Predicting fluid responsiveness in spontaneously breathing parturients via carotid artery blood flow and velocity time integral measured by carotid ultrasound: a prospective cohort study

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Research Article

Keywords: carotid artery blood flow, velocity time integral, ultrasonography, fluid responsiveness

Posted Date: April 27th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1566568/v1

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Abstract

Background

Present evidence suggests that the Doppler ultrasonographic indices, such as carotid artery blood flow (CABF) and velocity time integral (VTI), have the ability to predict fluid responsiveness in non-obstetric spontaneous breathing patients. The purpose of this study was to assess their capacity to predict fluid responsiveness in parturients.

Methods

In this study, a total of 72 full term singleton parturients undergoing cesarean delivery were included in this study and CABF, VTI, and hemodynamic parameters were recorded before and after fluid challenge and assessed by carotid artery ultrasonography. Fluid responsiveness was defined as an increase in stroke volume index (SVI) of 15% or more after the fluid challenge.

Results

Thirty-one (43%) patients were fluid responders. The area under the ROC curve to predict fluid responsiveness for CABF and VTI were 0.803 (95% CI, 0.701-0.905) and 0.821 (95% CI, 0.720-0.922). The optimal cut-off values of CABF and VTI for fluid responsiveness was 175.9 ml/min (sensitivity of 74.0%; specificity of 78.0%) and 8.7 cm/s (sensitivity of 67.0%; specificity of 90.0%). The grey zone for CABD and VTI were 114.2-175.9 ml/min and 6.8-8.7 cm/s.

Conclusions

Ultrasound evaluation of CABD and VTI seem to be the feasible parameters to predict fluid responsiveness in parturients undergoing elective cesarean delivery.

Trial registration

The trial was registered at the Chinese Clinical Trial Registry (ChiCTR) (www.chictr.org), registration number ChiCTR-ICR-1900022327. This study was approved by the Research Ethics Committee of Women's Hospital, Zhejiang University School of Medicine (20180120).

Background

There are many significant changes in hemodynamics during pregnancy, including blood volume, heart rate, stroke volume (SV), cardiac output (CO), vascular resistance, and colloid osmotic pressure (Fu,2018). These changes affect maternal and fetal oxygen transport, including oxygen affinity, delivery, and consumption (Kuhn et al.,2017). Therefore, predicting intraoperative fluid responsiveness is an important focus, as improper fluid treatment can lead to adverse outcomes (Kuhn et al.,2017).
Static and dynamic volume status assessment of fluid reactivity contributes to perioperative fluid management and has become an important tool in the diagnosis and treatment of obstetric anesthesia (Zieleskiewicz et al., 2018). Currently, a number of sonographic variables such as inferior vena cava collapsibility index (IVCCI) have been introduced to evaluate the volume status of non-obstetric patients with spontaneous breathing (Bortolotti et al., 2018; Weber et al., 2015). Similarly, some studies have found that parameters measured by carotid ultrasound, such as corrected flow time, can well predict volume responsiveness in spontaneously breathing patients (Kim et al., 2018; Xu et al., 2020). Importantly, one study demonstrated that changes in cardiac preload and cardiac output translate directly into changes in carotid blood flow, supporting the possibility that carotid blood flow can be a proxy for cardiac output (Sidor et al., 2020). Moreover, carotid artery blood flow may be a better indicator of cardiac output and is less affected by measurement problems than corrected carotid flow time (Ma et al., 2017).

However, it is still unclear whether VTI and CABF measured by ultrasound can be used as the variables of intravascular volume status and whether they have a certain guiding role in perioperative fluid therapy for spontaneous breathing parturients. The purpose of this study was to evaluate the predictive power of ultrasound measurement of CABF and VTI for fluid responsiveness in parturients undergoing elective cesarean delivery.

**Methods**

**Design, setting, and participants**

A single-center prospective cohort study was conducted at grade A tertiary hospital which was a large-scale obstetrics and gynecology hospital in China. We collected the perioperative data of all patients who underwent elective cesarean section between April 2019 and May 2019.

In our study, we recruited seventy-eight American Society of Anesthesiologists (ASA) Class I-II parturients with elective caesarean section. Women over 18 years of age who undergo routine prenatal examinations for a full-term single pregnancy and women over 37 weeks of gestation were included. Women with hypertension, preeclampsia, undergoing emergency cesarean section and women with a history of chronic cardiopulmonary diseases as well as liver or kidney failure were excluded.

**Study procedures**

No premedication was administered. Preoperative women with elective surgery routinely fast for 8 hours and no drinking for 2 hours. After the parturients enters the operating room, rest for 30 minutes while monitoring the electrocardiogram, pulse oxygen saturation and blood pressure. The parturients will undergo carotid ultrasound and transthoracic echocardiography separately. The ultrasound-guided predictive measurements of fluid responsiveness included CABG, VTI, stroke volume index (SVI), and hemodynamic parameters. They were measured before and five minutes after receiving a fluid challenge of 6% hydroxyethyl starch (130/0.4) 6 ml/kg ideal body weight [(height cm-70)*60%] over 10 min. Fluid responsiveness was determined by a 15% or more increase in SVI after fluid challenge by transthoracic
ultrasound. According to fluid responsiveness, the patients were divided into two groups: the Non-responders group and the Responders group. The patients were stable during the measurement period and did not receive any vasoactive drug therapy.

**Carotid ultrasonography**

CABF and VTI were measured by two anesthesiologists (Chun Wang and Jianjun Shen) with specialized ultrasound training. Prior to the study, they had completed carotid ultrasonography in 50 patients and were approved by sonographers. We placed the patients in the supine position with the images of carotid artery diameter and VTI obtained by SONIMAGE HS1 (KONICA MINOLTA Inc, Shanghai, China). The 6–13 MHz variable frequency probe was placed vertically in the neck, with the marker pointing to the patients’ head. The long axis B-mode image of the right common carotid artery was located at the lower margin of the thyroid cartilage. The sampling line was placed at the center of the carotid lumen, about 2cm from the bifurcation. The area under the pulse Doppler tracer VTI curve of carotid blood flow obtained by angle correction was determined by the automatic tracking of monopulse waveform. (Fig. 3). Carotid artery diameter and VTI were measured three times by the examiner and averaged for analysis. The ultrasound software automatically calculated the carotid blood flow per minute, and the formula is: carotid artery blood flow (mL/min) =\( \pi \times (\text{carotid artery diameter}/2)^2 \times (\text{VTI}) \times (60 \text{ seconds}) \) ((Ma et al.,2017)).

**Cardiac ultrasonography**

The measurement of cardiac stroke volume is performed by a professional ultrasound doctor (Xia Tao). The parturient is placed in the left lateral decubitus position and 1.5–4.5 MHZ phased array probe was used for SV examination. The diameter of the left ventricular outflow tract at the systolic aortic apex was measured by parasternal long axis echocardiography. The area of left ventricular outflow tract was calculated as \( \pi \times (\text{the square of the left ventricular outflow tract radius}) \) (Peachey et al.,2016). Aortic blood flow VTI was calculated from the area under the pulse-wave Doppler signal envelope obtained from the apical five-chamber cutting surface at the level of the aortic ring and was determined by the average value of five consecutive pulses in a complete respiratory cycle. SVI was calculated as (left ventricular outflow tract area x aortic flow VTI)/body surface area (BSA), and BSA was calculated as BSA(m2) = 0.0061xbody length (cm) + 0.0128xbody weight (kg)-0.1529 (Wang et al.,2013).

**Study endpoints**

The primary endpoint was to determine the predictive value of carotid artery blood flow and VTI for fluid responsiveness (\( \geq 15\% \) increases in SVI after fluid challenge) in spontaneous breathing parturients (Marik et al.,2013).

**Statistical analysis**

SPSS 23.0 (Chicago, IL, USA) was used for data statistical analysis. Based on the pilot study of 20 patients, we predicted that the difference in carotid artery blood flow before fluid challenge between the two groups was 65.6 ml/min and the standard deviation was 72.9 ml/min. The alpha risk is 5%, the
power is 90%, and at least 27 patients are needed for each group to detect differences. Normality of the data distribution was assessed using Kolmogorove-Smirnov and Shapiroe-Wilk tests. Continuous variables were expressed as mean (standard deviation) if data were normally distributed or median (interquartile range) if not. Categorical variables were expressed as absolute number (%). Responder and non-responder groups were compared with a paired t-test for normally distributed data, ManneWhiney U-test for non-normally distributed data, and X2 test or Fisher’s exact test, as appropriate, for categorical variables.

The receiver operating characteristic (ROC) curve was applied to discern the predictive ability of indicators. Area under the curve (AUC) provides a global measure of measurement accuracy. The guidelines recommend that $0.5 < \text{AUC} \leq 0.7$ represents low accuracy, $0.7 < \text{AUC} \leq 0.9$ suggests moderate accuracy, and $0.9 < \text{AUC} \leq 1.0$ stands for high accuracy. An AUC higher than 0.75 is considered good. We calculated the 95% confidence interval (CI), and $p < 0.05$ was considered as statistical significance. The “optimal” cut-off values were assessed by using maximizing Youden's index ($J = \text{Sensitivity} + \text{Specificity} - 1 = \text{Sensitivity} - \text{False-Positive Rate}$) (Cannesson et al., 2011). The cut-off values defining the gray area was determined by a correlation value of 90% sensitivity and 90 specificity (Coste et al., 2003). Importantly, the intra-observer variability (repeatability) and inter-observer variability (reproducibility) were evaluated in all patients of assessments of carotid artery blood flow and VTI. Variability was tested by dividing the absolute difference between the two values by their average value. Accordingly, the inter-observer reproducibility for carotid artery blood flow and VTI was also recognized in all data sets by calculating a coefficient of variation (CV) and an intraclass correlation coefficient (ICC). BlandeAltman plot was applied to test the inter-observer agreement in estimating carotid artery blood flow and VTI. A P-value < 0.05 (two-tailed).

Results

Participants and flow diagram

Of the 78 patients assessed for eligibility, 6 were excluded because of not meeting inclusion criteria ($n = 2$), declined to participate ($n = 2$), and other reasons($n = 2$). Therefore, 72 subjects were enrolled in the final analysis (Fig. 1). The main characteristics of the subjects were comparable between responders ($n = 31$) and non-responders ($n = 41$) (Table 1). There were no significant differences in patient characteristics between groups ($p > 0.05$) (Table 1).
Table 1
Patient Characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Responders group (n = 31)</th>
<th>Non-responders group (n = 41)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>32.9 ± 3.5</td>
<td>34.0 ± 4.8</td>
<td>0.265</td>
</tr>
<tr>
<td>ASA (I/II)</td>
<td>20/11</td>
<td>31/10</td>
<td>0.305</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>159.7 ± 5.6</td>
<td>159.8 ± 5.7</td>
<td>0.923</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>68.7 ± 8.0</td>
<td>67.9 ± 8.2</td>
<td>0.701</td>
</tr>
<tr>
<td>BMI</td>
<td>26.9 ± 3.1</td>
<td>26.6 ± 2.5</td>
<td>0.557</td>
</tr>
<tr>
<td>Duration of Surgery (min)</td>
<td>49.2 ± 14.5</td>
<td>52.2 ± 20.1</td>
<td>0.482</td>
</tr>
</tbody>
</table>

Values are numbers or means ± SD.

*p < 0.05 compared with Responders group

BMI: Body mass index (kg/m²); ASA: American Society of Anesthesiologists;

Haemodynamic variables before and after fluid challenge

Fluid challenge markedly increased SVI, carotid artery blood flow, and VTI in both the responders and the non-responders group (p < 0.05). (Table 2) (Fig. 2). Before fluid challenge, SVI, VTI, and carotid artery blood flow was obviously lower in responders than in non-responders (p < 0.05) (Table 2). In contrast, after fluid challenge, SVI, VTI, and carotid artery blood flow were all not significantly different between the two groups (Table 2). Both MAP and HR were not significantly different between the two groups before and after the fluid challenge (Table 2).
Table 2
Hemodynamic variables before and after uid challenge.

<table>
<thead>
<tr>
<th></th>
<th>Responders group</th>
<th>Non-responders group</th>
<th>P value</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n = 31 )</td>
<td>( n = 41 )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
<td></td>
</tr>
<tr>
<td>CABF (ml/min)</td>
<td>161.2 ± 50.4</td>
<td>317.3 ± 105.1*</td>
<td>236.4 ± 72.9#</td>
<td>321.7 ± 79.4*</td>
</tr>
<tr>
<td>VTI (cm/s)</td>
<td>9.0 ± 2.9</td>
<td>15.8 ± 4.8*</td>
<td>13.1 ± 3.9#</td>
<td>16.4 ± 3.7*</td>
</tr>
<tr>
<td>SVI (ml m(^{-2}))</td>
<td>61.7 ± 11.2</td>
<td>84.5 ± 16.0*</td>
<td>68.3 ± 13.2#</td>
<td>79.5 ± 16.4*</td>
</tr>
<tr>
<td>HR (beat min(^{-1}))</td>
<td>87.5 ± 14.3</td>
<td>88.2 ± 13.5</td>
<td>84.4 ± 11.7</td>
<td>83.2 ± 11.6</td>
</tr>
<tr>
<td>MAP (mmHg)</td>
<td>83.7 ± 7.5</td>
<td>89.3 ± 8.6</td>
<td>85.3 ± 14.9</td>
<td>90.8 ± 8.4</td>
</tr>
</tbody>
</table>

The data are reported as mean ± SD

*p < 0.05 compared with before uid challenge. #p < 0.05 compared with Responders group

SVI: stroke volume index; VTI: carotid artery velocity time integral; CABF: carotid artery blood flow.

MAP: Mean arterial pressure; HR: Heart rate.

The ability of carotid artery blood flow and VTI to predict fluid responsiveness

The area under the ROC curve to predict fluid responsiveness for carotid artery blood flow was 0.803 (95% CI, 0.701–0.905) and for VTI was 0.821 (95% CI, 0.720–0.922) (Fig. 2). The sensitivity and specificity for carotid artery blood flow and VTI are 74%, 78% and 67%, 90% (Table 3). Their cut-off values are 175.9 ml/min and 8.7 cm/s (Table 3).
Table 3
Prediction of fluid responsiveness by receiver operating characteristic curves of the baseline VTI and CABF.

<table>
<thead>
<tr>
<th></th>
<th>AUROC curve (95% CI)</th>
<th>P-value</th>
<th>Optimal cut-off value</th>
<th>Grey zone</th>
<th>Patients in grey zone (%)</th>
<th>Sensitivity (%) (95% CI)</th>
<th>Specificity (%) (95% CI)</th>
<th>Youden index</th>
</tr>
</thead>
<tbody>
<tr>
<td>VTI</td>
<td>0.821 (0.720–0.922)</td>
<td>0.0003</td>
<td>8.7 cm/s</td>
<td>6.8–8.7 cm/s</td>
<td>13(18%)</td>
<td>67.0(50.1–86.0)</td>
<td>90.0(80.0-100.0)</td>
<td>0.577</td>
</tr>
<tr>
<td>CABF</td>
<td>0.803 (0.701–0.905)</td>
<td>0.0001</td>
<td>175.9 ml/min</td>
<td>114.2–175.9</td>
<td>29(40%)</td>
<td>74.0(57.0–91.0)</td>
<td>78.0(64.0–92.0)</td>
<td>0.520</td>
</tr>
</tbody>
</table>

VTI: carotid artery velocity time integral; CABF: carotid artery blood flow; AUROC, area under the receiver operating characteristic; CI, confidence interval.

* Optimal cut-off values were determined by maximising the Youden index.

The inter-observer agreement in estimating VTI and carotid artery blood flow

For VTI measurements, intra-observer variability and inter-observer variability were 4.1 (2.6)% and 4.6 (2.9)%, respectively. For carotid artery blood flow measurements, inter-observer variability was 2.3 (2.0)% and 2.2 (1.6)%, respectively. Inter-observer reproducibility for estimating VTI was excellent, with an ICC of 0.992 (95% CI, 0.988–0.994) and a CV of 35.5%. Inter-observer reproducibility for estimating carotid artery blood flow was also excellent, with an ICC of 0.998 (95% CI, 0.997–0.999) and a CV of 36.2%. Using Bland-Altman analysis for evaluating inter-observer agreement in estimating VTI and carotid artery blood flow, the mean biases were −0.09 ms [with 95% limits of agreement (LOA) between −1.13 and 0.94 ms] and 1.09 (with 95% LOA between −8.07 and 10.26), respectively (Fig. 4).

Discussion

The assessment of circulating capacity and rehydration needs is the basis for recovery, but remains largely empirical. Recently, several arterial Doppler ultrasonography markers have been used to assess preoperative intravascular volume status in non-obstetric patients.14 However, assessing the intravascular volume of obstetric patients with spontaneous respiration remains a challenging task (Preau et al., 2017).

As we know, evaluation of common carotid artery (CCA) blood flow can provide valuable information regarding the hemodynamic status of a patient. In the recent years, the carotid artery VTI as well as measures of their variation induced by the respiratory cycle, have demonstrated a direct correlation with aortic VTI and have been proposed as fast and easy to obtain ultrasound measures for assessing fluid
responsiveness in intensive care unit patients (Pace et al., 2021). Importantly, Sidor et al. confirmed that total carotid flow (TCF) calculated based on volume-time integral (VTI) in the carotid artery showed positive correlation to cardiac output and carotid systolic VTI was one of the most promising indicators to assess fluid responsiveness and help fluid management in hemodynamically stable participants (Sidor et al., 2020). Interestingly, during passive leg raising (PLR), an increase of the VTI of subaortic blood flow (ΔVTI) above 12% predicted the response with a sensitivity and specificity of 75 [95% confidence interval (CI): 0.42–0.95] and 100% (95% CI: 0.72–1.00), respectively, ΔVTI combined with PLR could accurately predict fluid responsiveness in the specific setting of severe preeclampsia (SP) (Brun et al., 2013). In addition, measurement of the subaortic variation in the velocity time integral (VTI) after passive leg raising allows prediction of fluid responsiveness (Zieleskiewicz et al., 2018). In this context, our study showed that fluid challenge markedly increased VTI in both non-responders and responders groups and the area under the ROC curve to predict fluid responsiveness for VTI was 0.821, the sensitivity and specificity for carotid artery blood flow and VTI are 67%, 90%, with the cut-off values is 8.7 cm/s. Based on our findings, ultrasound measurements of VTI is displayed as an effective indice for predicting fluid responsiveness in pregnant women, suggesting that carotid artery VTI provides characterisation of the risk of capacity overload or insufficient during elective caesarean section under spinal anaesthesia, and therefore may allow individualised strategies for prevention and management. Further work is needed to validate the correlations of ΔVTI and stroke volume (SV) and cardiac index (Ci) and utilize these acquired carotid parameters to guide fluid management and predict fluid responsiveness in pregnant women.

Up to now, emerging evidence showed that carotid blood flow measurements correlated moderately with cardiac output and may be a better marker of cardiac output and less subject to measurements issues than corrected carotid flow time (Ma et al., 2017). Accordingly, carotid blood flow (CBF), which was calculated based on both systolic VTI and total VTI, correlated very strongly with SV, indicating that Doppler ultrasonography of the left common carotid artery (CCA) is able to estimate the SV and cardiac index (Ci) of critically ill children and therefore, the carotid Doppler ultrasonography may be considered as an alternative for estimating Ci when transthoracic echocardiography (TTE) is not feasible or available (Rubio et al., 2022). Of note, Gassner et al. found that intraclass correlation coefficient (ICC) analysis demonstrated almost perfect correlation (0.8152) between measurements of CO via ultrasound vs. invasive modalities, while the ICC between POCUS and the invasive measurement via PCA was 0.84 and via PA catheter 0.74, which showed a basic consistency between ultrasound and the two invasive devices and indicated that common carotid artery POCUS offers a non-invasive method of measuring the CO in the critically ill population (Gassner et al., 2014). As our results indicated, the predictability of carotid artery blood flow was comparable to that of carotid artery VTI with excellent interobserver agreement. Moreover, carotid artery blood flow yielded a cut-off value with the highest sensitivity and specificity. We also showed fluid challenge significantly increased carotid artery diameter and carotid artery blood flow in both two groups after the fluid challenge, suggesting their strong association with preload. Unfortunately, our findings were not consistent with previous study which stated that in patients with suspected sepsis, a fluid challenge did not result in a significant change in CBF, the reason may be due to the patient style and PLR (Liteplo et al., 2021). In the present study, we comprehensively evaluated the
ability of the carotid artery to predict volume responsiveness from both the carotid artery VTI and blood flow, which can provide more favorable evidence for the clinical use of the carotid artery in evaluating volume state. Thus, it remains to be verified through further studies and more clinical experience and identify the key limiting factors in using carotid ultrasound to determine fluid responsiveness.

This study has some limitations. First of all, in our study, only 72 women who chose elective cesarean section were enrolled. We will recruit more obstetric patients to explore the best ultrasound technique and the cutoff points for predicting fluid responsiveness and avoid overestimating the predictive power of these indices in our future studies. Second, this study was not conducted in women with gestational hypertension, preeclampsia, or emergency cesarean section, who are currently considered to be at high risk for hemodynamic instability. Future studies will determine the reliability and feasibility of ultrasonic techniques in predicting fluid responsiveness in pregnant women. Third, carotid artery blood flow and VTI are negatively correlated with systemic vascular resistance and are affected by left ventricular preload and myocardial strength. Therefore, many other factors that alter afterload also affect VTI and carotid artery blood flow (Sidor et al., 2020). In future studies, the predictive power of VTI and carotid blood flow in different populations and clinical settings should be evaluated. Fourth, in this study, ultrasound technology was only applied to perioperative parturients to accurately measure carotid artery blood flow and VTI to predict fluid responsiveness. Future studies will use ultrasound measurements of other peripheral arteries, such as the radial or brachial arteries, to predict fluid reactivity in pregnant women. Our study demonstrated that ultrasound evaluation of VTI and carotid artery blood flow appeared to be the accurate indicators of fluid responsiveness in pregnant women. Future researches should focus further on the accuracy and reliability of carotid artery blood flow and VTI, as well as their relations to other sonographic predictive measurements.

Conclusions

Our study addressed that ultrasound measurement of CABF and VTI appeared to be the valuable predictors of fluid responsiveness in pregnant women. Our findings contribute to the understanding of maternal volume status and fluid management in obstetric anesthesia and are expected to provide the new ultrasound evaluation methods for predicting maternal fluid reactivity. Further work is needed to validate these correlations between maternal volume status and different hemodynamic parameters in the CCA, namely CABF and VTI and utilize these acquired carotid parameters to guide fluid management and predict fluid responsiveness.

Abbreviations

CABF
carotid artery blood flow
VTI
velocity time integral
SVI
stroke volume index
SV
stroke volume
CO
cardiac output
ROC
The receiver operating characteristic
CI
confidence interval
IVCCI
inferior vena cava collapsibility index
ASA
American Society of Anesthesiologists
BSA
body surface area
AUC
area under the curve
CV
coefficient of variation
ICC
intraclass correlation coefficient
LOA
limits of agreement
CCA
common carotid artery
TCF
total carotid flow
PLR
passive leg raising
Ci
cardiac index
CBF
carotid blood flow
TTE
transthoracic echocardiography
ICC
intraclass correlation coefficient

Declarations
Ethics approval and consent to participate

This study was approved by the Research Ethics Committee of Women's Hospital, Zhejiang University School of Medicine (20180163). The written informed consents were provided by all patients.

Consent for publication: Not applicable.

Availability of data and materials: Not applicable.

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

Funding: No.

Authors' contributions:

Shaobing Dai was writing the manuscript. Chun Wang and Jianjun Shen performed the experiment and collected the patient data. Cardiac ultrasound completed by Xia Tao. Lili Xu analyzed the patient data and approved the final manuscript. All authors read and approved the final version of the manuscript.

Acknowledgements:

We would thank all staff of the Department of Anesthesia and the operation theatre for their help in the study.

References


**Figures**
Figure 1

The process of subject selection.

Among the 78 patients who met the inclusion criteria, 6 were excluded, 72 were agreed by consent, 72 were studied, 31 were in the Responders group and 41 were in the Non-responders group.
Figure 2

Individual responses to fluid challenge and ROC curve for VTI and CABF.

Upper row: individual responses to fluid challenge for VTI(A) and CABF(B). Responders are presented as blue full line and closed circles; Non-responders are presented as red dashed line and open circles.

Lower row: receiver operating characteristic curves showing the ability of VTI (C) and CABF (D) before fluid challenge to discriminate responders and non-responders.

The areas under the curves for VTI and CABF were 0.802 (95% confidence interval 0.706-0.898), 0.812 (95% confidence interval 0.714-0.909), and 0.846 (95% confidence interval 0.762-0.930), respectively.

Responders are represented by blue full lines and closed circles; Non-responders are represented by red dashed lines and open circles.

VTI carotid artery velocity time integral  CABF: carotid artery blood flow.
Figure 3

CAD and VTI.

CAD and VTI at 2 cm proximal to the carotid bulb were measured.

Figure 4

BlandeAltman plots for inter-observer agreement of VTI and CABF.
Red dotted lines indicate the mean difference (bias), and black dotted lines indicate the 95% limits of agreement (1.96 x standard deviation).