A Pilot Assessment of Carotid and Brachial Artery Blood Flow Estimation Using Ultrasound Doppler in Cardiac Surgery Patients

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Objectives: **To estimate carotid and brachial artery blood flow with Doppler ultrasound in cardiac surgery patients and relate such estimates to cardiac index, lactate levels, and markers of renal function.**

Design: **A prospective observational study.**

Setting: **A teaching hospital.**

Participants: **Twenty-five elective cardiac surgery patients.**

Interventions: **The authors measured bilateral carotid and brachial artery blood flows using Doppler ultrasound and, simultaneously, cardiac index using a pulmonary artery catheter; lactate and serum creatinine levels; and urine output. The relationship between these indices and biomarkers was assessed statistically.**

Measurements and Main Results: **Median carotid arterial blood flow was estimated at 0.323 L/min (interquartile ratio [IQR], 0.256-0.429 L/min) on the right and 0.308 L/min (IQR, 0.247–0.376 L/min) on the left at baseline. Median brachial arterial blood flow was estimated at 0.063 L/min (IQR, 0.039–0.115 L/min) on the right and 0.063 L/min (IQR, 0.039–0.081 L/min) on the left at baseline. There was a weak correlation between right- and left-sided flows (brachial: rho = 0.285; carotid: rho = 0.384) and between brachial and carotid flow (right: rho = 0.135, left: rho = 0.225). There also was a weak correlation between cardiac index and brachial flow (right: rho = 0.215; left: rho = 0.320) and carotid flow (left: rho = 0.159) immediately after surgery, and no correlation 1 day after surgery (right brachial: rho = -0.010; left brachial: rho = -0.064; left carotid: rho = –0.060). There were no significant correlations between carotid or brachial flows and lactate and serum creatinine levels or urine output.**

Conclusions: **In cardiac surgery patients, Doppler-estimated carotid and brachial arterial blood flows have only a weak correlation with cardiac index and no correlation with lactate or creatinine levels or urine output. Thus, Doppler estimation of these blood flows cannot be used to provide noninvasive estimates of cardiac index in patients after cardiac surgery.**

KEY WORDS: arterial Doppler blood flow, cardiac index, cardiac surgery

HEMODYNAMIC MONITORING of cardiac surgery patients in the intensive care unit (ICU) traditionally has focused on central circulatory parameters, including cardiac output (CO), right heart pressures, and systemic blood pressure. The assumption is that optimizing these centrally derived circulatory parameters will be reflected in improved organ and regional tissue perfusion. However, little is known about the actual relationship between central hemodynamics and markers of peripheral perfusion in critically ill patients, including after cardiac surgery.[1] For example, the relationship between brachial artery blood flow and cardiac index is understood poorly and has been investigated inconsistently because of different methodologies.[2,3] Similarly, the relationship between cardiac index and common carotid artery blood flow has not been investigated widely in humans and also is understood poorly.[4]

A predictable relationship between these peripheral blood flows and changes in cardiac index would suggest that changes to cardiac index would be reflected in changes to peripheral and central arterial flows. Conversely, measured central and peripheral arterial flows could be used to estimate CO. The latter is of practical interest because both brachial and common carotid artery flows theoretically can be estimated easily using Doppler ultrasound. These vessels are available readily to the critical care physician, and measurement of their respective blood flows may serve as a surrogate for cardiac index. If the relationship between carotid or brachial blood flow and cardiac index and/or other markers of perfusion (eg, lactate and creatinine levels and urine output) was reasonably robust, then this would allow the noninvasive assessment of cardiac index and obviate the use of expensive and/or invasive technology.

Recent research suggests that carotid artery blood flow can be used to predict volume responsiveness and that this correlates with central hemodynamic parameters in septic, ventilated patients in the ICU.[4] Moreover, studies of patients with heart failure have reported that brachial blood flow correlates with CO.[2,3] However, the robustness and reproducibility of these studies remain uncertain. For example, 1 study[3] only provided data on relative changes in carotid and brachial arterial flows, not absolute values, making it difficult to compare the findings with other studies.[4] Also, 2 of the aforementioned studies used plethysmography (an indirect method) to estimate changes in blood flow. Such data are not comparable easily with Doppler ultrasound data.[2,3]

Accordingly, the authors of this study sought to test the reproducibility and robustness of the relationship between estimates of carotid and brachial blood flows with cardiac index, the relationship between carotid and brachial blood flows, and the relationship between such peripheral flows and widely used clinical markers of perfusion (eg, lactate and creatinine levels and urine output) in cardiac surgery patients. The authors hypothesized that the cardiac index and/or markers of perfusion would show a good correlation with both carotid and brachial blood flows and that the measurements taken from both sides would show a very good-to-excellent correlation with each other.

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METHODS

A prospective observational study of serial measurements of CO and carotid and brachial arterial blood flows was performed in cardiac surgery patients. Written informed consent was obtained from every patient before inclusion in the study.

Approval from the local Health Human Research Ethics Committee (reference number LNR/13/Austin/265) was obtained.

Inclusion and Exclusion Criteria

The authors obtained a convenience sample of patients older than 18 years scheduled for an elective cardiac surgical procedure (with or without cardiopulmonary bypass).

Exclusion criteria were known history of peripheral vascular disease or cerebrovascular disease, aortic arch surgery, minimally invasive cardiac surgery, and emergency cardiac surgical procedures.

Study Protocol

The authors performed Doppler ultrasound measurements of the common carotid and brachial arterial blood flows before surgery, immediately after surgery in the ICU, and 24 hours postsurgery.

Hemodynamic Measurements

Before patients underwent cardiac surgery, the authors collected their demographic data, including age, sex, body weight and height, and operative procedure and took baseline measurements of blood pressure and serum lactate and serum creatinine levels. The authors performed postoperative measurements of CO (measured using a pulmonary artery catheter); mean arterial blood pressure; and regional markers of perfusion, including serum creatinine and arterial blood lactate levels and urinary output.

Ultrasound Measurements

Peripheral blood flow was measured in the right and left common carotid and brachial arteries at each time point using a commercially available ultrasound system (Philips Sparq Ultrasound, Koninklijke Philips, Eindhoven, Netherlands) and a 7- to 12-MHz variable frequency linear array transducer. The patients were positioned in the supine position for all measurements.

Ultrasound measurements of carotid and brachial arterial flows were performed 3 times: preoperatively (baseline), immediately on return to the ICU after surgery, and 1 day after surgery. In addition, Doppler ultrasound measurements of each vessel were repeated 3 times at every time point.

Blood flow was derived from the product of the vessels' cross-sectional area and the intensity-weighted mean blood flow velocity through the vessel. Imaging of the vessel was performed in the longitudinal plane, and the vessel's diameter was measured during the peak of the electrocardiogram T-wave. The cross-sectional area was assumed to be circular.

The second measurement was the time-averaged, intensity-weighted mean velocity, with a specified number of cardiac cycles (15 cycles) to average out respiratory variation. The measurement of the mean velocity was described by Gill et al[5] and requires the ultrasound intensity and the distribution of scatterers to be uniform throughout the sample volume. If this uniform insonification condition is met, the power spectral density of the Doppler signal represents the distribution of red cell velocities within the sample volume. The instantaneous spatial mean velocity then may be calculated from the intensity-weighted, instantaneous mean Doppler shift (the normalized first moment of the Doppler spectrum).[6] This was determined using pulsed-wave Doppler, with the sample volume adjusted to the width of the vessel at the point where the diameter width was measured. The Doppler angle was minimized to <60 degrees (Figs 1 and 2).

Data Analysis

Statistical analysis was performed using SPSS (IBM SPSS Statistics 22, IBM Corporation, NY). Normally distributed data are reported as means with standard deviations and were compared using Student's t-test. Non-normally distributed continuous data are reported as medians with either interquartile (IQR) or total range and were compared using the Mann-Whitney U test, Kruskal-Wallis test, or Friedman test, as appropriate. Categoric data are reported as proportions and were compared using the chi-square or Fisher's exact test. The relationship among variables was assessed using Spearman's rank correlation tests and expressed by the rho coefficient. Any correlation that lacked statistical significance was defined as absent. Correlations that showed statistical significance but had a rho value <0.4 were labeled as weak. A correlation with a rho value between 0.4 and 0.5 was labeled as modest, between 0.5 and 0.6 as good, between 0.6 and 0.7 as very good, between 0.7 and 0.8 as strong, and >0.8 as excellent. Bland-Altman analysis was used to assess bias and limits of agreement for paired blood flow measurements of the right and the left sides in the common carotid and brachial arteries.[7,8] Bias was defined as the mean difference between measurements. The upper and lower limits of agreement were defined as $\pm$ 1.96 standard deviation (SD) of the bias. A p value of ≤ 0.05 was considered statistically significant.

RESULTS

Patient Characteristics

The study was composed of 25 cardiac surgery patients before, immediately after, and 24 hours after surgery. Their demographic characteristics are presented in Table 1.

Hemodynamic Parameters

The patients' hemodynamic and physiologic characteristics before and after surgery are shown in Table 2.

Compared with baseline (systolic blood pressure [BP], 126 mmHg [IQR, 111.5-134.5 mmHg]; diastolic BP, 69 mmHg [IQR, 58.5-75.5 mmHg]), there were a decreases in systolic and diastolic blood pressures immediately after surgery (systolic BP, 115 mmHg [IQR, 100-127 mmHg]; diastolic BP, 62 mmHg [IQR 53-70 mmHg]) and 24 hours after surgery (systolic BP, 115 mmHg [IQR, 102-124 mmHg]; diastolic BP, 58 mmHg [IQR, 52-63 mmHg]).

The postoperative day 1 cardiac index increased (3 L/min/m^2 [IQR, 2.62-3.2 L/min/m^2]) compared with that measured