BRIEF REPORT

Inferior Vena Cava Percentage Collapse During Respiration Is Affected by the Sampling Location: An Ultrasound Study in Healthy Volunteers

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Abstract

Objectives: Physicians are unable to reliably determine intravascular volume status through the clinical examination. Respiratory variation in the diameter of the inferior vena cava (IVC) has been investigated as a noninvasive marker of intravascular volume status; however, there has been a lack of standardization across investigations. The authors evaluated three locations along the IVC to determine if there is clinical equivalence of the respiratory percent collapse at these sites. The objective of this study was to determine the importance of location when measuring the IVC diameter during quiet respiration.

Methods: Measurements of the IVC were obtained during quiet passive respiration in supine healthy volunteers. All images were recorded in B-mode, with cine-loop adjustments in real time, to ensure that maximum and minimum IVC dimensions were obtained. One-way repeated-measures analysis of variance (ANOVA) was used for comparison of IVC measurement sites.

Results: The mean (±SD) percentage collapse was 20% (±16%) at the level of the diaphragm, 30% (±21%) at the level of the hepatic vein inlet, and 35% (±22%) at the level of the left renal vein. ANOVA revealed a significant overall effect for location of measurement, with $F_{(2,35)} = 6.00$ and $p = 0.006$. Contrasts showed that the diaphragm percentage collapse was significantly smaller than the hepatic $(F_{(1,36)} = 5.14; p = 0.03)$ or renal caval index $(F_{(1,36)} = 11.85; p = 0.002)$.

Conclusions: Measurements of respiratory variation in IVC collapse in healthy volunteers are equivalent at the level of the left renal vein and at 2 cm caudal to the hepatic vein inlet. Measurements taken at the junction of the right atrium and IVC are not equivalent to the other sites; clinicians should avoid measuring percentage collapse of the IVC at this location.

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Determination of intravascular volume is an important step in the initial resuscitation and subsequent management of critically ill patients. Physicians are unable to reliably determine intravascular volume status through the clinical examination[1] and have pursued both invasive and noninvasive means of estimating intravascular volume. Respiratory variation in the an-

teroposterior diameter of the inferior vena cava (IVC) has been investigated as a noninvasive marker of intravascular volume status, correlating its percentage collapse to central venous pressure. However, despite more than 30 years of interest in this parameter, there has been a lack of standardization across investigations. Studies have included healthy volunteers,[2] continuous ambulatory peritoneal dialysis patients,[3] hemodialysis patients,[4,5] healthy volunteers at phlebotomy centers,[6] and critically ill patients in intensive care units.[7,8] In addition, the locations of IVC measurements differ across studies[9–19] (Table 1).

This study aimed to determine if the degree of IVC collapsibility (also referred to as ''caval index'') varied within the same subject at commonly measured sites. In addition to providing an opportunity to compare results among existing studies, we sought to determine if the IVC percentage collapse was similar at multiple

Table 1
IVC Measurement Sites

Reference	IVC Measurement Site
Barbier[7]	Just upstream of the origin of the suprahepatic vein
Blehar[9]	Immediately inferior to the confluence of the hepatic vein inlet
Brennan[4]	Within 2.5 cm of the caval–RA junction
Brennan[10]	Within 2 cm of the caval–RA junction
Feissel[8]	Approximately 3 cm from the RA
Grant[2]	Actual measurements in centimeters were not recorded
Kircher[11]	Within 2 cm of the caval–RA junction
Lichtenstein[12]	Left renal vein
Lyon[6]	2 cm distal of the IVC–hepatic vein junction
Minutiello[13]	Within 2 cm of the right atrium origin of the IVC
Mintz[14]	Inferior to the junction of the hepatic veins
Mitaka[15]	Few centimeters inferior to the hepatic vein junction with the RA
Moreno[16]	IVC diameter was measured below the level of the hepatic veins and a few centimeters inferior to its junction with the RA
Natori[17]	Not defined
Sakurai[3]	Site distal of the IVC–hepatic vein junction
Simonson[18]	Successive 10-mm IVC measurements starting at the diaphragm and continuing to 60 mm from the caval–RA junction
Tamaki[19]	Slightly peripheral point from hepatic inlet

IVC = inferior vena cava; RA = right atrium.

locations along its course. Such a finding would have relevance to the sonologist, as it is often difficult to obtain a clear view of the IVC along its entire course.

METHODS

Study Design

This was a prospective ultrasound (US) study in healthy human volunteers. The institutional review board approved the study protocol.

Study Setting and Population

The study was conducted at a large urban teaching hospital in Brooklyn, New York. Participants were medical students, nursing students, and residents who were present in the emergency department during the enrollment period and consented to have US images of their abdomen recorded. Only measurements of the IVC diameter were obtained; no physical characteristics of the volunteers were documented. Participants received no remuneration for their involvement.

Study Protocol

Measurements of the IVC were obtained during quiet passive respiration in supine healthy volunteers using a 5–1 MHz phased array transducer (SonoSite M-Turbo, Bothell WA). All images were recorded in B-mode (grayscale), with cine-loop adjustments in real time to ensure that maximum and minimum IVC dimensions were obtained. Some sonologists advocate the use of M-mode (motion mode) to calculate IVC dimensions during the respiratory cycle. Although M-mode does allow for superior temporal resolution in real time

(when compared to cine-loop B-mode), we feel that this results in potentially inaccurate measurements, as the natural movement of the diaphragm during respiration results in caudal displacement of the IVC and, in effect, measurement of two different locations during inspiration and expiration. The use of B-mode cine-loop measurements ensures that the IVC dimensions are calculated at the same cranial-caudal level throughout the respiratory cycle. Measurement of the IVC was performed at three locations: longitudinally at the junction of the IVC and the right atrium, longitudinally 2 cm caudal to the hepatic vein inlet, and transversely at the level of the left renal vein (Figure 1). The diameter of the IVC was measured in an anteroposterior plane. The minimum diameter of the vein was measured during a spontaneous inspiration at each site. The maximum diameter of the IVC was recorded at the same sites during any other point in the respiratory cycle. All images were obtained by a study investigator (DJW) and were reviewed by an US fellowship-trained emergency physician (MBS). The percentage collapse of the IVC was calculated as

[(Maximum diameter IVC in cm – Minimum diameter IVC in cm)/Maximum diameter IVC in cm] × 100.[17]

Data Analysis

We designed the study to have an 80% power to detect a 20% difference in percentage collapse of the IVC between measurement locations. Alpha was set at 0.05. The decision to use a 20% difference was based on its clinical relevance, as several authors have published discriminatory breakpoints near this value.[7,13] For this reason, within-subject variation of this magnitude at different sites would be of interest. The standard deviation (SD) for the calculation was determined from a pilot study of healthy volunteers at our institution. Our
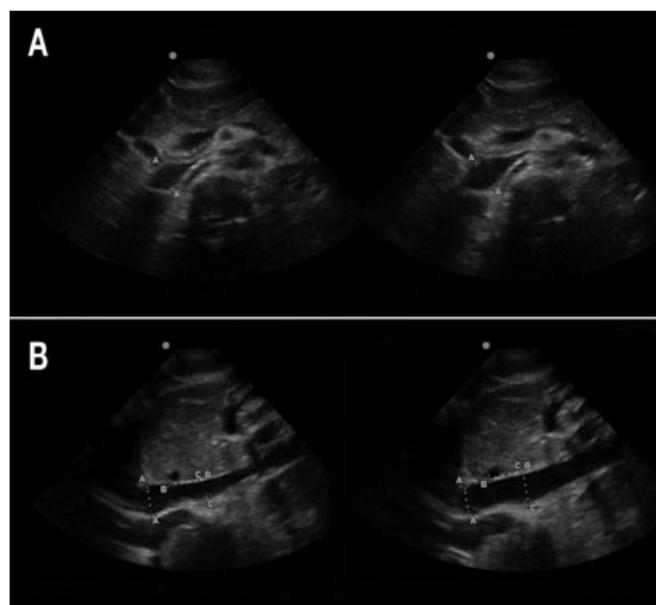

Figure 1. Transverse view of the inferior vena cava (IVC) during inspiration and expiration at the level of the left renal vein takeoff (A) and longitudinal view of the IVC during inspiration and expiration through the liver (B).

calculated sample size was 34 subjects. We planned to enroll 39 patients, which would allow 5% data loss in each group from inadequate IVC visualization.

One-way repeated-measures analysis of variance (ANOVA) was used for comparison of IVC measurement sites. Comparisons between all three sites were planned prior to data collection. All tests were two-sided, and analyses were performed using SAS JMP software, version 7.01 (SAS Institute; Cary, NC). A p-value of less than 0.05 was considered to indicate statistical significance.

RESULTS

Thirty-nine volunteers were recruited for enrollment in the study. Measurements were successfully obtained in all volunteers (100%) at the junction of the right atrium and IVC and at the takeoff of the left renal vein; in two volunteers (5%) the IVC could not be adequately visualized for measurement at the level of the hepatic vein inlet.

The mean (±SD) collapse was 20% (±16%) at the level of the diaphragm, 30% (±21%) at the level of the hepatic vein inlet, and 35% (±22%) at the level of the left renal vein. A scatterplot of percentage collapse by measurement site is shown in Figure 2. Results analyzed using one-way ANOVA repeated-measures design revealed a significant overall effect for location of mea-
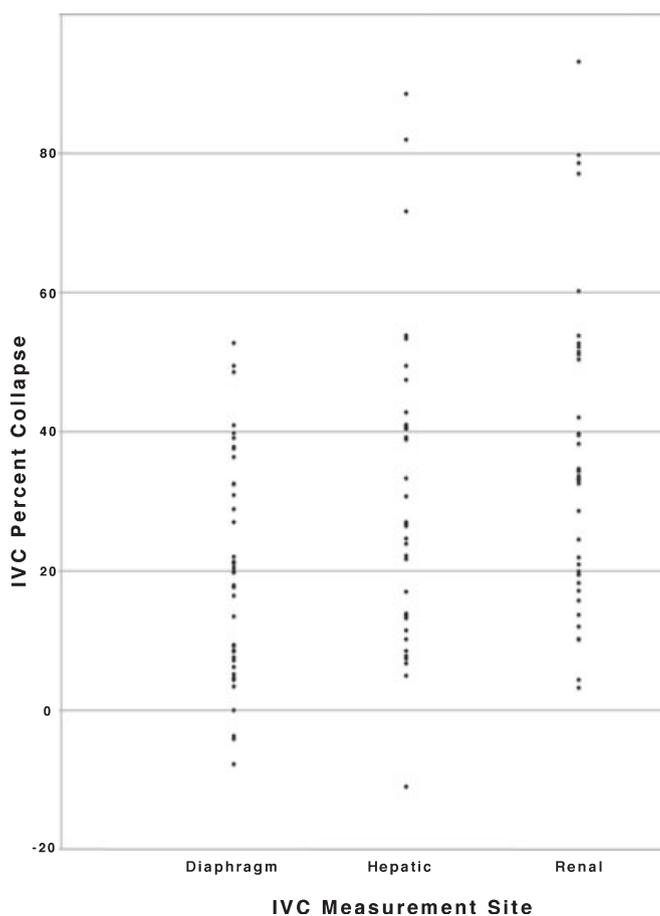

Figure 2. Scatterplot of inferior vena cava (IVC) percentage collapse by measurement site.

surement, with $F_{(2,35)} = 6.00$ and $p = 0.006$. Contrasts showed that the mean percentage collapse at the diaphragm was significantly smaller than that at the hepatic vein inlet ($F_{(1,36)} = 5.14$; $p = 0.03$) or the left renal vein ($F_{(1,36)} = 11.85$; $p = 0.002$). There was no difference between the mean percentage collapse at the level of the hepatic vein inlet and at the left renal vein measurement sites ($F_{(1,36)} = 1.38$; $p = 0.25$). Maulchy's test indicated that the assumption of sphericity had not been violated ($\chi^2 = 0.026$; $p = 0.98$).

DISCUSSION

Our study supports the measurement of respiratory variation in the IVC just caudad to the hepatic vein inlet or at the level of the left renal vein. By extension, this finding suggests comparability of studies that have used these two sites in prior investigations. Our observations have practical implications, as well: either site may be used clinically in the determination of volume status, as the situation may arise where one of the views is difficult to obtain. While the hepatic segment of the IVC is usually accessible to imaging, studies have reported a 10%–11% failure rate, and as much as 30% only fair image acquisitions of the hepatic segment.[4,10] In our study, only 2 of 39 subjects (5%) were unable to have the hepatic portion of the IVC adequately visualized for measurement, but were able to have the renal segment measured. Additionally, Lichtenstein[12] has described a "saber profile" of the IVC, caused by the incoming hepatic vein and appearing as a bulge in the longitudinal silhouette of the vena cava. In this situation, measurement of the IVC near the hepatic vein inlet may be unreliable and should be performed at the level of the left renal vein. Finally, the collapsibility of the hepatic portion of the IVC may be influenced by the surrounding parenchyma, with liver fibrosis or cirrhosis causing impaired diminution.[20] In conditions where overt liver disease is suspected, therefore, percentage collapse of the IVC may be measured more reliably at the left renal vein takeoff.

Our results also show that IVC percentage collapse at the junction of the right atrium and IVC was dissimilar to the other sites. This finding is perhaps not surprising, as the attachment of the muscular diaphragm may result in decreased compliance of the vessel at this location.

These results suggest that a similar IVC percentage collapse will be obtained at the level of either the left renal vein takeoff, or 2 cm caudal to the hepatic vein inlet, which offers clinicians some latitude for image acquisition. Further, we found that measurements at the junction of the right atrium and IVC were dissimilar to the other sites, and therefore clinicians should avoid sampling IVC dimensions at this location.

LIMITATIONS

This study was conducted in healthy volunteers; these findings need to be validated in hypotensive patients, as regional variations in IVC percentage collapse may be volume dependent. In addition, regional variation in the percentage collapse could be influenced by the infusion

of vasoconstrictors. A single operator performed all measurements; however, all images were reviewed by a fellowship-trained sonologist to ensure that adequate images were obtained. Finally, our protocol stipulated taking measurements during quiet respiration; employment of a sniff or more forceful inspiration by the study subject could have resulted in alternative discrimination between the measurement sites. Further investigation of these maneuvers is warranted.

CONCLUSIONS

Measurements of respiratory variation in inferior vena cava collapse in healthy volunteers are equivalent at the level of the left renal vein and 2 cm caudal to the hepatic vein inlet. Measurements taken at the junction of the right atrium and inferior vena cava are not equivalent to the other sites; clinicians should avoid measuring the percentage collapse of the inferior vena cava at this location.

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