Original paper

A comparison of the ultrasound measurement of the inferior vena cava obtained with cardiac and convex transducers

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Abstract

Background: Ultrasound measurement of the inferior vena cava diameter and its respiratory variability are amongst the predictors of fluid volume status. The primary purpose of the present study was to compare the consistency of inferior vena cava diameter measurements and the collapsibility index, obtained with convex and cardiac transducers. A secondary aim was to assess the agreement of the patient's allocation to one of the two groups: "fluid responder" or "fluid non-responder", based on inferior vena cava collapsibility index calculation made with two different probes. **Methods:** 20 experienced clinicians blinded to the purpose of the study analysed forty anonymized digital clips of images obtained during ultrasound examination of 20 patients. For each patient, one digital loop was recorded with a cardiac and the second with a convex probe. The participants were asked to determine the maximal and minimal diameters of the inferior vena cava in all presented films. An independent researcher performed a comparative analysis of the measurements conducted with both probes by all participants. The calculation of the collapsibility index and allocation to "fluid responder" or "fluid non-responder" group was performed at this stage of the study. **Results:** The comparison of measurements obtained with cardiac and convex probes showed no statistically significant differences in the measurements of the maximal and minimal dimensions and in the collapsibility index. We also noticed that the decision of allocation to the "fluid responder" or "non-responder" group was not probe-dependent. **Conclusion:** Both transducers can be used interchangeably for the estimation of the studied dimensions.

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Introduction

Quick and adequate intravenous fluid resuscitation is crucial in the management of critically ill patients, however excessive fluid administration has been shown to contribute to mortality[1,2].

It has been established that clinical examination alone is unreliable; therefore, more objective means of intravascular volume assessment have arisen[3–5]. Ultrasound measurement of the inferior vena cava (IVC) diameter and its respiratory variability have been proposed as a simple, non-invasive tool to estimate the fluid volume status and predict fluid responsiveness[6–8]. This vital clinical information may determine the choice of critical treatment, and have a decisive impact on patients' outcome.

In many studies, IVC collapsibility index (IVC-CI) over 40% was acknowledged as the cut-off value to differentiate "fluid responders (FR)" and "non- responders (FNR)" in spontaneously breathing patients[9,10].

IVC diameter assessment has been implemented into various simplified protocols used during evaluation of patients in a critical condition[11], and is thus often performed by clinicians in life-threatening scenarios. There is, however, an inconsistency in reporting, describing and determination of the recommended acquisition technique, including the methodology of performing IVC measurement[12]. Although both cardiac and convex transducers are used for IVC diameter assessment in clinical practice, we are not aware of any study comparing the consistency and accuracy of measurements performed with both probes.

The primary objective of the present study was to compare the consistency in IVC diameter measurements and the dynamic IVC-derived collapsibility index, obtained with convex and cardiac transducers. A secondary aim was to assess the agreement of patient allocation to one of the two groups: "fluid responder" or "fluid non-responder", based on IVC-CI calculation with two different probes.

Methods

A prospective observational study was performed in compliance with Helsinki declaration. Written informed consent was obtained from all patients. Institutional Bioethics Committee of the John Paul II Hospital in Kraków, Poland approved the study protocol (Ref. No.: DW-0700-017/14).

The methodology was consistent with international guidelines for observational studies[13]. The study was conducted in February 2015 in the Emergency Department (ED) of a tertiary care centre. The inclusion criteria were: consecutive patients aged >18 years old, spontaneously breathing, admitted to the cardiac ED with chest pain. Exclusion criteria were: atrial fibrillation, dyspnoea, inability to lie down in a supine position, and difficulty to obtain interpretable ultrasound images from the subcostal acoustic window.

All bedside ultrasound examinations were performed by two certified sonographers, both with at least 5-year experience in echocardiography and emergency ultrasound. Each patient was examined twice. The first examination was conducted with a cardiac and the second one with a convex probe. All examinations were performed with a portable ultrasound system equipped with a 1–5 MHz transthoracic phased-array (cardiac) and a 3.5–5 MHz curvilinear (convex) transducers (CX 50 Philips, Eindhoven, Netherlands).

All IVC views were obtained in a supine position. The inferior vena cava was visualized longitudinally in a subxiphoid view. The infrahepatic segment of the IVC was imaged as it entered the right atrium. At that stage, the images were stored as 5-second digital loops on the machine's hard drive.

During the second stage of the study, all digital loops (half performed with a cardiac, and half with a convex probe) stored in the ultrasound machine memory were reviewed by 20 clinicians with experience in focused cardiac ultrasound (at least 200 POCUS examinations' experience). All participants were blinded to the study allocation, and not aware they assessed twice IVC diameter of the same patient examined with two different transducers. To minimize the possible inconsistencies in the measurement technique, all participating physicians underwent a 30-minutes didactic course focused on relevant sonographic details of the study. Maximal and minimal IVC diameters (IVC max and IVC min, retrospectively) were measured in two dimensional (2D) mode, distally to the hepatic vein-IVC junction, over a single respiratory cycle, by tracking the distance between anterior and posterior walls perpendicular to the long axis of the vessel.

In the final stage of the study, reports and measurements performed by the participating clinicians were analysed by an independent researcher. Comparisons of the measurements were conducted for each pair of transducers (cardiac vs convex) for each patient. IVC-CI was calculated for each of the digital loops. The IVC collapsibility index (IVC-CI) was defined as: IVC-CI = (IVC max – IVC min) / IVC max and expressed as percentage. Based on IVC-CI calculation, patients were categorized to "fluid responder" (if IVC-CI $\geq$ 40%) or "fluid non-responder" (if IVC-CI <40%) group.

Statistical analysis

The study sample size resulted from logistic reasons, primarily the number of clinicians with experience in POCUS, which determined the number of patients enrolled in the study. As modelling of balanced systems is more efficient and tolerant of deviations from the assumptions of testing, we assumed the same number of physicians-evaluators and patients enrolled in the study ($n = 20$). Continuous variables are presented as mean values and standard deviation. Differences between measurements were assessed by repeated-measure two-way analysis of

variances (ANOVA), in which the first main factor was the type of transducer, and the second main factor was the sonographer evaluating the image. The statistical significance of the interaction between the two main factors was also examined, but multiple comparisons were excluded because of the 2 levels of the first factor (type of transducer) and the lack of interest in comparisons between physicians' evaluations.

Categorical data are reported as number and percentages. Proportions were compared by Pearson's chi^2 test.

All tests were two-sided. A *p*-value of <0.05 was considered as statistically significant. SAS 9.2 software was used for the statistical analysis. Figures were made with STATISTICA 8 software.

Results

Twenty patients (13 male, aged 45–74 years old, median 59 years old) were included in the study. In all studied patients (n = 20) the ultrasound examination rendered an interpretable view of IVC, and enabled measurements of its diameters with cardiac and convex transducers.

Thus, two digital loops of each of 20 patients were stored on the machine's hard drive. The whole analysed set comprised 800 elements (400 pairs). The participating clinicians represented the five following groups: 9 cardiology consultants, 2 internal medicine consultants, 2 anaesthesiology consultants, 5 cardiology residents and 2 internal medicine residents (with a minimum of four years of training completed). No differences were found between the two levels of the first main factor-type of transducer: in IVC min (*p* = 0.4127), IVC max (*p* = 0.1785), IVC delta (*p* = 0.6411) and IVC-CI (*p* = 0.9746). In the case of the second main factor (clinicians evaluating) there were statistically significant differences in IVC min (*p* = 0.0355), IVC max (*p* = 0.0272), IVC delta (*p* = 0.0262), and IVC-CI (*p* = 0.0069). No differences were observed in the interaction: type of the transducer* clinician. It means the differences between clinicians' assessments did not depend on the type of transducer. The results are summarized in Tab. 1. Figures 1, 2, 3 and 4 show interaction: type of the transducer*clinician.

We also did not notice a significant difference in the decision of allocation to one of the two groups: "fluid responder" [(cardiac (*n* = 151; 37.7%) vs convex (*n* = 168; 42%); *p* = 0.2196] or "fluid non-responder" that was probe-dependent. This means that the type of the probe used by the physician during examination did not determine the allocation to FR or FNR category.

Discussion

Our study shows a good agreement between IVC diameter measurements and IVC collapsibility index when imaging was performed with convex and cardiac ultrasound probes. A novel finding in this study is the observation that allocation to one of the groups: "fluid responders" or "fluid non-responder" was not probe-dependent. Thus, both transducers can be used interchangeably to predict fluid responsiveness. This is important information in POC practice, since both transducers are used commonly during IVC assessment.

Although current American and European guidelines do not recommend any particular probe for IVC measurements, it has not been entirely clear whether the results obtained with these two transducers are equal, or at least similar[14]. Although we did not observe it in our study, there are potentially few reasons for considerable discrepancies between measurements performed with these two probes. Both transducers have different characteristics and physical properties, such as operating at different centre frequencies (with bandwidth for cardiac 1–5 Mz vs convex 3.5–5 Mz), have different dimensions, footprints and shapes, and provide different image formats[15]. All mentioned technical differences might translate into different imaging angles and planes when using convex or cardiac probes. Differences in imaging angulations, in turn, may cause significant differences in IVC diameters measured with these two transducers. Although in numerous studies various aspects of IVC measurements were assessed[6,15,16], we did not find any study comparing the consistency of measurements performed with cardiac and convex probes.

Many studies have shown that the potential source of discrepancies in measurement of IVC might be the image acquisition modality, methodology and the patient's posi-

Parameter	Factor: transducer				Factor: clinician *	Interaction: transducer * clinician
	Cardiac transducer	Convex transducer	Relative Delta [%]	*p*	*p*	*p*
IVC$_{min}$ (mm)	12.6 ± 7.25	12.1 ± 7.37	4.1	0.4127	0.0355	0.6557
IVC$_{max}$ (mm)	17.9 ± 6.30	17.3 ± 6.55	3.5	0.1785	0.0272	0.6946
IVC delta (mm)	5.3 ± 2.85	5.2 ± 3.11	2.7	0.6411	0.0262	0.4222
IVC CI (%)	35.4 ± 24.5	35.3 ± 23.79	0.3	0.9746	0.0069	0.7062
IVC$_{min}$ – minimal inferior vena cava diameter; IVC$_{max}$ – maximal inferior vena cava diameter; IVC delta – maximal-minimal vena cava diameter ; IVC-CI – inferior vena cava collapsibility index						

Tab. 1. *The results of inferior vena cava diameters and ANOVA analysis of the assessed factors*

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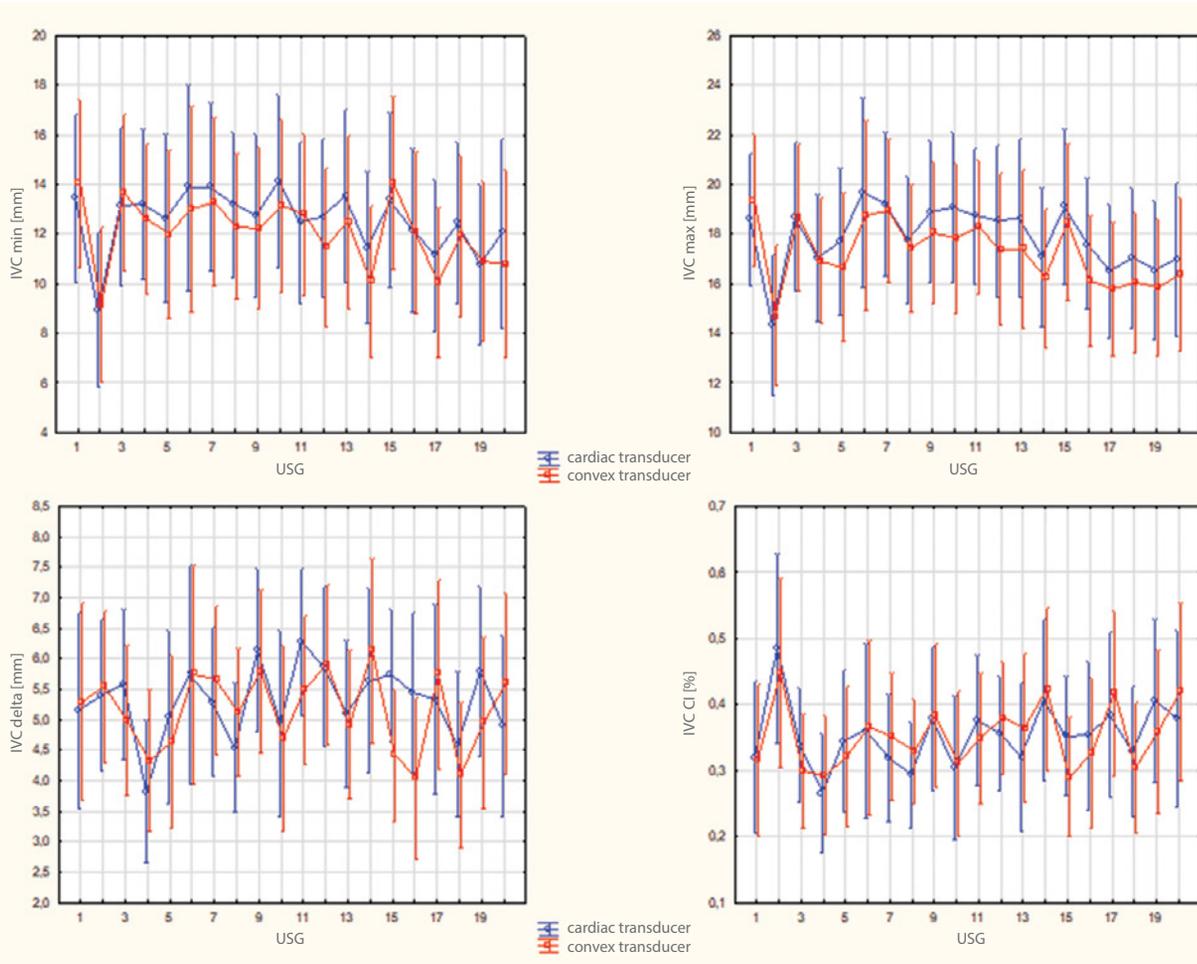
Fig. 1. *Interaction: type of the transducer* clinician. IVC$_{min}$ – minimal inferior vena cava diameter; IVC$_{max}$ – maximal inferior vena cava diameter; IVC delta – maximal-minimal inferior vena cava diameter; IVC CI – inferior vena cava collapsibility index*

tion during the assessment[17,18]. Finnerty *et al.*[12] showed that inter-rater reliability of IVC measurement was the highest for B-mode long axis sub-xiphoid view, compared with transabdominal short axis and right lateral coronal long axis view. The poorest reliability was related to motion-mode (M-mode) modalities. Another study, however, showed no significant difference between M-mode and 2-D measurements, and between long and short-axis IVC diameter measurements[10]. Wallace *et al.*[19] demonstrated equivalence in two anatomical approaches, namely, at the level of the left renal vein and 2 cm caudal to the hepatic vein inlet, both of which differ from measurements taken at the junction of the right atrium. Since we wanted to focus on the impact of the type of the probe on the measurements, minimizing the influence of other factors, we standardized the method of IVC diameter evaluation by the participants, holding the refreshing training prior to the study. Although we believed that this approach significantly reduced inter-observer variability resulting from various measurement techniques, we noticed significant differences in measurements between participants in minimal and maximal IVC dimensions.

There are some limitations of our study. The generalizability of our findings to other sonographers is limited by the relatively few numbers of examinations that obtained images for this study. All ultrasound examinations were performed by fairly experienced sonographers. It cannot be ruled out that results obtained by less competent physicians, especially in a life-threatening scenario, would have been different.

Conclusions

Cardiac and convex transducers can be used interchangeably for the estimation of dimensions of IVC and its respiratory variability.

Conflict of interest

The authors do not report any financial or personal connections with other persons or organizations, which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

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