Acta Neurochir (Wien) (2000) 142: 263–268

Acta Neurochirurgica

Intra-Operative Mapping of the Motor Cortex During Surgery in and Around the Motor Cortex

Th. Kombos, O. Suess, Th. Funk, BC. Kern and **M. Brock**

Neurochirurgische Klinik, Universitätsklinikum Benjamin Franklin, Freie Universität Berlin, Berlin, Germany

Summary

The intra-operative use of neurophysiological techniques allows reliable identification of the sensorimotor region, and constitutes a prerequisite for its anatomical and functional preservation. The present prospective study combines monopolar cortical stimulation (MCS) with the recording of phase reversal of somatosensory evoked potentials (SEP-PR) in a protocol for the intra-operative mapping of the motor cortex. Functional mapping of the motor cortex by SEP-PR and MCS was performed in 70 patients during surgery in and around the motor cortex. The central sulcus was identified by SEP-PR. Cortical motor mapping was then performed by monopolar anodal (400 Hz) stimulation. Motor responses were recorded by needle electrodes placed in the muscles of the contralateral extremities. Surgery was performed under general anaesthesia without muscle relaxants.

Intra-operative localization of the central sulcus by SEP-PR was possible in 68 patients (97.14%). Motor evoked potentials (MEP) were elicited following MCS in 67 cases (95.7%). In 3 cases no MEP was recorded, not even after maximal stimulation intensity, the central sulcus being localized by SEP-PR only. On the other hand, MCS allowed localizing the motor cortex in the 2 cases with no recordable SEP-PR. Thus, combining SEP-PR and MCS allowed intra-operative localization of the sensorimotor cortex in 100% of the cases.

Keywords: Intra-operative monitoring; motor cortex; cortical stimulation; phase reversal.

Introduction

The development of novel navigation systems thanks to the advances in imaging procedures during the past two decades has paved the way for the improvement of functional preservation during brain surgery. The more aggressive the approach, the better the survival rate and the quality of life [9, 18, 30, 32]. Therefore, intra-operative functional mapping techniques are of paramount importance in localizing functionally relevant areas and in allowing maximal resection with minimal morbidity.

The method of phase reversal of somatosensory evoked potential (SEP-PR) was introduced by Goldring *et al.* [25, 26] based on experience gained in epilepsy surgery. A number of studies have since described its application in tumour surgery [2–7, 17, 20, 23, 28, 33–35, 40, 41]. SEP-PR, however, allows intra-operative localization of the central sulcus but yields no functional information.

Only direct stimulation of the motor cortex ensures intra-operative identification of motor areas. Monopolar cortical stimulation (MCS), a technique recently described [16, 17, 39], allows quantitative and qualitative analysis of the recorded motor evoked potentials (MEPs). However, this is still very new, and has been called a ''technique in evolution'' by Cedzich *et al.* [17].

This prospective study combines MCS with SEP-PR in a protocol for intra-operative mapping of the motor areas. The protocol was evaluated according to the following criteria: safety and sensitivity for cortical motor areas.

Methods and Patients

Functional mapping of the motor cortex by SEP-PR and MCS was performed in 70 patients (39 males and 31 females aged 16 to 79, mean 56.2 years) during surgery in and around the motor cortex. The space-occupying lesions were located in the frontal lobe rostral to the precentral gyrus in 12 patients, in the precentral gyrus in 22, and in the parietal lobe in 19 patients. Seventeen lesions extended into more than one cerebral lobe. There were 34 (28.58%) lesions in the left and 36 (51.42%) in the right hemisphere. Patients with a lesion in or around the central region were included in the study. Patients previously operated on were excluded from the study. The topographic relationship between the lesion and the sensorimotor area was evaluated preoperatively in all patients by means of computed tomography or magnetic resonance imaging. Table 1 shows the histological diagnosis in this series of patients.

Table 1. *Histological Diagnosis in 70 Patients*

Histological diagnosis	Number of patients
Glioblastoma multiforme	23 (32.86%)
Low grade Glioma	8 (11.43%)
Astrocytoma (WHO II°)	(3)
Astrocytoma (WHO III°)	(4)
Oligoastocytoma (WHO II°)	(1)
Metastasis	21 (30%)
Arteriovenous Malformation	5 (7.14%)
Epidermoid	1 (1.43%)
Meningioma	12 (17.14%)
Total	70

Table 2. *Stimulation Parameters for the SEP-PR*

Stimulation method	Bipolar
Stimulation location	Median nerve (n = 67)
	Tibial nerve (n = 3)
Duration	0.2–0.3 ms
Intensity	10–50 mA
Frequency	2.3 Hz; 4.7 Hz; 9.1 Hz

Anaesthesia

All operations were performed under general intravenous anaesthesia (TIVA). Muscle relaxants were administered only for intubation, not during surgery. Anaesthesia was induced by Propofol (1–2 mg/kg) and Fentanyl (5–10 μg/kg). Propofol (75–125 μg/kg/h) was continuously given during surgery. Analgesia was achieved by Alfentanyl in 66 patients, Sulfentanyl in 2 and Fentanyl in another 2 patients. A standard anaesthesia regime was used. The effects of anaesthesia on intra-operative mapping was not the subject of the present study.

Monitoring Equipment

A Nicolet Viking IV (Nicolet Instruments, Biomedical Division, Madison, WI) was used for all examinations.

Somatosensory Evoked Potentials Phase Reversal (SEP-PR)

The median (n = 67) and tibial (n = 3) nerves contralateral to the lesion were stimulated. Stimulation parameters are given in Table 2.

Bipolar cortical SEPs were recorded with a strip (row of five or six electrodes embedded in silicon) or grid electrode (2 × 5; 3 × 5) (Ad-Tech; Ad Technic, WI) placed on the cortex. Following median nerve stimulation the strip was placed with an acute angle of approximately 65° to the central sulcus [40]. Following stimulation of the tibial nerve the strip was placed 0.5–1 cm from the midline perpendicular to the central sulcus. The position of the strip was modified until the largest N′20/P′30 or N′40/P′45 was recorded. The centres of the electrodes along the strip were 1.5 cm apart. The amplification band-pass was set at values of 100 Hz to 1 kHz, and 30 to 100 responses were averaged.

Monopolar Cortex Stimulation (MCS)

Identification of the central sulcus by SEP-PR was followed by functional mapping of the motor system.

Agnew [1] published requirements of safety for brain tissue (charge density not exciting 40 microcoulomb/phase/cm^2) are based on experiments with continuous stimulation of the brain. To our knowledge no data are published till today about the effect of electrical stimulation (bipolar or monopolar) on the human cortex. In the present study stimulation was performed with a short train (7 pulses) of monopolar, anodal, rectangular pulses applied to the cortex at a frequency of 400 Hz. These parameters were applied in 60 cases. In a further 8 cases a train of 7 pulses and a frequency of 500 Hz was used. In 2 patients a longer train (10 puses) was applied at a frquency of 500 Hz.

Table 3. *Stimulation and Recording Methods for MCS*

	Monopolar stimulation
Intensity	4.7–25 mA
Frequency	400–500 Hz
Train	7–10 Pulses
Pulse duration	0.1–0.7 ms
Filter	10 Hz–10 kHz
Sensitivity	20–100 μV/Div
Recording	needle electrodes

The cathode was located ipsilaterally on either Fp1 or Fp2, according to the 10–20 System. An intensity of 5 to 20 mA was applied with an impulse duration of 0.1 to 0.7 ms (Table 3). Stimulation intensity was gradually increased until action potentials were elicited in the target muscles. A constant voltage stimulator was used, and the maximum stimulation intensity was set at 25 mA.

Action potentials were recorded from the forearm flexor, thenar and quadriceps muscles contralateral to the side of stimulation. A pair of subdermal needle electrodes was used for recording.

The stimulation electrode, a single steel plate of 3.5 mm diameter embedded in silicon, was first placed on the cortical area from which the largest N′20/P′30 or N′40/P′45 were recorded. Following this first stimulation further stimulations, along the precentral gyrus and the frontal cortex adjacent to the precentral gyrus were performed. For the mapping procedure only the stimulation intensity was altered. The distance of the stimulation probe from the midline and from the central sulcus was measured for every stimulation point.

Results

Intra-operative localization of the central sulcus by SEP-PR was possible in 68 patients (97.14%) (Fig. 1). In two cases of parietal meningioma the recording electrodes could not be placed across the central sulcus. A typical postcentral cortical SEP with N20/P30 peaks was thus recorded, but a phase reversal was not observed. Following tibial nerve stimulation a parietal N40/P45 and a frontal N′40/P′45 was recorded. Median nerve stimulation was performed in 67 cases and tibial nerve stimulation in 3.

No complications were observed during the SEP-PR. The anaesthesia protocol used was compatible with the SEP-PR.

Functional mapping of the motor cortex by direct MCS followed SEP-PR in all 70 patients. MEPs were elicited following MCS in 67 cases (95.7%) (Fig. 2). In

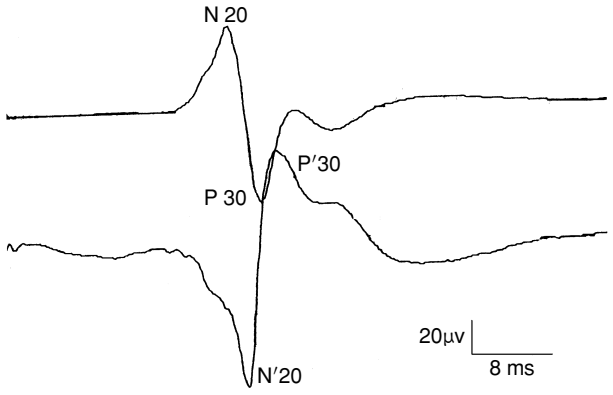

Fig. 1. Phase reversal of somatosensory evoked potentials as recorded following stimulation of the median nerve

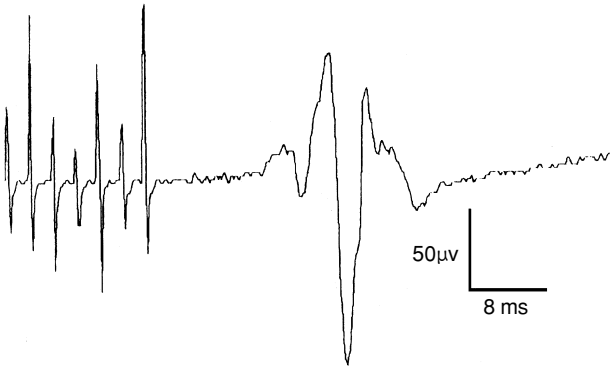

Fig. 2. Motor evoked potentials recorded from the thenar muscle as a result of direct cortical monopolar stimulation

3 cases no MEP was recorded, not even after maximal stimulation intensity. The first case was a parietal glioblastoma. Following SEP-PR, dislocation of the stimulation electrode occurred. No MEP could be elicited even after repositioning the electrode. There was no postoperative clinical deterioration. The second case was a glioblastoma infiltrating the precentral gyrus. The patient presented with a hemiparesis which remained unchanged postoperatively. The third case was a young patient with a cavernoma in the white matter of the precentral gyrus. Stimulation of the precentral gyrus elicited no MEP. The anatomical relationship of the mass to the precentral gyrus was determined intra-operatively by SEP-PR in all 3 cases.

There were no complications following MCS, particularly no intra-operative seizures. Following stimulation of the precentral gyrus the MEP latency of thenar muscles varried from 21.1 to 36.3 ms ($\bar{x}$ = 27.2 ms), that of the forearm flexors from 18.3 to 29.8 ms ($\bar{x}$ = 22.6 ms) and of the quadriceps muscle from 21.4 to 32.6 ms ($\bar{x}$ = 28.3 ms). Following stimulation of the frontal cortex adjacent to the precentral gyrus the MEP latency of thenar muscles varied from 22 to 35 ms ($\bar{x}$ = 27.8 ms), of the forearm flexors from 18 to 29.5 ms ($\bar{x}$ = 22.9 ms) and of the quadriceps muscle from 21.6 to 32.7 ms (($\bar{x}$ = 28.3 ms). There was no statistically significant difference from the MEP latency recorded following stimulation of the frontal cortex adjacent to the precentral gyrus to the MEP latency estimated following stimulation of the precentral gyrus.

The threshold intensity was lowest when the precentral gyrus was stimulated. The stimulation intensity varied from 6.1 to 11.5 mA ($\bar{x}$ = 9.8 mA) for the precentral gyrus whereas for stimulating the frontal lobe adjacent to the precentral gyrus stimulation intensity varied from 6.2 to 25 mA ($\bar{x}$ = 16.9 mA).

Motor response from the thenar muscle was recorded when stimulation of the precentral gyrus between 3 and 7 cm ($\bar{x}$ = 4.14 cm) from the midline was performed. Stimulating the precentral gyrus between 1 and 6 cm ($\bar{x}$ = 3.75 cm) from the midline elicited motor response in the forearm flexors and between 0 and 2.5 cm ($\bar{x}$ = 1.9 cm) from the quadriceps muscle.

Based on the pre-operative computer tomography and/or magnetic resonance imaging the topographic relation between the lesion and the sensorimotor area was estimated. In 40 cases the pre-operative estimated relation corresponded to the intra-operative estimated localization. However, in 30 cases the intra-operative estimated relation between lesion and sensorimotor cortex differed from the pre-operative estimation. In 19 cases the lesion was as pre-operatively determined nearer and in 11 cases more distant to the sensorimotor cortex.

Direct stimulation of the tumour elicited in none of the cases a motor response. Therefore, macroscopically total resection was possible in all cases. Following the mapping procedure, intra-operative monitoring of the motor system was performed by repetitive stimulation of the cortex. The results of the monitoring procedure and the functional outcome were not subject of the present study. These results were published elsewere [38].

Discussion

Electrical stimulation of the cerebral cortex was first performed by Bartholow in 1874 [11]. Cushing [19] used this technique to determine the anatomical relationship of the sensory strip to an adjacent tumour.

However, it was the epoch-making study of Penfield and Boldrey [36] that laid the foundation for intra-operative localization of the sensorimotor cortex.

In recent years, several studies [3, 8, 10, 12–14] have substantiated the necessity for intra-operative functional mapping and monitoring during surgery in and around the motor cortex. The method of phase reversal of somatosensory evoked potentials was first described by Goldring *et al.* [25, 26] for intra-operative localization of the central sulcus during surgery for epilepsy. Subsequent studies have demonstrated its usefulness also in tumour surgery [2–7, 17, 20, 23, 28, 33–35, 40, 41].

Phase reversal of somatosensory evoked potentials is based on the fact that the dipole of the afferent volley changes from the postcentral to the precentral gyrus. A somatosensory potential (N20/P30) can thus be recorded from the postcentral gyrus and its mirror image (P′20/N′30) from the precentral gyrus [40].

SEP-PR is associated with a success rate of over 90% for intra-operative localization of the central sulcus. King [31] reported 91% in 1987, Wood [40] 94% in 1988 and [17] 91% in 1996. In the present series, SEP phase reversal was recorded in 97.14% which corresponds to the results of other series.

The failure rate may be accounted for by several factors: 1st: the tumour related shifting of the central sulcus [17] 2nd: misplacement of the recording electrodes in relation to the anatomical location of the sensorimotor cortex [40]; the influence of narcotic agents and of brain oedema [17]. In the present study dural adhesions prevented correct placement of the electrodes in both ''failure-cases''.

As described by Taniguchi *et al.* [39], intravenous general anaesthesia with Propofol and Alfentanyl does not suppress the amplitudes of SEPs. This anaesthetic regime was used in the present study. Hence, recording of phase reversal of SEPs is a reliable method for identification of the central sulcus. However, this technique yields no information about motor function. Thus anatomical identification alone is not a sufficient safeguard against postoperative neurological deficits. Therefore, an additional method is necessary to map and monitor motor function.

Motor function can be tested under general anaesthesia by direct stimulation of the motor cortex. Bipolar stimulation was originally described by Fritsch and Hitzig [24]. This technique allows mapping of functional cortical and subcortical areas. A series of studies [3, 8, 13, 14, 21, 22] have demonstrated that bipolar cortex stimulation is a useful tool during surgery in and around the motor cortex. Until recently, it was the sole intra-operative mapping method. However, bipolar cortical stimulation does not allow an objective analysis. Moreover, the movements elicited by this form of stimulation are a major problem during microneurosurgery, thus preventing continuous monitoring of motor function during tumour resection. The rare induction of an intra-operative seizure by low-frequency stimulation is a further disadvantage of this technique.

Monopolar electrical stimulation of the pyramidal cells was first described by Hern [29]. Subsequently Gorman [27] compared several stimulation methods, and was able to demonstrate that monopolar stimulation requires less current intensity to elicit MEPs. The monopolar stimulus directly activates pyramidal axons [37] and induces repetitive excitation of the corticospinal tract [15]. Due to the high-frequency train, an accumulation of postsynaptic potentials activating the motoneurons is achieved even under general anaesthesia [15].

In 1993, Taniguchi *et al.* [39] described a modification of monopolar cortical stimulation: a high frequency (400–500 Hz) monopolar train of stimuli is able to elicit MEPs while reducing the required stimulation intensity by a factor of 50–100 as compared to the bipolar stimulation [13, 14, 21, 22, 31]. The first clinical experience with this new stimulation technique was reported by Cedzich *et al.* [17] in 1996. Under the above mentioned conditions no intra-operative seizure occurred either in our series or in that of Cedzich *et al.* [17]. The major advantage of this new technique is that it allows an objective analysis of the results. The recorded motor evoked potentials can be analysed with regard to their latency, amplitude and duration. Since movements never occur following monopolar cortical stimulation, repetitive stimulation is possible, ensuring continuous intra-operative monitoring of motor function [16, 17]. This is a further advantage of the method as compared to bipolar stimulation.

The success rate of MCS was 97% in the 58 patients of Cedzich *et al.* [17] and 95.7% in the 70 patients of the present study. In 3 cases no MEPs were recorded. In the first the failure of MCS was due to a technical problem, caused by dislocation of the stimulation electrode. In the second the tumour infiltrated the precentral gyrus causing destruction of the motor centres. Therefore, electrical stimulation of these ''functionless'' units elicited no MEPs. In the third case a cav-

ernoma located in the white matter of the precentral gyrus acted as a conduction block.

In the present study high frequency monopolar cortical stimulation was combined with phase reversal of somatosensory evoked potentials in an intra-operative protocol for localizing the motor cortex. In three cases of MCS failure, the central sulcus was localized by SEP-PR. On the other hand, MCS was capable of localizing the motor cortex in the two cases in which SEP-PR could not be recorded.

Thus, a combination of SEP-PR and MCS allowed intra-operative localization of the sensorimotor cortex in 100% of the cases. There were no complications associated with the employed techniques.

Both the somatosensory evoked potential phase reversal and the high frequency monopolar cortical stimulation have technical, anatomical and neurophysiological limitations. However, a sensitivity of 100% was achieved despite these limitations, since localization was always possible by at least one of the two methods.

References

1. Agnew W, McCreery D (1987) Considerations for safety in the use of electrical stimulation for motor evoked potentials. Neurosurgery 20: 143–147
2. Aiba T, Seki Y (1988) Intraoperative identification of the central sulcus: a practical method. Acta Neurochir (Wien) 42: 22–26
3. Allen A, Starr A, Nudleman K (1981) Assessment of sensory function in the operating room utilizing cerebral evoked potentials: a study of fifty-six surgically anesthetized patients. Clin Neurosurg 28: 457–481
4. Allison T (1982) Scalp and cortical recordings of initial somatosensory cortex activity to median nerve stimulation in man. Ann NY Acad Sci 388: 671–678
5. Allison T (1987) Localization of sensorimotor cortex in neurosurgery be recording of somatosensory evoked potentials. Yale J Biol Med 60: 143–150
6. Allison T, McCarthy G, Wood CC, Darcey TM, Spencer DD, Williamson PD (1989) Human cortical potentials evoked by stimulation of the median nerve. I. Cytoarchitectonic areas generating short-latency activity. J Neurophysiol 62: 694–710
7. Amassian VE, Cracco RQ (1987) Human cerebral cortex responses to contralateral transcranial stimulation. Neurosurgery 20: 148–155
8. Amassian VE, Stewart M, Quirk GJ, Rosenthal JL (1987) Physiological basis of motor effects of transient stimulus to cerebral cortex. Neurosurgery 20: 74–93
9. Ammirati M, Vick N, Liao Y, Ciric I, Mickhael M (1987) Effect of the extent of surgical resection on survival and quality of life in patients with supratentorial glioblastomas and anaplastic astrocytomas. Neurosurgery 21: 201–206
10. Barker AT, Freeston IL, Jalinous R, Merton PA, Morton HB (1985) Magnetic stimulation of human brain. J Physiol (Lond) 369: 3
11. Bartholow R (1874) Experimental investigations into functions of the human brain. Am J Med Sci 67: 305–313
12. Berger MS, Cohen WA, Ojemann GA (1990) Correlation of motor cortex brain mapping data with magnetic resonance imaging. J Neurosurg 72: 383–387
13. Berger MS, Kincaid J, Ojemann GA, Lettich BA (1989) Brain mapping techniques to maximize resection, safety and seizure control in children with brain tumours. Neurosurgery 25: 786–792
14. Berger MS, Ojemann GA, Lettich E (1990) Neurophysiological monitoring during astrocytoma surgery. Neurosurg Clin N Am 1: 65–80
15. Brickner RM (1940) A human cortical area producing repetitive phenomena when stimulated. J Neurophysiol 3: 128–130
16. Cedzich C, Pechstein U, Schramm J, Schäfer S (1998) Electrophysiological considerations regarding electrical stimulation of motor cortex and brain stem in humans. Neurosurgery 42: 527–532
17. Cedzich C, Taniguchi M, Schäfer S, Schramm J (1996) Somatosensory evoked potential phase reversal and direct motor cortex stimulation during surgery in and around the central region. Neurosurgery 38: 962–970
18. Ciric I, Ammirati M, Vick N, Mickhael M (1987) Supratentorial gliomas: surgical considerations and immediate postoperative results. Gross total resection versus partial resection. Neurosurgery 21: 21–26
19. Cushing H (1909) A note upon the Faradic stimulation of central gyrus in conscious patients. Brain 32: 42–53
20. Desmedt JE, Chéron G (1982) Somatosensory evoked potentials in man: subcortical and cortical components and their neural basis. Ann NY Acad Sci 388: 388–411
21. Ebeling U, Schmid UD, Reulen HJ (1990) Tumour surgery within the central motor strip: surgical results with aid of electrical motor cortex stimulation. Acta Neurochir (Wien) 101: 101–107
22. Ebeling U, Schmid UD, Ying H, Reulen HJ (1992) Safe surgery of lesions near the motor cortex using intra-operative mapping techniques: a report on 50 patients. Acta Neurochir (Wien) 119: 23–28
23. Firsching R, Klug N, Borner U, Sanker R (1992) Lesions of the sensorimotor region: somatosensory evoked potentials and ultrasound guided surgery. Acta Neurochir (Wien) 118: 87–90
24. Fritsch G, Hitzig E (1870) Über die elektrische Erregbarkeit des Grosshirns. Arch Anat Physiol Wiss Med 37: 300–332
25. Goldring S (1978) A method for surgical management of focal epilepsy, especially as it relates to children. J Neurosurgery 49: 344–356
26. Goldring S, Gregorie EM (1984) Surgical management of epilepsy using epidural recordings to localize the seizure focus. J Neurosurgery 60: 457–466
27. Gorman ALF (1966) Diffential patterns of activation of the pyramidal system elicited by surface anodal and cathodal cortical stimulation. J Physiol (Lond) 29: 547–564
28. Grundy BL (1983) Intraoperative monitoring of sensory-evoked potentials. Anesthesiology 58: 72–87
29. Hern EC, Landgren S, Phillips CG, Porter R (1962) Selective excitation of corticofugal neurones by surface-anodal stimulation of the baboon's motor cortex. J Physiol (Lond) 161: 73–90
30. Hirakawa K, Suzuki K, Ueda S, Nakawa Y, Yoshino E, Ibayashi N (1984) Multivariate analysis of factors affecting postoperative survival in malignant astrocytomas. J Neuroonco 12: 331–340
31. King RB, Schell GR (1987) Cortical localization and monitoring during cerebral operations. J Neurosurg 67: 210–219
32. Laws ER, Taylor WF, Clifton MP, Okazaki H (1984) Neurosurgical management of low grade astrocytoma of the cerebral hemispheres. J Neurosurg 61: 665–673

33. Lesser RP, Koehle R, Lüders H (1979) Effect of stimulus intensity on short latency somatosensory evoked potentials. Electroencephalogr Clin Neurophysiol 47: 377–382
34. Lüders H, Lesser RP, Hahn J (1983) Cortical somatosensory evoked potentials in response to hand stimulation. J Neurosurgery 58: 885–894
35. Nuwer MR (1991) Localization of motor cortex with median nerve somatosensory evoked potentials. In: Schramm J, Møller A (eds) Intraoperative neurophysiological monitoring. Springer, Berlin Heidelberg New York Tokyo, pp 63–71
36. Penfield W, Boldrey E (1937) Somatic motor and sensory representation in the cerebral cortex of man as studied by electrical stimulation. Brain 60: 389–443
37. Ranck JB Jr. (1975) Which elements are excited in electrical stimulation of mammalian central nervous system: a review. Brain Res 98: 417–440
38. Suess O (1999) Die Monopolare Kortex Stimulation (MKS): Eine neue Methode für intraoperatives neurophysiologisches Monitoring bei Operationen im, bzw. in der Nähe des Gyrus praecentralis. Inaugural Dissertation. Freie Universität Berlin
39. Taniguchi M, Cedzich C, Schramm J (1993) Modification of cortical stimulation for motor evoked potentials under general anesthesia: technical description. Neurosurgery 32: 219–226
40. Wood C, Spencer D, Allison T, McCarthy G, Williamson P, Goff W (1988) Localisation of human sensorimotor cortex during surgery by cortical surface recording of somatosensory evoked potentials. J Neurosurg 68: 99–111
41. Woolsey CN, Erickson TC, Gilson WE (1979) Localization in somatic sensory and motor areas of human cerebral cortex as determined by direct recording of evoked potentials and electrical stimulation. J Neurosurgery 51: 476–506

Comments

The authors describe the prospective use of combined intra-operative SEP phase reversal (SEP-PR) and monopolar cortical stimulation (MCS) in 70 neurosurgical procedures in the central region. They report that at least one of these methods was successfully applied in all cases. Their main conclusion is that intra-operative identification of the motor cortex was possible by this protocol with a sensitivity of 100% in their series.

The design of the study appears adequate with regard to its objective, to explore the suitability of the protocol for safe intra-operative identification of the motor cortex. The presentation is largely consistent.

It would be interesting to know how often and why the results of intra-operative neurophysiology had consequences with regard to the topographic relation of the lesion and the sensorimotor region presumed from pre-operative imaging or intra-operative anatomical findings.

As the authors point out, the identification of functionally eloquent areas is of paramount importance for maximal surgical results and preserved postoperative function. It would be of great interest, also with respect to the somewhat disappointing results presented previously (Ref. 37), to learn which surgical results could be achieved in this series in terms of cytoreduction, functional outcome, and survival.

J. Schramm

The importance of the intra-operative identification of the sensorimotor area by neurophysiological methods has been repeatedly and consistently demonstrated in the surgical resectior of lesions in and around this eloquent region. By doing this the extent of surgery can be tailored accordingly, and therefore the preservation of function can be mantained. The mapping of the motor cortex can be performed in several ways, including functional Magnetic Ressonance Imaging (fMRI).

Kombos *et al.* have been producing recently a considerable number of reports on this subject. In the present one the authors submit a prospective study made in a group of 70 patients combining monopolar cortical stimulation (MCS) with the recording of phase reversal evoked potentials (SEP-PR). The central sulcus could be identified in 97% by SEP-PR and in 95.7% by MCS. Yet the combination of the two techniques allowed the intra-operative localization of the sensorimotor cortex in every case, since the cases without response to one of the methods could be elicited by the other one.

Although we have had a similar experience with SEP-PR in a group of 17 patients, this technique has been abandoned in our protocols for cortical mapping in favour of awake cranioromy and cortical-subcortical stimulation since the motor areas spread over wider zones than the neural bank just anterior to the central sulcus. MCS is a new technique that looks very promising, indeed. Our work has been done using bipolar stimulation, with awake craniotomies for language and motor mapping. This was always guided and correlated with data obtained by pre-operative fMRIs studies.

I fully agree with the authors that intra-operative cortical mapping should be part of the routine methodology in the management of lesions located in high functional areas of the brain. The type of technique to be used is another question.

F. Isamat

Correspondence: Theodoros Kombos, M.D., Neurochirurgische Klinik, Universitätsklinikum Benjamin Franklin, Freie Universität Berlin, Hindenburgdamm 30, 12200 Berlin, Germany.