Original Article

Sonographic evaluation of intravascular volume status: Can internal jugular or femoral vein collapsibility be used in the absence of IVC visualization?

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Abstract:

INTRODUCTION: Inferior vena cava collapsibility index (IVC-CI) has been shown to correlate with both clinical and invasive assessment of intravascular volume status, but has important limitations such as the requirement for advanced sonographic skills, the degree of difficulty in obtaining those skills, and often challenging visualization of the IVC in the postoperative patient. The current study aims to explore the potential for using femoral (FV) or internal jugular (IJV) vein collapsibility as alternative sonographic options in the absence of adequate IVC visualization.

METHODS: A prospective, observational study comparing IVC-CI and Fem- and/or IJV-CI was performed in two intensive care units (ICU) between January 2012 and April 2014. Concurrent M-mode measurements of IVC-CI and FV- and/or IJV-CI were collected during each sonographic session. Measurements of IVC were obtained using standard technique. IJV-CI and FV-CI were measured using high-frequency, linear array ultrasound probe placed in the corresponding anatomic areas. Paired data were analyzed using coefficient of correlation/determination and Bland-Altman determination of measurement bias.

RESULTS: We performed paired ultrasound examination of IVC-IJV ($n = 39$) and IVC-FV ($n = 22$), in 40 patients (mean age 54.1; 40% women). Both FV-CI and IJV-CI scans took less time to complete than IVC-CI scans (both, $P < 0.02$). Correlations between IVC-CI/FV-CI ($R^2 = 0.41$) and IVC-CI/IJV-CI ($R^2 = 0.38$) were weak. There was a mean -3.5% measurement bias between IVC-CI and IJV-CI, with trend toward overestimation for IJV-CI with increasing collapsibility. In contrast, FV-CI underestimated collapsibility by approximately 3.8% across the measured collapsibility range.

CONCLUSION: Despite small measurement biases, correlations between IVC-CI and FV-/IJV-CI are weak. These results indicate that IJ-CI and FV-CI should not be used as a primary intravascular volume assessment tool for clinical decision support in the ICU. The authors propose that IJV-CI and FV-CI be reserved for clinical scenarios where sonographic acquisition of both IVC-CI or subclavian collapsibility are not feasible, especially when trended over time. Sonographers should be aware that IJV-CI tends to overestimate collapsibility when compared to IVC-CI, and FV-CI tends to underestimates collapsibility relative to IVC-CI.

Key words:

Femoral vein, hemodynamic resuscitation, intensive care unit, internal jugular vein, inferior vena cava; intravascular volume status assessment, portable ultrasound, point-of-care testing, venous collapsibility index

Intravascular fluid status estimation continues to be one of the greatest challenges in critical care medicine. Limitations of invasive hemodynamic monitoring are becoming increasingly apparent.[1-3] Although central venous pressure (CVP) has long been used to guide fluid management, data suggest that it fails to reliably correlate with effective intravascular volume.[4] Despite decades of clinical investigations, a clear strategy leading to better outcomes with the pulmonary artery catheter (PAC) has not been devised.[5] At the same time, the use of the PAC is associated with numerous potential complications, including intravascular thrombosis, infection, and vascular injury.[2] Furthermore, inappropriate clinical decisions and/or inaccurate data presents another form of risk when using the PAC.[2]

The more recently introduced minimally-invasive devices for hemodynamic monitoring are promising, but thus far they have either been found to be inconsistent or have fallen short of delivering as promised.[6,7] As clinical standards of care shift towards minimally- and non-invasive monitoring modalities, the search continues for parameters by which to guide fluid management. Studies suggest that focused bedside ultrasonography of the vena cava may have utility in assessing intravascular volume status.[3,8,9] Determination of inferior vena cava

(IVC) diameters and its collapsibility index (IVC-CI) has been found to correlate with intravascular volume status and clinical response to clinical interventions.[10-12] Collapsibility indices and diameter measurement used together may improve the predictive value of sonography of the IVC for determining right atrial pressures.[13] Subsequent studies comparing IVC-CI to central venous pressures (CVP) demonstrated an inverse relationship between these two parameters.[6,9,14]

Despite its potential advantages, sonographic IVC-CI visualization can be impaired by various factors, such as abdominal distension, bowel gas overlying the IVC, overlying tissue edema, complex abdominal wounds, masses causing external compression, elevated intra-abdominal pressure, and morbid obesity.[1,3,11] In order to maximize the utility of venous collapsibility as a viable, repeatable, noninvasive intravascular volume assessment modality, the fundamental principles must be preserved of portability, reliability, ease of teaching, availability, and applicability across various patient populations.

A previous study by our group demonstrated acceptable correlation between subclavian vein collapsibility index (SCV-CI) and IVC-CI.[15] Going a step further, the current study was performed to examine the utility of femoral vein collapsibility index (FV-CI) and internal jugular vein collapsibility index (IJV-CI) as possible alternatives for venous collapsibility estimation in the absence of IVC-CI or SCV-CI sonographic visualization.

Methods

Study design

A prospective, observational study utilizing a convenience sample of mixed surgical and medical ICU patients was performed at participating institutions after Institutional Review Board/Ethics Board approvals were obtained at the participating medical centers. All patients signed an informed consent prior to initiation of study-related activities. Focused sonographic evaluations of critically ill surgical patients were performed between January 1, 2012 and April 15, 2014.

Collected data included patient demographics (age, gender), physiologic severity assessments (APACHE II score), laboratory values, ventilatory settings, hemodynamic parameters (heart rate, blood pressure, central venous pressures) and sonographic measurements of IVC, femoral vein (FV) and internal jugular vein (IJV) collapsibility.

Simultaneous sonographic measurements of the IVC, FV and IJV were performed during each patient encounter according to the techniques outlined blow. IVC and FV/IJV measurements for each paired data set were performed by the same sonographer. Sonographers in this study were clinical providers credentialed by the institution to perform focused bedside sonographic exams. Providers included critical care specialists, surgeons, anesthesiologists, and emergency medicine physicians who underwent specific *a priori* training in the requisite ultrasound techniques. For each sonographic scan, the "time to data acquisition" was recorded independently by a bedside nurse who was not a study investigator. This was defined as the time interval between "probedown" to "vessel measurements made". The mean times to data acquisition were then compared between IVC-CI and FV-/IJV-CI approaches. In addition, we recorded head-of-bed elevation for each study patient during each bedside sonographic session.

Sonographic technique and equipment

All patients in this study underwent serial, simultaneous assessments of IVC-CI, FV-CI and IJV-CI using portable ultrasound device (M-Turbo™ by Sonosite Fuji Film, Bothell, WA). Sonographic evaluation of IVC-CI was performed according to the methodology described by the American Society of Echocardiography (via an initial B-mode paramedian 'longitudinal' long-axis window of the IVC above the level of the hepatic veins, within 0.5-3 cm from the right atrium, Figure 1, left). This technique has been outlined in detail elsewhere.[15-17] The standard curvilinear phased array transducer was used for the purposes of IVC-CI assessment. FV and IJV measurements were taken by first visualizing a cross-sectional B-mode window of the short axis of the vessel with the high-frequency linear array transducer. After the target vein was localized, the dynamic diameter change was recorded over time using the M-mode in order to identify and measure the minimum and maximum venous dimensions over the respiratory cycle [Figure 1].

The calculation of IVC collapsibility used in this investigation is slightly different than the method commonly described in the literature; that is the venous diameters are typically measured during end-inspiration and end-expiration in the respiratory cycle.[16] Our previous work demonstrated that it sufficient to record the minimum and the maximum venous diameters in order to calculate the collapsibility; this technique is particularly useful when approaching critically ill, mechanically ventilated patients.[1,15] The difference between the maximum (D*max*) and minimum (D*min*) diameters of the target vein is subsequently normalized to a percentage of the maximum diameter according to the formula shown below to yield the collapsibility index (CI):

$$CI = [(Dmax - Dmin)/Dmax] \times 100\%$$

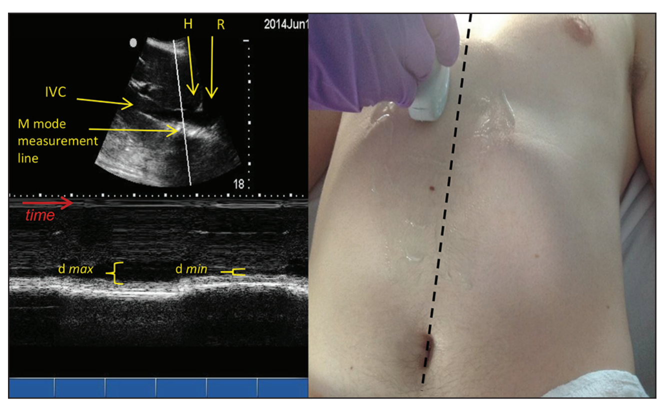

Figure 1: Determination of IVC collapsibility. At right, transducer position is demonstrated; anatomic midline is indicated by the dashed line. At left, M-mode tracing of the IVC. The white vertical line marks the line of measurement across the long-axis of the IVC. The hepatic veins (HV) and right atrium (RA) are visualized in this standard window. Brackets (left, bottom) denote the minimal (d_{min}) and maximal (d_{max}) diameters of the IVC measured over the entire respiratory cycle

For the assessment of the IJV collapsibility, we utilized the high frequency linear array transducer to obtain a cross sectional or short-axis window of the IJV in the mid- to lower antero-lateral neck [Figure 2]. As with sonography of the IVC, the IJ-CI was derived via M-mode assessment of the respiratory variation in the vein's diameter (minimum versus maximum) and subsequent normalization of the values to a standard collapsibility index [Figure 2]. For the assessment of the FV collapsibility, we similarly utilized the high frequency linear array transducer to obtain a cross sectional or short-axis view of the FV in the groin, between 1-2 inches below the level of the inguinal ligament [Figure 3]. As with sonography of the IVC, the FV-CI was derived via M-mode assessment of the variation in the vein's diameter (minimum versus maximum) and subsequent normalization of the values to a standard collapsibility index [Figure 3].

Data analysis. Demographics and general patient sample characteristics were tabulated and presented using standard descriptive statistics. Paired, concurrent measurements of IVC-CI, FV-CI, and IJV-CI were analyzed using the correlation coefficient and the Bland-Altman bias plot. Measurement bias was expressed in percent collapsibility. In addition, the values for "time to data acquisition" were compared between the two sonographic methods using two-tailed Student's *t*-test. Data were analyzed using SPSS 18 for Windows (IBM Corporation, Armonk, NY, USA). Statistical significance was set at alpha = 0.05.

Results

A total of forty SICU patients were examined with 93 total IVJ-IVC and 57 total FV-IVC paired measurements taken [Table 1]. Patients were critically ill and predominately mechanically ventilated (72%) but in relatively stable condition (median APACHE II = 9; SAPS = 28). Patients also tended to be substantially obese (median BMI = 31).

Internal jugular collapsibility

IJV-CI measurements took 55 seconds less time to acquire on average than their paired IVC-CI measurements; with some IVC measurements taking up to 5 minutes to acquire. Mean "time to data acquisition" was 34 seconds (range of 15-90 sec) for the IJV-CI versus 89 seconds for the IVC-CI (range of 15-300 sec; $P < 0.01$). In aggregate, paired measurements ($n = 93$) demonstrated poor correlation over a broad range of venous collapsibility indices on linear regression analysis ($R^2 = 0.38$) [Figure 4, left]. Bland-Altman bias analysis demonstrated a mean collapsibility measurement bias of –3.51% with a median collapsibility bias of –2.38%, suggesting that IJV-CI over-estimated collapsibility relative to IVC-CI [Figure 4, right]. This bias was smaller (approximately –1.5%) for IJV-CI values <30%, and increased to approximately –10% for IJV-CIs >60%.

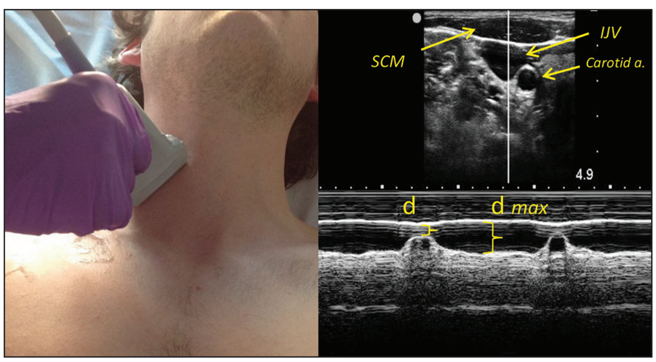

Figure 2: Technique for determination of IJ collapsibility. A transverse view of the IJ vein is taken using the M-mode; maximal and minimal diameters are measured then normalized to % collapsibility using the described methods

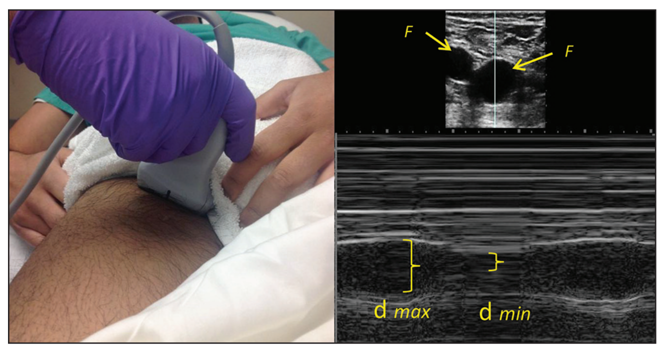

Figure 3: Technique for determination of femoral vein collapsibility. A transverse view of the femoral vein is obtained with the M-mode; maximal and minimal diameters are measured and normalized to %-collapsibility using the described methods

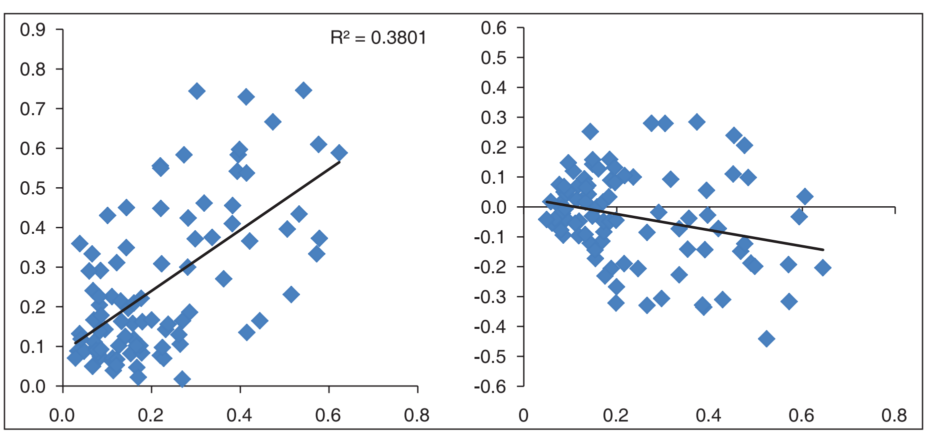

Figure 4: Regression plot of IVC-CI versus IJV-CI (left); Bland-Altman plot of IVC-CI versus IJV-CI (right)

Femoral venous collapsibility

Mean "time to data acquisition" was 36 seconds less for FV than for IVC in paired measurements (49 seconds for the FV-CI versus 85 seconds for the IVC-CI; $P < 0.02$). On linear regression analysis, paired measurements demonstrated poor correlation over the recorded range of venous collapsibility indices ($R^2 = 0.41$) [Figure 5, left]. The measurement bias trendline demonstrated a positive tendency which became more pronounced with increasing collapsibility values (~2% for collapsibility values <20% and ~10% for collapsibility ranges >40%) [Figure 5, right]. In practical terms this indicates that as the overall collapsibility increases, the FV-CI tends to progressively underestimate the percentage of venous collapse when compared to the IVC-CI.

Table 1: Basic demographic and sonographic characteristics of the study group

Study sample characteristics	Number (%)	Number
General demographics		
Number of patients (overall)	40	
Gender, % female	16/40 (40)	
Mean age±SD (years)	54.1±16.9	
[median, range]	[55, 21-85]	
APACHE II score (mean±SD)	11.7±6.19	
[median, range]	[9, 5-39]	
SAPS II score (mean±SD)	30.2±10.5	
[median, range]	[28, 12-51]	
Proportion mechanically ventilated (%)	29/40 (72.5)	
Body-mass index (BMI, mean±SD)	32.9±12.1	
[median, range]	[31,17-84]	
Sonographic characteristics	Internal Jugular Vein (IJV)	Femoral Vein (FV)
Total patients	39	22
Total data pairs measured	93	57
[per patient*]	2.4	2.6
Collapsibility (mean±SD)	25.5±19.9	12.9±8.4
[median]	18.6	11.4
Time to complete exam (seconds)	34 sec	49 sec

BMI = Body mass index, IVC-CI = Inferior vena cava collapsibility index, SD = Standard deviation, *Most study patients participated in more than one scanning session

Discussion

Previous studies have demonstrated clinical correlations between IVC measurements (collapsibility, absolute diameters) and traditional measures of intravascular volume status (central venous pressure), though a perfect linear correlation has yet to be demonstrated.[1,3,9,16] Brennen *et al.*, have produced an excellent report suggesting that the combination of collapsibility indices and diameter measurements may improve the ability to correlate sonographic measurements of the IVC with clinically significant categories of right atrial pressure (e.g. 0-10 mm Hg); though this study's exclusion of ventilated patients and lack of statistical significance limit the applicability of this approach to our investigation of predominately critically ill patients[13]. Volpicelli *et al.*, however have used a modified categorical method from Brennen *et al.*, alongside other ultrasound based clinical assessments to successfully predict etiology of shock in emergency department patients.[18] Evidence supporting the use of the subclavian vein (SCV) collapsibility has been previously published by our group as a potential alternative to IVC-CI during focused bedside sonographic assessment of intravascular volume status.[15] The current study aims to investigate the possibility of whether additional, more "peripherally" located sites (the FV and IJV) may be useful for sonographic volume status assessment. Our choice of uniquely using normalized collapsibility indices (as a validated, independent predictor of CVP and right atrial pressures) as the primary metric for comparison allows for a more standardized comparison between the differently sized IVC, IJV, and FV. We did not limit the enrollment to patients with central venous or arterial vascular access, as such invasive means of volume status determination were not utilized. While this strategy does not employ a gold standard for direct comparison of volume status, it does allow for a preliminary assessment of the utility of the IJV and FV as alternative sites for sonographic determination of volume status. Perhaps more importantly, this approach allows for the inclusion of critically ill patients without invasive vascular access (as would be the case for ED triage, a low acuity hospital ward, or resource limited settings) thereby improving the representativeness of our sample with respect to a substantial component of our target patient population.

The correlations between IJV-CI versus IVC-CI ($R^2 = 0.38$) and FV-CI versus IVC-CI ($R^2 = 0.41$), while positive, were both considerably weaker than the correlation between

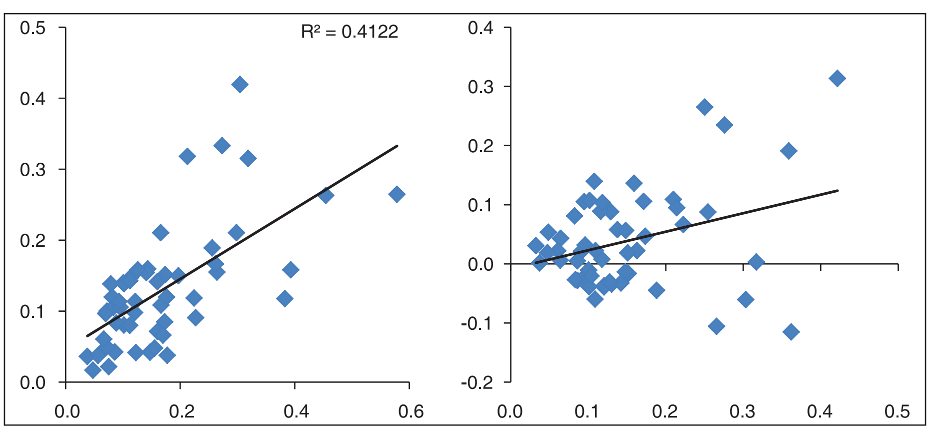

Figure 5: Regression plot of IVC-CI versus FV-CI (left); Bland-Altman plot of IVC-CI versus FV-CI (right)

SCV-CI and IVC-CI ($R^2 = 0.61$), as previously reported by our group.[15] These findings support our hypothesis that IJV-CI and FV-CI should be considered, at best, second- or third-line venous collapsibility measurement options after IVC-CI and SCV-CI, respectively. Among some of the positives, we noted that overall measurement biases were relatively small for both the IJV and FV collapsibility indices given the broad ranges that are used clinically. This is also consistent with our previous research demonstrating that SCV-CI measurement bias was minimal over the range of recorded samples and was considered to be clinically insignificant when compared to previously established values for clinically significant collapsibility ranges.[1,15]

There are several variables that could account for the weak correlation of IJV-CI and FV-CI with IVC-CI. First, both IJV and FV are relatively easier to externally compress than either the IVC during sonographic evaluation due to their comparatively exposed and superficial locations. Consequently, even small differences in pressure applied to the ultrasound probe during both the IJV and FV measurement acquisition may well account for a meaningful portion of the variation in measured collapsibility indices. However, our sonologists were cognizant of this potential pitfall, and recordings were made with consistent technique free of any appreciable deformation of venous geometry. Second, the current study did not define a standard head-of-bed angle of elevation among patients, which may be an additional source of bias due to variation in hydrostatic effects on both IJV and FV behavior. For example, when compared to the supine patient, IJV collapsibility may be greater when the head-of-bed is elevated at 30 degrees and FV-CI may appear comparatively elevated in the same position. Stricter standardization of training and technique as well as positioning may improve the quality of information obtained with these methods. Additionally, while it may not necessarily reflect IJ-CI and FV-CI measurements, the authors would like to point out that head-of-bed elevation was not shown to significantly influence IVC-CI measurement in a recently reported, large study.[17] Thirdly, there may be a small degree of variation introduced by our method of identification of the optimal level for the cross-sectional or short-axis windows of the IJV and FV. The visual targets for the IJV and FV are less precise, and thus a potential source of bias while the confluence of the hepatic veins serves as a helpful landmark for standardization of the IVC window. Finally, the use of cross-sectional or short axis windows with respect to IJV and FV image acquisition and the standard longitudinal or long axis window for imaging of the IVC may introduce some differences in measurement. As the M-mode samples in a functionally one-dimensional line, good sonographic technique that aims to obtain windows that minimize lateral motion of the target vessels should reduce these differences. The choice of reporting proportional indices rather than absolute measurements helps to reduce systemic error related to tendencies of over or under measurement and slight variations in angle of sampling by the process of normalization. Our Bland-Altman analysis suggests that there is a slightly positive systemic biases (~10%) at higher collapsibility indices for FV measurements, however, this is not reflected in the IJV measurements and likely is related to differences in target location rather than sonographic technique. Additionally, our previously published work comparing SCV to IVC collapsibility indices showed good correlation and minimal bias despite data acquisition with a cross sectional view of the SCV and a longitudinal view of the IVC.[14]

There are several specific clinical situations where IJV-CI or FV-CI may be useful. For example, when one is unable to access the abdominal anatomic area during operative procedures, the alternative venous locations may offer an approximation of IVC-CI measurement. In certain urgent situations, the IJV-CI or FV-CI are relatively easier and faster to obtain than IVC-CI measurements. Such situations may include a "quick-look" examination of jugular venous collapsibility in acute congestive heart failure, or conversely an abbreviated examination of the femoral collapsibility in the setting of hypovolemic shock. This is especially true when the collapsibility indices found on exam are relatively high. Once the patient has been stabilized, these measurements can be correlated with the more accurate IVC-CI, SVC-CI, or other hemodynamic and volume status measurements.

Limitations of this study include relatively small sample size, which affects our ability to generalize these results at the extremes of collapsibility values. The unique use of collapsibility indices for comparison may also be less accurate a predictor of volume status than a combined approach also including absolute diameter measurements. Also, the fact that all measurements were obtained by credentialed expert clinical sonologists may limit the applicability of our findings by less experienced operators. Prior to wider implementation of IVC-CI and FV-CI in clinical practice, further studies with larger patient samples and more diverse hemodynamic presentations should be carried out. Nevertheless, the current study provides an important foundation upon which such future clinical investigations can be built.

Conclusion

Internal jugular and femoral venous collapsibility assessments, although not as reliable as SCV collapsibility assessment, may be reasonable candidates for "second-line" alternative sites for sonographic volume status assessment to IVC-CI in the patient in whom visualization of the latter is impossible. Both IJV and FV measurements took less time to acquire than IVC-CI measurements. As with all novel volume assessment measurement techniques, further study is needed to examine FV-CI and IJV-CI compared to a gold standard metric and to determine the role of absolute measurement of the target vein diameters in the sonographic assessment of intravascular volume status in a broader range of clinical settings.

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