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Case Report

Malperfusion During Hypothermic Antegrade Cerebral Perfusion: Cerebral Perfusion Index—An Early Indicator Compared to Cerebral Oximetry

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HYPOTHERMIC CIRCULATORY arrest combined with selective cerebral perfusion commonly is employed to permit surgical repair of the ascending and transverse aorta. A variety of perfusion techniques are employed, including retrograde cerebral perfusion via the superior vena cava (SVC), unilateral antegrade cerebral perfusion (ACP) via the innominate or right subclavian arteries, or perfusion with selective cannulation of both carotid arteries.[1] The degree of hypothermia also varies markedly, from deep hypothermic levels (14-18°C) to more modest levels (26-28°C). A variety of neuromonitoring techniques are employed to assess the adequacy of the cerebral perfusion, including electroencephalogram (EEG) (raw and processed), regional cerebral saturation (RSO_2), and cerebral blood flow. Each is sensitive to different aspects of malperfusion with different response rates and thresholds for abnormality. The authors present a case of ACP monitored with both cerebral saturation and cerebral flow index, during which malposition of the ACP cannula occurred. The case is illustrative of the difference between these monitoring modalities.

Case Report

The patient is a 69-year-old man with a bicuspid aortic valve, dilatation of the ascending aorta, and coronary artery disease who was scheduled to undergo surgical replacement of the valve, root, and repair of the aortic dilatation (ascending aorta/hemiarch graft) and coronary bypass graft. Monitoring included right radial arterial and pulmonary artery catheters, cerebral oximetry (Nonin Medical, Minneapolis, MN), and cerebral blood flow index (CFI) (Ornim, Foxboro, MA). Both oximetry and flow monitors were placed on the forehead bilaterally, in accordance with the manufacturers' recommendations. The right radial artery was utilized to allow measurement of cerebral perfusion pressures during ACP via the innominate artery. Anesthesia was managed without inhaled agents due to a history of a hyperthermic incident following a previous anesthetic and was uneventful.

Cardiopulmonary bypass was initiated after cannulation of the ascending aorta and the right atrium, and the patient was cooled to 26°C. The innominate artery was cannulated and the ACP was initiated. The responses of the cerebral saturation and cerebral flow monitors are shown in Figure 1.

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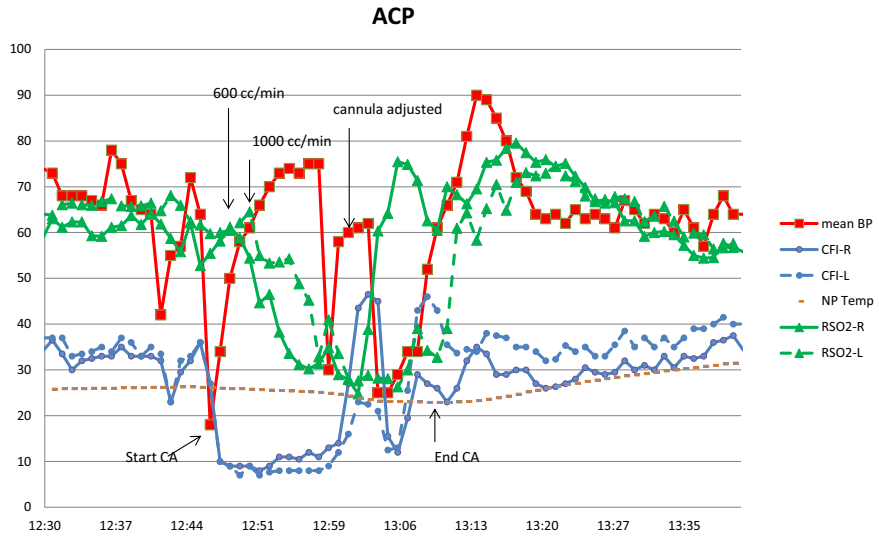

Fig 1. Comparison of Cerebral Flow Index (CFI) and Regional Oxygen Saturation (RSO_2). CA, circulatory arrest; mean BP, right radial artery blood pressure (in mmHg); CFI-R, CFI-L, cerebral flow index recorded from the right and left sides respectively; RSO_2-R, RSO_2-L, cerebral saturation measured from the right and left sides, respectively (in percentage); NP-temp, nasal temperature (in degrees Celsius).

When circulatory arrest was begun, perfusion to the innominate artery initially was set at 600 cc/min. The dramatic decrease in cerebral flow index prompted an increase to 1,000 cc/min, but the CFI did not change. Initially, the cerebral saturations remained at acceptable levels, although after several minutes, they began to decline, reaching values below 30% by the end of ACP. Shortly before ending ACP, the surgeon adjusted the innominate artery cannula, producing a dramatic increase in cerebral blood flow index and oxygenation. Flow to the right hemisphere, as reflected by CFI, increased before and more dramatically than flow to the left side and changes in saturation likewise occurred first on the right. There is also a brief reduction in pressure in preparation for termination of circulatory arrest that reduced the flow bilaterally. After the resumption of normal perfusion through the new aortic graft, both blood flows and saturation values showed a typical, but modest, hyperemic rebound which quickly resolved. The remainder of the case was uneventful and the patient demonstrated no postoperative neurologic sequelae.

Discussion

The c-Flow monitor utilizes a unique technique for assessing cerebral blood flow. The technology combines monochromatic laser and pulsed ultrasound, which interact due to the compression of tissue by the ultrasound wave. This interaction allows the measurement to be performed at a time following the ultrasound pulse that corresponds to approximately 2 cm of sound transmission in human tissue, approximately the depth of the cerebral cortex below the skin.[2] Artifact due to flow in superficial tissues is effectively eliminated by this technique. Because the measurement is not calibrated, it is shown as an index rather than absolute blood flow. Several studies have attempted to validate the effectiveness of CFI to monitor cerebral blood flow (CBF). Schwarz used CFI to monitor CBF during induction and intubation in 72 patients and found similar results in previous studies using transcranial Doppler.[3] Schyz compared CFI and xenon single emission proton computer tomography to detect changes in CBF in 10 healthy subjects in response to a 1-gram bolus of acetazolamide and found similar blood flows at 15 minutes but not 60 minutes. The authors proposed that the difference at 60 minutes may be to a different response between white and gray matter. CFI, a regional measurement, captures mostly gray matter versus xenon single emission proton computer tomography which captures both white and gray matter.[4]

As shown in Figure 1, the CFI decreased dramatically at the start of circulatory arrest with no appreciable change in cerebral saturations for several minutes. This is not surprising since the cerebral metabolic rate is reduced by somewhat more than 50% at the 26°C perfusion temperature.[1] This reduction in oxygen consumption is beneficial in that it allows the tissue to tolerate longer periods of ischemia, but it is problematic for the use of cerebral saturation as an indicator of hypoperfusion. The changes in saturation take considerable time to reach levels that would be concerning, and by that time, the surgeon has committed to the surgical technique and may not be in a position to modify it to improve cerebral perfusion.

Furthermore, neither a well-established critical cerebral ischemic saturation nor a critical time of low saturation has been demonstrated in the literature. Kurth et al used a piglet model as a surrogate for infants, and they artificially manipulated cerebral saturation to 35% and found a time-dependent critical ischemic threshold of 2 hours. Beyond this time point, each hour had a 15% increase incidence of ischemic injury.[5] Levy et al discovered a critical ischemic threshold of 47% saturation via confirmation of EEG changes in normothermic adult patients with induced ventricular fibrillation while undergoing implantation of a defibulator.[6] Ausman et al studied patients undergoing cerebral aneurysm repair in whom deep

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hypothermic (18°C) arrest was induced without cerebral perfusion, and the results concluded that ischemic injury occurred if saturation fell below 35% and arrest was greater than 45 minutes.[7] Mohandas et al suggested that a fall in RSO_2 > 20% of baseline or an absolute value of 50% was associated with an adverse postoperative neurological outcomes in patients undergoing cardiopulmonary bypass.[8] Nonin Medical, the manufacturer of the cerebral oximetry, recommends an ischemic threshold of 50% saturation or 20% to 25% decline from baseline saturation level and references the Mohandas study. The recommendation of a specific critical saturation level may not apply to hypothermic circulatory arrest in which physiologic conditions are greatly altered. In any case, the threshold for intervention while monitoring cerebral saturation appears to be a combination of saturation and duration.

In comparison to cerebral saturation, the CFI responds almost immediately and provides a robust indication of malperfusion. The rapid response also makes it a useful tool to assess the effectiveness of therapeutic manipulations. However, because it is not a measurement of absolute blood flow, it is less effective at identifying when flow is below the ischemic threshold. It is also notable that the CFI did not fall to 0 even though circumstances suggest that blood flow was not going to the brain. It is possible that a small amount of cerebral perfusion was occurring via the right vertebral artery, and some carotid artery flow might have been occurring despite the malposition of the cannula. However, in other situations, including complete circulatory arrest without cerebral perfusion, the authors have seen similar values (between 0 and 10) and believe that this approximates the value obtained during the no-flow state with the current technology.

Other noninvasive methods of monitoring cerebral blood flow include transcutaneous Doppler ultrasound of carotid arteries and transpharyngeal imaging with transesophageal echocardiography. Pulido reported the use of intermittent carotid Doppler to verify cerebral perfusion in a case in which the femoral artery was chosen for cardiopulmonary bypass while repairing a complex aortic pseudoaneurysm located close to the axillary artery in a 50-year-old man.[9] Augoustides used transcranial Doppler to detect brachiocephalic malperfusion during aortic cross clamping despite unchanged right radial arterial tracings during a complex type-A dissection in a 49-year-old man.[10] Waje reports the use of a transesophageal echocardiography probe to capture transpharyngeal imaging of the left and right common carotid as well as the left and right internal jugular vein to confirm retrograde perfusion during repair of type-A aortic dissection with severe aortic regurgitation in a 63-year-old male.[11] Both methods of transcutaneous carotid Doppler and transpharyngeal imaging offer noninvasive cerebral flow analysis; however, each method requires the anesthesiologist's dedicated attention, and both methods are intermittent compared to CFI, which is a simpler, continuous monitor that enables the anesthesiologist to tend to other tasks.

In summary, the case above demonstrates the value of adding the c-Flow technique as a continuous monitor of cerebral perfusion during complex aortic reconstruction cases. The main advantage of the c-Flow technique is that it provides an earlier warning of inadequate perfusion compared to cerebral oxymetry.

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