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ORIGINAL INVESTIGATION

Comparative study between suprasternal and apical windows: a user-friendly cardiac output measurement for the anesthesiologist☆

Rafaela Souto e Souza [a,*], Wendhell Barros de Melo [a], Claudia Maria Vilas Freire [a], Walkiria Wingester Vilas Boas [a]

[a] *Hospital das Clínicas da Universidade Federal de Minas Gerais (HC/UFMG), Belo Horizonte, MG, Brazil*

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Non-invasive monitoring;
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Abstract
Introduction: Transthoracic echocardiography is a safe and readily available tool for noninvasive monitoring of Cardiac Output (CO). The use of the suprasternal window situated at the sternal notch can be an alternative approach for estimating blood flow. The present study aimed to compare two methods of CO calculation. We compared the descending aorta Velocity-Time Integral (VTI) measurement from the suprasternal window view with the standard technique to determine CO that uses VTI measurements from the LVOT (Left Ventricular Outflow Tract) view. We also aimed to find out whether after basic training a non-echocardiographer operator can obtain reproducible measurements of VTI using this approach.
Methods: In the first part of the study, 26 patients without known cardiovascular diseases were evaluated and VTI data were acquired from the suprasternal window by a non-echocardiographer and an echocardiographer. Next, 17 patients were evaluated by an echocardiographer only and VTI and CO measurements were obtained from suprasternal and apical windows. Data were analyzed using the Bland and Altman method (BA), correlation and regression.
Results: We found a strong correlation between measurements obtained by a non-expert and an expert echocardiographer and detected that an inexperienced trainee can acquire VTI measurements from the suprasternal window view. Regarding agreement between CO measurements, data obtained showed a positive correlation and the Bland and Altman analysis presented a total variation of 38.9%.

☆ Study conducted at the Hospital das Clínicas da Universidade Federal de Minas Gerais – HC/UFMG.
* Corresponding author.
E-mail: ssoutorafaela@gmail.com (R.S. Souza).

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Conclusion: Regarding accuracy, it is likely that TTE (Transthoracic Echocardiogram) measurements of CO from the suprasternal window view are comparable to other minimally invasive techniques currently available. Due to its user-friendliness and low cost, it can be a convenient technique for obtaining perioperative hemodynamic measurements, even by inexperienced operators.

Introduction

Cardiac Output (CO) is essential for oxygen supply to tissues and CO calculation has an important role in patient management during anesthesia and critical care.[1,2] CO measurements by thermodilution via Pulmonary Artery Catheter (PAC) is the most frequently used technique to obtain clinical reference and comparative values,[2,3] albeit randomized studies in critically ill patients assessing this method did not show improvements in mortality.[4–6] Furthermore, the risks related to the technique prompted a reduction in its use, and currently clinicians are inclined to use more accurate and less invasive methods to provide hemodynamic management for patients undergoing major surgeries.[3,7,8]

To date, there is no available gold standard method for obtaining noninvasive or minimally invasive measurements of CO due to the lack of accuracy and precision in measurements.[2,9] Among the methods and technologies available in recent years, Doppler echocardiography (Doppler-based) has been a valuable tool to assess and quantify CO. The method uses the principle that the blood flow velocity determined by Doppler sound waves is evenly distributed in the cross-sectional area of the vessel it passes through. Thus, the cross-sectional area times the mean flow velocity (Velocity-Time Integral – VTI) equals the volume of blood that passes through the vessel (Systolic Volume – SV).[3,10,11] When this volume is multiplied by the heart rate, the value of CO is obtained.

In clinically stable patients, Doppler-based CO measurements performed by an experienced cardiologist have reliable accuracy when compared with CO measurements using the PAC thermodilution method.[3,12–14] In 1984, studying patients without stenotic or regurgitant valve injury, Lewis et al validated the Doppler-based determination of the flow in the Left Ventricular Outflow Tract (LVOT) to calculate SV and CO.[10] In addition to providing noninvasive cardiac output determination, this tool is very useful for ER and ICU practitioners, as they can proficiently perform basic echocardiography exams to assess ventricular function and fluid status after fairly short training in the acquisition and interpretation of images.[15]

Perioperatively, the standard CO measurement using the LVOT cross-section area from the parasternal long axis view, multiplied by the VTI of the LVOT flow obtained from the 5-chamber apical window is not practical or feasible, because of patient position on the operating table and the presence of sterile drapes.[16] In this situation, calculating the VTI of the descending aorta from the suprasternal window can be an alternative for CO determination. Thus, the main objective of this study was to compare VTI measurements of blood flow by Doppler ultrasonography in the descending aorta from the suprasternal window of the transthoracic echocardiogram with VTI measurements of the LVOT flow, which is the standard approach for measuring CO. We believe there is a significant correlation between the measurements obtained from both windows by a specialized echocardiographer, and that a non-echocardiographer operator (3rdyear anesthesiology resident) will obtain satisfactory CO measurements from the suprasternal window, after basic training comprising a 12-h practice under professional guidance and performing at least 30 CO measurements on 15 different volunteers.

Methods

Selection of participants

The study was conducted after approval of the Ethics and Research Committee of Hospital das Clínicas, UFMG CAAE 05997118.9.0000.5149. Data were acquired at two different sessions, from May to June 2019. We included volunteers with over 18 years of age, from both sexes, able to understand and cooperate during all phases of measurements. We excluded subjects presenting history of cardiovascular disease and/or previous cardiac surgery and offering technical impediments to perform the measurements due to anatomical features (one participant was excluded due to silicone implanted prosthesis). Eventually we included 26 volunteers in the analysis in the first part of the study, in which VTI data were acquired from the suprasternal window by an inexperienced operator and by a specialist echocardiographer. In the second part of the study, 17 patients were examined only by the specialized echocardiographer with VTI and CO data acquisition from the suprasternal and apical windows. During all ultrasound measurements, Noninvasive Blood Pressure (NIBP) and pulse oximetry were monitored, and Heart Rate (HR) and mean arterial pressure were recorded by an Omni 612 monitor manufactured by Omnimed.

Echocardiographic Doppler measurements

Echocardiographic data were acquired using the US Philips Epiq 7 and Philips CX50 equipment (Philips Ultrasound Systems, Bothell, WA) and a 2–5 MHz sector transducer. In the first part of the study, measurements were performed by two operators in sequence, one specialized echocardiographer with extensive experience in the method (ECO) and one without experience (non-ECO). Both operators acquired VTI

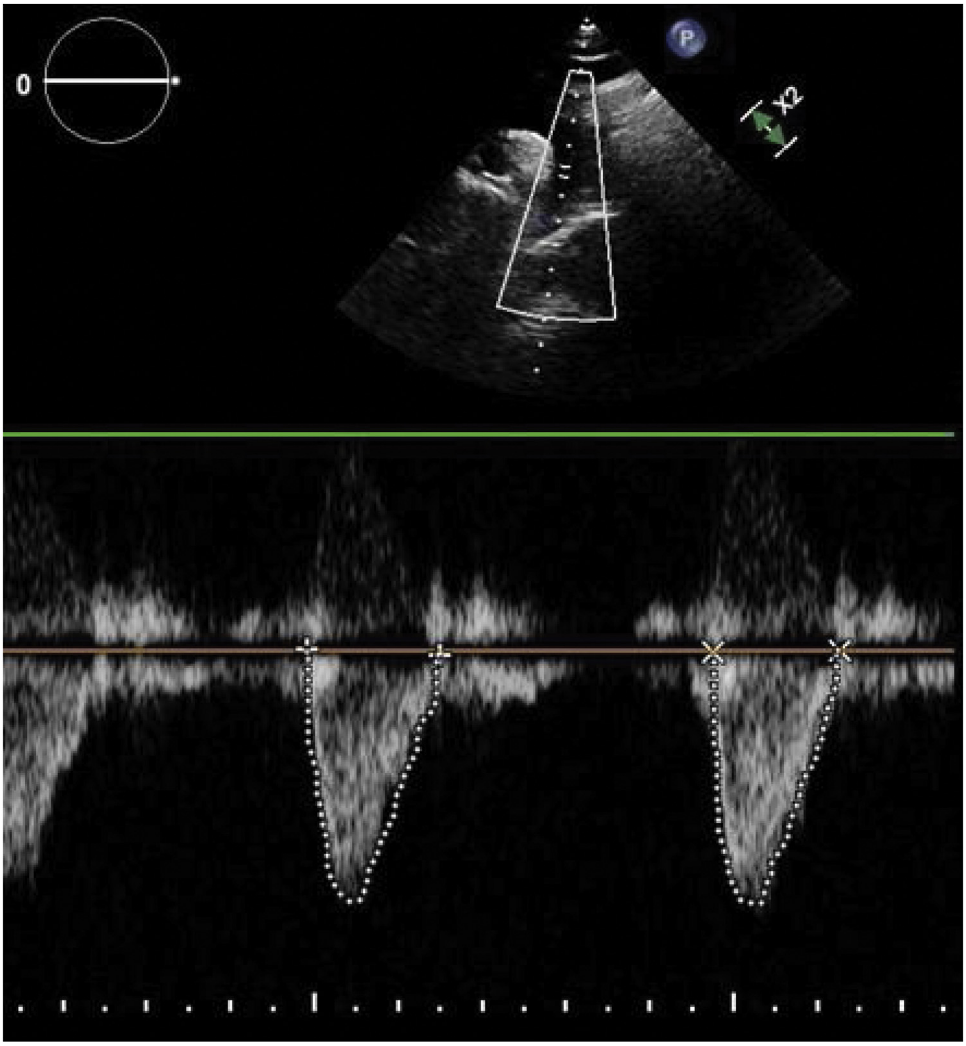

Figure 1 Echocardiographic image with the suprasternal window captured by an inexperienced operator. Measurements obtained from VTI after proper alignment.

measurements by Continuous-Wave Doppler (CW) from the suprasternal window. As the patient was in a supine position, this window was considered satisfactory when the aortic arch image was captured in its long axis, with the views of the takeoff of the innominate, left common carotid and left subclavian arteries. In the second part of the study, only the specialized echocardiographer performed measurements of VTI by continuous-wave Doppler from the suprasternal window and pulsed-wave Doppler in LVOT from the 5-chamber apical window, in addition to the measurement of the LVOT diameter (LVOTd) from the long axis parasternal window, with the volunteer in the left lateral position. The following equation was used to calculate the LVOT cross-section area: $A = 0.785 \times (LVOTd)$.[2] The cardiac output value was calculated in the classic way, that is, using the VTI obtained from LVOT times area of LVOT times heart rate at the time of the exam, as in the equation: $CO = VTI \times A \times HR$. In addition, cardiac output was calculated with the VTIs from the suprasternal window using the area value obtained from LVOT. The rationale for not using the descending aorta diameter was that the literature has documented well that the lateral resolution of the ultrasound is unfit to measure the diameter of the descending aorta.[17]

Data analysis

Data were analyzed using SPSS version 20 and MedCalc version 19.0.5. The normality of data distribution was confirmed using a Kolmogorov-Smirnov test. Data are reported as mean $\pm$ standard deviation.

Pearson's correlation coefficient was used to verify the association among variables. To analyze the agreement between the measurements of VTI obtained from the suprasternal window with the measurements of VTI of LVOT obtained from the 5-chamber apical view we used the Bland-Altman analysis, a scatter plot of the difference between the means of the methods in relation to their mean and standard deviation.[18] The cardiac output estimated with the measurement of VTI acquired from the suprasternal window was also submitted to linear regression analysis. The level of significance adopted was 5% ($p < 0.05$ was considered statistically significant). The significance of the sample was tested *a pos-*

Table 1 Characteristics of patients (mean ± standard deviation).

Patient Characteristics	n = 26	n = 17
Age (years)	29 ± 6	30.71 ± 7.1
Height (cm)	1.72 ± 0.09	1.72 ± 0.09
Weight (Kg)	67.56 ± 11.35	68.44 ± 10.52
Gender (F/M)	12 (46.2%) / 14 (53.8%)	7 (41.2%) / 10 (58.8%)

teriori by the GPower software, and satisfactory power was found (> 80%).

Results

Table 1 shows the characteristics of the volunteers evaluated in the two parts of the study. Column 1 shows the 26 participants evaluated by both researchers and column 2 shows the 17 participants evaluated from different windows by the same echocardiographer. Cardiac output was calculated using the formula: CO = VTI × A × FC (where VTI = Integral Velocity-Time; A = vessel cross-section area; HR = Heart Rate). Figure 1 shows an example of an image captured from the suprasternal window by an inexperienced operator during VTI measurements.

The *r* correlation between VTI measurements obtained by the two operators from the suprasternal window with the CW Doppler was 0.85. The analysis using the Bland Altman plot indicated an error percentage of 27.3% for the measurements made with the CW Doppler with a 95% limit of agreement, between 3.7 cm and 4.1 cm (Fig. 2).

Regarding agreement of the VTIs acquired from the apical and suprasternal windows, the sample with 17 evaluated participants showed satisfactory power. The *r* correlation between VTI at LVOT and VTI from the suprasternal window was 0.52. The Bland-Altman analysis showed a bias of 5.66 cm.s^{-1}, with 95% limit of agreement, between 0.79 cm and 12.11 cm and an error percentage of 52.6% (Fig. 3).

CO was calculated using the measurement of VTI from the suprasternal window with the CW Doppler and the cross-section area of LVOT. Then this CO value was compared to the standard determination of CO from LVOT. The *r* correlation between both determinations was 0.78 with adequate significance, and the regression equation obtained was: standard CO = 587.58 + 0.68 × CW suprasternal CO. The Bland-Altman analysis presented bias of 1459.3 mL with 95% limit of agreement, between 428.2 mL and 2490.4 mL and an error percentage was 38.9% (Fig. 4).

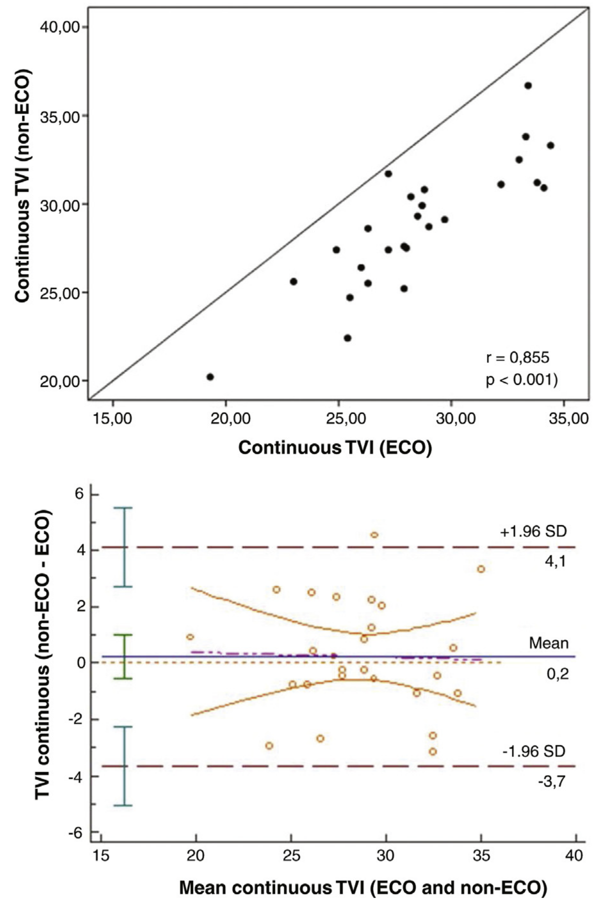

Figure 2 Correction plot between continuous VTI measurements performed by an experienced (ECO) and inexperienced (non-ECO) operator.

Discussion

When a new technique for measurement of a clinical variable is introduced, it is usually compared to an established reference technique. Usually, the implementation of the new technique depends on its degree of agreement with the reference technique and the potential benefits offered by the new method.[19] Our study revealed that that the limits of agreement (or proportion of the mean CO also described as error percentage) after the Bland Altman analysis was 38.9% when the measurements of CO obtained with echo Doppler from the suprasternal technique was compared to the standard technique of measurement from the LVOT. Critchley and Critchley established that the variation between a new method of CO measurement and the reference method is acceptable if the limits of agreement between them are less than 30%.[20] However, although Bland Altman is a useful tool for describing the limits of agreement between two methods of measurement, conclusions about acceptability between the techniques are a matter of opinion and not just science. Analytical methods for comparing CO measurement tools need to go beyond that approach to provide insights into the role of technology in clinical practice and decision making.[21]

Several studies have revealed that the existing non-invasive techniques show an average variation of CO measurement of around 40%,[2,8,9,12] and consequently they do not meet the established value. Our data presented values comparable to those techniques. In addition, Peyton and Chong suggest that 45% could be the acceptable error percentage for CO measurement, which is a more realistic accuracy expectation in clinical practice. They also underscore that the effectiveness of a clinical monitor comprises several factors in addition to absolute accuracy, such as safety, convenience, adaptability, and cost.[8] Furthermore, during perioperative care, from the viewpoint

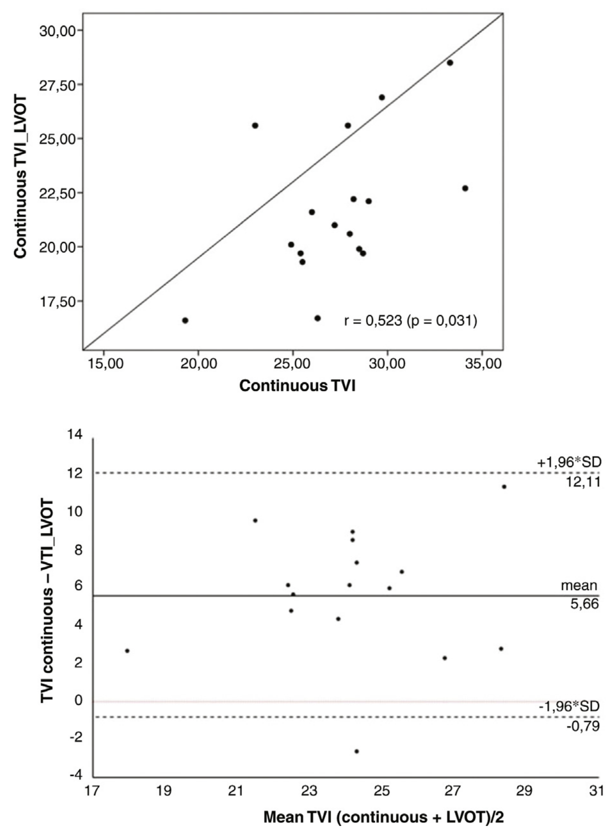

Figure 3 Correlation and Bland Altman between VTIs in LVOT and in the suprasternal window performed by an echocardiographic operator.

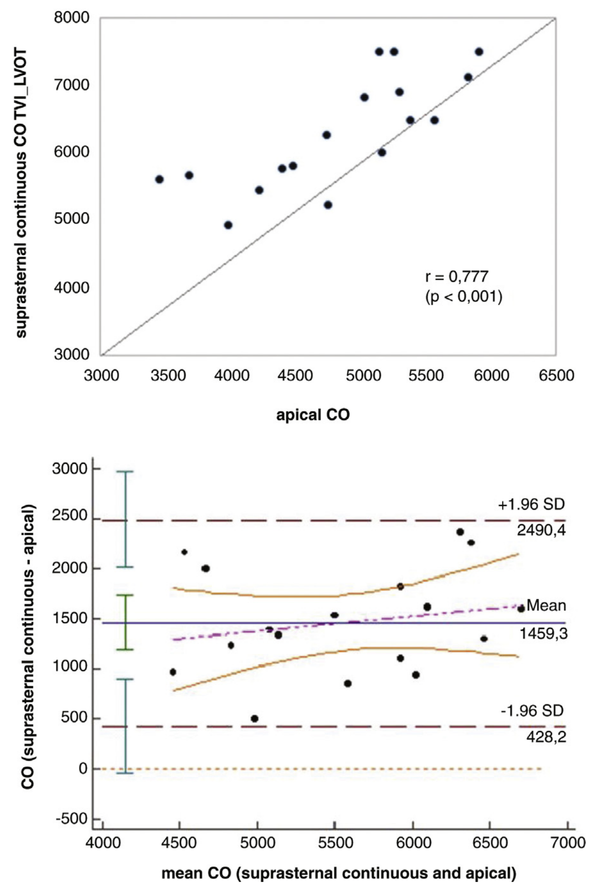

Figure 4 Correlation and Bland Altman between classic continuous CO and suprasternal window.

of decision making it is more important to have real-time access to the trend of the measurement, rather than a single isolated measurement. Real-time tracking of CO value oscillations using serial measurements is undoubtedly more important than the monitor's ability to provide a single, accurate measurement under stable conditions.[8] Analysis of the suprasternal VTI for CO calculation can be straightforward and can provide a sequence of CO measurements. Thus, even if we may be skeptical about one absolute value reading, this technique is still reliable as we can monitor the stroke volume trend and the effect of interventions during intermediate and major surgeries.

Standard echocardiography has evolved in recent years and with the development of compact, portable, and high-quality devices, it can now be performed at any site.[22] This monitoring is a new concept that has gained acceptance in several areas, comprising cardiology, emergency medicine, anesthesiology, obstetrics, and critical care. TTE (Transthoracic Echocardiogram) has been used in several steps of the decision-making process during patient management and, therefore, an increased number of anesthesiologists are getting TTE training and using it in their routine practice.[19,22,23] Sequential assessment of vital parameters perioperatively impacts anesthetic management. The more feasible and available the technique, the greater the ease and safety in managing critically ill patients. Bergamaschi et al revealed that physicians that were working at an ICU and were not cardiologists, after brief training on how to operate the echo Doppler device and determine VTI, were able to accurately calculate CO of ICU patients under mechanical ventilation.[15] Likewise, our data found that the inexperienced operator, after basic training, was able to estimate the value of VTI and CO quickly and accurately in patients without cardiovascular disorder. Thus, an anesthesiologist, after a relatively short standard TTE training, might be able to properly obtain measurements from the suprasternal window. On the other hand, as echocardiography is used to guide therapeutic decisions, one must consider the existence of inter-observer measurement variability and strive for technical excellence to provide accurate measurements.[24]

The thermodilution inference method, previously widely used as a standard technique for CO measurement, does not reflect the real CO, as there are inherent errors of accuracy and precision (10–20%) due to fluctuations in CO during the breath cycle, in addition to technique limitations.[19,25,26] Thus, the search for alternatives for less invasive hemodynamic monitoring intensifies every day and numerous monitors have already been developed. Nevertheless, when evaluating the role of new devices for calculating CO in clinical settings, the cornerstone question to be answered is whether the new device replacing the thermodilution CO determination can be used to provide guidance for clinical decisions. Despite the large number of studies evaluating new CO devices, few have answered this fundamental question.[21] In addition, another question to be considered is whether these CO monitors would positively change patient clinical outcomes rather than only delivering measurements that would not modify patient management. The ideal monitor should be non-invasive or minimally invasive, provide accurate and reproducible readings, have favorable limits of agreement when compared to PAC, be dependable under different physiological conditions and be affordable. Finally, it should offer continuous measurements and have the ability to assess the impact of therapeutic interventions (e.g., hemodynamic response to administered fluids or vasoactive drugs). Thus far, no device has met all these criteria,[27] so it is necessary to keep studying patients in which CO monitoring is crucial to determine the range of values in which an intervention would or would not be well recommended. The impact of these decisions on patient outcome is the major issue and will require the development of further protocols based on studies involving larger patient populations.[21]

The limitations of our work are the small sample size, the determination from the window is investigator dependent as it requires basic and continuous training in the technique, and even though most studies used PAC measurements as a reference and assessed the method under anesthesia our study lacks PAC measurements because we evaluated only healthy and awake participants. In addition, although the measurement of the diameter in the descending aorta is not appropriate, the diameter measurement in the LVOT is not the ideal site to perform the calculation of CO when using VTI in the descending aorta from the suprasternal window.

In conclusion, our data indicate that measurements of CO by TTE from the suprasternal window are comparable to other minimally invasive techniques currently available. Due to its user-friendliness, low cost, capability to deliver reliable measurements enabling to monitor trends in stroke volume and the effect of interventions such as administration of fluids and inotropic and vasoactive drugs, it can be considered a suitable perioperative technique for acquiring hemodynamic parameters and calculating CO, including inexperienced operators. Additional investigations with larger samples should be carried out to complement and further validate our data.

Conflicts of interest

The authors declare no conflicts of interest.

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