques.

IVC physiology in critically-ill patients is complex and depends on a number of factors other than the volume status of the patient; for example tidal volume, mode of ventilation and differences between thoracic and abdominal pressures. These factors are often dynamic in critically-ill patients and a limitation of this study was its use of healthy volunteers only. As expected these euvolaemic, non-ventilated individuals exhibited minimal variations in the LVOT VTi Doppler signal. There was slightly more variation in the calibre of the IVC, but in almost all cases this was within accepted physiological norms. It would be worthwhile repeating this exercise in a cohort of critically-ill patients who would be expected to exhibit a wider variation in IVC and VTi measurements.

Conclusion

Although focused echocardiography is not, to our knowledge, currently used by nursing staff, critical care nurses commonly assimilate data from monitoring devices to assist in decision-making. In the deployed military critical care setting, focused echocardiography is currently the only available tool for monitoring global flow and volume status. Demonstrating that the technique can be successfully taught to a group of specialist nurses suggests that this method of intravascular volume assessment has wide utility within deployed environments across the DMS.

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