



Monitoring cerebral ischemia during cerebrovascular surgery

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Abstract

Patients undergoing intracranial cerebrovascular surgery under general anesthesia are at risk of cerebral ischemia due to the nature of the surgery and/or the underlying cerebrovascular occlusive disease. It is thus imperative to reliably and continuously monitor cerebral perfusion during this type of surgery to timely reverse ischemic processes. The aim of this review is to discuss the techniques currently available for monitoring cerebral ischemia during cerebrovascular surgery with a focus on the advantages and disadvantages of each technique.

Keywords: cerebrovascular surgery, cerebral ischemia, intraoperative monitoring

Introduction

Craniotomy, which is used in cerebrovascular surgeries such as aneurysmclipping, resection of arteriovenous malformation, and extracranial intracranial bypass, is associated with a high risk of cerebral ischemia. These patients often have significant comorbidities, either a diagnosed cerebrovascular occlusive disease or risk factors for cerebrovascular diseases that increase the risk of cerebral ischemia. In addition, these surgeries frequently require temporary occlusion of major intracranial arteries, which can interfere with brain perfusion. Moreover, to access the major cerebral arteries that sit at the skull base, more forceful retraction is needed than in surgeries involving superficial cerebral structures, which carries the risk of retraction-related injury and compression-related ischemia. Therefore, it is important to continuously monitor the perfusion of cerebral regions

at risk of ischemia during cerebrovascular surgery to timely detect and reverse any ischemic processes. Unlike carotid endarterectomy and some neuro-interventional radiology procedures that can be performed under regional anesthesia during which neurological function can be closely monitored, intracranial cerebrovascular surgeries are usually performed under general anesthesia and thus require various monitoring techniques to detect intraoperative cerebral ischemia. This paper reviews the various techniques that are currently available to monitor cerebral ischemia during intracranial cerebrovascular surgery under general anesthesia.

Transcranial doppler (TCD)

Intuitively, an ideal monitor for cerebral ischemia should be able to continuously monitor actual cerebral

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blood flow during surgery. However, there is currently no technology that can achieve this goal, although TCD has been used as a surrogate for monitoring cerebral blood flow. Details of TCD technology have been previously described^[1-2]. The middle cerebral artery is the most frequently monitored one by TCD. However, the intraoperative application of TCD during intracranial cerebrovascular surgery has several limitations. First, TCD monitors the velocity, not the mass of the blood flow in the insonated major intracranial artery. Therefore, it tracks change in cerebral blood flow only when the diameter of the artery being insonated remains constant. Second, the continuous application of TCD during every craniotomy is impractical. It is difficult for operators to reach the patient's head to adjust the device because the head is prepared and draped for surgery. In addition, the probe and the circumferential strap that is used to stabilize the probe can breach the sterile surgical field. Finally, TCD monitors flow velocity in the proximal major artery but not in the small distal arteries. As a result, if the ischemic territory involves a distal artery unrelated to the proximal major artery being insonated, the ischemic process may not be detected by the conventional approach of TCD.

Neurophysiological monitoring

Electroencephalography and evoked potentials can be used to detect neural changes induced by cerebral ischemia and are frequently used by surgeons and anesthesiologists for intraoperative monitoring.

Electroencephalography (EEG)

The neural activity monitored by EEG is produced by the summation of the extracellular current fluctuations originating in the most superficial layers of the neocortex. These "current fluctuations" can be recorded as distinct waves or frequency bands and are categorized as beta (13-25 Hz), alpha (8-12), theta (4-7.5 Hz), or delta (0.5-4Hz) rhythms^[3]. These frequencies can be recorded from electrodes placed either on the scalp or directly on the brain (i.e. electrocorticography), with the latter probably more sensitive to cerebral ischemia than EEGs recorded on the scalp. Martin *et al.*^[4] reported that EEGs recorded from cortical strip electrodes detected ischemic changes more frequently than those recorded from scalp electrodes during vascular obliteration. Regardless of the recording site, the EEG activity can be displayed in either a raw data format or as its processed derivatives (e.g. spectral edge). Changes in the EEG that correlate with cerebral ischemia can be interpreted as fast over slow activity (alpha over

delta)^[3,5], variability of the relative alpha (6-14Hz/1-20Hz)^[5], the post-stimulation alpha/delta ratio (8-13Hz/1-4Hz)^[3], new-onset decreases in amplitude/frequency and asymmetry^[6], mean amplitude, as well as suppression percentage and trend analysis of the total power (1-30Hz)^[7]. However, multiple factors can interfere with EEG signals including artifacts, scalp swelling, medications, metabolic changes, hydrocephalus, and rebleeding^[8]. The anesthetic depth is one of the most important factors affecting EEG tracing in anesthetized patients. Therefore, the interpretation of a significant change in EEG must take place in the context of all factors that have the potential to affect EEG tracing. The diagnosis of cerebral ischemia based on changes in EEG can only be made after excluding these factors. To facilitate detection of surgery-related cerebral ischemia, it is crucial to maintain a stable anesthetic depth and stable physiological parameters such as blood pressure, cardiac output, hemoglobin concentration, oxygen saturation, and carbon dioxide level. Furthermore, during intracranial cerebrovascular surgery, the area that can be used for monitoring is limited and only a limited number of electrodes can be placed on the patient's scalp or cortex. Therefore, the ischemic region can be missed if it is not covered by EEG monitoring.

Evoked potentials

Evoked potentials monitor the functional integrity of a specific neural pathway. Various types of evoked potentials have been used to monitor cerebral ischemia, including somatosensory evoked potential (SSEP), motor evoked potential (MEP), and brainstem auditory evoked potential (BAEP). Multiple factors can affect the signals of evoked potentials, including neural ischemia, injury and transection, as well as anesthetic agents, in addition to physiological disturbances such as hypotension, hypoxia, anemia, and hypothermia.

SSEPs monitor the integrity of the dorsal-column-medial lemniscal pathway to the somatosensory projection area. Pertinent SSEP parameters include the amplitude and latency of the N20 (the first negative peak on the cortical waveform), the N13 component (subcortical peak), as well as the central conduction time (CCT, the latency between N13 to N20). SSEP changes are considered significant when the amplitude of the N20 cortical response decreases > 50% from the baselines^[9], the latency (N19/P24) increases > 10%^[10], or the CCT increases > 1 ms^[9]. The slope-measure is defined as the relative slope of the amplitude and latency at each evoked potential peak compared to the baseline value. This simple slope-measure is useful during intraoperative SSEP monitoring because it has a

detection time that is as early as or earlier than that of the conventional peak-to-trough method^[11]. SSEPs can detect parenchymal injury of the superficial territories supplied by the middle cerebral artery, the distal anterior cerebral artery, and the medium high basilar artery^[9]. However, similar to EEG, SSEPs are vulnerable to the effects of anesthesia. Intravenous anesthetics (e.g. propofol), halogenated agents and nitrous oxide produce a suppressive effect on SSEPs, causing amplitude attenuation and latency prolongation of the cortical (N20) but not subcortical (N13) component^[12-13]. Florence *et al.*^[14] reported a sensitivity of 51% and a specificity of 96% for SSEP monitoring in predicting intraoperative cerebral ischemia. Sahaya *et al.*^[6] found that the irreversible changes in SSEP monitoring had a sensitivity of 85.7% and a specificity of 100% in predicting postoperative neurologic deficits.

In recent years, the routine use of MEP monitoring during intracranial cerebrovascular surgery has been adopted by a number of neurosurgical centers^[15]. MEPs monitor the functional integrity of the corticospinal tract (CST), as well as the vascular territory of a number of cerebral vessels that perfuse it. Stimulation of the motor strip can be accomplished by electrodes placed at the C1 and C2 locations of the standardized international 10-20 system^[16], or through grid-electrodes placed directly on the brain surface. One of the major advantages of direct cortical stimulation is that it requires less voltage to elicit an MEP response. Higher voltages can impact the extent of patient movement, which is disruptive to the surgical procedure^[17]. On the other hand, electrodes placed on the brain surface may jeopardize the bridging veins^[18]. However, a study by Motoyama *et al.*^[17] demonstrated that combined transcranial and cortical MEP monitoring improves the feasibility and reliability of this technique during the surgical clipping of unruptured aneurysms. Criteria for a significant change in the MEPs remain controversial. Some authors advocated increases in the voltage threshold of over 100 V as being significant^[16-17,19], while others suggested that the complete loss of the MEP response was more predictive of cerebral ischemia^[16]. As with most electrophysiological modalities, MEPs are highly sensitive to the depressive effects of anesthesia. When MEPs are monitored, the anesthesia is typically maintained using total intravenous anesthesia comprised of different agents, though muscle relaxants are avoided^[16]. The use of MEPs is important to identify compromised flow in the perforating arteries, which are difficult to assess by pure microscopic inspection^[20]. In a cohort of 100 cases, the sensitivity of MEP to detect postoperative motor paresis was approximately 91%-100%. Furthermore, the authors found that the use of

MEPs led to changes in the surgical strategy in 70% of the cases in which MEP changes occurred^[21].

BAEP is obtained by applying ear clicks through earplugs, which generates seven waves. The changes in BAEP are considered significant when the amplitudes of the wave III and V decrease, the latency of the fifth peak (or the fourth-fifth complex) is more than 50% prolonged, and the latency of the fifth peak or the interpeak latency (I-V) is prolonged more than 1 ms^[9,22-23]. BAEP is a useful monitoring technique for aneurysm surgery involving the posterior circulation and is more resistant to the effects of anesthetic agents^[12-13]. However, BAEP or SSEP monitoring alone is not considered reliable for detecting ischemia during the surgical clipping of aneurysms of the basilar apex due to neither the BAEP nor SSEP pathway is included in the territories perfused by the relevant vessels^[22]. The combined use of BAEP and SSEP monitoring is recommended to increase the sensitivity for detecting ischemia during aneurysm clipping involving the basilar tip, as well as the superior and inferior posterior cerebellar arteries^[9].

Cerebral oximetry based on near-infrared spectroscopy

Cerebral oximetry based on near-infrared spectroscopy measures the hemoglobin oxygen saturation of the mixed arterial, capillary, and venous blood in the superficial brain region illuminated by near-infrared light. The balance between cerebral tissue oxygen consumption and supply essentially determines the oxygen saturation measured by oximetry. It is a noninvasive, continuous, and portable monitoring technique. However, its use during cerebrovascular surgery involving craniotomy is limited for the following reasons. First, the probes placed on the forehead may contaminate the sterile surgical field if the incision is close to the forehead. Second, air is frequently entrapped between the cranial bone and the brain tissue during surgery, which significantly interferes with the cerebral oximetry signal. Third, the results of cerebral tissue oxygen saturation monitoring can be influenced by other factors such as skin color, gender, contamination of the extra-cerebral layers, and the volume ratio of the arterial to venous blood in the frontal lobe. The impact of these factors needs to be considered when interpreting cerebral oximetry, and it is recommended to evaluate trends rather than absolute values in guiding clinical management. Lastly, cerebral oximetry only monitors the anterior cerebral circulation (internal carotid artery territory), and can miss ischemic processes of the posterior cerebral circulation (verteb-

ral-basilar artery territory). Overall, the role of cerebral oximetry in the monitoring for cerebral ischemia during cerebrovascular surgery needs further elucidation.

Conclusions

The characteristics of an ideal technique to monitor cerebral ischemia during intracranial cerebrovascular surgery include accuracy, complete coverage of every brain region, continuousness, non-invasiveness, low cost, and non-interference with surgery. Currently, there is no technique that meets all of these criteria. The combined use of different modalities may be more reliable in detecting cerebral ischemia than any modality alone. Future studies should focus on developing techniques that meet the above criteria and are able to specifically monitor the brain regions at risk for ischemia.

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