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Perspective

Neuromonitoring during adult cardiac surgery

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Introduction

The brain has been considered an index organ for global tissue perfusion because of the physiological processes aimed at flow preservation to vital organs of the body[1].When cerebral perfusion is compromised, other organs are likely inadequately perfused as well. It would therefore be prudent to monitor cerebral perfusion based on the proposition that interventions aimed at its preservation will likely result in adequate tissue perfusion of the whole body and reduced complications related to ischemia of various organs.

It is worth emphasizing the difference between tissue perfusion and tissue oxygen supply. It is a consensus that the normal oxygen supply/demand ratio is important to normal tissue metabolic physiology at the molecular level. Because oxygen demand is largely related to perfusion, it is perfusion that remains the main focus of all clinicians in the cardiac operating room[1].

Very brief periods of cerebral hypoperfusion occur frequently during cardiac surgery due to a multitude of factors (reduced cardiac output, low pump flow, decreased perfusion pressure, etc.) but are of minute clinical significance. It is prolonged or cumulative hypoperfusion, particularly in watershed areas of the brain, undetected by standard monitors such as arterial blood pressure or pulse oximetry, that leads to brain tissue injury and adverse outcomes[2]. To date, no device has been developed that can reliably, continuously and non-invasively monitor global cerebral tissue perfusion directly. A number of existing monitors can indirectly assess regional cerebral perfusion and provide information useful in managing cerebral blood flow and oxygen supply.

Cerebral oximetry

Cerebral tissue oximetry operates *via* measurement of hemoglobin saturation of the mixed arterial, capillary and venous blood in superficial frontal lobe being illuminated by near-infrared light. The number represents the ratio of the oxygenated hemoglob in to total hemoglobin, with the frequently reported range of 50-80 and bilateral (right and left) hemisphere difference of no more than 10 points. Desaturation below 50% or more than 20% below baseline, obtained in an awake, non-sedated patient breathing room air, has been used as the threshold of intervention in cardiac patients. Previous evidence shows that interventions aimed at maintaining cerebral saturation at baseline correlate with reduced neuropsychological complications and decreased length of hospital stay[2-4].

The benefit of the monitor is that it is non-invasive and as such poses virtually no known harm to the patient. It is portable, easy to apply and operate as well as interpret. The cost is moderate and can be justified by the beneficial outcome it associates with. It is now considered by many experts in the field as a standard of monitoring during cardiac surgery[2]. Given that both hemispheres are monitored, it can differentiate between global and unilateral causes of hypoperfusion, such as head position or unilateral vessel occlusion. Because the technology does not require pulsatile flow, it offers an advantage during cardiopulmonary bypass or in patients with non-pulsatile arterial flow (e.g. patients with left ventricular assist devices).

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The limitations of the monitor are few but significant: first, it samples a small area of regional tissue in the frontal lobe which is supplied by both anterior and middle cerebral arteries (internal carotid artery), therefore excluding the portion of the brain perfused by the posterior circulation. Second, the monitoring sensors are applied on the scalp and despite efforts to reduce extracranial signal contamination, a minor degree of contamination still exists. The sensors are sensitive to external light as well as abnormalities in cranial tissue structure or thickness (skull defects or space occupying lesions, frontal sinus pathology, scalp hematoma or severe edema). Sensors should not be placed on shaved skin as hair follicles (particularly of dark hair) absorb light and can significantly alter the monitor output. Good pad adherence to the scalp is critical in obtaining a consistent value and moisture build-up under the sensor over time may affect output.

Neurophysiological monitors

Various methods monitoring neuronal transmission have been evaluated for use in cardiac surgery. From cortical activity monitors (raw and processed electroencephalogram) to deeper structure assessment (various sensory and motor evoked potentials) all have shown some benefit in detecting or confirming neuronal injury. The most common limiting factor to the practical application of these methods is the need for specialized equipment, personnel trained in correct data gathering and interpretation, as well as constant vigilance to potential output changes[5-6].

Somatosensory evoked potentials have very limited application in cardiac surgery due to their sensitivity to hypnotic effect of anesthetic drugs, body temperature, acid-base status, oxygen content, flow pulsatility and others. All of the above fluctuate frequently in the cardiac operating room, reducing the practicality of this monitoring modality. Motor evoked potentials have proven useful in descending aortic reconstructive surgery, but are subject to similar limitations as well as susceptibility to neuromuscular blockade[5].

Electroencephalogram is the most commonly used monitor of neuronal activity in the operating room. It has been shown to aid in early detection of cortical tissue oxygen supply/demand imbalance. Unfortunately, EEG monitors are highly non-specific for ischemic injury per se, as not every imbalance is related to variations in blood flow. Other confounders may include non-convulsive seizure activity or prior sub-clinical traumatic cortical injury for example[6].

With the development of bispectral index monitor (BIS), which simplifies the user interface EEG display to a single number obtained from placing an adhesive pad on the patient's forehead, the popularity of processed EEG has risen. BIS was initially designed as a depth of anesthesia monitor to prevent awareness. Several studies have since examined the effect of depth of anesthesia (measured by BIS) on post-operative outcomes and found that EEG over-suppression (correlating to BIS of <40 for prolonged periods of time) is related to adverse neurological outcomes as well as higher 1-year mortality[7-8]. Whether this reflects a neurotoxic effect of anesthetic drugs or greater susceptibility of already abnormal brains to anesthetics remains unclear[9]. However, BIS monitoring can aid in maintaining the anesthetic depth at a level sufficient for hypnosis without over-suppression[6]. In addition, four channel BIS pads for monitoring bilateral frontal cortex are available. These offer an advantage of displaying differences in EEG from right to left hemisphere, further aiding in interpreting cortical imbalance in neuronal activity.

EEG can also be helpful in assessing brain activity during deep hypothermic circulatory arrest. A flat line should be pursued, as that indicates neuronal quiescence. During periods of rewarming, neuronal hyperactivity is undesirable as it implies high metabolic demand which is not yet met by oxygen supply, due to temperature related vascular dysfunction constricting blood flow to the brain[6].

The limitation to BIS application is signal contamination from external electrical sources (electrocautery use in close proximity) as well as intrinsic electromyographic activity. The latter can be easily eliminated by administration of muscle relaxants.

Transcranial Doppler ultrasound

Transcranial Doppler ultrasound (TCD) is typically used to monitor flow in the middle cerebral artery, as it carries approximately 40% of the hemispheric blood flow. Because Doppler shift measures velocity, not mass of blood carried through the vessel, the flow of blood is an estimation based on a predefined artery size. Nomograms are available that describe normal systolic and diastolic flow velocities[6].

During cardiac surgery, several important applications of TCD have been proven useful. First, the determination of systolic and diastolic baselines prior to surgical manipulation will allow for the development of an intervention threshold by the clinician. Generally, a reduction of mean systolic velocity by 60% or absence of diastolic velocity is considered signs of hypoperfusion. During non-pulsatile flow, a velocity reduction of 80% is considered an ischemic threshold. Intraoperative changes in flow velocities can be related to head position, cannulae position or insufficient pump flow/blood pressure[6,10]. Second, TCD is useful in monitoring efficacy of selective cerebral perfusion during circulatory arrest, as it will detect both antegrade and retrograde flow in the middle cerebral artery. Lastly, TCD has an ability to detect an embolic event, which appears as high-intensity transient signals (HITS) on the spectral envelope display. Unfortunately, HITS can easily be mistaken for artifact by an untrained eye. In addition, the device is not capable of differentiating gaseous from particulate emboli. Maintaining constant probe position during surgery is also a challenge, as it requires a band strapped around the patient's head holding the probe covered in sterile sleeve in situ.

Summary

Despite their limitations, all the methods described above share one significant benefit: they are non-invasive and portable. Combined together, they can provide answers to complex questions related to preserving adequate brain perfusion during cardiac surgery. For example, significant EEG signal suppression coupled with normal NIRS and TCD velocities suggest depth of anesthesia as a culprit, not ischemia. In another example, low TCD velocities during rewarming from hypothermic bypass coupled with relatively normal NIRS and high activity EEG indicate cranial vessel vasoconstriction and uncoupling of blood flow from cerebral metabolism. Because standard monitors correlate poorly with neuromonitors, it seems intuitive to add monitors that will help protect the most important organ in the body. The current literature, albeit not abundant, certainly demonstrates favorable outcomes in patients subject to neuromonitoring during cardiac surgery.

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