Transcranial Doppler Changes in Patients Treated with Extracorporeal Membrane Oxygenation

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Background: Transcranial Doppler (TCD) has significant implications for neurovascular assessment in patients being treated with venoarterial–extracorporeal membrane oxygenation (VA-ECMO). However, there have been no studies demonstrating the changes in pulsatility indices (PIs) seen in these patients. Nonpulsatile waveforms are seen during on-pump coronary artery bypass graft, but low or low–normal PIs have never been reported. It is important to be aware of these changes, as they can be misinterpreted as cerebral vasodilation, vasoconstriction, increased intracranial pressures (ICPs), or cerebral circulatory arrest. *Methods:* Data from 11 TCDs from 8 patients on VA-ECMO in the Cedars Sinai Medical Center Cardiac Surgical Intensive Care Unit were reviewed. Mean pulsatility indices were calculated for each patient using Gosling's PI formula. The values obtained were correlated with ejection fraction (EF) values obtained from a transthoracic or transesophageal echocardiogram. *Results:* PIs were globally low or absent in all 11 TCDs. In 3 patients, TCDs were performed at the initiation and conclusion of the VA-ECMO cannulation. The PI values for these TCDs correlated directly with changes in EFs. Also, an abrupt rise in PI to normal value was seen with the placement of a total artificial heart and the return of pulsatile circulation. *Conclusions:* We demonstrate that PIs on TCDs in patients treated with VA-ECMO are either low or cannot be calculated depending on the severity of myocardial suppression, and should not be mistaken for cerebral vasodilation or cerebral circulatory arrest. Moreover, rising PIs in these patients can represent improving cardiac function and should not be confused with elevated ICPs. **Key Words:** Transcranial Doppler—extracorporeal membrane oxygenation—pulsatility index—ejection fraction.

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Introduction

Transcranial Doppler (TCD) is an important tool for assessing the neurovascular status of patients being treated with venoarterial–extracorporeal membrane oxygenation (VA-ECMO). It is very helpful to determine adequacy of antithrombotic or antiplatelet therapy for stroke prevention, specifically because it can be performed at bedside and repeated with radiation risks. The normal values of cerebral blood flow velocity and pulsatility index (PI) are significantly distorted by nonpulsatile VA-ECMO circulation. To date, there have been no studies demonstrating the changes in PIs seen in patients treated with VA-ECMO. In the present study, we describe the changes in PIs seen in patients on extracorporeal membrane oxygenation (ECMO) and the rationale for these changes, and

also describe why all of these should not be misinterpreted as cerebral vasodilation, vasoconstriction, increased intracranial pressures (ICPs), or cerebral circulatory arrest.

Methods

The TCDs were performed as per the Neurovascular Laboratory protocol for detection of cerebral microemboli by registered vascular technologists. The machines used for performing TCDs were either Sonara (Natus Neurology, WI, USA) or Spencer TCD machines (Spencer Technologies, WA, USA). Studies were ordered by cardiac surgical intensivists or consulting neurointensivists/neurologists. All studies performed on VA-ECMO patients in the Cardiac Surgical Intensive Care Unit of Cedars-Sinai Medical Center between February 2015 and March 2016 were included. We reviewed 11 consecutive TCDs from 8 patients. Chart reviews were conducted after approval from the Cedars-Sinai Institutional Review Board. Patients treated with venovenous ECMO were not included, as these patients still have relatively preserved pulsatile circulation unlike VA-ECMO. Indication for VA-ECMO was cardiogenic shock or cardiac arrest. The indications for performing the TCDs were either detection of vasospasm or monitoring of microemboli to target antithrombotic therapy for stroke prevention.

The range of PI for the respective blood vessels and the number of insonations performed are included in Table 1. Mean pulsatility indices (MPIs) are included for ease of representation, and a grand MPI (mean of all MPIs) is also calculated. To determine whether the left ventricular systolic ejection fraction (EF) had a correlation with the PIs, we incorporated EF into the data as well. All EFs were determined using either a transthoracic or transesophageal echocardiogram completed within 24 hours of TCD acquisition.

Gosling's PI is calculated using the formula (PSV – EDV)/MFV, where PSV is the peak systolic velocity, EDV is the end diastolic velocity, and MFV is the mean flow velocity. PI has a direct correlation with cerebral vascular resistance. The normal PI value is between .5 and 1.19.[1] PI has been shown to have a positive correlation with ICP; a PI change of 2.4% can reflect a 1 mmHg change in ICP.[2] The correlation between PI and ICP is demonstrated to be independent of the type of intracerebral pathology.[3]

Results

Eleven TCD results from 8 patients are summarized in Table 1. The MPIs and grand MPIs were low, low–normal, or not calculable in all 11 TCDs across all insonated vessels. The lowering of PIs is seen in both anterior and posterior circulations. For example, as shown in Figure 1 for patient 1, the PIs at a 55-mm depth of insonation for right and left middle cerebral arteries are well below normal limits.

Importantly, as can be seen in patients 2, 3, and 4 (Table 1), the PI changes had a direct correlation with changes in EFs. For patient 4, there is an abrupt rise in PI to normal value as there is placement of a total artificial heart and return of pulsatile circulation, as shown in Figure 2. Patient 7 represents a case of nondemonstrable PIs in the setting of the most severely diminished cardiac function of all patients; this finding is likely related to the complete lack of systolic upstroke.

Discussion

VA-ECMO is performed to provide circulatory support in patients suffering cardiogenic shock or cardiac arrest. Mechanical support serves as a bridge to the improvement of cardiac function, placement of ventricular assist devices, or heart transplant.[4-6] TCD remains an important tool for neurological assessment in these patients. TCD has numerous advantages over other modalities such as being noninvasive, being available at bedside, and being repeatable without the risk of radiation.

There are very limited studies looking at TCDs on adult patients treated with ECMO. Nonpulsatile waveforms have been noted on TCDs during ECMO in sheep.[7] Similar TCD findings are seen for patients getting mechanical circulatory support (on-pump) during a coronary artery bypass graft. In these patients, nonpulsatile waveforms are seen, but low PIs have not been reported.[8] Similar to our observations, TCDs in children have been noted to have low velocities, which increase after decannulation.[9] To our knowledge, this is the first investigation of TCD findings in a large series of adult patients on mechanical circulatory support.

The circulation with VA-ECMO can be nonpulsatile if myocardial function is significantly suppressed.[10] Correspondingly, data from patient 7 in our study shows a nonpulsatile TCD waveform due to a severely diminished EF. The presence of low PIs can be explained by the pulsations created by the severely diminished yet mildly preserved systolic heart function. This systolic function of the heart gives rise to the upstroke observed on TCDs. The perceived diastolic phase for calculation of PIs is the nonpulsatile flow generated by the ECMO circuit. Moreover, as the EF increases, the systolic upstroke increases in amplitude, resulting in higher PIs. This theory is demonstrated in patients 2, 3, and 4 and is further corroborated by the findings for patient 4, wherein, following placement of total artificial heart and ECMO decannulation, PI values return to normal.

This observation has major implications for the use of TCDs in patients on ECMO. Low PIs or lack of systolic upstroke should not be mistaken for cerebral vasodilation in these patients. An EF of less than 10% can give rise to a nonpulsatile TCD waveform. Moreover, when TCDs are being trended in these patients, the rising PIs could be from improving EF and not globally elevated