Several studies indicate that IONM is a valuable diagnostic tool to monitor the functional integrity of neural structures and to increase safety during cerebrovascular surgery.5,6,11,12,17,20,22,26,28,33 Also, the sensitivity of CMAPs, which in some publications are referred to as motor evoked potentials or MEPs, was shown to be superior to that of SSEPs.10,21,24,37 Thus, IONM, and especially CMAP monitoring, is applied in many neurosurgical departments during cerebrovascular procedures.2 Nevertheless, the application of IONM is controversial because even in true-positive IONM events the surgeon often cannot react in time to prevent cerebral lesions.38 Also, while IONM has become a widely accepted standard during aneurysm clipping, there still are no data on its value for EC-IC bypass surgery.1,24,28,32,38

Regarding EC-IC bypass surgery, specific techniques

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Abbreviations used in this paper: CMAP = compound motor action potential; EC-IC = extracranial-intracranial; ELANA = excimer laser-assisted nonocclusive anastomosis; ICA = internal carotid artery; ICG = indocyanine green; IOF = intraoperative flowmetry; IONM = intraoperative neurophysiological monitoring; SSEP = somatosensory evoked potentials; TCES = transcranial electrical stimulation.
have been established that allow for a more blood flow-oriented monitoring of patients. For example, IOF has been introduced as an effective means to detect vascular insufficiency during aneurysm and bypass surgery.\(^1\) This technique uses a perivascular probe to measure the ultrasonic transit time of the blood within large-caliber vessels. Another flow-oriented monitoring technique is ICG fluorescence angiography, which allows for a direct visual assessment of vessel patency during aneurysm and bypass surgery.\(^25,40\)

Until now, there have mainly been anecdotal reports on the value of IONM during EC-IC bypass surgery.\(^3\) Consequently, it remains unclear which concept, IONM or flow-oriented analyses, is superior in these cases and should be recommended for intraoperative surveillance.

Therefore, we performed an observational study to test the hypothesis that IONM provides additional useful information to flow-oriented strategies during EC-IC bypass procedures to reassure the surgeon of the patient’s functional situation and increase patient safety. Another goal was to examine to what extent IONM has an influence on the course of EC-IC bypass surgery.

**Methods**

_**Intraoperative Neurophysiological Monitoring**_

Data collection was approved by the ethics committee of the Charité-Universitätsmedizin, Berlin. Patient consent was obtained in each case. Intraoperative neurophysiological monitoring was performed according to an established protocol at our department.\(^13\) General anesthesia was induced and maintained intravenously with propofol and fentanyl. Neuromuscular blocking agents (for example, rocuronium) were only used for intubation but not during surgery. The Nicolet Endeavor system (Cardinal Healthcare) was used in all cases for electrical stimulation and recordings. Motor cortex stimulation was performed by repetitive anodal TCES. The stimulation electrodes were placed at positions C3 and C4 according to the standardized International 10–20 EEG system. We applied trains of 5 monopolar, anodal constant-current electrical pulses of 0.3-msec duration at a frequency of 500 Hz. Stimulation intensity was adjusted to a slight suprathreshold level with a maximum of 400 V. Once anesthesia has achieved a steady state, intraoperative baseline values were established. Using pairs of subdermal needle electrodes, CMAPs were recorded from the forearm flexor, thenar, and tibialis anterior muscles contralateral to the side of stimulation. Recording filters were set to a low of 100 Hz and a high of 1.5 kHz. For median nerve SSEPs, the electrodes were placed at C3’ and C4’ with a reference electrode at Fz according to the international 10–20 system. The SSEPs were conducted by stimulation of the nerve at the wrist by using square-wave electrical pulses of 200-msec duration at a slight suprathreshold level and a 5.1-Hz stimulation rate. Primary IONM was performed using CMAPs. In case of unsuccessful or unclear CMAP recording, SSEPs were used as a second-line monitoring tool. A reduction of the CMAP amplitude of 50% and/or an increase of the CMAP peak latency of more than 10% compared with the baseline value was defined as a significant event during IONM.\(^12,37\) In these cases, fluctuation of anesthesia, changes of blood pressure, the inspirational oxygen fraction, and electrode contacts were checked to exclude nonsurgical factors for CMAP events. In case of an event, the surgeon was informed immediately.

_Surgical Technique_

All surgical procedures were conducted by the senior author (PV). Extracranial-intracranial bypass surgery was performed using radial artery (intermediate-flow) or saphenous vein (high-flow) grafts. The decision of which vessel to use was based on the estimated blood flow needed in the recipient vessel (radial artery graft 60–100 ml/100 g/min; saphenous vein > 100 ml/100 g/min). An ELANA procedure was conducted if deemed necessary by the surgeon to reduce the risk of ischemia during bypass anastomosis.\(^14,15,19,36\) Otherwise, the graft was transplanted using a standard technique under 100% oxygen insufflation and elevation of systolic blood pressure to 140–160 mm Hg. The aneurysms were treated in the same surgical session after the bypass had been established, by direct clip reconstruction, trapping, or parent artery occlusion (proximal or distal) for flow reversal.

Several steps of the surgery are crucial and were therefore more intensely monitored: at first, each vessel segment that is originally determined as the location for the distal bypass anastomosis is temporarily clipped for 3–5 minutes to test its ischemic tolerance. Next, the phase of bypass construction (proximal and distal) is closely monitored because, here, temporary clips are applied to the vessels near the anastomoses. Finally, the moment of aneurysm occlusion—whether this occlusion is proximal or distal, or done by trapping or by vessel reconstruction—poses significant risk of ischemia and therefore also belongs to the phases of surgery in which the surgical team closely follows potential changes in IONM parameters.

_Intraoperative ICG Angiography_

The technique we used for ICG angiography has been previously described.\(^25\) After bypass completion, a concentration of 0.2–0.5 mg/kg of ICG was applied intravenously and consequently circulated into the cerebral arteries. The OPMI Pentero surgical microscope (Carl Zeiss) was used to visualize the distal anastomosis site of the EC-IC bypass via near-infrared light. The passage of ICG through the bypass was recorded digitally.

_Intraoperative Sonographic Flowmetry_

After the bypass was completed, IOF was performed using the HT 331 flow Q-C-meter (Transonic Systems Inc.), as described previously.\(^1\) The flow-sensing probe was directly placed on the bypass measuring the ultrasonic transit time of the blood and calculating a flow rate in milliliters per minute.

_Neurological Examination_

All patients underwent a complete neurological examination 1 day before surgery, 1 day after surgery, and on the day of discharge from our department. Muscle
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strength was evaluated using the British Medical Research Council muscle strength system.4

**Results**

Between July 2008 and January 2012, 31 patients (16 males and 15 females) with 31 aneurysms and 1 bilateral occlusion of the ICAs underwent 32 cerebrovascular procedures with IONM. The age of the patients ranged from 14 to 76 years (mean 50.2 years). In 22 procedures, an intermediate-flow EC-IC bypass was established using a radial artery graft. In the other 10 procedures, a high-flow EC-IC bypass was created using a saphenous vein graft; of these, 5 were conducted using the ELANA technique. Of the 32 procedures, the indications for surgery were large, complex, or giant aneurysms (n = 31) or an occlusion of both carotid arteries and restricted vascularization by the vertebral arteries (n = 1). Aneurysms were located at the ICA in 12 cases, the middle cerebral artery in 14 cases, the anterior communicating artery in 3 cases, and the basilar bifurcation in 2 cases. Aneurysm treatment consisted of proximal occlusion in 16 cases, distal occlusion in 6 cases, trapping in 4 cases, and direct clip reconstruction in 3 cases. In 2 patients with aneurysms, no direct aneurysm occlusion was conducted. In all cases, bypass patency was examined intraoperatively by IOF and ICG angiography. The mean temporary clipping time of the recipient vessel during the establishment of the distal bypass anastomosis was 25 ± 7 minutes (± SD).

The placement of the electrodes took less than 15 minutes per case. The delay for the start of the surgery was less than 1 minute because the surgical procedure could start immediately after placement of the transcranial electrodes, whereas the rest of the limb electrodes were placed during the surgical approach. The mean monitoring time per patient was 408 ± 102 minutes. The mean CMAP latency values were 33.7 ± 3.8 msec in the thenar muscles, 27.8 ± 3.4 msec in the forearm flexors, and 36.2 ± 6.2 msec in the tibialis anterior muscles. The mean CMAP duration was 22 ± 9.7 msec for the thenar muscles, 26.1 ± 7.8 msec for the forearm flexors, and 16.3 ± 3.3 msec for the tibialis anterior muscles. The mean CMAP amplitudes were 192.3 ± 142.6 μV for the thenar muscles, 243 ± 116.6 μV for the forearm flexors, and 212 ± 112.6 μV for the tibialis anterior muscles. The CMAP stimulation intensity ranged between 128 and 400 V (mean 292 ± 42 V).

During 2 of 32 procedures, CMAPs could not be recorded due to technical problems. Here, SSEPs were used to monitor functional integrity of the cortex without events. Therefore, 30 procedures (cases) were monitored using CMAPs.

In 19 (63%) of these 30 surgeries, CMAPs remained unchanged, as exemplified in Fig. 1. Within the group of 11 procedures (37%) that involved CMAP alterations, 15 CMAP events were observed, as exemplified in Fig. 2.

**CMAP Event During Test Occlusion of the Recipient Vessel**

In 4 (13%) of 30 cases, the CMAP event occurred during the temporary test occlusion of the vessel segment that was originally determined to be the location of the bypass anastomosis. In all these cases, the temporary clip was therefore removed, and the CMAPs recovered fully. In 3 cases these events prompted the surgeon to look for a more distal segment (for example, M2 instead of M3), which was then chosen as the location for the distal bypass anastomosis and led to no further CMAP events. In 1 case the surgeon decided to change the surgical strategy from a conventional bypass anastomosis to ELANA, which was then carried out without further CMAP events.

**CMAP Events During Bypass Anastomosis**

Despite tolerance to the initial test clip occlusion, in 3
cases (10%) a CMAP event was recorded during intracranial bypass anastomosis. In each of these cases, the surgeon reacted by increasing the speed of suturing and ordering the systolic blood pressure to be raised up to 180 mm Hg. In all these cases, CMAP changes were fully reversible either by the increase in systolic blood pressure (2 cases) or after completion of the anastomosis when the bypass was opened and reperfusion was established (1 case).

**CMAP Events During Proximal or Distal Aneurysm Occlusion**

We recorded CMAP events during proximal aneurysm occlusion in 3 cases (10%) and during distal aneurysm occlusion in 2 cases (7%). These 5 CMAP events were observed 144 ± 52 seconds after application of the clip and were all addressed by removal of the clip within 45 ± 14 seconds (Fig. 3). This led to full CMAP recovery within 108 ± 39 seconds in all 5 cases. The CMAP events during proximal occlusion were interpreted as relevant indicators of potential ischemic compromise due to occlusion of perforators by the clip. In 2 of these cases, the surgeon responded by repositioning the clip. In the other case, the occlusion strategy was changed from a proximal one to a distal one, which was then uneventful.

Both CMAP events after distal aneurysm occlusion prompted the surgeon to not occlude the relevant vessel segment at all out of concern for patient safety. Therefore, the bypass served to reduce flow through the aneurysm; it also served as a form of protection for potential future endovascular aneurysm treatment.

**CMAP Event Linked to Blood Pressure Fluctuation**

In 1 case (3%), we observed a CMAP event 26 minutes after the bypass had been established uneventfully. Since no relevant surgical steps or complications had taken place at the moment of the CMAP event, we looked for anesthesiological complications. It turned out that the systolic blood pressure ranged too low, at around 100 mm Hg, most likely due to fluctuations in medication dosages during an exchange of an infusion system. The systolic blood pressure was immediately increased to 160 mm Hg by norepinephrine infusion, which resulted in full CMAP recovery.

**CMAP Event Due to Thrombosis of the Bypass Graft**

In 1 case (3%) a CMAP event occurred after EC-IC bypass anastomosis and proximal occlusion of the aneurysm had been completed and wound closure was in process. Twenty-four minutes earlier, ICG angiography and IOF had confirmed proper function of the bypass and complete aneurysm occlusion. The response to this CMAP event was to reopen the wound and reevaluate the bypass patency by IOF. When IOF showed no flow through the radial artery graft heparin was administered intravenously. Also, papaverine was applied topically and systolic blood pressure elevated. Even though IOF showed reestablishment of the flow through the bypass, the CMAPs did not recover.

**CMAP Event After ICG Application**

In 1 case (3%) we observed a CMAP event 30 seconds after application of ICG for the evaluation of bypass patency. This event lasted for 70 seconds and resolved spontaneously. In this case no reaction by the surgeon followed, since neither surgical nor anesthesiological events had preceded and the event was self-limiting.

**IOF and ICG Angiography**

In each of the 32 procedures, IOF and ICG angiography were conducted after the EC-IC bypass had been established. All regular IOF measurements showed sufficient bypass perfusion with a mean of 68 ± 21 ml/minute for intermediate flow bypass and 110 ± 32 ml/minute for high-flow bypass. In the 1 case in which a CMAP event occurred during skin closure, a second IOF measurement was conducted that showed thrombosis of the bypass graft, which resolved after the treatment described above.

**CMAP Events and Clinical Outcome**

The clinical outcome of patients with CMAP events is summarized in Table 1. No new postoperative motor deficit was observed in the 19 patients in whom no CMAP events were demonstrated.

In 37% of the 32 procedures, 15 CMAP events oc-

**TABLE 1: Intraoperative CMAP monitoring events and corresponding motor status 1 day after surgery**

<table>
<thead>
<tr>
<th>CMAP Event*</th>
<th>New Motor Deficit 1 Day Postop</th>
</tr>
</thead>
<tbody>
<tr>
<td>reversible (n = 14)</td>
<td>13 1 0</td>
</tr>
<tr>
<td>irreversible (n = 1)</td>
<td>0 0 1</td>
</tr>
<tr>
<td>none (n = 19)</td>
<td>19 0 0</td>
</tr>
</tbody>
</table>

* Values in parentheses indicate the number of events or nonevents correlating to motor outcome.
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curred: 14 events showed a full recovery and 1 event no CMAP recovery.

In the group of 14 reversible CMAP events, on Day 1 after surgery motor function was unchanged in 13 cases, while a reversible new hemiparesis (Grade 3/5) was shown in 1 case. In this patient, postoperative CT and MRI revealed no signs of bleeding or ischemia. Therefore, a potential vasospasm was treated using mild hypertensive therapy for 4 days, during which the hemiparesis fully recovered.

In 1 of the 13 cases without a new motor deficit on Day 1 postoperatively, a new hemiparesis occurred 5 days later. In this patient the aneurysm had been distally occluded at all but one M3 branches due to a reversible CMAP deterioration at this location. The delayed hemiparesis was caused by rupture of an aneurysm that led to an intracerebral hematoma. In a second procedure, the hematoma was evacuated and distal aneurysm occlusion completed by clipping the originally preserved M3 branch. The patient remained hemiplegic.

In the 1 patient with an irreversible CMAP event during skin closure due to thrombosis of the bypass graft, there was a postoperative Grade 1/5 hemiparesis. Furthermore, global aphasia was observed. Two weeks later, at transfer to rehabilitation, the patient’s motor function had improved to Grade 3/5. The sensory component of the aphasia had also improved, while the motor aphasia remained unchanged.

Discussion

This observational study is the first to systematically evaluate IONM in a series of EC-IC bypass procedures. Its results support the view that IONM, especially CMAP monitoring, provides valuable information during EC-IC bypass surgery and plays an important role in the surgeon’s intraoperative decision making. We present the results of 32 high- and intermediate-flow-bypass procedures in 31 patients who underwent continuous IONM. While no false-negative events occurred, 14 reversible and 1 irreversible CMAP events were detected.

One of the main messages of this study is that in patients without CMAP events there were no new deficits after surgery. Such remarkable specificity of IONM is known from cerebrovascular nonbypass procedures and helps the surgeon to realize which critical moves during surgery might be of risk to the patient.20,37 Also, all patients who experienced a new neurological deficit after surgery had either a reversible (1 case) or an irreversible (1 case) CMAP event. This suggests good sensitivity of IONM in cerebrovascular bypass operations. Another important point of our study is that there is a good chance of no permanent new postoperative motor deficits if CMAP events are reversible during surgery. Only 1 of the 14 reversible CMAP events caused a new neurological deficit, which fully resolved before the patient was discharged. However, one has to stress that the study was not powered to establish a causal relationship between the surgeon’s reactions to CMAP events and the absence of neurological deficits in most patients. To have established this relationship, we would have had to compare our patient cohort to a group of patients in which CMAP events would not have been responded to by the surgeon. Such a group was not possible because not responding to potentially critical CMAP events is generally viewed as not conducive to good clinical practice.

Nevertheless, IONM helped to detect potentially critical events during test occlusion of the recipient vessel (13%), during bypass anastomosis (10%), during proximal or distal aneurysm occlusion (17%), during an unintended phase of low blood pressure (3%), after thrombosis of a bypass graft (3%), and on application of ICG for intraoperative angiography (3%).

The surgical team’s responses to these events were followed by recovery of the CMAP events in all but 1 case. This ability to respond and thereby resolve a critical situation means that IONM provides a unique advantage during cerebrovascular surgery, in which clips can be removed or relocated to reestablish perfusion through vessel branches or nonvisible perforating vessels. This option often does not exist in tumor surgery, in which CMAP events are more frequently irreversible due to definite resection of viable brain matter.

The first of such critical phases during EC-IC bypass surgery is the test occlusion of the vessel that is determined to be the recipient of the distal bypass anastomosis. Even though preoperative angiography with balloon occlusion tests is of undisputed value, the only true intraoperative surveillance of cerebral functionality during this surgical phase is offered by IONM. Our data suggest that IONM might help in distinguishing between low and high ischemic tolerance. We identified 4 potentially critical cases during test occlusion in which the operative strategy was changed in response to the CMAP events.

The next critical phase is the process of bypass anastomosis, since it can only be conducted if the vessel receiving the anastomosis is temporarily clipped, unless the ELANA technique is applied. Intraoperative monitoring identified 3 cases in which, despite unremarkable initial ischemic tolerance testing, CMAPs deteriorated as more time elapsed during anastomosis placement. The surgeon reacted by increasing the speed of suturing and also ordering that systolic blood pressure be increased to 180 mm Hg. This increase in blood pressure might, of course, increase the risk of rupture of the yet untreated aneurysm. However, IONM helps to balance the risk of aneurysm rupture against the risk of ischemic stroke during bypass anastomosis. Without IONM in this phase, an aneurysm might be occluded successfully at the cost of ischemia in the vessel territory distal to the bypass.

Another advantage of IONM in the treatment of complex and giant aneurysms is that it can unmask unintended clip occlusion of crucial perforating vessels that might otherwise be hidden behind a calcified or thrombosed aneurysm neck.27 We observed 5 cases in which CMAP events occurred after proximal or distal aneurysm occlusion of partially thrombosed aneurysms with limited exposure of the aneurysm’s environment. All of these events recovered upon removal of the clip and therefore—especially in the cases of proximal aneurysm occlusion—might have been caused by compromised perforators. Although after relocation of the proximal aneurysm clips no further CMAP
events occurred, the CMAP events occurring during distal aneurysm occlusion were so persistent that in these 2 cases no distal clip occlusion of the aneurysm was conducted. The disadvantages of this strategy became apparent in the 1 patient with delayed bleeding (5 days after surgery) due to aneurysm rupture. Here, a giant M3 aneurysm had only been partially occluded distally (only 2 of 3 emanating M3 branches clipped) due to a CMAP event that had been reversible but had occurred repetitively whenever attempts had been made to occlude this branch. The surgeon had therefore decided not to clip this branch, so the aneurysm remained perfused with only 1 outlet instead of the 3 prior outlets. Five days postoperatively the aneurysm ruptured after the patient had initially recovered, uneventfully, from surgery. The patient was taken back to the operating room and the open aneurysm outlet was clipped. Nevertheless, the patient remained hemiplegic. In the aftermath of this case, one might argue that if IONM had not produced a CMAP event the surgeon would have initially conducted a complete distal occlusion and therefore the aneurysm would not have remained perfused and might not have ruptured later on. However, the CMAP event suggested that an initial complete distal occlusion of the aneurysm might have led to an ischemic stroke and was therefore not a relevant option.

In 1 case, a CMAP event was interpreted as indicating reduced ischemic tolerance during an unintended phase of hypotension caused by fluctuations in sedative medication dosage during surgery. Phases of reduced blood pressure are known to be associated with deterioration of evoked potentials during vascular and spinal surgery.8,18,28,38,39 This shows that successful cerebrovascular surgery also depends on good communication with the anesthesiologist. Evoked potentials, especially CMAPs, are known to be sensitive to pharmacological and physiological factors.7,30 A significant number of false-positive findings in IONM are attributed to the anesthesia regimen.6,18 However, if a possible reason for a CMAP event can be identified, as in our case a phase of hypotension, IONM is the only tool to assess whether this poses additional risk to patient safety. Nevertheless, neuroprotective actions—like an elevation of arterial blood pressure—that are taken as a response to CMAP deteriorations might also influence the predictive value of IONM, since such temporarily optimized conditions cannot be maintained postoperatively. This could therefore lead to false-negative IONM events after such an intervention. To prevent such intraoperative ischemic events during hypotensive phases, one might discuss the introduction of preoperative neurophysiological test monitoring under normal blood pressure and reduced blood pressure conditions.

In 1 case we observed a self-limiting CMAP event right after ICG application. This event could potentially indicate mild vasospasm of a perforator as a reaction to ICG. Nevertheless, because the CMAPs recovered spontaneously, the effect ICG might have had on vessel perfusion in this singular instance seems negligible.

In another case, IONM helped in detecting a bypass graft thrombosis while skin closure was in process. When the wound was reopened, bypass thrombosis was confirmed by IOF and was treated successfully by heparin infusion and topical application of papaverine. Nevertheless, the CMAP changes did not recover and the patient experienced a new high-grade hemiparesis and global aphasia, which both showed only minimal recovery until the patient was discharged to rehabilitation.

When comparing the results of IONM to those of IOF and ICG angiography, one notices that in cases of reversible CMAP events during completion of the bypass anastomoses there were no consecutive negative findings on IOF and ICG angiography. These 2 flow-oriented techniques exclusively allow for a rather macroscopic assessment of bypass functionality after its completion. In contrast, IONM has the advantage of indicating functional loss even before the bypass is completed and therefore before IOF and ICG angiography are undertaken. Another advantage of IONM over ICG angiography and IOF is that the latter 2 techniques have little value for direct visualization of perforator perfusion, especially in giant or partially thrombosed aneurysms, where these vessels often cannot be adequately exposed.21 Intraoperative monitoring directly alerts the surgeon to potential perforator compromise even if ICG angiography shows satisfactory aneurysm occlusion. These 2 critical phases alone, bypass construction and aneurysm occlusion, are thought to be responsible for a large part of the perioperative risk, with morbidity and mortality rates between 7% and 15%.16,29,31 Of course, a continuous monitoring tool like IONM with high temporal resolution has advantages over snapshot-like monitoring tools such as IOF or ICG angiography. While IOF and ICG angiography provide valuable information on vessel patency and blood flow rate, IONM directly assesses the functionality of the motor cortex and the pyramidal tract.23 It also offers the option of modifying surgical strategies as they unfold, leaving room for dynamic decision processes.24,28,32,38

Another important role for IONM during EC-IC bypass surgery is that, unlike the other tools, it informs the surgeon about whether the present flow through a bypass graft is sufficient. It is often difficult to tell in advance which kind of bypass graft might be suited for which patient. Indocyanine green angiography and IOF only produce data on whether there is flow and how fast it is. They cannot determine, based on that specific blood flow, whether cerebral functionality is maintained. Intraoperative neurophysiological monitoring lets the surgeon know whether the chosen strategy is the right one and, if not, whether a different bypass graft should be used. A theoretical alternative here would be intraoperative measurement of cerebral blood flow within brain tissue, which, however, has the disadvantage that it only offers a quite narrow spatial resolution.5

Certain limitations of our study should be discussed. For one, we did not examine a control group of patients undergoing EC-IC bypass surgery without IONM or without a response to critical CMAP events. However, because IONM has become a common tool in neurosurgery, we feel that not providing it for all patients would be unethical. Furthermore, the number of cases (n = 32 procedures) in our study is not large enough to allow for an exact assessment of the influence of IONM on the clinical outcome in our cohort. Thus, we cannot argue that patient
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outcome was solely dependent on IONM and the changes in surgical strategies it evoked. Also, we did not verify the CMAP events with a separate technique to objectify their relevance. False-positive events can therefore not be ruled out. Transcranial magnet stimulation would be an option for this, but it is not used in bypass procedures at our department.

Another limitation is the exclusive application of TCES without comparison to a group of patients undergoing direct cortical stimulation, which is often viewed as providing more subtle information during IONM. Nevertheless, TCES has been shown to be a similarly successful monitoring tool as direct cortical stimulation during complex vascular surgery. Also, the application of TCES during vascular surgery is reasonable since the motor cortex is usually not exposed and therefore cannot be easily monitored by a direct cortical stimulation grid electrode. Furthermore, TCES does not disturb the surgeon’s view of the operative field, especially considering that the standard pterional approach is usually conducted with a relatively small craniotomy.

Conclusions

Intraoperative neurophysiological monitoring was able to alert the surgeon to potentially critical events during EC-IC bypass procedures. Indocyanine green angiography and IOF are established and important tools to use during cerebral bypass surgery, but they do not provide continuous functional monitoring. In contrast, IONM provides an assessment of brain functionality not only during bypass completion or aneurysm clipping, but also during other critical phases in which ischemic events might otherwise go unnoticed. Therefore, IONM offers important real-time information for the surgeon and thereby may increase patient safety during EC-IC bypass surgery.

Disclosure

The authors report no conflict of interest concerning the materials and methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Dengler, Cabralja, Vajkoczy. Acquisition of data: Dengler, Cabralja, Faust, Vajkoczy. Analysis and interpretation of data: Dengler, Cabralja, Kombos. Drafting the article: Dengler, Cabralja. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Administrative/technical/material support: all authors. Study supervision: Vajkoczy.

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