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Review Article

Intraoperative neurophysiologic monitoring during endovascular treatment for cerebral aneurysms

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ABSTRACT

Treatment for cerebral aneurysms is performed because cerebral aneurysm poses a risk of future neurologic deficits due to intracranial hemorrhage. Such surgical and endovascular treatment are prophylactic to prevent future harm to patients. Ironically, these procedures themselves pose similar risks. During endovascular treatment for cerebral aneurysms, intraoperative neurophysiologic monitoring (IONM) can be used to assess the functional state of the brain. Through performing IONM, it is possible to alert to surgeon to signs of ischemia as early as possible so that an intervention might be reversed or the surgical course altered to avert permanent ischemic damage. IONM of continuous electroencephalography, somatosensory evoked potentials, brainstem auditory evoked potentials and transcranial motor evoked potentials during endovascular procedure can provide real-time information about the function of the nervous system and thereby provide warning to the surgical team when sign of ischemia or hemorrhage are present. This article aimed to review endovascular process for cerebral aneurysms and the methods and usefulness of IONM during endovascular treatment for cerebral aneurysms.

Keywords: endovascular treatment; intracranial aneurysm; intraoperative neurophysiological monitoring

Introduction

Intracranial aneurysms are abnormal expansions of arterial walls within the brain. They are a common neurovascular condition, and efforts have been focused on reducing the associated morbidity and mortality rates [1]. The approach to managing unruptured aneurysms has involved treatment prior to rupture, while the treatment of ruptured aneurysms focuses on preventing rebleeding. Endovascular coiling has become a mainstay in intracranial aneurysm treatment since the International Subarachnoid Aneurysm Trial [2,3]. Intracranial aneurysms vary in their size, shape and location. Saccular aneurysms are the most common [1]. Saccular aneurysms have a neck at their origin on the main artery and then a sac-like outpouching (dome) that can expand over time. Fusiform aneurysms are focal dilatation of the entire circumference of the vessel. This appears as an elongated, tubular or spindle-like swelling in the artery. Dissecting aneurysms form as blood flows through a false lumen while the true lumen may be collapsed. Saccular aneurysms are the most frequent type considered for surgical or endovascular intervention. When cerebral aneurysms require surgical intervention, it is important to note the vascular territories of the vessels at risk during intervention [1,4,5]. Understanding which brain structures are at risk for ischemia during the procedure would guide which intraoperative neurophysiological monitoring (IONM) modalities would be most useful for detecting ischemia. Also, there should be an awareness of the limitations of IONM techniques being used to prevent additional neuronal deficit. This article provides a review of the endovascular process for treating cerebral aneurysms and explores the methods and utility of IONM during endovascular treatment.

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Endovascular Procedure

The majority of endovascular aneurysm occlusion procedures are conducted under general anesthesia. To mitigate the risk of thromboembolic events, systemic heparin is administered during the procedure using different protocols. Recent studies have demonstrated that the inclusion of oral antiplatelet medications can effectively reduce the occurrence of thromboembolic events [6]. Endovascular procedures can have catastrophic risks, such as intraprocedure aneurysm rupture, intravascular thrombus, embolus, misplaced or herniated coils, vasospasm, arterial dissecion and arterial rupture [1]. Thus, these procedures are performed in centers with full surgical and neurointensive care.

Vascular access is established through a femoral puncture, and a femoral sheath is inserted to maintain access. A guiding catheter is then introduced through the sheath, and a complete angiography is performed to visualize the blood vessels. Using fluoroscopy guidance, the guiding catheter is carefully advanced into the specific artery of interest that provides access to the targeted lesion. The goal of endovascular embolization, also known as endovascular coiling, is to separate the aneurysm from the main artery by filling the aneurysm sac with embolic material while maintaining blood flow in the parent vessel. Various embolic agents have been used in the past, but detachable coils have become the most commonly utilized method. These coils come in different helical diameters, lengths, and flexibilities. They are typically constructed from platinum and other materials, and some may have coatings that encourage clot formation.

Once the guiding catheter reaches the aneurysm site, a microcatheter, attached to a coil, is inserted into the guiding catheter. As the microcatheter is advanced into the aneurysm, an electric current separates the coil from the microcatheter. Multiple coils are then carefully packed into the aneurysm sac, effectively blocking blood flow into the sac and causing any existing blood within to clot, closing off the aneurysm from the main vessel. In the case of wide-necked aneurysms, additional measures may be necessary. This can involve the use of a stent or a balloon. Stent-assisted coiling involves the placement of a permanent stent in the main artery. The stent is positioned over the opening of the aneurysm and acts as a support to keep the coils within the sac. Balloon-assisted coiling, on the other hand, involves the simultaneous insertion of a coil-containing microcatheter and a balloon catheter through the guiding sheath. The deflated balloon catheter is positioned in the main artery, across the neck of the aneurysm. In case coils migrate into the main artery, the balloon is inflated to secure the coils in the aneurysm without compromising the lumen of the parent vessel. Alternatively, coils may be placed while the balloon is inflated, and subsequent deflation of the balloon, under fluoroscopy, ensures that the coils remain within the sac after deflation. Flow diversion devices represent a recent development in endovascular aneurysm treatment. These devices, resembling mesh stents, are placed inside the parent artery to cover the aneurysm opening. By diverting blood flow away from the aneurysm and redirecting it along the normal course of the blood vessel, these devices promote closure of the aneurysm and provide support for healing of the blood vessel wall. Although this technique is relatively new, a recent meta-analysis indicates that the use of flow diversion devices in treating intracranial aneurysms is both feasible and effective, with high rates of complete occlusion [7]. Unfortunately, the endovascular aneurysm treatment procedure is not without risks. There is a 4% morbidity rate and a 5% mortality rate associated with the procedure. These complications arise from various factors, including subarachnoid hemorrhage, intraparenchymal hemorrhagic and ischemic strokes, and perforating artery infarction. Patients with posterior circulation aneurysms are particularly susceptible to these complications.

Intraoperative Neurophysiological Monitoring (IONM) during Endovascular Interventions for Cerebral Aneurysms

1. Electroencephalography (EEG) and somatosensory evoked potentials (SSEPs)

EEG monitoring during endovascular procedure can be challenging because EEG is very sensitive to changes in anesthetic agents [8]. During endovascular procedures, EEG monitoring plays a crucial role in detecting brain ischemia. The initial sign of ischemia is the loss of higher frequency waveforms, followed by amplitude asymmetry [9,10]. A decrease in fast activity is typically considered the first indicator of ongoing ischemia. However, due to the use of fluoroscopy during endovascular surgeries, the number of EEG electrodes on the scalp may be limited to prevent electrode artifacts from interfering with vascular images. This limitation can reduce the sensitivity of EEG monitoring in this setting. The EEG anesthesia pattern can fluctuate and is often influenced by anesthesia, analgesia, and systemic factors such as mean arterial pressure. These anesthesia-related changes can complicate the interpretation of EEG readings. However, there are instances when maintaining a stable level of anesthesia is preferred, but a deeper level of anesthesia may be sought to protect the brain or if there is a sudden decrease in blood pressure due to bleeding. In such cases, the EEG is expected to exhibit burst suppression or even complete suppression. SSEPs are particularly valuable in situations where the EEG may be challenging to interpret. SSEPs can still be recorded even when the patient is under the influence of barbiturates, which can produce a flat EEG. Additionally, SSEPs have simpler warning criteria that are easier to detect compared to EEG. SSEPs are also sensitive to detecting brainstem ischemia, which is an advantage over EEG. To enhance the detection of ischemia, many medical centers utilize a combination of SSEPs and EEG. This multi-modal approach helps to improve the overall ability to identify and monitor ischemic events during endovascular procedures [11]. SSEPs offer an advantage over EEG in their ability to assess deep subcortical and brainstem structures. When there is ischemic damage to cortical or subcortical neurons, SSEPs demonstrate a decrease in amplitude and an accompanying increase in signal latency. A common warning criterion used to alert the surgeon of significant EEG changes is a 50% drop in amplitude, a 50% decrease in alpha and beta frequencies, or a doubling of slow frequencies. SSEPs changes are particularly noteworthy when they occur unilaterally, indicating a localized impact. Bilateral changes, on the other hand, often suggest systemic factors like anesthesia or blood pressure fluctuations.

Among SSEPs markers, the cortical N20 is considered the most sensitive indicator of ischemia. A significant change in the N20 waveform includes a reduction of 50% or more in amplitude or a latency prolongation of 10% or more. Monitoring these changes in the N20 SSEPs component can provide crucial insights into the presence and progression of ischemic events during endovascular procedures.

2. Motor evoked potentials (MEPs)

The ability to assess the motor cortex and motor pathways in neurovascular procedures is attractive because SSEPs monitoring may not always indicate isolated motor pathway ischemia. While the cortex receives a shared blood supply for both motor and sensory fibers, with the middle cerebral artery (MCA) supplying the upper limb sensory and motor areas and the anterior cerebral artery (ACA) supplying the lower limb sensory and motor areas, subcortical ischemia caused by damage to perforating arteries can result in a pure motor deficit that may go undetected by SSEPs monitoring. Therefore, relying solely on SSEPs may not capture isolated motor pathway ischemia, highlighting the importance of considering other monitoring techniques or clinical observations during neurovascular procedures to ensure comprehensive assessment and detection of potential deficits [12]. To record transcranial electrical MEPs, strong electrical stimulation ranging from 180 to 500 volts is applied through scalp needles in a series of five to seven monopolar pulses with 3-millisecond interstimulus intervals. The anode is ideally positioned over the motor region, while MEPs are recorded using needle electrodes inserted into contralateral muscles [13]. However, there are drawbacks to using MEPs monitoring in neurovascular procedures. One limitation is the significant influence of anesthetic agents and neuromuscular blocking agents commonly administered during neurovascular surgery. These

agents can interfere with the recording of MEPs. Additionally, neurovascular surgery often involves settings such as deep anesthesia, lowered blood pressure, or the use of paralytics, which are incompatible with MEP recording. Another inherent issue with MEPs monitoring is patient movement or jerking, which can affect the reliability of the recordings. Surgeons typically prefer minimal or no patient movement during neurovascular procedures. However, a study involving 220 patients reported that only 3% of cases experienced movement that was deemed unacceptable and prevented the use of MEPs in their vascular surgery [14]. Another disadvantage of the use of MEPs for IONM in neurovascular procedure is the lack of experimental correlation between MEPs amplitude and brain perfusion.

3. Brainstem auditory evoked potentials (BAEPs)

BAEPs monitoring is a helpful addition to IONM for neurovascular procedure involving the posterior circulation [15]. BAEPs have a significant advantage over other IONM modalities in that they are less affected by the effects of anesthesia. However, their coverage area is limited compared to SSEPs. BAEPs primarily assess the auditory nerve, pons, midbrain, and potentially the mesencephalon. The blood supply to the side of the pons and the cerebellum is provided by the anterior inferior cerebellar artery (AICA) and the superior cerebellar artery, both of which are branches of the basilar artery (BA). The AICA also has a branch called the labyrinthine artery that supplies the inner ear. Additionally, the BA gives off approximately 12 pontine arteries that supply the medial pons. Consequently, BAEPs are effective in detecting ischemia in these specific territories. However, they may not be as sensitive in identifying ischemic lesions in other areas of the brainstem that are not directly related to the auditory pathways.

Utility of Intraoperative Neurophysiological Monitoring (IONM) during Endovascular Interventions for Cerebral Aneurysms

During endovascular procedures, IONM serves as a valuable tool for detecting ischemic changes. However, it is important to note that false negatives can still occur, where ischemic events may not be detected by the monitoring. In a prospective study involving 63 patients, the first-stage endovascular treatment of cerebral aneurysms was performed. The procedures included coil embolization (41%), balloon-remodeling coiling (25%), stent-assisted coiling (16%), balloon-stent-assisted coiling (14%), and balloon test occlusion (BTO; 3%) [16]. In the study, IONM was conducted using EEG, SSEPs, and BAEPs, depending on the specific vascular territory at risk. Among the patients undergoing balloon-remodeling coil embolization, three individuals (4.8%) exhibited changes in SSEPs or BAEPs without concurrent EEG changes. These alterations occurred within 5 to 10 minutes after balloon inflation. In all cases, the balloon was promptly deflated, and the potentials returned to baseline without any resulting neurological deficits. Of note, 10 patients (15.9%) displayed abnormal angiographic findings without concurrent changes in SSEPs, BAEPs, or EEG. Five of these patients experienced permanent post-procedural deficits, including visual field defects in three cases and hemiparesis in two cases. It is important to recognize that SSEPs and BAEPs monitoring may not indicate ischemia in certain regions, such as the occipital lobes or primary motor cortex. This example highlights the suboptimal sensitivity of EEG monitoring, despite its broader spatial coverage. Another study involving 35 patients who underwent IONM (using EEG, SSEPs, or BAEPs) during 50 endovascular procedures for cerebral aneurysms (including balloon test occlusion, coil embolization, and permanent vessel occlusion) revealed that IONM changes influenced the management approach in seven patients [17]. The occurrence of transient neurologic deficits in two patients without concurrent changes in IONM results indicates false-negative outcomes. This highlights the limitation of IONM in detecting all potential issues during endovascular aneurysm procedures. To address this, it is recommended to combine IONM with intermittent assessment of angiograms during the procedure. False negatives in IONM can arise because not all vascular territories of the brain can be adequately

assessed. SSEPs, for example, only monitor a small portion of the cortical territory supplied by the MCA and ACA, as well as selected subcortical and brainstem structures such as the ventral posterolateral nucleus of the thalamus and the medial lemniscus, respectively. BAEPs monitoring focuses on detecting ischemia specific to the auditory pathways in the brainstem. However, in procedures involving the posterior circulation, SSEPs and BAEPs monitoring may not capture ischemia in the occipital lobes or cerebellum. EEG, on the other hand, provides a more comprehensive assessment of cerebral ischemia. However, it is not highly sensitive for detecting ischemia affecting a small volume of tissue, and it is not useful for monitoring the posterior fossa. Therefore, a combination of IONM techniques and intermittent angiogram assessment is recommended to overcome the limitations and improve the detection of potential issues during endovascular aneurysm procedures.

Conclusion

Despite increasing clinical experience and technological improvements, the procedure complications unfortunately still occur in the endovascular procedure for cerebral aneurysms. By utilizing IONM such as EEG, SSEPs, MEPs and BAEPs, we can detect neuronal injury as early as possible and prevent to occur serious neuronal injury. While there are some limitations in the utilization of each IONM modality, it can enable the early detection of neuronal injury such as ischemia during the endovascular procedure for cerebral aneurysms and facilitate a more secure treatment when applying IONM appropriately.

Ethical approval

Not applicable.

Conflicts of interest

No potential conflict of interest relevant to this article was reported.

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