Somatosensory Evoked Potential Identification of Sensorimotor Cortex in Removal of Intracranial Neoplasms

David W. Rowed, David A. Houlden and Devsur G. Basavakumar

ABSTRACT: ***Objective:*** To assess the ease and reliability of routine use of somatosensory evoked potentials (SSEPs) for identification of sensorimotor cortex in brain tumour removal and to document its influence on the performance and outcome of surgery. ***Methods:*** SSEPs in response to contralateral median nerve stimulation were recorded from the cortical surface by means of a four lead electrode strip. Polarity reversal of short latency SSEP waves was used to identify the position of the central sulcus in 46 consecutive craniotomies for removal of metastases, gliomas, or meningiomas located in, near, or overlying sensorimotor cortex. ***Results:*** SSEPs were successfully recorded in 43/46 cases (94%) with demonstration of polarity reversal in 42/43 (98%). SSEP localization led to modification of 14/42 (33%) procedures, most frequently because of either displacement or involvement of sensorimotor cortex by tumour. Six patients (14%) developed new neurological deficits but none of these was attributable to incorrect identification of sensorimotor cortex. ***Conclusions:*** SSEP polarity reversal is a simple, reliable, accurate, and inexpensive method of localizing sensorimotor cortex under general anaesthesia. Correct identification is possible when sensorimotor cortex is displaced or when surface anatomy is obscured by tumour. Routine use of this technique should be considered in all procedures for lesions located near the central sulcus.

RÉSUMÉ: Identification par des potentiels évoqués somesthésiques du cortex sensitivomoteur dans l'ablation des néoplasies intracrâniennes. ***Objectif:*** Le but de cette étude est d'évaluer la facilité et la fiabilité de l'utilisation de routine des potentiels évoqués somesthésiques (PES) pour l'identification du cortex sensitivomoteur dans l'ablation de tumeurs cérébrales et de documenter son influence sur l'exécution et l'issue de la chirurgie. ***Méthodes:*** Les PES par stimulation du nerf médian contralatéral ont été enregistrés sur la surface corticale au moyen d'une bande de quatre électrodes. L'inversion de polarité des ondes PES de latence courte a été utilisée pour identifier la position de la scissure centrale chez 46 cas de crâniotomies effectuées pour faire l'ablation de métastases, de gliomes ou de méningiomes localisés dans, près de ou sur le cortex sensitivomoteur. ***Résultats:*** Les PES ont été enregistrés avec succès chez 43 des 46 cas (94%) avec démonstration d'une inversion de polarité chez 42 des 43 cas (98%). La localisation par les PES a mené à des modifications de l'intervention chez 14 cas sur 42 (33%), le plus souvent parce que le cortex sensitivomoteur était déplacé ou envahi par la tumeur. Six patients (14%) ont présenté de nouveaux déficits neurologiques. Cependant, aucun de ces déficits n'était attribuable à une identification erronée du cortex sensitivomoteur. ***Conclusions:*** L'inversion de polarité des PES est une méthode simple, fiable, précise et peu coûteuse pour localiser le cortex sensitivomoteur sous anesthésie générale. L'identification précise est possible quand le cortex sensitivomoteur est déplacé ou quand l'anatomie de surface est masqués par la tumeur. L'utilisation de routine de cette technique devrait être considérée dans toutes les interventions sur des lésions qui sont localisées près de la scissure centrale.

Can. J. Neurol. Sci. 1997; 24: 116-120

Surgical removal of intracranial neoplasms located near the central sulcus entails a risk of postoperative neurological deficits. Visual identification of the central sulcus and the pre- and postcentral gyri in the operative field may be difficult. Moreover, structural and functional localization may not precisely coincide. This is especially true for speech centres but may apply to some extent to sensory and motor areas as well.[1,2]

Broughton discovered that polarity reversal of early SSEP waveforms occurs across the central sulcus.[3-5] This provided a simple method for functional localization of primary sensorimotor cortex. Further experience has confirmed the reliability of this technique, though failing to resolve the controversy that

From the Sunnybrook Health Science Centre, University of Toronto, Toronto.
RECEIVED JULY 5, 1996. ACCEPTED IN FINAL FORM OCTOBER 2, 1996.
Reprint requests to: D.W. Rowed, Division of Neurosurgery, Ste. A134, Sunnybrook Health Science Centre, 2075 Bayview Avenue, North York, Ontario, Canada M4N 3M5

surrounds cortical SSEP generators.[6-20] Intraoperative electrophysiological identification of primary sensory and motor cortices by this means is neither difficult nor time consuming.[16,17,21-25] We have routinely used this technique during removal of neoplasms located near the central sulcus and believe it should be more widely applied in day-to-day neurosurgical practice.

Materials and Methods

Patient Population

Intraoperative identification of primary sensorimotor cortex by SSEP monitoring has been carried out in 46 consecutive patients undergoing resection of tumours near the central sulcus between January 1991 and September 1995. All were adult, 26 were female, and 20 male. Twenty-three (50%) had metastatic tumours, 15 (33%) had gliomas, and 8 (17%) meningiomas.

Nineteen tumours (41%) involved the left cerebral hemisphere and 27 (59%) the right hemisphere. Twenty-two (48%) were predominantly or entirely parietal in location, and 24 (52%) were completely or mainly frontal in location.

Anaesthesia

Patients had a general anaesthetic which usually consisted of nitrous oxide (50-60%) and oxygen with isofluorane (0.5 - 1%) supplemented by fentanyl. Neuromuscular blockade was initiated to improve the signal-to-noise ratio after establishing appropriate median nerve stimulus intensity.

Stimulation and Recording Techniques

Contralateral median nerve was stimulated at the wrist using a constant current 200 microsecond square wave pulse, a stimulus rate of 3.1 Hz and a stimulus intensity of double the thenar motor threshold. Bipolar subdermal needle electrodes were used for stimulation. Peripheral nerve responses were recorded intraoperatively from surface electrodes placed at the elbow or Erb's point to ensure adequacy of median nerve stimulation. Intraoperative cortical SSEP recordings were obtained from a 4 lead strip electrode (Model T-WS-4, Ad-Tech Medical Instrument Corporation, Racine, Wisconsin) placed directly on cerebral cortex perpendicular to and straddling the central sulcus near the estimated position of hand area of primary sensorimotor cortex. The strip electrode was moved vertically, toward the vertex and toward the skull base, until a maximum amplitude N20/P30 waveform was obtained, before moving anteriorly and posteriorly to establish the position of polarity reversal. Typically 2-4 moves were required with a recording time of 25-65 seconds in each position.

The small four lead electrode could easily be placed beyond the confines of exposed cortex at craniotomy by carefully sliding it subdurally in the desired direction. Cortical electrodes were referenced to a subcutaneous needle electrode in the contralateral scalp (Grass Instruments, Quincy, Massachusetts).

Recordings were typically obtained using an amplifier gain of 50,000 and sweep duration of 50 milliseconds (Cadwell Instruments, Kenniwick, Washington and Clark-Davis, London, Ontario). Low and high cut filters were typically 10 and 2,000 Hz respectively. Frequently the early cortical SSEP waveform polarity reversal could be seen in single 4 channel oscilloscope sweeps. Normally the polarity reversal of early cortical SSEP waveforms was seen using a 4 channel average of 50-100 responses (Figure 1) but the polarity reversal was frequently seen in single sweeps (without averaging). In most cases, SSEP monitoring continued during tumour removal.

Direct stimulation of motor cortex was performed in selected cases using established brain stimulation parameters and the same 4 lead strip electrode.[1,24] The two electrodes most directly overlying motor cortex as identified by SSEP were used to directly stimulate and thus confirm the position of primary motor cortex.

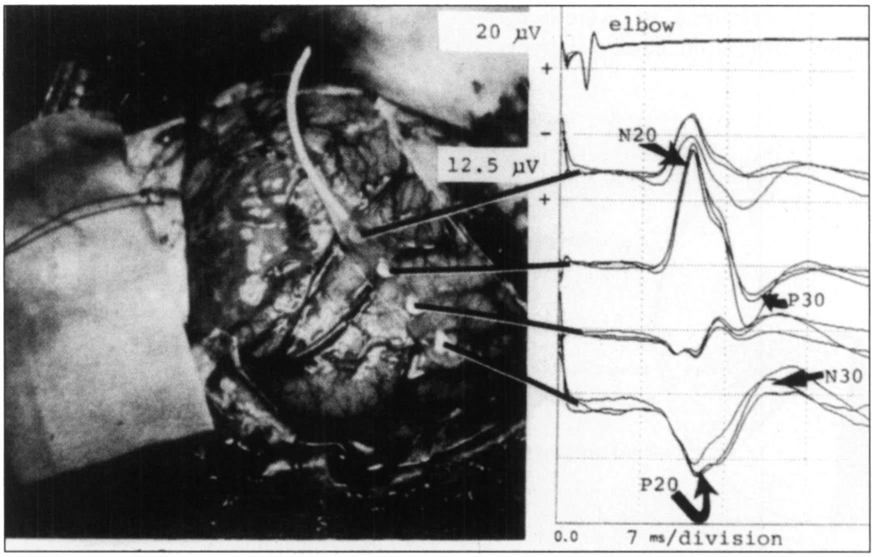

Figure 1: SSEP waveform recorded from a 4 lead cortical strip electrode following contralateral median nerve stimulation. Cortical electrode 1 is on the brain surface closest to the top of the photograph. Polarity reversal of the early cortical SSEP waveform N20/P30 occurs between electrodes 2 and 4 indicating the central sulcus lies between them. A peripheral nerve response was simultaneously recorded from the elbow (top trace) to ensure adequacy of stimulation.

RESULTS

Reliability of SSEP Polarity Reversal Across the Central Sulcus

Intraoperative SSEP was successfully recorded in 43 cases (94%). Clearly identifiable polarity reversal of the N20/P30 waveform across the central sulcus was present in 42 of these cases (98%). The remaining patient did not have polarity reversal despite a large amplitude waveform. In this case we assumed the electrode that recorded the largest SSEP waveform was positioned over the somatosensory cortex. This assumption was verified by the bipolar cortical recording technique of Gregorie and Goldring.[23]

Effect of SSEP Localization On Surgical Procedure

In 33/42 cases (79%) SSEP identification of sensorimotor cortex by the neurophysiologist agreed with visual identification of pre- and postcentral gyri by the neurosurgeon. In 9 cases (21%) visual and SSEP localization did not agree, thereby affecting the surgical procedure. In 6 (14%) of these the discrepancy appeared to be explained by cortical displacement due to tumour mass (Figure 2). In 2 (5%) cases the surface anatomy was obliterated by glioma and visual identification of the pre- and postcentral gyri was impossible. In the one remaining case the reason was uncertain. In 5 additional cases there was agreement between visual and SSEP localization but the surgical procedure was directly influenced by SSEP findings. In 4 (10%) of these, all with metastatic tumours, partial or subtotal resection was carried out because part of the tumour lay directly beneath motor cortex. In none of these cases could this be clearly appreciated in the preoperative imaging. In the 5th case (2%) continuous intraoperative recordings from the cortical strip electrode showed SSEP deterioration during tumour removal (Figure 3) which led to the identification of intracerebral hemorrhage by ultrasonography. The hemorrhage underlay primary sensory cortex and was some distance from the tumour bed, probably related to retraction. In the remaining 28/42 (67%) visual and SSEP identification of pre- and postcentral gyri were in agreement and surgery was not modified on the basis of intraoperative monitoring (Figure 2).

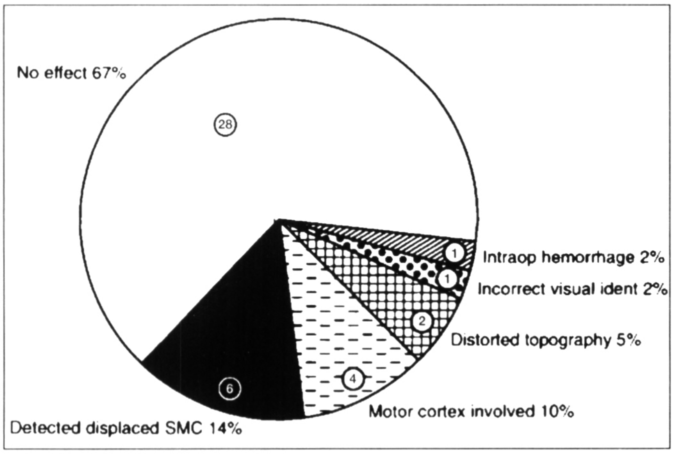

Figure 2: Effect of SSEP localization on surgical procedure. SMC = sensorimotor cortex. Incorrect visual ident indicates one patient in whom SSEP localization disagreed with visual localization for no apparent reason. Circled numbers indicate number of patients.

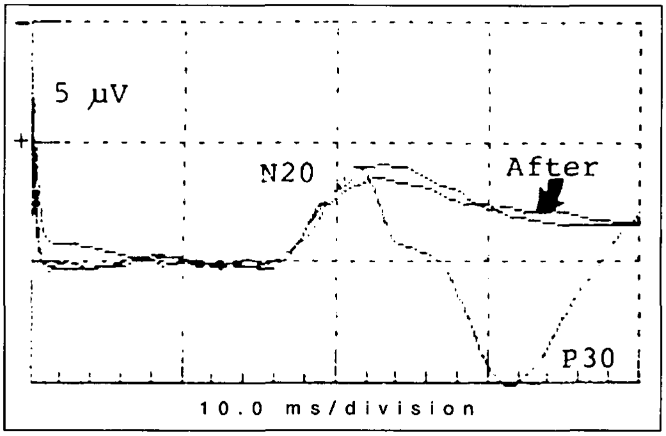

Figure 3: SSEPs obtained from one electrode placed on the post-central gyrus during tumour removal. Intraoperative deterioration of the P30 waveform (After) led to identification of intracerebral hemorrhage by ultrasound.

Neurological Outcome

Twenty-four patients (57%) were neurologically unchanged postoperatively, 12 (29%) showed variable improvement in neurological deficit, and 6 (14%) demonstrated an increase in neurological deficit postoperatively. In 5 of the 6 an increase in edema was noted in the postoperative CT scan. In some instances this was extensive and involved much of the operated hemisphere. In 1 patient with glioblastoma multiforme the increase in deficit was related to intraoperative intracerebral hemorrhage as described above. One patient (2%) with a malignant glioma died on the third postoperative day because of uncontrollable postoperative malignant cerebral edema. None of the postoperative increases in neurological deficit were judged attributable to incorrect identification of sensorimotor cortex.

DISCUSSION

Reliability of Cortical SSEP Polarity Reversal

Reliability of obtaining intraoperative SSEPs (94%) in the present series and the consistency of obtaining SSEP polarity reversal (98%) when the SSEP was present facilitates routine application of this technique. Others have demonstrated similar reliability.[2,11,21-23,25,26]

Nuwer et al.[27] have suggested that use of a 20 electrode array may be time saving and we would agree, provided that 18-20 recording channels are available. Two to ten positions of our 4 electrode strip were required to identify maximum N20/P30 amplitude and polarity reversal (2-4 positions in most patients). Total recording time, therefore, was 3-10 minutes and this compares favourably with recording time using a larger array.[27] In addition to being less expensive, the 4 electrode strip is more easily manipulated, allowing placement beyond the confines of the craniotomy or on the medial surface of the hemisphere for leg area motor stimulation.

Use of a dural reference electrode, rather than a scalp electrode, may reduce electromyographic artifact if neuromuscular blockade is not employed.

Polarity reversal of the N20/P30 waveform may be the result of a tangentially oriented dipolar generator in the posterior lip of

https://doi.org/10.1017/S0317167100021430 Published online by Cambridge University Press

Allison.[6,7] Allison has postulated that this generator is located in area 3b of somatosensory cortex. Others have suggested that the P20/N30 waveform recorded anterior to the central sulcus has a separate generator which is radially oriented and lies anterior to the central sulcus.[9,17,28]

The P25/N35 wave is seen centrally on either side of the sulcus and Allison has proposed that it originates from a radially oriented dipole in area 1.[6,26] Though the theory of Allison et al. appears to fit most of the observed facts with the exception of the slightly longer latency of P20 when compared to N20, detailed review of SSEP generators is beyond the scope of this discussion. The consistency of polarity reversal across the central sulcus in cortical recordings is agreed on by all authors.[6-15,17-20]

Polarity reversal of early SSEP waveforms has been reported in locations away from the central sulcus.[29] Though our objective has not been to record extensively over the convexity of the cerebral hemisphere beyond the confines of our craniotomy, we have never observed this phenomenon.

Effect of SSEP Localization On Surgical Procedure

Intraoperative visual identification of the pre- and postcentral gyri may be extremely difficult. Variations in topography, obliteration of surface markings, by glial tumours in particular, displacement by tumour mass, etc., contribute to this difficulty particularly with relatively small craniotomies. Alternative means of identification include image guided navigation systems, functional MRI (fMRI) and awake craniotomy with stimulation.[1,30-37] Image guided navigation systems, like the ISG wand, do not take account of movement of the intracranial structures after craniotomy in the presence of mass lesions. fMRI is not widely available and may be misleading because the preoperative location of primary motor cortex may change after opening the craniotomy. Awake craniotomy is uncomfortable, time consuming, and usually requires a larger craniotomy.[25] Direct cortical stimulation is indispensable for identification of speech areas, but is unnecessary, in our view, for localization of sensorimotor cortex. We occasionally employ direct cortical stimulation for identification of primary motor cortex and subcortical motor fibres but we have found this method to be less reliable than the SSEP localization of sensorimotor cortex in patients under general anaesthesia.

Localization of sensorimotor cortex with SSEP altered the surgical procedure when SSEP polarity reversal confirmed that the tumour involved the primary motor cortex. In these patients less aggressive tumour excision was performed in order to avoid postoperative morbidity. Preoperative imaging did not conclusively demonstrate the relationship to primary motor cortex in these cases. The one patient in whom visual and SSEP localization of sensorimotor cortex did not agree (despite normal surface anatomy and lack of mass effect) may reflect the fact that structural and functional localization do not always coincide. The fact that visual and SSEP localization did not agree in 21% of patients is not surprising since tumour may displace or obliterate the surface anatomy of the sensorimotor cortex. With experience we have come to accept SSEP as the "gold standard" whenever consistent polarity reversal can be demonstrated. The lack of postoperative neurological deficits attributable to faulty localization of sensorimotor cortex reinforces our belief in the validity of this technique.

In one instance intraoperative SSEP monitoring alerted us to the presence of an unexpected intraoperative hemorrhage which was removed.

Neurological Outcome

Eighty-six per cent of the patients had good or excellent clinical results postoperatively in that they were either neurologically unchanged or improved. This is noteworthy in that all of these neoplasms were located close to the central sulcus. New postoperative deficits occurred in 6 patients (14%) four of whom had meningiomas, two of which were recurrent. Increased morbidity in patients with central meningiomas has been reported by others.[28] The deficits in these patients are not greatly influenced by identification of sensorimotor cortex since the intent of the surgical procedure is complete removal of the tumour regardless of where it is situated. One patient with recurrent meningioma had a dense hemiplegia preoperatively. The quality of SSEP recordings at the conclusion of tumour removal led us to believe that some postoperative improvement could be anticipated. In this patient motor function improved significantly in the early postoperative period.

The remaining two patients had glial tumours. One of these patients experienced an unanticipated intraoperative hemorrhage and might well have fared more poorly had this not been recognized by the SSEP and promptly evacuated. The other patient developed malignant postoperative brain edema and died on the third postoperative day.

In one-third of our cases the conduct of operation was influenced directly by the SSEP because it altered the localization of primary sensorimotor cortex, dictated incomplete or subtotal removal of some tumours, or alerted us to new and unexpected pathology. SSEP localization of the sensorimotor cortex was never responsible for incorrect identification leading to postoperative neurological deficits.

Summary

Intraoperative visual identification of the sensorimotor cortex is difficult. Identification of the sensorimotor cortex using SSEP was successful in almost all patients undergoing surgery for removal of neoplasms situated close to primary motor or sensory cortex and it directly affected the surgical procedure in one-third of cases. It is a simple, reliable and inexpensive technique which is not time consuming. It is applicable under usual conditions of anaesthesia including neuromuscular blockade provided excessive concentrations of inhalation agents are not employed. We believe this technique has been underutilized in neurosurgical practice and recommend routine use of this technique for safe resection of lesions located near the central sulcus.

Acknowledgements

The authors thank Ken Klettke for technical assistance and Jill Cain and Jan Cross for preparation of the manuscript.

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