Comparison of Carotid Blood Flow measured by Ultrasound and cardiac output in Patients undergoing Cardiac Surgery

Xinyi Bu  
Nanjing Medical University

Yong Zhang  
Nanjing Medical University

Lihai Chen  
Nanjing Medical University

Jiacong Liu  
Nanjing Medical University

Yamei Zhao  
Nanjing Medical University

Hongwei Shi  
Nanjing Medical University

Yali Ge (✉️ ge_yl@163.com)  
Nanjing Medical University

Research Article

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Abstract

In general, cerebral blood flow accounts for 10–15% of cardiac output (CO), of which about 75% was delivered through the carotid arteries. Hence, if carotid blood flow (CBF) is constantly proportional to CO with high reproducibility and reliability, it would be of great value to measure CBF alternatively to CO. The aim of our study was to measure CBF in different cardiac cycles by ultrasound: Systolic carotid blood flow (SCF), Diastolic carotid blood flow (DCF) and Total (systolic and diastolic) carotid blood flow (TCF). And to investigate the direct correlation between CBF and CO. Whether the above correlation persisted when CO < 3.5/min. Patients aged 65 to 80 years old, undergoing elective cardiac surgery were included in this study. CBF and CO were measured by ultrasound and TEE respectively at 5 min, 10 min, and 15 min after induction of anesthesia. For all patients, the correlation coefficients between SCF and CO, TCF and CO were 0.41, 0.32 respectively, which were statistically significant, but not between DCF and CO. When CO < 3.5L/min, there was no significant correlation between either SCF, TCF or DCF and CO. It is suggested that systolic carotid blood flow should be used as a better index to replace CO. However, when the patient's heart function is poor, it is not recommended to use, and the method of direct measurement of CO is essential.

1 Introduction

The monitoring and evaluation of cardiac output (CO) is of great significance in diseases diagnosis and management, especially in critically ill patients with rapid hemodynamic changes. Pulmonary artery catheterization is normally utilized for CO measurement, but this invasive procedure can cause multiple complications, required to be performed by trained physicians. Transthoracic echocardiography (TTE) is another method that can monitor CO and hemodynamic safely and effectively. However, TTE is not always available because of poor patient positioning or hampered by surgical incisions. Similarly, transesophageal echocardiography (TEE) for assessing CO has also showed some limitations, in which general anesthesia is inevitable. Thus, it is still challenging to monitor CO clinically.

In general, cerebral blood flow accounts for 10–15% of CO [1, 2], of which about 75% was delivered through the carotid arteries while the remaining 25% through the vertebral arteries [3, 4]. Hence, if CBF is constantly proportional to CO with high reproducibility and reliability, it would be of great value to measure carotid blood flow (CBF) alternatively to CO.

However, the relationship between CBF and CO is controversial and relative study is still scarce in some extent. Some studies suggested that CBF could be used to predict volume responsiveness, and increased CO led to an increase in CBF [5], while others suggested that there was no correlation or even negative correlation between CBF and CO [6].

Therefore, the objective of this study was to investigate the direct correlation between CBF and CO. We hypothesized that measurement of CBF could be a good substitute for CO, even under more extreme
hemodynamic conditions, for a wider range of critically ill patients. We proposed to test its reproducibility and robustness stability in patients undergoing cardiac surgery.

2 Materials And Methods

2.1 Patients

This was an observational study conducted from March 2022 to June 2022. This study had been reviewed and approved by the ethical committee of Nanjing First Hospital, China (KY20220204-01). Inclusion, exclusion and withdrawal criteria of this study: 1) Inclusion criteria: Patients aged 65 to 80 years old, scheduled for elective cardiac surgery. 2) Exclusion criteria: History of neck surgery or trauma, peripheral vascular disease, BMI > 30 kg/m$^2$, carotid stenosis > 50%, neurological diseases affecting CBF: history of cerebrovascular disease, dementia, epilepsy and stroke, patients with non-sinus rhythm, aortic valve insufficiency (moderate or severe). 3) Withdrawal criteria: Patients with new stenosis and plaque were found by carotid ultrasound.

2.2 Research parameters

CBF and CO were measured by ultrasound and TEE respectively at 5 min, 10 min, and 15 min after induction of anesthesia (all time points were before the start of operation, and hemodynamics were stable for at least 60s during measurements).

2.3 Independence and simultaneity of measurement

CBF and CO were performed independently and simultaneously by two experienced physicians. All ultrasound indexes were the average values of 3 consecutive complete cardiac cycles.

2.4 Measurement of CBF by ultrasound

The patient was placed in the supine position with full exposure of neck and head towards to the contralateral side. A linear array transducer (Philips ultrasound, CX50 Diagnostic ultrasound system) was placed on the patient's left neck and the carotid artery was positioned in the center of the screen, after excluding the new onset stenosis and plaque in cross section. The probe was then rotated 90° to obtain a satisfactory long-axis image of the carotid artery, and the maximum diameter of the vessel was displayed by adjusting the acoustic beam. The inner diameter of carotid artery and Doppler blood flow parameters were measured at the level of the lower border of the thyroid cartilage and 2 cm proximal to the carotid bifurcation.

1) Measurement of Doppler blood flow parameters:

The Doppler sampling line was placed in the center of the vessel, and the sampling direction was approximately parallel to the vessel direction with the Doppler angle kept between 45° and 60°. The sampling volume was adjusted by 1 mm, and the spectral Doppler scale was set low enough to fill the available space without aliasing. When the image on the screen was full, freezed the image. The
instrument's built-in software sketched and measured the systolic velocity time integral (VTIs), diastolic velocity time integral (VTId), and total (systolic and diastolic) velocity time integrals (VTIt).

2) Measurement of internal diameter of carotid artery:

The inner diameter of the blood vessel was measured at the sampling volume site. The endovascular diameter, determined as the vertical distance between the endovascular lines, was measured at end-systole (Ds), and end-diastole (Dd) and total systolic and diastolic (Dt), \( Dt = (Ds + Dd)/2 \).

3) Calculation of CBF:

Assume that the cross-sectional area of the carotid artery is circular. CBF was derived from the cross sectional area of the vessel and the velocity time integral VTI.

Systolic carotid blood flow (SCF) = \( \pi Ds^2 \times VTIs \times HR / 4 \)

Diastolic carotid blood flow (DCF) = \( \pi Dd^2 \times VTId \times HR / 4 \)

Total carotid blood flow (TCF) = \( \pi Dt^2 \times VTIt \times HR / 4 \)

2.5 Measurement of CO

Performed by the other independent doctor through TEE. The velocity time integral (VTI) of the left ventricular outflow tract (LVOT) was measured in the deep transgastric left ventricular long-axis view, and the diameter of the LVOT (D) was measured in the mid-esophageal LVOT view.

\[ CO = \pi D^2 \times VTI \times HR / 4 \]

2.6 Statistical Analyses

SPSS 19.0 statistical software was used for data analysis. Normally distributed continuous variables were expressed as mean ± standard deviation (\( x \pm s \)), and independent samples t-test was used for comparison between groups. Non-normally distributed variables were expressed as median (M) and interquartile range (IQR), and the rank sum test was used for comparison between groups. The count data were expressed as cases (%), and the Fisher exact probability method and \( \chi^2 \) test were used for comparison between groups. Scatter plots of SCF, DCF, TCF and CO were established respectively, and the correlation coefficients were analyzed among them. When patients were in extreme hemodynamic condition \( CO < 3.5/min \), statistical analysis of the correlation between corresponding SCF, DCF, TCF and CO. \( P<0.05 \) was considered a statistically significant difference.

3 Results

3.1 Patients
A total of 23 patients were included in this study. The correlation between CBF and CO was independent of time. Data were collected at 5 min, 10 min, and 15 min after induction of anesthesia, with three bundles of results for each patient, and 69 results of SCF, DCF, TCF and CO were collected respectively from 23 patients. Table 1 shows the patients’ characteristics, CBF and CO.

Table 1
Patients’ characteristics, carotid blood flow and cardiac output

<table>
<thead>
<tr>
<th>N</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>70.96 ± 4.36</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>68.78 ± 9.81</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.69 ± 0.06</td>
</tr>
<tr>
<td>Male/Female, n</td>
<td>18/5</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>23.93 ± 2.91</td>
</tr>
<tr>
<td>SCF, L/min</td>
<td>0.41 [0.30–0.56]</td>
</tr>
<tr>
<td>DCF, L/min</td>
<td>0.30 [0.20–0.42]</td>
</tr>
<tr>
<td>TCF, L/min</td>
<td>0.74 [0.54–0.97]</td>
</tr>
<tr>
<td>CO, L/min</td>
<td>4.20 ± 1.23</td>
</tr>
</tbody>
</table>

Values are median [IQR], count or mean ± SD

3.2 Correlation between CBF and CO

Figure 2 shows the correlation coefficients between SCF, DCF, TCF and CO were 0.41 (P < 0.001), 0.10 (P > 0.05) and 0.32 (P < 0.01), respectively.

3.3 When CO < 3.5 L/min

7 of the 23 patients had CO < 3.5 L/min with 21 results of SCF, DCF, TCF and CO obtained respectively from them. Figure 3 shows the correlation coefficients between SCF, DCF, TCF and CO was 0.28 (P > 0.05), −0.09 (P > 0.05), and 0.13 (P > 0.05) respectively.

4 Discussion

This study showed a significant correlation between CBF measured by ultrasound and CO measured by TEE. The correlation coefficients between SCF and CO, TCF and CO were statistically significant, but not between DCF and CO. When CO < 3.5L/min, there was no significant correlation between either SCF, TCF or DCF and CO. It suggests that SCF is a good alternative to CO in patients with preserved CO (≥3.5L/min).
It is still controversial whether the measurement of CBF can be used as a substitute for CO. Weber et al. compared the correlation between CBF and cardiac index (CI) in 11 healthy volunteers and found weak or no correlation [7]. Besides, the same authors found a negative correlation between CBF and CI in 25 patients with normal CI before and after cardiac surgery [6]. According to the author, although most CO is delivered to the brain through the carotid artery, CBF is strictly regulated, and changes in CO do not necessarily lead to proportional changes in CBF, which is highly unpredictable and variable. Lassen found that CBF displayed an autonomic regulation function under normal conditions (MAP between 50–150 mmHg), resulting in relatively stable CBF [8]. However, different views had been proposed recently. Skytioti reported that, the internal carotid blood flow (ICBF) was correlated with the changes in CO in healthy and awake people, even if the MAP remained unchanged [9]. Olese found that under a stable level of anesthesia, an increase in MAP from 60–65 to 80–85 mmHg increases ICBF by 15%. An increase in MAP from 60–65 to 70–75 mmHg increased ICBF by 7%, and a further increase in MAP to 80–85 mmHg increased ICBF by 8% [10]. These findings were in contrast to the classical autonomic brain regulation.

Other scholars had suggested that CBF can be a substitute for CO. Skytioti et al studied the process from waking state to anesthesia, pneumoperitoneum and head elevation head-up position in ASA class I-II patients undergoing elective laparoscopic surgery [11]. It was found that a decrease in CI of 1 L·min$^{-1}$·m$^{-2}$ predicted a decrease in ICBF of 88 ml/min. The authors suggested that the significant decrease in ICBF was related to the decrease in CO. In addition, a strong correlation of 0.96 close to 1 between ultrasonic measured CBF and TTE measured CO was reported by Fazelinejad [12].

All the above studies used total (systolic and diastolic) CBF to compare with CO. Sidor et al emphasized the importance of using systolic carotid blood flow SCF. The authors believed that DCF of diastolic carotid blood flow was less dependent on stroke volume [13]. It was the result of the kinetic energy and inertia of the heart to the blood stream and the reflex of aortic valve closure in early diastole. These may account for the different results of the current study, which deserved more research.

Peng et al enrolled 148 ICU patients with different primary diseases and compared the correlation between CBF ×10 and CO, showing a correlation coefficient of 0.537 [14]. However, in patients with septic shock, multiple trauma and respiratory failure, the correlation coefficients between CBF and CO were low, attributing to the small sample sizes. In a group of 34 critically ill patients, Marik et al measured CBF to assess fluid responsiveness induced by passive leg raising and observed a 25% increase in stroke volume index and a 79% increase in CBF [5]. Our results showed that there was no significant correlation between SCF, DCF, TCF and CO when CO < 3.5L/min. It indicates that for patients with poor cardiac function, it is not suitable to estimate CO by CBF, and it is more accurate to measure cardiac function directly.

Previous studies assumed that the internal diameter of the carotid artery was constant and only the effect of VTI on blood flow was considered. However, changes in CBF are partly due to changes in VTI, as well as carotid internal diameter, so carotid arteries should not be considered as rigid vessels [11]. In our study, Ds, Dd and Dt in different cardiac cycles were studied to avoid the influence of internal diameter
alterations on the results. Moreover, the correlation between SCF, DCF, TCF and CO was analyzed respectively, which increased the accuracy of the study.

There are limitations in this study. Firstly, only left CBF data were obtained in our study, because a CVP catheter was placed in the right side of the patient. However, we also took into account that in most patients, the right carotid artery originates from the brachiocephalic artery and the left carotid artery originates directly from the aorta.

5 Conclusion

There was a significant correlation between CBF measured by ultrasound and CO measured by TEE. The correlation between systolic carotid blood flow SCF and CO is more obvious. It is suggested that systolic carotid blood flow SCF should be used as a better index to replace CO. However, when the patient's heart function is poor, it is not recommended to use, and the method of direct measurement of CO is essential. It is hoped that in the future, continuous ultrasound monitoring of CBF can provide more ideas for the diagnosis and treatment of patients.

Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Xinyi Bu, Yong Zhang and Lihai Chen. The first draft of the manuscript was written by Xinyi Bu and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics approval

This study had been reviewed and approved by the ethical committee of Nanjing First Hospital, China (KY20220204-01).

References


Figures

Figure 1

Measurement of CBF by ultrasound
Figure 2

Correlation between SCF, DCF, TCF and CO. (n=69, 69 and 69, respectively)
Figure 3

The correlation between SCF, DCF, TCF and CO when CO < 3.5L/min. (n=21, 21 and 21, respectively)