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Neurophysiologic Monitoring in Posterior Fossa Surgery
I. Technical Principles, Applicability and Limitations

J. Schramm, E. Watanabe, C. Strauss, and **R. Fahlbusch**

Neurochirurgische Klinik, Universität Erlangen-Nürnberg, Federal Republic of Germany

Summary

In 135 cases of posterior fossa surgery almost exclusively in the cerebellopontine angle (CPA) intraoperative monitoring of brainstem acoustic evoked potentials (BAEP) and partly somatosensory evoked potentials (SEP) was performed. The series consisted of 20 microvascular decompressions, 63 acoustic neurinomas, 7 vascular lesions and 45 other space occupying lesions, mostly in the CPA. BAEP monitoring alone was employed in 76 cases, combined BAEP und SEP monitoring less frequently. The technique of anaesthesia and intraoperative monitoring is presented in detail including an analysis of technical problems (17 in 135 = 13% of cases) and technical failures (11 of 135 = 8%). The results of monitoring brainstem pathways contralateral to the lesion are detailed. It is concluded that the technical principles of evoked potential monitoring in posterior fossa surgery are well established. The applications and limits of this technique including its modifications are described.

Keywords: Brainstem acoustic evoked potentials; intraoperative monitoring; cerebellopontine angle; somatosensory evoked potentials; neurovascular decompression; acoustic neurinoma.

Since the first reports on the concept of intraoperative monitoring of sensory pathway function by continuous recording of evoked potentials[6–9, 13, 14, 24, 25] numerous reports have described the results of intraoperative BAEP monitoring for posterior fossa tumour surgery[2–5,23,27], neurovascular decompression surgery[4, 8,25,26] and neurovascular surgery[15]. This extensive body of literature including case reports with promising results concerning the value of intraoperative EP monitoring[6, 9, 18–20, 22, 26], has so far answered some questions. But just as many questions—many of them arising during ongoing research in this field—have been left unanswered. Previous publications from our group have pinpointed several useful aspects in the intraoperative and perioperative use of evoked potentials in neurosurgery but in a recent more detailed study[27], it has been pointed out that a larger number of cases has to be analyzed, preferrably subgrouped into acoustic neurinoma cases, microvascular decompression cases and other space-occupying lesions. After applying this technique for several years we felt that an analysis based on more than 130 cases may give some useful information. We have therefore analyzed our case material and present the results in several sections. This article covers mainly the case material, the techniques, the limitations and the problems.

Patients

135 consecutive cases monitored during surgery in the posterior fossa, most of them in the cerebellopontine angle (CPA) were evaluated. The series consists of 63 cases of acoustic neurinoma (AN), 20 cases of microvascular decompression (MD) and 52 other lesions (OL). The 52 other lesions were subdivided into space-occupying (n = 45) and vascular lesions (n = 7): 18 were in the CPA, 26 extended into the CPA, 5 were approached through the CPA, and three were 4th ventricle tumours. In the decompression series there were 14 cases of trigeminal neuralgia and 6 cases of facial nerve spasm. The diagnoses in the other lesions were: meningioma 27, miscellaneous 2, metastasis 2, haemangioblastoma 1, epidermoid or craniopharyngioma 5, astrocytoma 3, ependymoma 3, metastases 2. Only two of the acoustic neurinomas were smaller than 20 mm, 34 were up to 30 mm, 22 were between 31 and 40 mm, 5 were larger than 40 mm. Of the other 48 lesions, one was an AV malformation between 30 and 40 mm; one tumour was up to 20 mm, 18 were up to 30 mm, 32 up to 40 mm and 18 were larger than 40 mm. The majority of the petroclival meningiomas and all epidermoids extended into all cranial fossas. In a previous study 8 of the 63 acoustic neurinoma cases, 17 of the 52 other lesions and 4 of the neurovascular decompressions had been included[27].

Methods

BAEP

All tumour patients had preoperative otoneurological evaluation and all neurovascular decompressison cases with clinically abnormal

hearing had the same. All patients had pre- and postoperative BAEP testing. Routine audiometric testing consisted in pure tone audiometry, for the postoperative evaluation of preserved hearing the AN cases monitored during the last 2 years also had speech audiometry. BAEP testing was routinely performed pre- and postoperatively using the same technique as intraoperatively, except for several cases at the beginning of the series. 85dB (nHL), 11.3/sec click-stimuli were generated by pulses of 100 µs. In the last 2 years the stimulation rate was increased to 21.3/sec to reduce the analysis time and to improve feedback. The contralateral ear was masked with white noise at 55dB (nHL). Except for a few initial cases we now routinely use a silicone tube extension (20 cm) to small earphones. Recently we have introduced the new Nicolet ear piece stimulator unit with built-in tube extension. BAEP are recorded continuously throughout surgery. One average consists of at least 1.500, sometimes 2.000 single runs and two averages were superimposed to document reproducibility. At the start of the study two averages with rarefaction clicks were followed by two averages with condensation clicks. We now use one click polarity only, usually the one which gives better potentials, but make a control recording with the other click polarity if a significant change in the BAEP is observed[19]. Recordings were made initially using disc electrodes, now from needle electrodes placed at Cz and clip-electrodes on both earlobes (A1, A2). The ground electrode is placed at Fz preferrably behind the hairline. The Nicolet CA 1000 and the Pathfinder I signal averager were used. A two channel recording configuration with 256 addresses per channel was available. Recording bandpass was 150 to 3.000 Hz, analysis time routinely 10 ms, if latencies were markedly elevated, up to 20 ms. The electrode impedances with surface electrodes were usually around 1 kΩ, with needle electrodes between 3 and 4 kΩ. Cleaning paste (Omniprep, Weaver & Co., U.S.A.) and electrolyte adhesive paste (TECA Corp. U.S.A.) were used. Both electrode types were secured by two layers of sterile adhesive paper drapes: other techniques may be as safe and quicker[28].

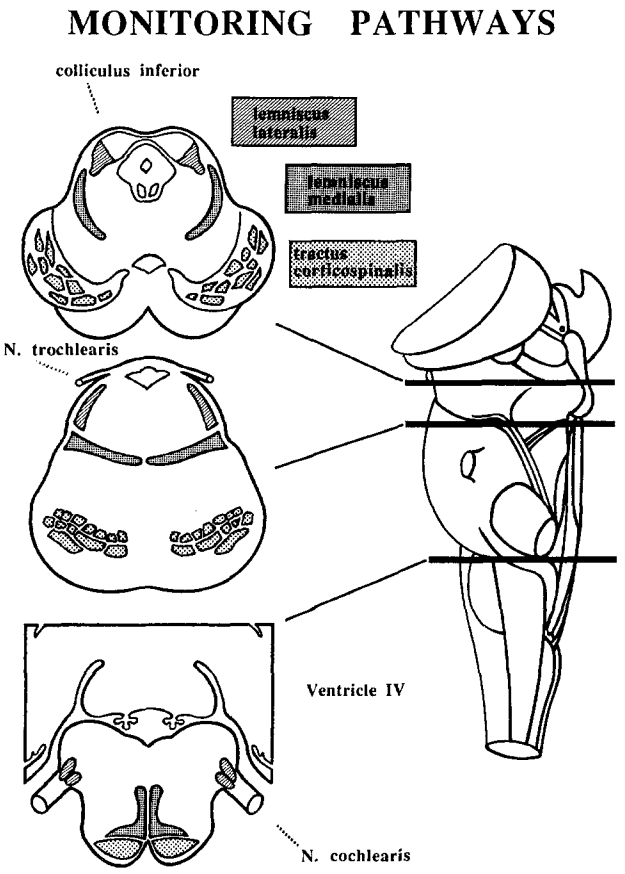

Fig. 1. Schematic representation of location of acoustic, somatosensory and motor pathways in the posterior fossa

SEP

For somatosensory evoked potential monitoring median nerve stimuation was used with a frequency of 5.3 Hz. Recordings were performed over the contralateral scalp (C3′/C4′–Fz) and at the neck (Cv7–Fz). Analysis time was 30 to 50 ms, a two channel setup was used. SEP monitoring usually concentrated on the side of the brainstem where the trepanation and the prospective manipulation was located. For lesions above the obex this means that median nerve stimulation contralateral to the side of the lesion had to be used. Lesions extending down to the foramen magnum or lying exclusively in the lower portion of the CPA were monitored using ipsilateral median nerve stimulation. Contralateral SEP were recorded from time to time as a biological control of the system and the effects of anaesthesia.

Conduction Monitoring

Although preoperative BAEP were routinely obtained, the first traces after induction of anaesthesia were used as base-line for the evaluation of intraoperative BAEP changes. Monitoring was done continuously. In bimodal monitoring two BAEP averages are followed by two SEP averages. This routine sequence may be changed as intraoperative manipulations require. During dissection within the meatus, for example, only BAEP averages will be done whereas dissection of the capsule along the brainstem and its larger vessels will be monitored by the two modes. Recently we have used a programme (written by E. W.) on the Pathfinder I which allows SEP and BAEP to be monitored alternatively in a semi-automatic fashion. After the patient has been wired up for median nerve and acoustic stimulation and recording using all 6 channels of the Nicolet Pathfinder I, the programme switches internally from one stimulation and recording mode to the next stimulation and recording mode and automatically chooses the pre-set technical parameters and electrode locations. With non-programmable averagers the change of stimulus location requires many switches to be operated by hand, which takes time, delays acquisitation of data and is prone to mistakes.

Data Handling

All averaged traces were stored on floppy discs and plotted out at a later time or more recently during operation, if needed. A monitoring protocol was kept with times, notes on the anaesthetic protocol, drugs given, comments from the surgeon, comments from the monitoring person and comments on the quality of evoked potentials. Relevant data concerning the patient (electrode positions, positioning, tumour location etc.) were also included. The total of 135 cases was evaluated in detail by four persons, at least two of them working together for at least 2 1/2 years and all personnel involved sharing overlapping time periods. Most cases were discussed in regular meetings of the neuromonitoring group. Based on the primary data (averages) the classification of secondary data (e.g. potential loss) was repeatedly checked. The final evaluation was done

from a data base on a personal computer, the programme of which was written by one of us (E. W.) on a standard D-base III system (Ashton-Tate). The data base for each case included pre- and postoperative neurological data, and detailed intraoperative evoked potential findings, including changes. The data base also contained a case evaluation file and numerous comment files with enough space for filing open questions, interpretations and available observations.

Anaesthesia

The standard anaesthetic regime consisted of a fentanyl-N_2O-muscle relaxant anaesthesia with flunitrazepam as a premedication. We tried to avoid halogenated anaesthetics (66 out of 135 cases), but ethrane in a concentration up to 0.4 vol.% had to be used in 42 cases and in 27 patients in a concentration of over 0.5 vol%. This narcosis prolongs the BAEP latencies by 0.1 ms, except wave I. The addition of enflurance increases wave V latency by approximately 0.1 to 0.2 ms, but by using the values after induction of anaesthesia a latency increase for wave V of approximately 0.1 ms only has to be taken into account. With the increase in our knowledge and following the growing body of literature on the effects of anaesthetics on evoked potentials [7, 7, 10, 11, 29, 31] we managed to conduct anaesthesia with very little or even without N_2O in a certain number of cases.

Although nitrous oxide does not influence BAEP, it reduces the amplitude of the primary complex of the median nerve SEP (N20). In cases with no or little nitrous oxide rather high doses of fentanyl had to be used. Fentanyl influences amplitude and latency of cortical EPs only little, even in high doses. For BAEP the latency of wave V increases slightly. The high fentanyl doses often necessitated that the patient was brought to the intensive care unit with anaesthesia still acting and therefore prolonged intubation was necessary. Currently we use fentanyl in rather high doses as the main agent but do supplement it with a halogenated agent which is given in a continuous and low concentration, for example ethrane 0.4 to 0.6%.

After surgery for large acoustic neurinoma cases intubation for 1 to 3 days after surgery was maintained routinely. The main reason for using halogenated agents was a rise in blood pressure. In the later phase of our experience blood pressure was also managed with either sodium nitroprusside or calcium-antagonists nimodipine and nifedipine. 17 patients were operated upon in the sitting position, the others in the lateral decubitus position.

Results

Limitations and Technical Problems:

Monitoring may be hampered or impossible for several reasons. These causes have been classified as technical limitations and technical problems. The main technical limitation—deafness—is forseeable, whereas technical problems characteristically come as a surprise.

Technical Limitations:

Not unexpectedly a proportion of our patients were deaf before surgey: 29 of 63 acoustic neurinomas and 3 out of 72 other lesions. Therefore, monitoring on the tumour-affected side was impossible in 32 of the tumour cases, but possible in all 20 microvascular decompression cases. Preoperative deafness thus eliminates a rather high proportion of tumour patients from effective ipsilateral acoustic nerve monitoring: 29 of 63 neurinomas and 3 out of 52 other tumours. On top of that in 11 patients (5 acoustic neurinomas, 6 other tumours) who had some residual preoperative hearing, no BAEP monitoring was possible, because they had no reproducible BAEP during the procedure (Table 1).

Table 1. *Technical Limitations*

	AN 63	OTHERS 72	SUM 135
NO IPSILATERAL BAEP MONITORING USEFUL	**39**	**16**	**54**
PAT. DEAF: NO BAEP	29	3	32
MARKED HEARING LOSS: NO OR POOR BAEP	5	6	11
INTRAOPERATIVE TECHNICAL BAEP LOSS	4	7	11

Technical Problems:

Marked or severe temporary or permanent problems in obtaining useful BAEP occurred in 17 cases. They were due to artefacts (n=9), recording electrodes (n=2), stimulation electrodes (n=4), and of unknown cause (n=2). These problems were correctable in 5 cases and not correctable in 12 cases. Principally all electrode problems were either avoidable or detectable within a short time and therefore remediable. If these technical problems arose during a non-critical phase of surgery like trepanation, these cases were considered successful monitoring procedures as monitoring was

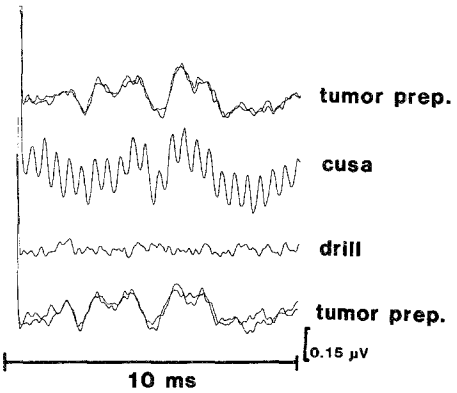

Fig. 2. Some artefacts encountered in a right acoustic neurinoma. The left ear was stimulated with 90 dB, recordings were from Cz-Al. During the application of the ultrasonic aspirator a high frequency noise is superimposed and during the use of the microdrill no BAEPs are available, possible due to the noise directly applied to the inner ear by bone conduction

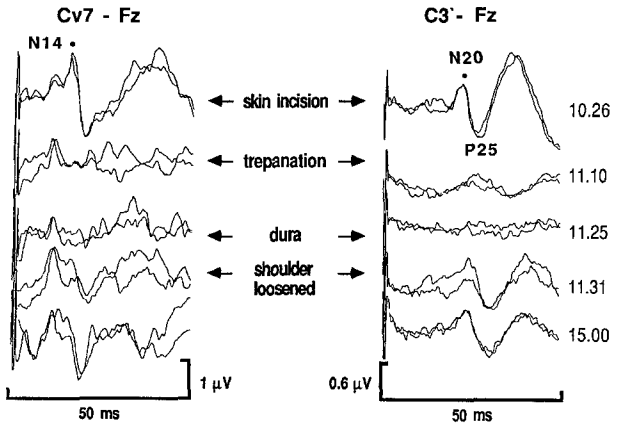

Fig. 3. Adverse effect of positioning on cortical median nerve SEP due to brachial plexus traction. This patient had a posterior fossa meningioma and surgery was performed in the lateral park bench position through a suboccipital craniectomy. Normal cervical and cortical SEP were available shortly after positioning, but cortical SEP gradually disappeared. As the contralateral median nerve SEP and the BAEP remained constant, this could not be an effect of anaesthesia, and as these effects occurred during trepanation and were completed before any brain manipulation the reason should be outside the posterior fossa. After the strap retaining the shoulder was loosened cortical SEP recovered immediately

possible during tumour exposure and resection (one of 12 non-correctable technical failures). Therefore, in 11 cases monitoring was impossible solely for technical reasons. Thus, the technical failure rate was 11 cases out of 135, corresponding to circa 8%. Recording problems occurred during the use of the ultrasonic aspirator and monopolar coagulation. Therefore we soon routinely interrupted the averaging process while the ultrasonic aspirator was in action, whereas coagulation artefacts were suppressed by automatic artefact rejection (Fig. 2).

In 3 cases somatosensory evoked potentials became temporarily unobtainable either after positioning or early during surgery because of traction on the brachial plexus (Fig. 3). The loss of both the neck SEP and the cortical SEP in combination with good technical availability of BAEP indicated a peripheral source of this SEP abnormality. Loosening the retraction of the shoulder necessary in the lateral park bench position led to resolution of this problem with time.

Bimodal Monitoring

Bimodal monitoring was introduced only recently because it was felt that BAEP pathways only represent a very small proportion of the cross section of the brainstem (Fig. 1). 25 acoustic neurinomas, 1 angioma, 3 aneurysms, 10 microvascular decompressions and 21

Table 2. *Relation of SEP and BAEP Changes* (n = 26) *in Bimodal Monitoring* (n = 55) (= constant EP, ↓ = intraoperative deterioration and/or loss, ∅ = absence of EPs)

	BAEP = SEP ↓	BAEP ↓ SEP =	∅ BAEP SEP =	BAEP ↓ SEP ↓
AN	1	2	2	2
OTHERS	4	8	2	5
TOTAL	5	10	4	7

other lesions were monitored using BAEP and SEP. A useful evaluation was possible in 55 of these cases. The relationship of BAEP and SEP changes in this subgroup is shown in Table 2. It is remarkable, that both modalities may remain constant, deteriorate, or may disappear, but quite independently from each other. We have never seen SEP changes in microvascular decompression cases. It was frequent that the BAEP deteriorated while the SEP remained constant (N = 10). That the SEP deteriorated whereas the BAEP remained constant (N = 5) was less frequently seen. Remarkably enough there was even one acoustic neurinoma with constant BAEP but a deterioration in SEPs. Four of five cases with this combination of EP changes belonged to the other tumour or vascular lesion group.

Of the 10 cases with BAEP deterioration and constant SEP, two patients were deaf postoperatively and 2 more patients were deaf out of the four with preoperative BAEP loss and constant SEP. Of the 7 patients with deteriorating BAEP or intraoperative BAEP loss plus SEP deterioration 2 patients were deaf.

The most remarkable finding in this group of bimodal monitoring is, however, that the BAEP and SEP behave quite differently and this reflects the different influences of intraoperative traction, coagulation and indirect brainstem manipulation on the pathways. Two of the SEP changes were definitely attributable to an increase in the ethrane-concentration. After some time we discovered that the sitting position was responsible for a large proportion of the SEP changes. The most common SEP changes seen in the sitting group were profound alterations associations with the release of CSF with opening of the parapontine cistern or with collapse of the brain hemispheres in the sitting position. A detailed presentation of these SEP alterations caused by influx of air in the sitting position will be presented elsewhere[32].

It should also be noted that BAEP and SEP alterations observed in bimodal monitoring do not always occur simultaneously. The simultaneous changes in SEP and BAEP were the two cases explained due to

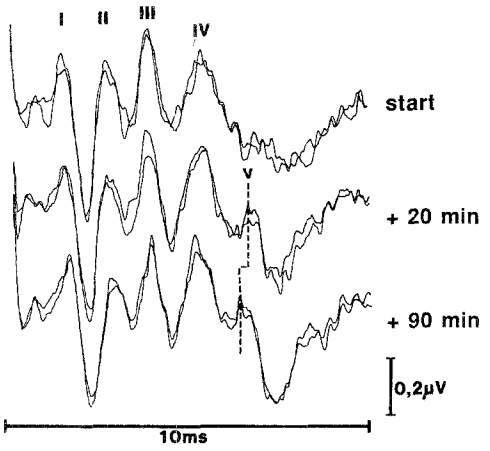

Fig. 4. Improvement in contralateral BAEP in a 45 year old woman with a partly cystic right-sided acoustic neurinoma. The BAEP on the affected side showed only wave I and II whereas on the non-affected side waves I to IV were clearly seen. Twenty minutes after evacuating the tumour cyst wave V reappeared quite clearly and after further 70 minutes the latency of the contralateral wave V had shortened. Wave I of the ipsilateral BAEP on the affected ear remained constant throughout surgery. The patient was able to hear postoperatively

anaesthesia. Often SEP changed due to the influx of air and BAEP changed at quite another time point obviously associated with manipulation of the tumour and brainstem. None of the cases with significant morbidity and mortality (except hearing loss) was observed in the group with bimodal monitoring. Therefore, it is yet impossible to make a judgement about the value of the bimodal monitoring technique at this time.

Contralateral Monitoring

Contralateral monitoring of BAEP may be encountered in two different ways. The contralateral pathways may be monitored afer contralateral stimulation only and this alternative will be covered in this section. Theoretically the contralateral half of the upper brainstem can also be monitored by using contralateral recordings after ipsilateral stimulation. But if a functioning ipsilateral acoustic nerve is present, ipsilateral monitoring would be preferred in that situation. Additional contralateral monitoring was performed in a total of 88 patients (41 acoustic neurinomas, 15 microvascular decompressions, 32 other lesions). In only 3 of them (3 other lesions) contralateral BAEP monitoring was the only modality used. To offer at least brainstem monitoring to those patients where ipsilateral acoustic pathway monitoring was impossible due to deafness, ipsi- and contralateral BAEP recording was performed following stimulation of the contralateral healthy ear. The number of significant changes in this group was very small. 12 cases showed changes in contralateral BAEP: 6 out of 44 acoustic neurinomas, 5 out of 32 other lesions. No microvascular decompression case showed contralateral BAEP changes, except in one a technical potential loss. A closer look into the cases with EP-changes after contralateral ear stimulation shows that 2 of the 6 acoustic neurinomas were bilateral acoustic neurinomas. The tumour size in the OL group were up to 30 mm in 4 cases, up to 50 mm in 5 cases and 60 mm in two cases. This shows that the subgroup with EP-changes after contralateral stimulations contains comparatively more large and very large tumours related to the total number of cases (Figs. 4 and 5). Among these tumours with contralateral BAEP changes were two of the 5 true operative mortalities of the whole series. Therefore, quite remarkably, although only 11 out of 86 cases with contralateral monitoring showed intraoperative changes, two of the 5 cases of operative mortality belong into these 11 cases with changes in contralateral BAEP, the remaining 6 cases without

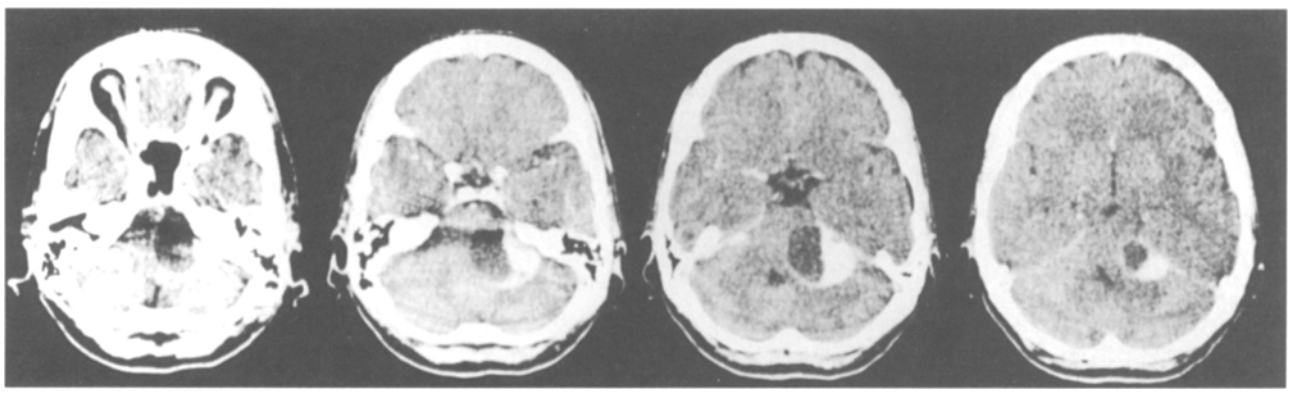

Fig. 5. CT-scan from the same patient as in Fig. 4. Partly cystic acoustic neurinoma with preserved hearing pre- and postoperative

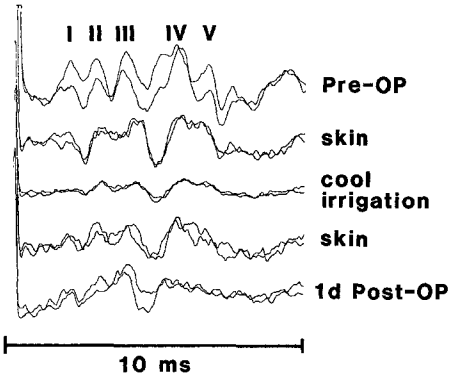

Fig. 6. Contralateral BAEP recorded from Cz-Al in right-sided acoustic neurinoma. As the patient was deaf preoperatively only contralateral monitoring was possible, giving well reproducible BAEP with all five peaks. At closure of the skin all waves were available without latency delay as compared to postinduction values. This patient developed a hemiparesis on the second day, slowly lost consciousness and died on the seventh day, possibly due to a vascular brain-stem lesion. The stable intraoperative contralateral BAEP gave no clue as to the developing brainstem lesion, which may have been due to thrombosis of a brainstem vessel developing in the postoperative period. This was the only true brainstem mortality in our series

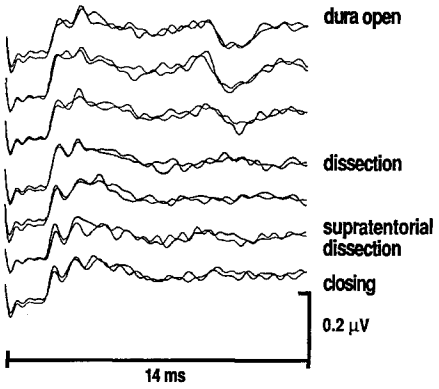

Fig. 7. BAEP after stimulation of the left ear in a patient with large left petroclival meningioma approached by a combined subtemporal-suboccipital approach. The BAEP were altered but wave I and wave V were clearly discernible. This patient was comatose and hemiplegic postoperatively and remained apallic. The CT scan (Fig. 8) demonstrated a lesion mainly located in the ventrolateral and ventromedial brainstem possibly due to damage of perforating branches from the superior cerebellar artery, which affects mainly the left motor pathways and the formatio reticularis. The preservation of wave I and the loss of wave V suggest that the acoustic pathway was disturbed in the upper brainstem, although losses of wave V without these severe sequelae have been observed quite frequently

postoperative morbidity or mortality were 4 meningiomas and 2 other tumours. In conclusion in contralateral monitoring intraoperative BAEP changes are observed only in a small proportion of cases (11 of 86). All these changes were not dramatic, most of them

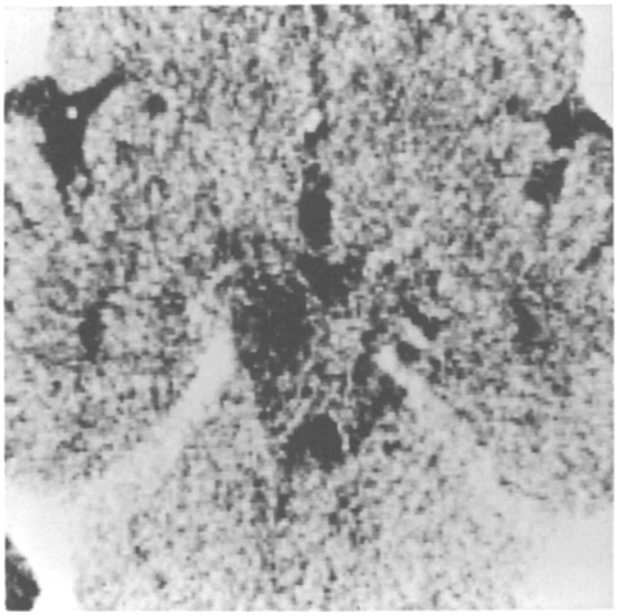

Fig. 8. Enlarged CT scan at the level of the tentorial notch showing a hypodense lesion in the left ventral aspect of the brainstem in a patient with left petroclival meningioma (and hemiplegia on the right side) on the fifth postoperative day. The BAEP of this patient are shown in Fig. 7

were transitory. The patients affected by these changes had a tendency to have larger tumours. Despite the fact that contralateral changes were rather less dramatic and rare, 3 of those who died in the perioperative phase (n = 5) or from a pulmonary embolus one month later (n = 1) belong to this small subgroup. The only brainstem death in the whole series therefore could not be predicted from ipsilateral BAEP, as these were unobtainable and contralateral BAEP showed no marked changes (Fig. 6). The two cases with severe brainstem morbidity showed no particularly dramatic BAEP changes (Fig. 7). In one of them the lesion could be demonstrated confined to the ventral aspect of the left cerebral peduncle (Fig. 8).

Discussion

The need for presentation of data separatedly for acoustic neurinomas, other tumours, and microvascular decompression cases has been pointed out in a previous publication of 31 cases[27]. When we started this monitoring series it was as yet unclear how BAEP behaved intraoperatively even in those cases without postoperative neurological deterioration[10]. The valuable contributions from the groups that initiated this kind of work[3,4,6,9,13,15] presented numerous interesting findings. It soon became clear that there is a difference

in monitoring patients with a primarily intact brainstem and cranial nerves such as MD and tumour cases. The degree of "normal or acceptable" changes to be expected during microvascular decompressions, during non-CPA-surgery and during ipsi- and contralateral CPA surgery has been pointed out[4, 10, 26].

The need to monitor these lesions comes from the well known morbidity. Loss of hearing is observed in microvascular decompression at a frequency of between 2 and 7%, in small series even higher[12, 16]. Valentine Logue has highlighted the dangers of petroclival meningiomas by saying that "these tumours have a sinister reputation". Despite often incomplete removal morbidity may be high even in experienced hands. As the number of patients with a significant postoperative morbidity or mortality in the bimodal sub-group was zero the main aspect of bimodal monitoring, namely the detection of brainstem lesions, cannot usefully be presented here. Only some effects concerning the application of the technique and the avoidance of the detrimental effect of the sitting position have been worked out. By positioning the recording electrode for the somatosensory evoked potential more basal in a temporal location (T3', T4') instead of the usual central position (C3', C4') the sudden drop in amplitude as often encountered in the sitting position can be avoided and therefore the risk of misinterpreting the sudden changes is minimized[32].

Technique

Among the technical aspects many no longer need discussion. In the meantime it is accepted that in the intraoperative setting the stimulation rate for BAEP may be increased up to 22 Hz. Other points like recording bandpass, analysis time and electrode impedances need no further discussion because they are universally agreed upon. The minimization of click artefacts by the use of a silicon tube-extension as used in our laboratory and others for several years has now found its way to the average accessories suppliers. Most groups still use 1500 to 2000 single runs for one average despite the fact that Prichep *et al.* some time ago advocated the system of the sliding average based on small groups of subaverages[23]. Very recently Bertrand *et al.* (1987) have suggested a method to speed up the averaging process which usually takes between 2 and 3 minutes for one run and may last too long during critical stages of dissection to give useful information to the surgeon[1]. Often the situation becomes worse if the recording is technically not satisfying, when it may take several minutes for one average. Curiously enough, the question of click polarity which has been addressed for the clinical neurophysiological setting is hardly ever mentioned in the monitoring literature. The irritating facts are that one may have a very marked change using one click polarity which may be very much less marked than in the other click polarity[19].

After initially changing between rarefaction and condensation clicks we now use mainly one click polarity which is from time to time supplemented by a recording in the other click polarity, especially if some significant change becomes evident on the screen.

The conduct of anaesthesia in our monitoring cases has been a problem at least during the first 1 1/2 years. This problem originated in the lack of experience on our side and on our neuroanaesthetist's side. In the meantime, however, many studies about the effects of single anaesthetic drugs have been conducted and these effects are well known both for subcortical and cortical SEP and BAEP[7, 10, 11, 17, 29, 31]. During anaesthesia usually a combination of several drugs is used, the effects of which may be very different and affect various EP-components in a different way[11, 17]. We have now learned to live with halogenated agents as long as the concentration is not higher than 0.5 vol.%. We have stopped worrying about the small latency increases observed particularly for wave V after the use of these agents and we have learned to distinguish them from other causes of potential change. Our neuro-anaesthesists have become more relaxed with the use of very high doses of fentanyl and a liberal use of nimodipine or sodium nitroprusside. Our tendency to operate on most cerebellopontine angle lesions in the lateral decubitus position led us to discover rather late the adverse effects of the influx of air into the subdural space onto cortical SEPs as described previously by others[18, 30]. There were also 3 cases of brachial plexus stretching with unilateral potential loss which took us quite a while to discover when it occurred the first time.

Technical Limitations and Problems

The distinction between limitations and problems seems useful. One knows in advance that ipsilateral monitoring in a deaf patient is not possible and this type of limitation is not counted as a technical failure which one could have avoided with a better technique. The fact that a large proportion of acoustic neurinomas has either no BAEP or poor BAEP and is therefore not available for ipsilateral monitoring represents an obvious limitation of the use of this technique in acous-

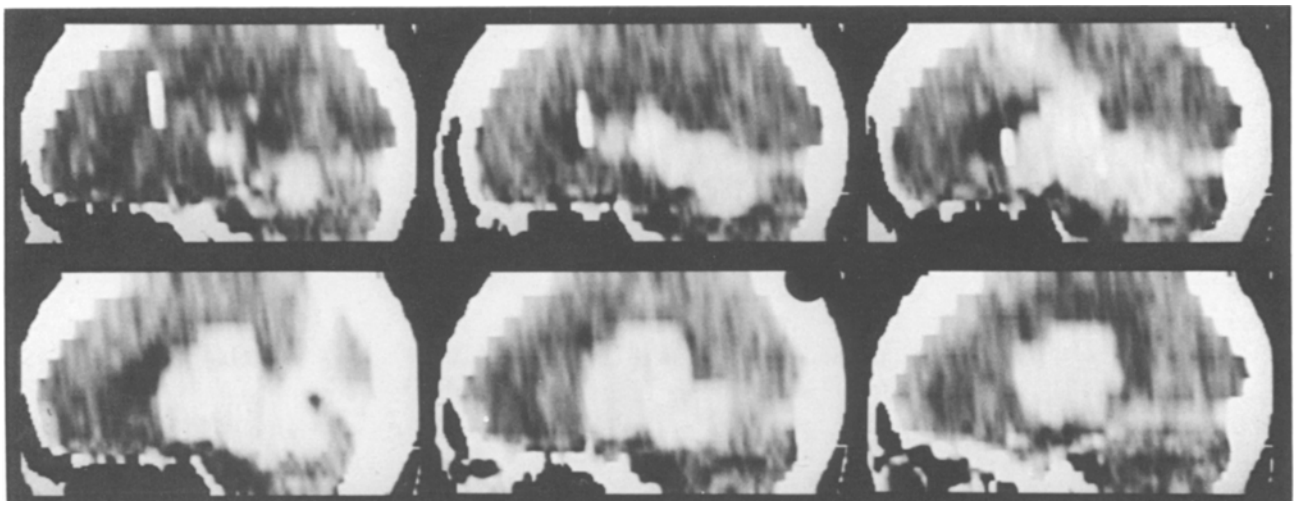

Fig. 9. Reformatted CTs of a huge meningioma probably arising from the tentorial notch and reaching from the posterior fossa through the third ventricle into both lateral ventricles. The brainstem was compressed markedly and this is considered a case where bilateral and bimodal SEP and BAEP monitoring might be useful. In fact, encouraged by constantly normal SEP and BAEP this tumour was removed in one session via a left median occipital transtentorial approach except for a 1 cm remnant laterally to the right of the vena Galeni

tic neurinomas. Whether the use of contralateral monitoring is of help in this situation remains doubtful. There have been reports on contralateral BAEP changes both experimentally[21, 33, 34] and clinically[2, 10] but in our own experience contralateral changes were rare, usually not severar and had a tendency to occur in a group of patients with rather large lesions comprising a high proportion of the overall mortality and morbidity. This seems only to indicate that these patients are more affected by their tumours than the average of our group. But a direct use of contralateral monitoring cannot be advocated from our findings. We tend to give up contralateral monitoring for this reason. The technical failure rate of approximately 8.5% is still high, although our initial experience was somewhat more positive[27]. The main source of this are AC artefacts, which are often not removable from the system and several times caused cessation of monitoring.

So the question remains open whether a deaf patient with a large CPA or petroclival meningioma should be monitored by contralateral stimulation. At present we would be inclined to monitor the large meningioma cases in this way but we would no longer monitor acoustic neurinomas via the contralateral route. Contralateral monitoring seems only useful in particularly dangerous lesions like angiomas or in particularly large lesions (Fig. 9). Contralateral monitoring is now definitely considered unnecessary in microvascular decompression.

It should be pointed out that the indication for intraoperative monitoring in most of these cases was mainly to gain experience. Although some of the knowledge we have presented in this paper became clear during the time we continued to monitor these cases because we felt more experience is necessary and also because other groups had supported some of the ideas[2].

In summary it may be concluded that the technical principles of evoked potential monitoring for posterior fossa surgery are well established by several groups. The techniques used depend on the lesion to be monitored, the expected difficulty of surgery, and the anatomical particulars. The applicability of these techniques is also established, although the value of certain techniques like contralateral monitoring in deaf patients with small lesions does not seem to be useful. The application of bimodal or multimodal monitoring, although it seems theoretically more promising, has yet to prove that it gives more information to the surgeon. The limitations of neurophysiological monitoring have become quite clear. The requirements of the type of anaesthesia which would be ideal for intraoperative neurophysiological monitoring interfere with immediate postoperative waking-up and therefore, anaesthesia for monitoring is a compromise which has to take into account anaesthesia-induced EP alterations. Deafness is a severe biological limitation as it makes ipsilateral BAEP unavailable for monitoring in a proportion of CPA surgery cases. A certain rate of technical failures seems to be unavoidable, although it may be kept very low in those centres where the actual

monitoring procedure is in the hands of the same technicians for many years. There also technical limitations due to the time needed to obtain good BAEP averages, but recent advances in technology promises future improvements.

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Prof. Dr. med. Johannes Schramm, Neurochirurgische Klinik, Universität Erlangen-Nürnberg, Schwabachanlage 6, D-8520 Erlangen, Federal Republic of Germany.