ORIGINAL RESEARCH PAPERS

Feasibility of measuring left ventricular outflow tract velocity time integral as a predictor for stroke volume in pregnant women in labor

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ABSTRACT

Background: Pregnancy is a time of significant hemodynamic changes. Maintaining adequate cardiac output (CO) and uteroplacental perfusion is a priority in parturients, for favorable maternal-fetal outcomes. Blood pressure is commonly used as a surrogate for CO, although it may poorly correlate with stroke volume (SV) and CO in some cases. An alternative approach is SV estimation using transthoracic echocardiography (TTE) based on the velocity-time integral (VTI) of the left ventricular outflow tract (LVOT). Although VTI has been validated as a tool to estimate SV and CO in acute care contexts, its feasibility and utility in obstetric anesthesia remain unexplored. Therefore, the objective of this study is to evaluate the feasibility and reproducibility of LVOT VTI measurements in parturients during labor.

Methods: Following research ethics board approval, 55 full term pregnant female patients with a singleton pregnancy were recruited. TTE was used to calculate the LVOT VTI for each patient by the same anesthesiologist twice. Feasibility of obtaining the LVOT VTI was evaluated using time for image acquisition and the 3-Point Likert Scale for Imaging Quality. Intraclass correlation coefficients (ICC) were used to estimate intra-rater reliability.

Results: LVOT VTI was obtained for all participants on both attempts. Mean time needed to obtain measurements was 63.7 seconds (95%CI 56.5 to 70.8) on the 1st attempt and 44.2 seconds (95%CI 38.7 to 49.8) on the 2nd

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attempt. Eighty-one (73.6%) images were rated as optimal, 29 (26.3%) were rated as suboptimal. Intra-rater reliability was excellent (ICC was 0.94 (95%CI 0.92 to 0.95).

Conclusion: In singleton parturients, LVOT VTI measurements can be routinely obtained in a timely fashion with excellent intra-rater reliability during labor. These results support the feasibility of LVOT VTI to estimate and trend SV.

Key words: PoCUS, Echocardiography, cardiac output, Obstetrics

Introduction

Pregnancy is a time of significant hemodynamic change (1,2), which can be especially impactful in parturients with cardiovascular disease (CVD). Despite advances in peripartum care, CVD is the leading cause of maternal mortality in developed countries (3), with the most recent data indicating that CVD contributes to 27% of U.S. pregnancy-related deaths (4). Therefore optimizing care of parturients with complex cardiovascular considerations is a shared goal of anesthesiologists and obstetricians.

A cornerstone of managing parturients with CVD is maintenance of adequate cardiac output (CO) and uteroplacental perfusion. Blood pressure (BP) and heart rate (HR) are commonly used as a surrogate for CO. However, BP can correlate poorly with stroke volume (SV) and CO, especially in parturients with preeclampsia (PE), one of the most common medical and cardiovascular complications of pregnancy (incidence 4.6% of pregnancies worldwide) (5). This is because BP is strongly influenced by systemic vascular resistance (SVR) (6,7), which is typically increased in PE, but inconsistently impacts CO (8-11). Moreover, when managing patients with CVD and/or PE for surgical delivery, provision of spinal anesthesia further decouples the correlation between BP and CO due to acute changes in SVR (7,12). Therefore, consistent, feasible and accurate approaches to estimate CO are required to support optimal care for high-risk parturients.

While numerous studies have evaluated different CO monitors during delivery, gold standard approaches such as pulmonary artery catheterization (PAC) using thermodilution or dye dilution techniques are typically not feasible in the obstetric population due to invasiveness and risk of complications (6,13,14). In contrast, transthoracic echocardiography (TTE) is emerging as a technique for CO estimation in pregnancy due to its non-invasive nature and absence of ionizing radiation (11,15,16). Previous studies have validated TTE in pregnancy against thermodilution techniques, demonstrating strong correlations with CO estimation in healthy (17) and severely ill pregnant women with an intraclass correlation coefficients (ICC) of 0.94 between both methods (2,11,18,19).

Recently, abbreviated echocardiographic examinations, such as point-of-care ultrasound (PoCUS) or Focused Cardiac Ultrasound (FoCUS), which are delivered in the active clinical context and require a more basic level of competence have been developed to provide, among other details, SV and CO estimation at the bedside (15,20-25).

Transthoracic echocardiography-based CO estimation typically requires integration of multiple measurements and views (i.e., left ventricular outflow tract (LVOT) diameter to calculate LVOT area as well as Doppler alignment) to calculate SV and CO. This approach can be time-consuming and technically challenging in dynamic acute care environments, such as labor and delivery. Moreover, relying on the measured LVOT area can cause large errors in SV estimation since any measurement errors in the LVOT diameter will be squared (LVOT area is calculated as πr^2) (26). However, because the LVOT diameter is almost constant for each patient (as is the LVOT area), in clinical practice changes to SV and CO can be trended without measuring the LVOT because any change in the SV should be due to changes in LVOT velocity-time integral (VTI). (27-33) In contrast to multiview

approaches to CO estimation using TTE, PoCUS providers can rapidly trend changes in SV and CO using only the VTI, while omitting repeated LVOT diameter measurements that can introduce error and inefficiency—as the primary source of variability remains the LVOT VTI measurement itself. While several studies have established the feasibility of full TTE-based SV and CO estimation in pregnancy, these were typically performed in stable, non-laboring women under controlled conditions by expert echocardiographers. In contrast, the dynamic environment of labor and delivery presents unique physiologic, positional, and acoustic challenges that may influence image quality and acquisition time. Evaluating the feasibility of a simplified, single-view LVOT VTI-only PoCUS approach performed by anesthesia providers in this real-world context therefore represents a distinct and clinically relevant research question.

Although VTI has been validated as a tool to estimate SV and CO in acute care contexts such as sepsis, shock, and emergency medicine (27,30,34-41), its feasibility and utility in obstetric anesthesia remain unexplored. Given the unique physiological changes of pregnancy and the rapid hemodynamic shifts associated with neuraxial anesthesia and delivery, LVOT VTI may represent a simpler, faster, and informative approach for guiding fluid management and anesthetic care in high-risk parturients. As a step toward future evaluation of LVOT VTI based CO monitoring in obstetric anesthesia care, our objective was to evaluate the feasibility and reproducibility of LVOT VTI measurements in parturients during labor, both in cesarean and vaginal deliveries.

Methods

Design and population

Following research ethics board (Protocol ID#: 20220028-01H) approval we conducted an observational, cross-sectional study. Reporting follows the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (42). Following written informed consent, consecutive full term female patients with a singleton pregnancy, coming for labor either with normal vaginal delivery or elective CS were enrolled in our study. Inclusion criteria were: singleton pregnancy, gestational age of 36-42 weeks. Exclusion criteria were: patient refusal to participate, multiple gestation, BMI > 40, polyhydramnios, CVD, PE, LVOT abnormalities, valvular lesions, and any obstetrical emergencies (e.g., antepartum hemorrhage, fetal distress).

Measurements

We used a single view (apical 5-chamber (A5C) view) to capture LVOT VTI measurements, which is specifically designed to accommodate the fast-paced environment of the operating room (OR) or labor ward. All measurements of VTI were collected by one of three PoCUS trained (according to the current recommendations regarding the level of training, having performed a minimum of at least 40 FoCUS scans independently to become competent in PoCUS) anesthesiologists (43). For each participant, a single one of these anesthesiologists captured two LVOT VTI measurements, with participants laying in the left lateral tilt position (of at least 30 degrees) to minimize aortocaval compression. The lateral tilt was achieved using a pelvic wedge placed under the right hip to achieve at least 30° left lateral tilt. The two VTI measurements were obtained consecutively during the same scanning session, with approximately 1–2 minutes between acquisitions. LVOT VTI (also known as stroke distance) is the distance that blood travels in the LVOT's area (assumed to be a cylinder in a normal heart). Using the A5C view, VTI is estimated via pulsed wave Doppler (PW) sample placed in the LVOT immediately proximal to the aortic valve, just below the hinge points of the aortic valve leaflets to obtain thin spectral envelopes. **(**Figure 1**)** The outer boundaries of the Doppler signals were traced using a commercially available calibrated offline analysis system (available on the Phillips Sparq Ultrasound system 795090CC™) to measure the area under the curve (VTI expressed in cm) (44,45). All images of the A5C view and corresponding VTI measurements obtained were stored.

As feasible PoCUS VTI-based CO monitoring will require acquisition of scans of adequate quality in

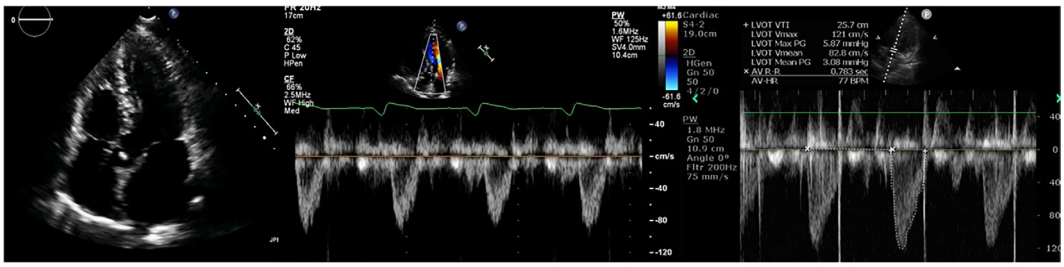

Figure 1. LVOT VTI obtained by tracing the envelope of the LVOT flow produced with pulsed wave doppler interrogation, obtained in an A5C view.

Table 1. 3-point Likert Scale for Rating Imaging Quality for LVOT VTI measurement which has been adapted from a previously published scale used before by Dinh et al. (47)

Clear apical 5-chamber view with proper alignment of the pulse Doppler sample volume parallel to the aortic flow with minimal spectral broadening	Optimal VTI	2
Pulse Doppler sample volume not completely parallel to flow but within 20°	Suboptimal VTI	1
Completely unobtainable images of apical 5- chamber view or extremely large pulsed-wave Doppler angle to flow	Unobtainable VTI	0

a reasonable period of time, we used two assessments of feasibility. First, we used a 3-point Likert scale adapted from from Dinh et al **(**Table 1**)** to rate A5C image quality (46,47). Images with a quality rating of 1 or 2 were considered acceptable as they allow for proper calculation of the LVOT VTI as the doppler beam would have been parallel or within 20° of the direction of blood flow (45). This quality rating scale was applied by a PoCUS trained anesthesiologist who did not perform the examination.

Next, the time (in seconds) required to obtain the LVOT VTI values for each patient were recorded as the time from the beginning of the PoCUS examination to the time where the spectral PW doppler waveform at the level of the LVOT was acquired.

Sample size

Sample size for this study was focused on achieving adequate precision around estimation of the ICC. We assumed an ICC of 0.8, which would represent good reliability, but which was conservative relative to values obtained on previous studies (ICCs exceeding 0.85) showing high intra and inter observer reliability of LVOT VTI measurements on non-laboring pregnant patients (11,16), and patients in emergency department (47). To obtain a precision of +/-0.1, we estimated requiring 51 participants, which was increased to 55 to account for up to 5% possible dropouts (48).

Analysis

SAS version 9.4 for Windows (SAS Institute, Cary NC) was used for all analyses. Baseline characteristics of our sample were calculated using means and standard deviations for continuous variables and counts with proportions for categorical variables.

Our primary analysis estimated intra-rater reliability using the ICC (3,1) value from a linear mixed model (PROC MIXED) as we had two measurements taken by a single rater for each participant (49). The model accounted for repeated measures, clustered by participant, using a compound symmetry covariance matrix. Wald 95% confidence intervals were concurrently estimated. We also created a Bland Altman plot to communicate the levels of agreement between the two measures (50), the overall bias between the 1st and 2nd VTI measurement, and to graphically display

whether paired measurements were within ±15% of one another. This band was used only as a visual reference based on thresholds commonly applied to define fluid responsiveness in hemodynamic monitoring studies, and not as a formal cutoff for measurement agreement or error (51).

We also estimated the proportion of images rated as acceptable (i.e., rating of 1 or 2 on the 3-point Likert Scale for Imaging Quality) with a 95% confidence interval using the binomial distribution. The mean time required to obtain an image was estimated as a mean and 95%CI in seconds.

Results

Participant demographics

We included 55 parturients with a mean age of 34.0 years (SD 5.4 years), and a mean body mass index of 31.2 kg/m^2 (SD 4.3 kg/m^2). Sixteen patients (29%) were primigravida, and mean gestational age at the time of the scan was 38.9 weeks (SD 1.2 weeks). Forty-four patients (80 %) delivered by CS and eleven patients (20%) delivered vaginally. Further characteristics are reported in Table 2.

Velocity time integral, ICC and agreement

We were able to get LVOT VTI measurements for all our patients on both attempts. The mean VTI for the first measurement was 21.0 cm (95%CI 20 to 22), and the second was 20.7 cm (95%CI 19.7 to 21.7). The estimated ICC was 0.94 (95%CI 0.92 to 0.95), which suggests excellent intra-rater reliability between the 2 measurements. **(**Figure 2**)**

The Bland Altman Plot suggested minimal bias (<1 cm less in the 2nd measurement vs. the 1st), and that almost all paired measurements were within the levels of agreement. Forty seven of 55 paired measurements (85.5%) were within 15% of one another.

Image quality and feasibility measurements

For the 1st image obtained for each patient, 40 out of 55 patients (73%) had an image quality score of 2, 15 (27%) had an image quality score of 1, and none

Table 2. Demographics characteristics and Obstetrics variables. Data are expressed in mean ± SD or number (%).

Age		34.0 ± 5.4
BMI		31.2 ± 4.3
Gestational age		38.9 ± 1.2
Primigravida		16 (29%)
Mode of delivery	CS	44 (80%)
	Vaginal	11 (20%)
Medical history		
No comorbidities		20 (36%)
DM		6 (11%)
Hypothyroid		6 (11%)
GDM		4 (7%)
Asthma		3 (5%)
HTN		2 (4%)
Anemia		2 (4%)
GERD		2 (4%)
Anxiety		2 (4%)
Others		8 (15%)

Abbreviations: BMI: body mass index, CS: cesarean section, DM: diabetes mellites, GDM: gestational diabetes mellites, HTN: hypertension.

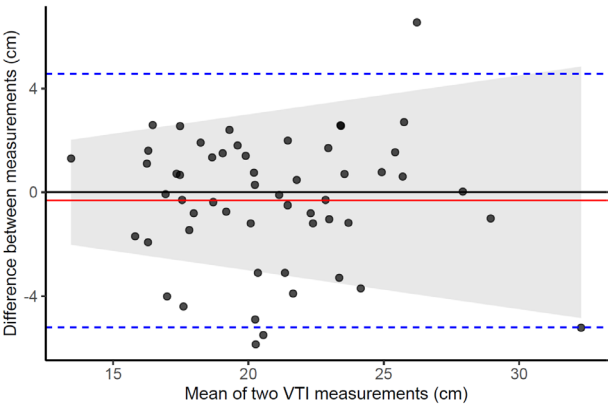

Figure 2. Bland Altman plot displaying agreement between the 1st and 2nd VTI measurement. Each point represents the mean of two VTI measurements (x-axis, cm) and their difference (y-axis, cm) for the same subject. The solid black line denotes perfect agreement, while the red line represents the mean bias between repeated measurements. The dashed blue lines show the 95% limits of agreement (bias ± 1.96 standard deviations of the differences). The shaded grey band illustrates a ±15% zone relative to the mean VTI, consistent with thresholds commonly used to define clinically acceptable agreement in hemodynamic monitoring (although this zone has not been validated in obstetrical anesthesia specifically).

Table 3. 1st and 2nd image quality according to 3-point Likert scale.

	1st image quality*			
2nd image quality*		2	1	0
2		37	4	0
1		3	11	0
0		0	0	0

*Image quality was assessed using a 3-point Likert scale for rating imaging Quality for LVOT VTI measurement which has been adapted from a previously published scale used before by Dinh et al.[47]

had an image quality score of zero. For the 2nd image obtained, 41 patients (75%) had an image quality score of 2, 14 (25%) had an image quality score of 1, and none had an image quality score of zero. **(**Table 3**)**

Comparing image quality for the 1st vs 2nd measurement within each participant revealed that an image quality score of 2 was achieved for both measurements in 37 participants (67%), 11 (20%) participants had an image quality score of 1 in both attempts, 4 (7%) participants had an image quality score of 1 on 1st attempt and an image quality score of 2 on 2nd attempt, while only 3 (5%) participants had an image quality score of 2 on the 1st attempt and an image quality score of 1 on 2nd attempt. **(**Table 3**)**

The average time to obtain the images and calculate the VTI measurements for the 1st attempt was 63.7 seconds (95%CI 56.5 to 70.8) while the average time to do the same for the 2nd attempt was 44.2 seconds (95%CI 38.7 to 49.8).

Discussion

In a single center study using PoCUS echocardiography to estimate SV in term, singleton parturients, we found that the VTI could be calculated with excellent intra-rater reliability (ICC 0.94) using the apical five chamber view, and that required images could be feasibly captured, as evidenced by adequate image quality and low required time for image acquisition (mean 64 seconds). To our knowledge, this is the first prospective study to specifically assess the feasibility and reproducibility of focused LVOT VTI-only measurements performed by PoCUS-trained anesthesiologists in actively laboring parturients. Prior investigations demonstrating TTE feasibility in pregnancy were conducted in stable, non-laboring patients and relied on full SV and CO calculations, often performed by expert echocardiographers under controlled conditions. These results suggest that VTI measurement could be feasibly used to assess trends in hemodynamic status and guide management by anesthesia providers with appropriate training for parturients during labor, whether they are undergoing CS or vaginal deliveries. Feasibility and application of VTI measurements in parturients with CVD, such as PE, and at different stages of labor remains to be demonstrated. Future research will also be required to evaluate improvements in care and outcomes that could result from VTI-guided hemodynamic management.

The American Society of Echocardiography as well as the European Society of Intensive Care Medicine have both recommended the use of echocardiography for assessment of SV and CO to determine responses to medical and surgical therapies (30,35). Use of echocardiography in pregnant patients is also increasing. Recent obstetric guidelines emphasize the importance echocardiography skills in diagnosing and managing CVD in pregnancy. Use of echocardiography in parturients is further supported by available data demonstrating the accuracy of TTE in estimating CO, such as a systematic review and meta-analysis of 68 studies by Zhang et. al., which found no difference between CO measurements by echocardiography vs. thermodilution along with high levels of agreement (ICC 0.94) (52). Furthermore, parturients are generally accepting of ultrasound examinations as the technique is non-invasive and is frequently performed as part of their obstetric management. Accordingly, case reports suggest benefits of point of care echocardiography in facilitating early identification of maladaptive responses to the hemodynamic changes of pregnancy that require intervention (2,19,25). Protocols are also emerging to structurally inform care, such as the ROSE (Rapid Obstetric Screening Echocardiography) protocol, proposed by Dennis et al., as a bedside algorithm to differentiate obstetric-specific causes of hemodynamic compromise in critically ill parturients, primarily using the parasternal and apical windows (19). Therefore, next steps in increasing adoption of

echocardiography in bedside management of parturients requires an understanding of how feasibly this technique can be applied in the busy clinical setting of labour and delivery wards.

Given the rapid and unpredictable pace of obstetric anesthesia care, using LVOT VTI as a lone point of assessment of SV and CO appears promising, as LVOT VTI can be obtained from a single apical view without requiring measurement of LVOT diameter. This makes VTI a practical surrogate for trending hemodynamics, while avoiding the potential errors and inefficiencies of full CO calculations. Outside of obstetric anesthesia, evidence supports the use LVOT VTI to guide the management of shock (34,36,37) as it correlates well with indices of perfusion, and outperforms ejection fraction in predicting outcomes in patients with heart failure (38,39). A retrospective analysis of patients with cardiogenic shock admitted to cardiac intensive care with a TTE done within 1 day of admission has showed that LVOT VTI was the most important single TTE variable for predicting mortality (40). In emergency medicine, LVOT VTI variation in response to preload-modifying maneuvers or respiratory changes, rather than the absolute value of VTI, has been shown to predict volume responsiveness in patients with hemodynamic instability (27,41). While an assessment of CO based on a single view is promising, quantifying the feasibility of a VTI-specific PoCUS exam is required to inform future research and care.

While to our knowledge no VTI feasibility data specific to obstetrical anesthesia are available, a feasibility study in the emergency department demonstrated that focused LVOT VTI measurements could be obtained by emergency medicine fellows in an average of 144 seconds (2.4 minutes), compared with 446 seconds for a full focused cardiac exam (53). In contrast, our data suggest an even faster time to exam completion in obstetric anesthesia by PoCUS-trained anesthesiologists (mean 64 seconds). This is considerably faster than the average time reported for a full focused cardiac ultrasound exam in the emergency department (mean 446 seconds) by Betcher et al, underscoring the potential efficiency of a single-view LVOT VTI-only approach in obstetric anesthesia practice (53). Importantly, our data also assessed further important feasibility metrics by demonstrating that all exams performed were of adequate quality to allow for VTI calculation, and that these calculations were reliably estimated (ICC 0.94). In fact, the multiple assessments by the same provider used in our study reflect expected use of VTI measurement in obstetrical anesthesia, where providers would be likely to complete serial measurements across the peripartum period to trend SV and CO in the face of the physiologic stress and fluid shifts inherent in the delivery process. Promisingly, our results estimated low bias (<1 cm lower in the 2nd vs. 1st measure, a difference of only 3.8%), that 95% of measures fell within limits of agreement, and that 85% of measures agreed within 15%, which is a typically accepted zone of agreement for hemodynamic monitoring values such as pulse pressure variation, stroke volume variation, and systolic pressure variation (51). However, we acknowledge that this ±15% threshold is derived from studies defining preload responsiveness rather than measurement reproducibility, and it should not be interpreted as a validated cutoff for acceptable measurement error in VTI assessments. The optimal limit of agreement for LVOT VTI reproducibility in obstetric settings remains to be established.

Future research will be required to evaluate whether improvements in care and outcomes (at both maternal and fetal levels) could result from VTI-guided hemodynamic management. Our findings establish foundational feasibility data that can support subsequent studies evaluating clinical implementation and outcome impacts of LVOT VTI-guided monitoring during labor. This line of research should also extend to hemodynamic assessment and management of parturients with high peripartum cardiac risk as well as investigating how factors like uterine contractions, fluid management, vasopressor selection could affect SV and CO at different stages of labor. In addition, researchers could evaluate whether management based on VTI-based CO estimates result in non-inferior outcomes to full CO evaluation using TTE, which Dennis and colleagues have shown can be used to estimate CO in healthy parturients undergoing CS (16), as well as in those with untreated PE (11). In addition, assessing inter-rater reliability in future studies will be an important next step to confirm reproducibility across different providers.

Strengths and limitations

Our study has strengths and limitations. Our data represent measurements from 3 different providers, which supports generalizability, however, data were single center, and all providers were experienced in PoCUS. While the feasibility of our study was enhanced through enrollment of healthy parturients with singleton pregnancy and BMI less than 40 kg/m^2, data from higher risk parturients and those with higher BMI (which can be a barrier to image acquisition) are needed. Future studies should also include parturients with PE, cardiac disease, or higher BMI, as these populations may present additional imaging challenges but could benefit most from detailed hemodynamic assessment. Future studies that include inter-rater reliability will further advance our understanding of feasibility of VTI measurement for CO estimation. Additionally, whether acceptable zones of agreement applied in other acute care areas are directly applicable to obstetrics remains to be determined.

Conclusion

Our data suggests that velocity time integral measurements of the left ventricular outflow tract can be feasibly captured in a timely fashion with excellent intra-rater reliability in healthy, singleton parturients during labor. As good quality images can be reliably obtained using the A5C view by trained providers, future research should extend this approach to hemodynamic assessment and management of parturients with high peripartum cardiac risk at different stages of labor.

List of abbreviation

A5C: Apical five-chamber view
BP: Blood pressure
BMI: Body mass index
CI: Confidence interval
CO: Cardiac output
CS: Cesarean section
CVD: Cardiovascular disease
FoCUS: Focused cardiac ultrasound
HR: Heart rate
ICC: Intraclass correlation coefficient
LVOT: Left ventricular outflow tract
PAC: Pulmonary artery catheter
PE: Preeclampsia
PoCUS: Point-of-care ultrasound
PW: Pulsed-wave Doppler
ROSE: Rapid Obstetric Screening Echocardiography
SD: Standard deviation
STROBE: Strengthening the Reporting of Observational Studies in Epidemiology
SV: Stroke volume
SVR: Systemic vascular resistance
TTE: Transthoracic echocardiography
VTI: Velocity–time integral

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Availability of Data and Material: The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate: This study was approved by the Ottawa Health Science Network Research Ethics Board (Protocol ID#: 20220028-01H). Written informed consent was obtained from all individual participants included in the study. All procedures performed were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments.

Consent for Publication Written informed consent was obtained from all participants for publication of anonymized data.

Competing Interests: The authors declare that they have no competing interests.

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