Acta Neurochir (Wien) (2007) 149: 357–364
DOI 10.1007/s00701-007-1119-z
Printed in The Netherlands

Acta Neurochirurgica

Clinical Article

Use of intraoperative monitoring of somatosensory evoked potentials to prevent ischaemic stroke after surgical exclusion of middle cerebral artery aneurysms

G. Penchet[1], **P. Arné**[2], **E. Cuny**[1], **P. Monteil**[1], **H. Loiseau**[1], and **J.-P. Castel**[1]

[1] Service de Neurochirurgie, Centre Hospitalier Pellegrin, Université Victor Segalen Bordeaux 2, Bordeaux, France
[2] Service de Neurophysiologie Clinique, Centre Hospitalier Pellegrin, Université Victor Segalen Bordeaux 2, CNRS UMR 5543, Bordeaux, France

Received June 1, 2006; accepted December 20, 2006; published online March 28, 2007

Summary

Objective. The aim of this study was to assess the value of monitoring somatosensory evoked potentials (SEP) in the prevention of ischaemic stroke occurring during surgical exclusion of middle cerebral artery aneurysms.

Methods. SEP monitoring was performed during the surgical exclusion of 131 aneurysms in 122 patients. All SEP variations over 30% were notified to the surgeon and those over 50% were considered as highly significant. If this happened, and in concert with the conduct of the operation, a return to the basal level was systematically sought.

Results. Post-operative ischemic stroke was observed after 15 (11.4%) operations, leading to a permanent neurological deficit in 12 (9.2%). During nine (6.9%) operations there was a highly significant SEP change that persisted, or was only partially reversed, after corrective procedure. Nine of these patients had a post-operative ischaemic stroke. In 25 (19%), operations there was a highly significant SEP change followed by complete recovery. Of these 25 patients, 2 suffered a post-operative ischemic stroke. Following 49 operations (37.4%) with less significant SEP modifications, 4 patients suffered a post-operative stroke (8%). A stroke did not occur in the 48 (36.6%) operations during which there was not a variation in SEP. The strokes were related to temporary clipping in 9 patients to definitive clipping in 3 to sylvian fissure opening in 1 to brain retraction in and to dissection of the aneurysm in 1 (1 case).

Conclusion. Changes in the SEP correlated well with the occurrence of post-operative stroke. This early detection of ischemia directs attention to the need for measures such as withdrawal of temporary clipping or identification of another factor (e.g. release of brain retraction or repositioning of an occlusive clip) so that the risk of post-operative is reduced.

Keywords: Intracranial aneurysms; somatosensory evoked potential; intraoperative monitoring; temporary occlusion; cerebral ischemia; middle cerebral artery.

Introduction

An intraoperative ischaemic event during surgical exclusion of an intra-cranial aneurysm is a leading cause of permanent post-operative morbidity and mortality. Such events occur in up to 20 and 5% of operations for a middle cerebral artery aneurysm [8]. So far, the method of minimising the incidence of such complications has been by continuous intraoperative monitoring of regional cerebral blood flow (rCBF). However, the close correlation between somatosensory evoked potentials (SEP) and rCBF levels observed experimentally makes, SEP monitoring an appealing alternative way to assess the risk of ischaemia [32].

SEP monitoring involves recording and analysing the neuronal electrical activity of the primary somesthesic

cortex (post-rolandic gyrus) in order to obtain information about the integrity of the central somatosensory pathways [32]. The value of SEP monitoring during surgical treatment of middle cerebral aneurysms reflects a number of anatomical factors. For example, the somatosensory areas, with cortical representation of the face and the upper limb, is supplied by the ascending parietal artery arising from the upper or the middle tract of the middle cerebral artery. Thus, the adequacy of rCBF in the territory of the middle cerebral can be evaluated indirectly by stimulating the controlateral median nerve at the wrist.

It is essential to know the amplitude of the N20 peak corresponding to the evoked parietal response. A reduction in the N20 peak amplitude by more than 50% compared to its absolute values indicates that rCBF values have fallen to around 12–16 mL/100 g/min [16, 19, 35]. This corresponds to potentially reversible cerebral ischaemia whereas, prolonged maintenance of a low rCBF may induce a cerebral infarct. In addition, it has been shown that the greater the drop in the rCBF, the faster the onset of the cerebral infarction [7, 11]. Consequently, SEP modifications precede the occurrence of an irreversible ischaemic lesion and may provide the basis for immediate corrective procedures [33].

The goal of our study was to assess if SEP monitoring, in combination with immediate and corrective procedures for changes in SEP can reduce the occurrence of ischemic lesions occurring during surgical exclusion of aneurysms of the middle cerebral artery.

Patients and methods

A retrospective review was made of 122 consecutive patients, admitted between 1995 and 2002 suffering from an aneurysm of a middle cerebral artery. SEP monitoring was performed during the surgical exclusion of 133 aneurysms (111 ruptured aneurysms, including 11 with a second middle cerebral aneurysm mirroring the ruptured one and 11 with isolated asymptomatic intact aneurysms).

In all 111 patients with aneurysmal rupture, subarachnoid hemorrhage was clinically and radiologically evaluated using WFNS [39] and Fisher's [4] classifications, respectively. In these patients treatment with intravenous Nimodipine (0.3/mL/kg) and 30–50 mL/kg/day fluid intake was begun as soon as possible. Central venous pressure and arterial pressure were continuously monitored routinely. Depending upon the clinical condition at diagnosis and/or the date of admission, surgical exclusion was performed before day 3 or after day 10.

The anaesthetic protocol included a narcotic (protocol) and morphinomimetics (fentanyl and, more recently, remifentanyl). Such drugs have little effect on SEP monitoring. Hypotensive and/or hypothermia protocols and/or cerebral protection using high doses of barbiturates were never used.

To facilitate the surgical approach, a lumbar drainage (closed system – slow CSF evacuation of 40–60 mL) was used in most cases. A fronto-pterional approach extending to the cranial base was used as a routine. The sylvian fissure was opened with a surgical microscope and smooth retractors (Greenberg type). Temporary clipping of the proximal trunk of the middle cerebral artery was used as a rule at the end of aneurysmal dissection to facilitate definitive clipping and to avoid arterial stenosis.

Electrophysiological recording

SEP monitoring was performed in all patients. Controlateral median nerve stimulation was performed with a skin electrode using a rectangular impulse (0.15 ms, 4 Hz, 20 mA). SEP recording was performed using subcutaneous electrodes implanted in the cervical region (C2 level) and bilaterally in the parietal regions. A reference electrode was implanted in the frontal region. N20 peak amplitude was chosen as the quantification parameter and was analysed in comparison to the amplitude obtained before opening the dura.

A reference value (N20 peak amplitude) was defined at the beginning of the operation under stable anesthesthetic conditions. In all patients, SEP monitoring was conducted until scalp closure. The main changes in SEP (>30% decrease in N20 peak) were taken to be likely to be due to ischemia. During temporary clipping, the time of occurrence, duration and time to normalization of these parameters were recorded and analysed.

Intraoperative management

The surgeon was notified of all SEP variations over 30%. Variations over 30% were considered as significant modifications, and those over 50%, as highly significant. According to the stage of operation, a return to the basal level was systematically sought if these conditions developed. All significant SEP modifications led to delay in temporary clipping while waiting for a return to the basal level. If the SEP amplitude decreased between 30 and 50%, intermittent and repetitive temporary clipping was performed. The SEP had to normalise before the next temporary clipping. Sometimes, repeated tem-

Table 1. *Characteristics of 15 patients with a stroke after operation on a middle cerebral artery aneurysm*

Patient	Age	WFNS grade	Fisher grading of SAH on CT scan	Temporary clip	Duration of temporary clipping	Change in SEP	Recovery of SEP	Cause of change	Mechanism of interference with blood flow	location of stroke	Outcome on Glasgow outcome scale
1	61	1	4	+	4mn30	HS	No	TC	FR	MCA	MD
2	76	3	3	+	1mn30	HS	C	TC	FR	MCA	SD
3	63	1	1	+	<1mn	HS	C	TC	FR	MCA	GR
4	51	2	3	+	2mn55	HS	P	TC	FR	MCA	MD
5	61	1	3	+	4mn15	LS	C	TC	PAO	LSA	MD
6	51	1	2	+	2mn35	LS	C	TC	PAO	LSA	MD
7	45	1	4	+	9mn15	LS	C	Post TC	PAO	MCA	GR
8	57	3	3	+	5mn40	HS	No	Post TC	FR	MCA	MD
9	41	1	2	+	6mn40	HS	P	Post TC	FR	MCA	SD
10	35	1	3	+	<1mn	HS	P	Clip	FR	MCA	SD
11	48	3	1	+	1mn45	HS	P	Clip	FR	MCA	MD
12	52	1	2	+	3mn40	LS	C	Clip	PAO	LSA	GR
13	45	4	4	+	3mn20	HS	P	Dissect	PAO	MCA	SD
14	45	2	3	−	0	HS	P	Dissect	PAO	MCA	SD
15	45	1	3	+	3mn50	HS	P	BR	FR	MCA	MD

SEP Somatosensory evoked potentials; *HS* significant reduction of N20 peak amplitude (>50%); *LS* less significant reduction of N20 peak amplitude (between 50 and 30%); *P* partial recovery of SEP change during surgery; *C* complete recovery of SEP change during surgery ; *TC* temporary clipping; *Post TC* after temporary clipping removal; *Clip* definitive clipping; Dissect aneurysm dissection; *BR* brain retractor; *FR* flow related; *PAO* permanent artery occlusion; *MCA* middle cerebral artery; *LSA* lenticulostriate artery. Glasgow outcome scale: *GR* Good recovery, *MD* moderate disability, *SD* severe disability.

porary clipping was performed depending upon the operative conduct. If the SEP did not change, the duration of temporary clipping was guided by the surgical difficulties and anatomical conditions encountered.

Post-operative management

Post-operative status was evaluated by clinical examination and CT scan. All patients with a hypodensity in the territory of the aneurysmal MCA within the first 48 h after surgery, with or without deterioration in their neurological condition, were considered as having an intervention-related ischemic event. The origin of any stroke was assigned through comparisons with the intraoperative SEP events, in particular the stage of the surgical procedure when SEP events occurred, and the CT scan results as flow related (used of TC or dissection arterial spasm for examples) or permanent arterial occlusion (occlusion of lenticulo-striate artery for example) (Table 1).

All patients were clinically re-evaluated at 1-month after the SAH using the Glasgow Outcome Scale (GOS).

Results

One hundred and twenty-two consecutive patients with 133 aneurysms of the middle cerebral artery were treated. These were ruptured aneurysms in 111 cases, including 11 patients with another controlateral unruptured aneurysm mirroring the ruptured one and 11 patients with an asymptomatic unruptured aneurysm found during headache assessment.

Temporary clipping of the middle cerebral artery main trunk was used in 120 operations (90.2%). In 118 instances, temporary clipping was used in order to facilitate dissection and/or definitive clipping and also was used in 2 cases of premature and uncontrolled rupture. The median duration of clipping(s) was 3 min 25 s (range 30 s–21 min) (Table 2). In 15 instances (12.5%), the total duration of temporary clipping was more than 5 min, and in 3 (2.5%) exceeded 15 min. A significant SEP modifications was observed 67 times (55.8%) during temporary clipping.

Clinical assessment one month after surgery showed that 86 patients (70.5%) had made good recovery (i.e. without disability), 22 (18%) were moderately and, 12 (9.8%) severely disabled; none were vegetative but 2 (1.6%) had died.

Table 2. *Relation of electrophysiological and clinical events to duration of temporary clipping*

Event	Mean duration of occlusion ± standard deviation	Range
HS or LS SEP modifications	2mn50 ± 3mn50	<1mn–21mn
NS or no SEP modifications	3mn10 ± 2mn15	<1mn–14mn20
Post-procedural stroke	3mn30 ± 2mn20	<1mn–9mn15
No post-procedural stroke	3mn ± 2mn50	<1mn–21mn

HS Highly significant reduction of N20 peak amplitude (>50%); *LS* less significant (between 50 and 30%); *NS* non-significant reduction of N20 peak amplitude; *SEP* somatosensory evoked potentials.

Table 3. *Changes in SEP, cause reversibility and stroke after operations in 120 patients*

SEP findings	Number of events	Number of operations (%)	Causation		Number with a stroke after operation
			Temporary clipping	Others	
Highly significant change* in SEP	38	34 (25.9%)	25	9	11
Recovery:					
None		*2*	*2*	*0*	*2*
Partial		*7*	*2*	*5*	*7*
Total		*25*	*21*	*4*	*2*
Less significant change** in SEP	50	49 (37.4%)	42	7	4
No change in SEP***	0	48 (36.6%)	53	–	0
Total	88	131†	120	16	15

SEP Somatosensory evoked potentials. * Reducing the N20 peak amplitude more than 50%. ** Reducing the N20 peak amplitude between 50 and 30%. *** Without reducing the N20 peak amplitude or reducing less than 30%. † The 2 remaining patients had no SEP at baseline because of haematoma with controlateral sensory-motor hemiplegia.

SEP monitoring and stroke

Intraoperative SEP monitoring was performed in all the patients in this series but on 2 occasions, no signal was obtained before opening of the dura. In these 2 patients an intracerebral haematoma was associated with a controlateral sensory-motor hemiplegia, so they were excluded from the study.

During these 131 operations, four different kinds of SEP monitoring development were noted according to the N20 peak amplitude decrease and the improvement of this N20 peak amplitude after corrective treatment (temporary clipping removal, definitive clipping modification, or brain retractor removal) (Table 3).

Highly significant SEP event (decrease of more than 50% of N20 peak amplitude) and none or partial improvement after corrective treatment

A highly significant SEP event occurred in 34 operations (25.9%). In 9 there was either no (2 patients) or partial (7 patients) improvement after treatment of the SEP event. A stoke occurred in each of these 9 patients.

Highly significant SEP event (decrease of more than 50% of the N20 peak amplitude) and complete improvement after treatment

Among the 34 operations with a highly significant SEP event, there was complete improvement after treatment of the SEP event in 25. A stroke occurred in 2 patients (8%).

Less significant SEP event (decrease between 30 and 50% of the N20 peak amplitude)

A moderately significant SEP event occurred in 49 surgical procedures (37.4%). Treatment of these SEP events was always effective with complete recovery of the initial N20 peak level. Among these patients, 4 strokes occurred.

No significant SEP event (decrease of less than 30% of the N20 peak amplitude)

There was not an SEP event in 48 operations. None of these patients had a stroke (0%).

Efficacy of treatment of significant SEP event to prevent post-operative stroke

Significant SEP events occurred in 83 operations (63.3%). This always led to an effort to institute appropriate corrective treatment.

Treatment of significant SEP events not followed by a stroke

Significant SEP events without a post-operative stroke occurred in 68 operations (52%). In these patients, peroperative etiological treatment of the SEP event always achieved complete recovery of the N20 peak height to its initial level.

- In 58 operations, the significant SEP events were related to the use of temporary clipping, so the risk of ischemia was appreciated. In each of these patients, removal of the temporary clip was followed by complete recovery of the initial N20 peak level and none had a post-operative stroke.
- In the other 10 patients, the significant SEP events were related to defective occlusive clipping (7) or to brain retractor positioning (3), so that the ischemia situation was unexpected. In these situations, SEP modifications were always highly significant events (i.e. a

decrease by more than 50% of N20 peak amplitude). Repositioning of the clip or the brain retractor was followed by complete recovery of the initial N20 peak amplitude and again none had a post-operative stroke.

Ineffective treatment of significant SEP events and a post-operative stroke

A post-operative ischaemic stroke was observed in 15 patients (11.4% of 131 surgical procedures without pre-operative hemiplegia) resulting in a permanent neurological deficit in 12 (9.2%) (Table 2). No death or vegetative state occurred in this group. Each of these 15 strokes followed a significant SEP event. In 9 patients, l treatment of the significant SEP event was ineffective and all of these strokes were all located within the MCA territory.

Effective treatment of significant SEP events but post-operative stroke

Despite effective treatment of the significant SEP event with complete recovery of the initial N20 peak amplitude, a post-operative stroke occurred in 6 cases. These unexpected strokes were located within the territory of the lenticulo-striate arteries in 3 cases and in the distal part of the MCA territory in 3 others.

Etiology of strokes

Temporary clipping was related to the stroke in 9 instances. Among these, the stroke was located within the middle cerebral artery territory in 7, and in the territory of the lenticulo-striate arteries in the other two.

In 6 patients the stroke was related to causes other than temporary clipping. In 3 the stroke was related to definitive clipping and was located within the distal part of the MCA territory in 2 patients and in the territory of the lenticulo-striate arteries in one.

In the remaining 3 patients, the stroke was related to opening of the sylvian fissure (one), to dissection of the aneurysm (one) and to brain retractor positioning (one). In these 3 patients, the stroke occurred in the distal part of the territory of the middle cerebral artery.

Discussion

In this series of 131 operations on a patient without a hemiplegia, 15 intraoperative strokes (11.5%) occurred, resulting in a permanent neurological deficit in 12 (9.2%). A significant deterioration of SEP amplitude without complete intraoperative electrophysiological recovery in 9 patients was followed by stroke with neurological deficits in each patient (100%). On the other hand, when highly significant SEP modifications were corrected by intraoperative procedures, a stroke was observed in only 9 of 34 patients When there was a less significant SEP event, an ischemic stroke followed in only 4 of 49 patients ischemic stroke was not observed when there were no changes in SEP amplitude (0%).

Reliability of SEP monitoring for assessment of the risk of ischaemia

The reliability of SEP monitoring during intracranial aneurysmal surgery as a method of predicting post-operative complications has been widely discussed [5, 12, 18, 20, 21, 30, 43]. In our experience, electrophysiological monitoring was always reliable in patients without a pre-operative hemiplegia.

Specificity

A post-operative ischemic stroke was observed in all our patients in whom a significant SEP alteration was detected that could not be immediately corrected. The specificity of significant SEP modifications associated with the absence of complete electrophysiological intraoperative recovery was 100%. In a series of 30 patients with a middle cerebral aneurysm having intraoperative monitoring, Lazorthes *et al.* [15] found a similar correlation between intraoperative SEP monitoring information and post-operative neurological status in 93.3% of patients.

Sensitivity

The limitations of SEP monitoring are known. For example, it does not allow intraoperative evaluation of the motor pathways. In the vast majority of cases, the lenticulo-striate arteries arise in the M1 part of the middle cerebral artery. An anatomical study has shown that these arteries arise form its divisions in about 15% of cases [42]. Since they cross the anterior perforated space, they supply the caudate nucleus and the anterior part of the internal capsule [27, 40]. Stroke involving the lenticulo-striate arteries leads to a pure controlateral motor deficit that SEP monitoring cannot detect.

Six false negatives were observed in our series (4.6% of the operations). Two patients who displayed highly

SEP deterioration with a quick normalization and 4 patients with less significant intraoperative SEP modifications with normalisation developed an ischemic stroke. In 4 of these cerebral infarcts, the precise etiology was discovered. Deep infarcts (without loss of sensation were observed in 3 patients within the territory of the lenticulo-striate arteries and an immediate post-operative total sylvian stroke resulting from a possible thromboembolic migration of internal carotid origin occurred in the other one.

The frequency of 'false negatives' after operation on an aneurysm of the middle cerebral artery ranges from 0 to 4% [5, 13, 15, 18, 20, 31]. In 134 operations with intraoperative SEP monitoring, Schramm *et al.* [30] found only one false negative among the 40 patients with a middle cerebral artery aneurysm. False negatives have been reported in other localisations [9]. For aneurysms located at the basilar trunk bifurcation, small strokes located within the brainstem without sensory deficit occur in about 25% of patients [6, 17]. These false negatives explain the sensitivity of 60% observed in our series. Nevertheless, SEP monitoring is a useful indicator of the risk of ischaemia during operation on a middle cerebral artery aneurysm.

Motor evoked potentials (MEPs) monitoring may have value in the prediction of pure motor deficit. In recent series [10, 23, 25, 36, 37], high sensitivity has been reported, with, in particular, detection of blood flow insufficiency in lenticulostriate artery territory [10]. Furthermore, MEP deterioration may arise earlier than with SEP monitoring [23]. However, two have to be investigated further. First, feasibility may be limited by muscular movements induced by electrical stimulation and there is a need to define a much better stimulation's paradigm [23]. Second, intraoperative induced seizures have been described and, though rare, may represent an important limitation of MEPs monitoring in aneurysm surgery [36].

Temporary clipping

The rationale for temporary clipping is that it provides vascular control within the parent vessel territory allowing involvement of the arterial supplying system [2, 38]. Many advantages of this technique have been described [3, 14, 20, 24, 28, 29] e.g. dissection of large aneurysms or of weakened aneurysmal walls, ease of detachment of vascular adhesions to the aneurysmal sack, and easier aneurysmal mobilization, thus improving definitive clipping at the aneurysmal neck. Finally, reduction of transmural pressure reduces the risk of intraoperative rupture [2, 28]. On the other hand, temporary clipping increases the risk of ischemia in the corresponding arterial territory [14, 26, 29]. SEP monitoring has been advocated in order to decrease intraoperative ischemic events while cretaining the benefit of temporary clipping, a finding confirmed by our series.

It is difficult to define a permissible temporary clipping time for each patient. Lavine *et al.* [14] reported that occlusion of the middle cerebral aretetry trunk lasting less than 10 min was safe (mean duration of 13.6 ± 10.6 min for patients without brain ischemic injury), but in our experience, there is important interindividual variability and no clear cut time can be defined (Table 3). This variability may depend on the anaesthetic protocol used [3, 14, 24, 29] but also on the severity and persistence of initial ischemia caused by aneurysmal rupture [41] or pre-existence of rCBF impairment. Furthermore, tolerance of temporary occlusion may be modified intraoperatively, for example, after the prolonged use of brain retraction.

A significant SEP event related to temporary clipping occurred in 67 of our patients. Without SEP monitoring, the ischemic stroke rate would have been higher than observed. Indeed, only 9 patients (7.5%) exhibited a post-operative ischemic stroke related to temporary clipping guided by correction of significant SEP changes.

Temporary clipping without SEP monitoring has been reported. In a series of 100 aneurysms (ruptured or not, all localisations, no hypotensive or hypothermic protocol), a post-operative stroke after temporary clipping was observed in 19% of patients, and in 26% if it was a middle cerebral aneurysm [29]. These results were confirmed by a subsequent study in which temporary clipping-related strokes were observed in 22.4% of patients surgically treated for either a ruptured or intact middle cerebral aneurysm [14]. Nevertheless, in a series of 29 MCA aneurysms, Ogilvy *et al.* [24] reported a 10.3% occurrence of post-operative stroke. However, patients who had a transient deficit (less than 12-hour duration) were excluded.

The number of ischemic events in our series is comparable to the rate reported in similar series (i.e. using temporary clipping under SEP monitoring). The reported incidence of such events ranges from 0 to 12% [1, 20, 22, 30]. Careful analysis of these data is mandatory because of the various anaesthetic protocols used (depending upon the use of hypothermia and/or controlled hypotension [22, 30, 31] and/or cerebral protection) [14, 20, 24, 29].

Others causes of SEP modifications

Unexpected (i.e. not temporary clipping-related) SEP variations were recorded 16 times (12.2%). The presumed causes were as follows: frontal or temporal lobe retraction, dissection of the aneurysm, premature rupture, and definitive clipping of the aneurysm inducing MCA occlusion or collateral vessel bending. Similar mechanisms have been frequently reported by others [5, 6, 18, 30, 34]. As in our series, definitive clipping and cerebral retraction were the main causes.

Significant SEP modifications must be reported to the surgical team, because this information can lead to a systematic l search for a cause and adequate corrective maneuvers. In our cases in which such SEP modifications were recorded, changes to the surgical procedure allowed SEP normalisation in 10 patients (7.6%). If such measures are not taken, persistent electrophysiological ischemia could lead to post-operative stroke within the arterial territory concerned and to a higher post-operative morbidity and mortality.

Conclusions

The prevention of ischaemia during an operation on a middle cerebral artery aneurysm involves several factors including preservation of cerebral perfusion pressure and cerebral protection protocols. However, surgery itself may lead to unexpected critical cerebral ischemia. In such cases, and to differing degrees, SEP monitoring appears to be a very reliable indicator. First, there is a good correlation between SEP recordings and the occurrence of post-operative stroke. Second, identification of SEP modifications allows early detection of ischemia. During such situations, withdrawal of temporary clipping or identification of another etiological factor (brain retraction definitive clip location, and arterial compression) is mandatory. In this way, the rate of post-operative stroke can easily be reduced. Even though false negatives occur, they are rare and do not diminish the impact of SEP monitoring during microsurgical operative treatment of aneurysms of the middle cerebral artery.

References

1. Buchthal A, Belopavlovic M, Mooij JJ (1988) Evoked potential monitoring and temporary clipping in cerebral aneurysm surgery. Acta Neurochir (Wien) 93: 28–36
2. Castel JP, Frerebeau P, Lagarrigue J, Moreau JJ (1994) Traitement neuro-chirurgical des anévrysmes intra-crâniens. Neurochirurgie 40: 31–66
3. Charbel FT, Ausman JI, Diaz FG, Malik GM, Dujovny M, Sanders J (1991) Temporary clipping in aneurysm surgery: technique and results. Surg Neurol 36: 83–90
4. Fisher CM, Kistler JP, Davis JM (1980) Relation of cerebral vasospasm to subarachnoid hemorrhage visualized by computerized tomographic scanning. Neurosurgery 6: 1–9
5. Friedman WA, Chadwick GM, Verhoeven FJ, Mahla M, Day AL (1991) Monitoring of somatosensory evoked potentials during surgery for middle cerebral artery aneurysms. Neurosurgery 29: 83–88
6. Friedman WA, Kaplan BL, Day AL, Sypert GW, Curran MT (1987) Evoked potential monitoring during aneurysm operation: observations after fifty cases. Neurosurgery 20: 678–687
7. Heiss WD, Rosner G (1983) Functional recovery of cortical neurons as related to degree and duration of ischemia. Ann Neurol 14: 294–301
8. Heros RC (1985) Middle cerebral artery aneurysms. In: Wilkins RH, Rengachary SS (eds) Neurosurgery, vol 2. McGraw-Hill Inc, New York, pp 1376–1383
9. Holland NR (1998) Subcortical strokes from intracranial aneurysm surgery: implications for intraoperative neuromonitoring. J Clin Neurophysiol 15: 439–446
10. Horiuchi K, Suzuki K, Sasaki T, Matsumoto M, Sakuma J, Konno Y, Oinuma M, Itakura T, Kodama N (2005) Intraoperative monitoring of blood flow insufficiency during surgery of middle cerebral artery aneurysms. J Neurosurg 103: 275–283
11. Jones TH, Morawetz RB, Crowell RM, Marcoux FW, FitzGibbon SJ, DeGirolami U, Ojemann RG (1981) Thresholds of focal cerebral ischemia in awake monkeys. J Neurosurg 54: 773–782
12. Kidooka M, Nakasu Y, Watanabe K, Matsuda M, Handa J (1987) Monitoring of somatosensory evoked potentials during aneurysm surgery. Surg Neurol 27: 69–76
13. Krieger D, Adams HP, Albert F, von Haken M, Hacke W (1992) Pure motor hemiparesis with stable somatosensory evoked potential monitoring during aneurysm surgery: case report. Neurosurgery 31: 145–150
14. Lavine SD, Masri LS, Levy ML, Giannotta SL (1997) Temporary occlusion of the middle cerebral artery in intracranial aneurysm surgery: time limitation and advantage of brain protection. J Neurosurg 87: 817–824
15. Lazorthes Y, Sonilhac F, Lagarrigue J, Scavazza R (1992) La surveillance des potentiels évoqués somesthésiques dans la chirurgie des anévrysmes sylviens. Neurochirurgie 38: 333–346
16. Lesnick JE, Michele JJ, Simeone FA, DeFeo S, Welsh FA (1984) Alteration of somatosensory evoked potentials in response to global ischemia. J Neurosurg 60: 490–494
17. Little JR, Lesser RP, Luders H (1987) Electrophysiological monitoring during basilar aneurysm operation. Neurosurgery 20: 421–427
18. Lopez JR, Chang SD, Steinberg GK (1999) The use of electrophysiological monitoring in the intraoperative management of intracranial aneurysms. J Neurol Neurosurg Psychiatry 66: 189–196
19. Meyer KL, Dempsey RJ, Roy MW, Donaldson DL (1985) Somatosensory evoked potentials as a measure of experimental cerebral ischemia. J Neurosurg 62: 269–275
20. Mizoi K, Yoshimoto T (1993) Permissible temporary occlusion time in aneurysm surgery as evaluated by evoked potential monitoring. Neurosurgery 33: 434–440
21. Momma F, Wang AD, Symon L (1987) Effects of temporary arterial occlusion on somatosensory evoked responses in aneurysm surgery. Surg Neurol 27: 343–352
22. Mooij JJ, Buchthal A, Belopavlovic M (1987) Somatosensory evoked potential monitoring of temporary middle cerebral artery occlusion during aneurysm operation. Neurosurgery 21: 492–496
23. Neuloh G, Schramm J (2004) Monitoring of motor evoked potentials compared with somatosensory evoked potentials and microvascular Doppler ultrasonography in cerebral aneurysm surgery. J Neurosurg 100: 389–399

24. Ogilvy CS, Carter BS, Kaplan S, Rich C, Crowell RM (1996) Temporary vessel occlusion for aneurysm surgery: risk factors for stroke in patients protected by induced hypothermia and hypertension and intravenous mannitol administration. J Neurosurg 84: 785–791
25. Quinones-Hinojosa A, Alam M, Lyon R, Yingling CD, Lawton MT (2004) Transcranial motor evoked potentials during basilar artery aneurysm surgery: technique application for 30 consecutive patients. Neurosurgery 54: 916–924
26. Richling B, Griesmayr G, Lametschwandtner A, Scheilbrandner W (1979) Endothelial lesions after temporary clipping. A comparative study. J Neurosurg 51: 654–661
27. Rosner SS, Rhoton AL Jr, Ono M, Barry M (1984) Microsurgical anatomy of the anterior perforating arteries. J Neurosurg 61: 468–485
28. Samaha E, Rizk T, Nohra G, Mohasseb G, Okais N (1999) Le clampage temporaire réglé dans la chirurgie anévrismale intracrânienne. A propos de 54 cas. Neurochirurgie 45: 24–28
29. Samson D, Batjer HH, Bowman G, Mootz L, Krippner WJ Jr, Meyer YJ, Allen BC (1994) A clinical study of the parameters and effects of temporary arterial occlusion in the management of intracranial aneurysms. Neurosurgery 34: 22–28
30. Schramm J, Koht A, Schmidt G, Pechstein U, Taniguchi M, Fahlbusch R (1990) Surgical and electrophysiological observations during clipping of 134 aneurysms with evoked potential monitoring. Neurosurgery 26: 61–70
31. Schramm J, Zentner J, Pechstein U (1994) Intraoperative SEP monitoring in aneurysm surgery. Neurol Res 16: 20–22
32. Skirboll S, Newell DW (1998) Noninvasive physiologic evaluation of the aneurysm patient. Neurosurg Clin N Am 9: 463–483
33. Symon L, Momma F, Murota T (1988) Assessment of reversible cerebral ischaemia in man: intraoperative monitoring of the somatosensory evoked response. Acta Neurochir Suppl 42: 3–7
34. Symon L, Wang AD, Costa e Silva IE, Gentili F (1984) Preoperative use of somatosensory evoked responses in aneurysm surgery. J Neurosurg 60: 269–275
35. Symon L (1980) The relationship between CBF, evoked potentials and the clinical features in cerebral ischaemia. Acta Neurol Scand Suppl 78: 175–190
36. Szelenyi A, Kothbauer K, de Camargo AB, Langer D, Flamm ES, Deletis V (2005) Motor evoked potential monitoring during cerebral aneurysm surgery: technical aspects and comparison of transcranial and direct cortical stimulation. Neurosurgery 57(4) Suppl: 331–338
37. Szelenyi A, Bueno de Camargo A, Flamm E, Deletis V (2003) Neurophysiological criteria for intraoperative prediction of pure motor hemiplegia during aneurysm surgery. Case report. J Neurosurg 99: 575–578
38. Taylor CL, Selman WR (1998) Temporary vascular occlusion during cerebral aneurysm surgery. Neurosurg Clin N Am 9: 673–679
39. Teasdale GM, Drake CG, Hunt W, Kassell N, Sano K, Pertuiset B, De Villiers JC (1988) A universal subarachnoid hemorrhage scale: report of a committee of the World Federation of Neurosurgical Societies. J Neurol Neurosurg Psychiatry 51: 1457
40. Umansky F, Juarez SM, Dujovny M, Ausman JI, Diaz FG, Gomes F, Mirchandani HG, Ray WJ (1984) Microsurgical anatomy of the proximal segments of the middle cerebral artery. J Neurosurg 61: 458–467
41. van der Schaaf I, Wermer MJ, van der Graaf Y, Hoff RG, Rinkel GJ, Velthuis BK (2006) CT after subarachnoid hemorrhage: relation of cerebral perfusion to delayed cerebral ischemia. Neurology 66: 1533–1538
42. Vincentelli F, Caruso G, Andriamamonjy C, Rabehanta P, Graziani N, Grisoli F, Gouaze A, Vigouroux RP (1990) Etude micro-anatomique des branches collatérales perforantes de l'artère cérébrale moyenne. Neurochirurgie 36: 3–14
43. Wang AD, Cone J, Symon L, Costa e Silva IE (1984) Somatosensory evoked potential monitoring during the management of aneurysmal SAH. J Neurosurg 60: 264–268

Comments

The authors provide an interesting report of 131 aneurysms treated in 122 patients with middle cerebral artery aneurysms. Somatosensory evoked potentials were monitored in all patients and used to identify patients that were of medium and high risk of developing postoperative infarction. Interestingly, the authors find 9 strokes that occurred and were indicated intraoperatively by the somatosensory evoked responses.

The authors have tried to provide us with a breakdown of the actual etiology of the strokes, which I believe is critical in this type of analysis. In patients with subarachnoid hemorrhage, vasospasm and distributional type stroke may occur, despite the best surgical procedure and good aneurysm clipping. However the authors have shown us that when there is a significant alteration in somatosensory evoked potential, then temporary clipping may well be the etiology of the stroke, and this occurred in 6 of their patients.

The authors are to be commended for their contribution to the literature on temporary vessel occlusion and aneurysm surgery. As is well known, temporary vessel occlusion does soften the aneurysm sac and make ultimate aneurysmal dissection and clipping significantly more straightforward. The safety of this maneuver is sometimes difficult to study, and the authors have provided us with more information regarding this particular issue.

Christopher S. Ogilvy
Boston, Massachusetts

The present results from a fairly large number of MCA aneurysm clipping procedures conducted under SEP monitoring demonstrate that there are still unexpected observations to make with this well established method.

There was a high rate of significant SEP changes during temporary clipping (TC), which was routinely performed in this series, despite a very short median TC time of 3.5 min, with a clipping time below 5 min in 85% of cases. This is in conspicuous contrast to many corresponding figures reported in the literature and highlights the potentially important role of general surgical conditions during TC such as, e.g., brain retraction, as is briefly discussed here. At the same time these results once again raise questions about the adequacy of routine temporary clipping during aneurysm surgery, even with monitoring available as in the present series.

The low sensitivity of SEP monitoring alone with regard to motor pathway ischemia is also well brought out here. It reminds us that there is motor evoked potential monitoring available now for motor tract monitoring during aneurysm surgery, as has been recently discussed in a number of publications.

Johannes Schramm and *Georg Neuloh*
Bonn, Germany

Correspondence: G. Penchet, Service de Neurochirurgie, Centre Hospitalier Pellegrin – CHU Bordeaux, 1 Place Amélie-Raba Léon, 33076 Bordeaux, France. e-mail: guillaume.penchet@chu-bordeaux.fr