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The Transcranial Doppler Sonography for Optimal Monitoring and Optimization of Cerebral Perfusion in Aortic Arch Surgery: A Case Series

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ABSTRACT

Objective: To analyze the feasibility and advantages of transcranial doppler sonography (TCD) for monitoring and optimization of selective cerebral perfusion (SCP) in aortic arch surgery.

Methods: From April 2013 to April 2014, nine patients with extensive aortic pathology underwent surgery under moderate hypothermic cardiac arrest with unilateral antegrade SCP under TCD monitoring in our institution. Adequate sonographic window and visualization of circle of Willis were to be confirmed. Intraoperatively, a cerebral cross-filling of the contralateral cerebral arteries on the unilateral SCP was to be confirmed with TCD. If no cross-filling was confirmed, an optimization of the SCP was performed via increasing cerebral flow and increasing PCO2. If not successful, the SCP was to be switched to bilateral perfusion. Air bubble hits were recorded at the termination of SCP.

Results: A sonographic window was confirmed in all patients. Procedural success was 100%. The mean operative time was 298 ± 89 minutes. Adequate cross-filling was confirmed in 8 patients. In 1 patient, inadequate cross-filling was detected by TCD and an optimization of cerebral flow was necessary, which was successfully confirmed by TCD. There was no conversion to bilateral perfusion. Extensive air bubble hits were confirmed in 1 patient, who suffered a postoperative stroke. The 30-day mortality rate was 0.

Conclusion: The TCD is feasible for cerebral perfusion monitoring in aortic surgery. It enables a confirmation of adequacy of cerebral perfusion strategy or the need for its optimization. Documentation of calcific or air-bubble hits might add insight into patients suffering postoperative neurological deficits.

INTRODUCTION

Aortic arch surgery remains one of the most challenging cardiovascular surgeries in adult cardiac surgery. To ensure the procedural success and to improve the postoperative outcome, hypothermic circulatory arrest with selective cerebral perfusion has been increasingly used [Okita 2015]. Yet this requires not only a high surgical expertise, but also excellent management and monitoring strategies. Otherwise, cerebral malperfusion may occur and result in stroke or temporary neurologic dysfunction (TND) [Estrera 2005].

The use of transcranial doppler sonography (TCD) has been reported in intraoperative monitoring of cerebral blood flow by providing instant, noninvasive, continuous, and visual feedback [Rasulo 2008; Ghazy 2016]. Furthermore, TCD has been found to be useful in detecting cerebral air emboli in patients undergoing open heart surgery despite the standard de-airing process [Yeh 2003; Doblar 2004; van der Linden 1991].

The main objective in this study was to investigate the use of TCD in intraoperative monitoring and optimization of cerebral blood flow under SCP in complex aortic arch surgeries. Here we present our early experience.

METHODS

From April 2013 to April 2014, patients who were diagnosed with type A aortic dissection or aortic arch aneurysm and underwent aortic arch repair in our center were included in a prospective registry and scanned for inclusion in this study. The inclusion criteria comprised age above 18 years old, undergoing the surgical repair under moderate hypothermic circulatory arrest with unilateral antegrade cerebral perfusion, and availability of an experienced examiner for TCD. The exclusion criteria were patient declining inclusion in the prospective registry, patient's submission to any period of complete circulatory arrest with no SCP, hypothermic arrest below 27°C or higher than 30°C core temperature, and unavailability of experienced examiner to perform TCD.

Hemodynamics and Cerebral Perfusion Monitoring

The TCD was performed using a standard S4 echocardiography probe (Philips, Hamburg, Germany), which was routinely performed transtemporaly from the patient's left side [Ghazy 2016]. For the elective cases, the TCD was performed 1 day preoperatively as a part of the preoperative preparation to confirm a sonographic window. In emergency cases, the TCD was performed only intraoperatively.

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In all procedures, arterial lines (Arterial leadercath, Vygon, Ecouen, France) were placed in the left and right radial artery and left femoral artery to monitor blood pressure in the upper and lower body. Neurologic activity was monitored intraoperatively by an electroencephalograph (EEG).

Anesthesia

Anesthesia induction was achieved using thiopental and maintained using sevofluran through a single-lumen endotracheal tube. Rocuronium was used for muscle relaxation, and fentanyl for analgesia. Blood pressure was monitored invasively via bilateral radial and unilateral femoral artery catheters (Arterial leadercath, Vygon, Ecouen, France). A central vein catheter (Arrow Multi-Lumen Central Venous Catheterization Set, Teleflex Medical, Westmeath, Ireland) was placed into the internal jugular vein to introduce medications and monitor central venous pressure. Core body temperature was monitored via Foley catheter, and brain temperature was monitored via nasopharyngeal probe. Thiopental was administered directly before commencing SCP. Intraoperative brain activity and adequate SCP were monitored by biradial pressure monitoring, EEG, and TCD.

Surgical Technique and Perfusion Management

Cardiopulmonary bypass (CPB) was applied via arterial cannulation of the brachiocephalic trunk and venous cannulation of the right atrium. After lowering the core temperature to 28°C, the unilateral antegrade SCP via the brachiocephalic trunk was commenced. The blood pressure was monitored in both radial arteries, and blood flow in both hemispheres was monitored and documented with TCD. If no cerebral cross-filling (ie adequate left-hemisphere perfusion over the cerebral communicators of the circle of Willis) was documented with TCD, the SCP flow was increased (eg, from 1.5 to 2.0 L/min) and the PCO_2 was elevated to 45 mmHg to induce a vasodilatation in the communicators of the circle of Willis. In case the cross-filling was still not confirmed, the SCP was to be switched from unilateral to bilateral SCP. Standard total or hemi-arch replacement was then performed. This was followed by clamping of the new prosthesis and releasing the supra-aortic vessel-clamps marking the end of SCP. The procedures were then completed in a standard manner.

Postoperative Imaging

CT angiography was routinely performed on the 7th postoperative day before hospital discharge. This, as well as further follow-up imaging studies, were performed in accordance with, evaluated, and confirmed by our university's multidisciplinary board for aortic diseases.

STATISTICAL ANALYSIS

The results of distribution analysis of continuous variables are presented as mean ± SD. The binary variables are presented as a percentage of the study population. All statistical analyses were carried out using JMP (version 6.0.0) software (SAS Institute, Cary, NC, USA).

Table 1. Preoperative Data Analysis

Demographic data	
Mean age at operation	62 ± 15 years
Male sex, n (%)	5 (55)
Cardiac profile	
Poor LVEF, % (EF < 30%)	0
Aortic valve disease, n (%)	3 (33)
Mitral valve disease, n (%)	1 (11.1)
Tricuspid valve disease, n (%)	1 (11.1)
Pulmonary hypertension, %	0
Comorbidities	
Arterial hypertension, n (%)	7 (77)
Diabetes mellitus, n (%)	5 (55)
COPD, %	0
Smoking, %	0
Aortic vascular profile	
Isolated dissection, n (%)	7 (77)
Isolated aneurysm, n (%)	2 (22)
Combined disease, %	0
Carotid artery stenosis, n (%)	1 (11)
Risk factors, %	
Previous neurological insult	0
Peripheral vascular disease	0
Chronic renal failure	0
Previous cardiovascular operation	0

LVEF indicates left ventricular ejection fraction; NYHA, New York Heart Association; COPD, chronic obstructive pulmonary disease.

RESULTS

Preoperative Data Analysis

Nine patients were included in the study. The preoperative data and comorbidities are listed in Table 1. The patients suffered various comorbidities and risk factors, with arterial hypertension (77%) and diabetes (55%) being the most prevalent. Chronic obstructive pulmonary disease (COPD) and smoking were excluded in all patients while left carotid artery stenosis was present in 1 patient. Seven patients (77%) were diagnosed with aortic dissection and did not undergo a preoperative TCD screening; the remaining 2 (22%) suffered from aortic aneurysm and were subjected to TCD screening, which revealed adequate sonographic windows and cerebral communicators. Other than 1 patient with Type A dissection who suffered a preoperative altered consciousness, there were no preoperative cerebrovascular incidents.

Intraoperative Data Analysis

The mean operative, CPB, and SCP times were 298 ± 89, 147 ± 32, and 77 ± 17 minutes respectively. The mean core

Table 2. Intra- and Postoperative Data Analysis

Mean operative time, min	298 ± 89
Cardiac support, n (%)	2 (22)
Mean circulatory arrest time, min	77 ± 17
Core temperature under HCA	28 ± 0.8°C
Mean CPB time, min	147 ± 32
Median ICU stay, d	3 [range 3-6.5]
Median ventilation time, h	14 [range 8-31]
Postoperative bleeding, n (%)	7 (77)
Rethoracotomy, n (%)	1 (11)
Tamponade, n (%)	1 (11)
Permanent neurological deficits, n (%)	1 (11)
Postoperative acute renal failure, n (%)	3 (33)
Postoperative need for dialysis, n (%)	1 (11)
Mortality, %	0
Mean hospital stay, d	17 ± 13

HCA indicates hypothermic circulatory arrest; CPB, cardiopulmonary bypass.

temperature was 28 ± 0.8°C. Unilateral SCP was sufficient in all patients. The intraoperative TCD showed that adequate reversal of flow in the communicators with adequate cross-filling and bihemispherical perfusion was initially achieved in 8 patients. In 1 patient, the cross-filling on unilateral SCP was initially insufficient, but improved after increasing the SCP flow to 2 L/min and increasing the PCO_2 to 45 mmHg. No switch to bilateral SCP was necessary. Extensive air bubble high intensity transient signals (HITS) were recorded with the termination of SCP and recommencing of body perfusion in 1 patient.

Postoperative Data Analysis

Table 2 shows the detailed postoperative data. Two patients (22%) required inotropic support. Postoperative bleeding over 1000 mL/24 occurred in 7 patients (77%). One patient suffered a pericardial tamponade and had to be reoperated. One patient (11%) suffered from postoperative stroke that developed into hemiplegia (the same patient who suffered intraoperative extensive air-bubble HITS). Three patients (33%) experienced renal failure. However, only 1 patient (11%) needed dialysis. The mean ICU stay was 8 ± 15 days (with a median of 3 days and interquartile region of 3-6 days). The mean hospital stay was 16 ± 13 days. The 30 day mortality was 0%.

DISCUSSION

The success of aortic arch surgery under hypothermic circulatory arrest with SCP is dependent on the efficacy of the SCP. Inadequate SCP will have a detrimental effect on the outcome. Undetected and without effective and timely intervention, this could lead to permanent neurological damage and unfavorable long-term consequences [Estrera 2005]. Therefore, ensuring adequate cerebral perfusion is of monumental importance.

There is more than one modality to monitor the adequacy of cerebral perfusion. These modalities should be considered as complimentary rather than competitive. The near infrared spectroscopy (NIRS) has been increasingly used for qualitative evaluation of the cerebral perfusion [Urbanski 2013]. It delivers an objective evaluation of the total management strategy. The TCD adds a direct visualization of the cerebral blood flow and its distribution, and enables the operative team to optimize the cerebral protection strategy using the TCD momentary live feedback, optimally well before an effect is seen in NIRS. These additive capabilities of the TCD can be of great use in patients undergoing complex aortic arch surgery to enable an effective cerebral protection throughout the procedure. As seen in the patient of this series who did not show an adequate cross-filling at the beginning of SCP, the deficient cerebral perfusion was detected, managed, and the success of management was confirmed by TCD, maintaining favorable NIRS values throughout this critical phase. To further evaluate the synergistic effect of multimodal monitoring, TCD-training has been expanded in our institution to include the whole cardiac anesthesia team, and a study was initiated in 2015 investigating the efficacy and correlation of TCD and NIRS in complex aortic surgery. The results are expected to be published in the near future.

An additive diagnostic advantage of using TCD is the detection of microemboli that might hit the cerebral circulation, whether in the form of air emboli (eg due to inadequate de-airing), or calcific tissue debris (eg after explantation of the aortic valve) [Doblar 2004]. Detection of these emboli might add insight to the etiology of the postoperative cerebrovascular incidents that are sometimes seen in patients undergoing aortic arch surgery despite adequate cerebral protection. Timely detection of these emboli may also help in identifying the problem and developing an intraoperative management strategy before a cerebral infarction develops. Yeh and his colleagues reported a case where TCD effectively detected intraoperative air embolism, which was successfully managed by a brief retrograde cerebral perfusion, emphasizing the key role played by multimodal neuromonitoring in injury prevention [Yeh 2003].

Conclusion

The TCD is a safe, noninvasive, and feasible additive tool for cerebral perfusion monitoring in complex aortic surgery. The perioperative monitoring of cerebral blood flow using TCD provides valuable real-time feedback on hemodynamic changes and enables a confirmation of adequacy of intraoperative cerebral perfusion strategy or the need for its optimization. Documentation of calcific or air emboli might add insight into patients suffering postoperative neurological deficits.

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