

## Localization of Sensorimotor Cortex in Neurosurgery by Recording of Somatosensory Evoked Potentials

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The current method of localizing somatosensory and motor cortex during neurosurgical removal of abnormal tissue is Penfield's method of cortical stimulation. While useful, this method has drawbacks, in particular the need to operate under local anesthesia. Another method of localization, described here, involves intra-operative recording of short-latency somatosensory evoked potentials to stimulation of the contralateral median nerve, from electrodes placed directly on central cortex. Proper localization involves identification of potentials which invert in polarity across the central sulcus, identification of other potentials which are largest in the medial portion of the hand area of somatosensory cortex and do not polarity invert, and determination of the region of maximal potential amplitude. This method of localization works equally well whether the patient is under local or general anesthesia, but it occasionally fails in patients with tumors abutting or invading the hand area of sensorimotor cortex.

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### INTRODUCTION

In patients in whom a resection of abnormal cerebral tissue is to be made it is often desirable to localize critical areas such as motor cortex. The classical way of accomplishing this is Penfield's method of cortical stimulation [1,2]. Although mapping of sensory and motor responses elicited by cortical stimulation is undeniably useful for localization, it has two drawbacks. First, stimulation of motor cortex sometimes elicits reported sensations, and, conversely, stimulation of sensory cortex sometimes elicits movements. Without extensive mapping, the identity of the precentral and postcentral gyri may be ambiguous. Second, and of more concern, effective use of stimulation mapping requires the use of local anesthesia. General anesthesia precludes reports of sensations and makes difficult the evocation of discrete movements. Adequate localization thus requires the patient to be awake, an unpleasant experience for the patient and the surgical team alike.

Another solution to the problem of intra-operative localization, based on the recording of somatosensory evoked potentials (SEPs) from the cortical surface, will be described. It is particularly appropriate to describe this work here because it began in 1972 when Dr. Glaser, together with P.D. Williamson, R. Mattson, and J. VanGilder, initiated the diagnosis and surgical treatment of partial complex epilepsy at the Yale-New Haven and West Haven VA Medical Centers. As part of this program we decided to see whether the evoked potential technique might provide a more satisfactory localization. Initially the project involved W.R. Goff, in addition to those already named, and is currently helped greatly by the collaboration of C.C. Wood, G.

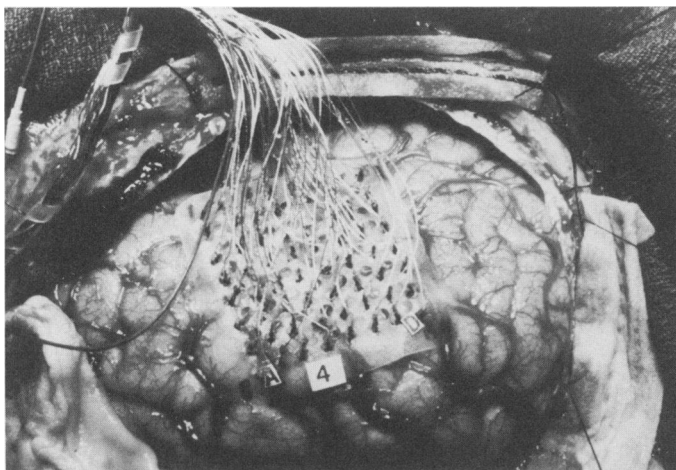


FIG. 1. A 64-electrode array for intra-operative recording from the cortical surface. An  $8 \times 8$  grid of 2 mm diameter silver ball electrodes is fixed to a Silastic sheet; electrode spacing is 5 mm. Fewer electrodes could be used, but the array would probably have to be moved more until adequate localization is obtained. The reference is a needle electrode (*upper left*) placed in temporal muscle.

McCarthy, and J. Jasiorkowski in the Neuropsychology Laboratory, and by D.D. Spencer in the Section of Neurosurgery.

#### METHODS

Following craniotomy and reflection of the dura, an array of electrodes is placed in the presumed vicinity of the hand area of sensorimotor cortex. We have tried a variety of electrode types and configurations and currently use the 64-electrode array shown in Fig. 1. SEPs are recorded to stimulation (2/second, 0.5 msec duration constant-current pulses) of the contralateral median nerve at an intensity producing a moderate thumb twitch (determined prior to possible use of a muscle relaxant). A guess is made as to the identity of the central sulcus (CS), the electrode array is placed over it in what is estimated to be the hand area, and an exploratory recording is made. Since the potentials recorded from the cortical surface are large (50–300  $\mu$ V), averages of 32 responses are sufficient to yield a reliable recording. Two or three averages are obtained to insure replicability of results. If the hand sensorimotor area appears to have been correctly identified, the entire array is then recorded from. If the initial guess was incorrect (as occurs about half the time in our experience, especially in tumor cases with distortion of the cortex), the array is moved until localization is achieved.

#### WAVEFORM CRITERIA FOR LOCALIZATION

Figure 2B shows examples of potentials recorded from the left hemisphere. They are labeled according to their polarity and approximate peak latency in milliseconds, and reflect the initial activation of neurons in sensorimotor cortex in response to median nerve stimulation. The SEP recorded from somatosensory cortex consists of N20 and P30 potentials and from motor cortex an approximate mirror-image waveform consisting of P20 and N30 potentials is seen. Polarity inversion of these potentials across an anatomical sulcus is a major criterion for identification of the CS. Such a pattern is seen in all patients from whom adequate recordings can be obtained. The most likely neurophysiological explanation for the polarity inversion is that these potentials are generated in cytoarchitectonic area 3b, which in humans is located in the posterior bank of the CS (Fig. 2A). This explanation is favored by some [3–6], while

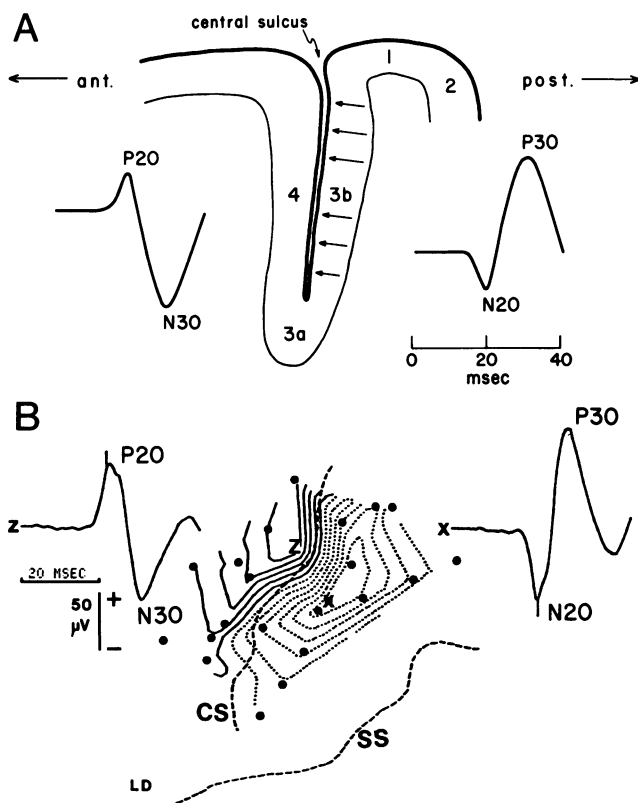


FIG. 2. A. Schematic SEPs evoked by contralateral median nerve stimulation recorded at locations anterior and posterior to the central sulcus (CS), and their hypothesized dipole source in the posterior bank of the CS in area 3b. B. Cortical surface SEPs to right median nerve stimulation, recorded from left hemisphere in an awake but sedated patient undergoing removal of a left frontal lobe tumor. Iso-voltage contour map (solid lines indicate positive voltage, dashed lines negative voltage) shows the distribution of potential at about the peak of N20 and P20, at the latency indicated by the cursors. Note polarity inversion across the CS. SS, Sylvian sulcus.

others believe that the P20-N30 and N20-P30 potentials are generated in motor and somatosensory cortex respectively [7-10]. Whatever the correct explanation, this pattern of potentials is recorded from all patients, with the exceptions noted below.

In addition to the 20- and 30-msec potentials just described, recordings in the immediate vicinity (within 3-4 mm) of the CS show additional potentials, as illustrated in Fig. 3. From the medial portion of the hand area of somatosensory cortex (location 3) a P25 potential is recorded, sometimes followed by an N35 potential. In some patients this activity—which we believe is generated primarily in the anterior portion of the crown of somatosensory cortex in cytoarchitectonic area 1—is small relative to the 20- and 30-msec potentials, but sometimes it is quite large, as in Fig. 4, location 1. The postcentral P25 and N35 components are only a few msec later than the precentral P20 and N30 components and may be confused with them. In some patients additional positive peaks in the 28-33 msec range are recorded very near the CS, interpolated between the postcentral N20-P30 and precentral P20-N30 potentials. The 28-33 msec potentials also appear to be generated mainly in area 1. Whatever their exact waveform, these potentials are recorded only in the immediate vicinity of the CS and thus aid in identifying it.

The distribution of short-latency SEPs is summarized schematically in Fig. 5. All these potentials are recorded at largest amplitude from sensorimotor cortex, although the 20- and 30-msec potentials are also recorded at smaller amplitude from the gyri adjacent to the postcentral and precentral gyri. Due to the orientation of the CS, and to

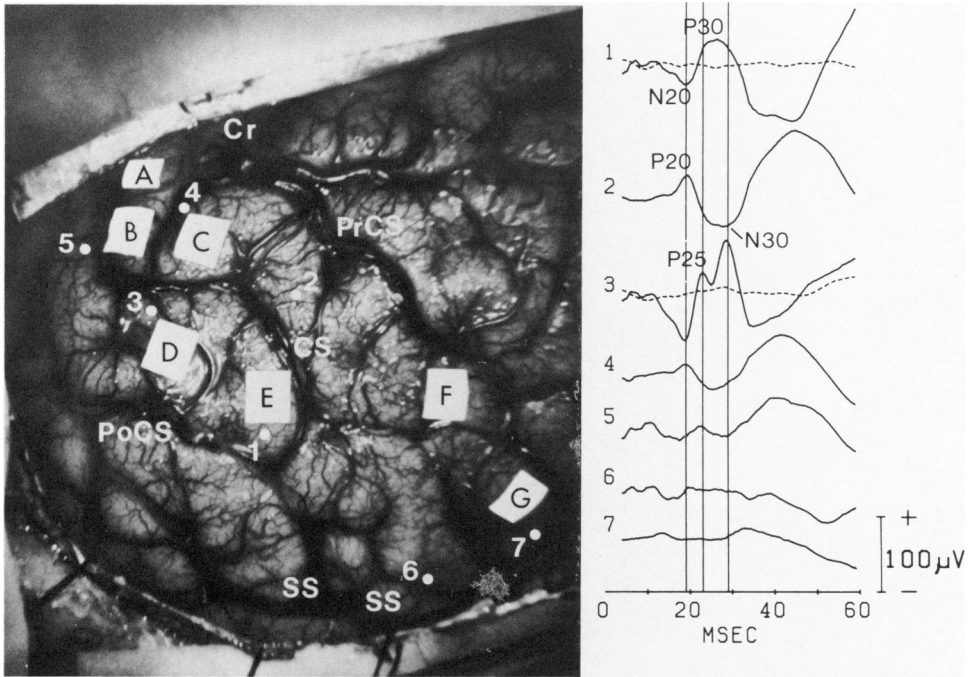


FIG. 3. SEPs in relation to the anatomy of sensorimotor cortex and to the results of cortical stimulation. *Left:* Right hemisphere, local anesthesia. Results of cortical stimulation (stimulation tickets have been labeled): A, arm flexion; B, wrist extension; C, wrist and elbow flexion; D, tingling in fourth and fifth digits; E, tingling in second digit; F, mouth movement; G, jaw movement. All sensory and motor responses refer to contralateral side of body. Cr, margin of craniotomy; PoCS, postcentral sulcus; PrCS, precentral sulcus. *Right:* SEPs recorded from locations shown at left. Solid lines are potentials evoked by contralateral median nerve stimulation; dashed lines are to ipsilateral stimulation; these SEPs are generated only by contralateral stimulation. Isolatency lines are at the approximate peak of P20 and N20 (19 msec), P25 (23 msec), and N30 and P30 (27 msec). Note that P25 is recorded from a region of postcentral gyrus medial to the region from which the mirror-image 20- and 30-msec potentials were recorded.

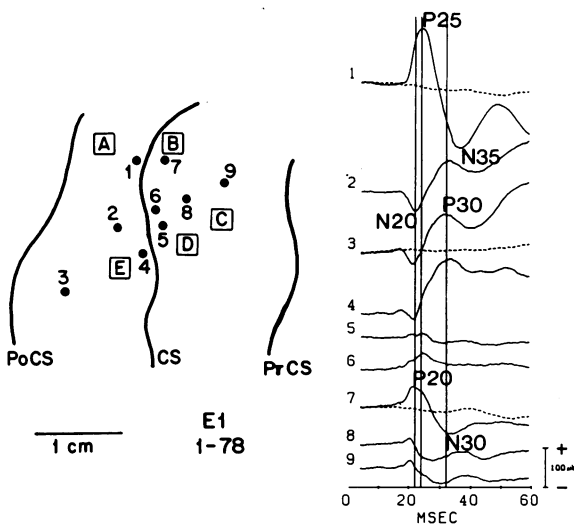


FIG. 4. SEPs in relation to the anatomy of sensorimotor cortex and to the results of cortical stimulation. *Left:* Right hemisphere, local anesthesia. Cortical stimulation: A, throbbing sensation in hand and forearm; B, forearm flexion and finger movement; C, forearm flexion and extension of fingers; D, flexion of fingers and hand; E, tingling in fourth digit. *Right:* SEPs recorded from locations shown at left. Isolatency lines are at the approximate peak of P20 and N20 (21 msec), P25 (24 msec), and N30 and P30 (32 msec).

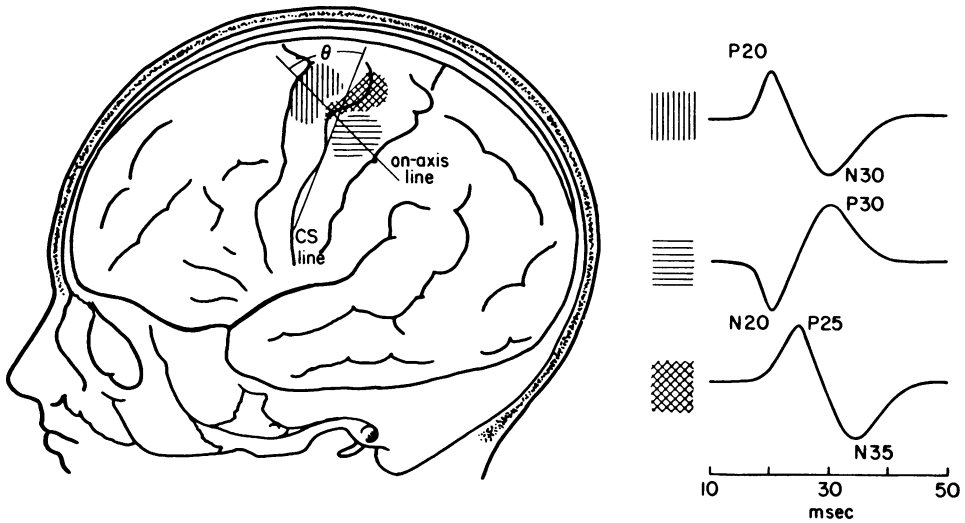


FIG. 5. Schematic summary of the waveform and topography of SEPs useful in localizing somatosensory and motor cortex. The region of motor cortex in which the largest P20 and N30 potentials are recorded is indicated by vertical lines, and the region of somatosensory cortex in which the largest N20 and P30 potentials are recorded is indicated by horizontal lines. The region of largest P25 (and N35, if present) is shown as a cross-hatched area; P25 is largest in somatosensory cortex about 1 cm medial to the largest N20 and P30 and is also seen at smaller amplitude in a region near the CS between the 20- and 30-msec potentials. The "on-axis" line connects the centers of the 20- and 30-msec potential fields. This line forms an acute angle (about  $70^\circ$ ) with a line parallel to the CS ("CS line") due to a medially directed bend in the CS in the hand area.

the fact that it often makes a medially directed bend in the hand area, the region of large amplitude SEPs forms an acute angle with the midline (Fig. 5). The practical implication of this anatomical arrangement is that it is desirable to orient the electrode array acutely along this "on-axis line" rather than along an "off-axis line" which may be perpendicular to the overall course of the CS but which does not record the precentral P20 and N30 potentials (Fig. 6). Failure to record these potentials can also occur if the medial margin of the craniotomy passes through the hand area parallel to the midline, exposing the postcentral N20-P30 region but leaving the precentral P20-N30 region unexposed.

#### AMPLITUDE CRITERION FOR LOCALIZATION

Regardless of specific component identification, the largest SEPs are recorded from somatosensory cortex. Examination of raw waveforms or topographic plots of summed voltage in the 20–40 msec latency range allows localization of the CS as the sulcus a few millimeters anterior to the region of maximal potential.

#### COMPARISON OF LOCALIZATION BY SEP RECORDING AND BY CORTICAL STIMULATION

In 26 patients operated under local anesthesia, we also localized motor and somatosensory cortex by cortical stimulation (e.g., Figs. 3 and 4). In all cases, localization by the two methods was in agreement, except in one patient in whom only motor responses were obtained to stimulation of both somatosensory and motor cortex

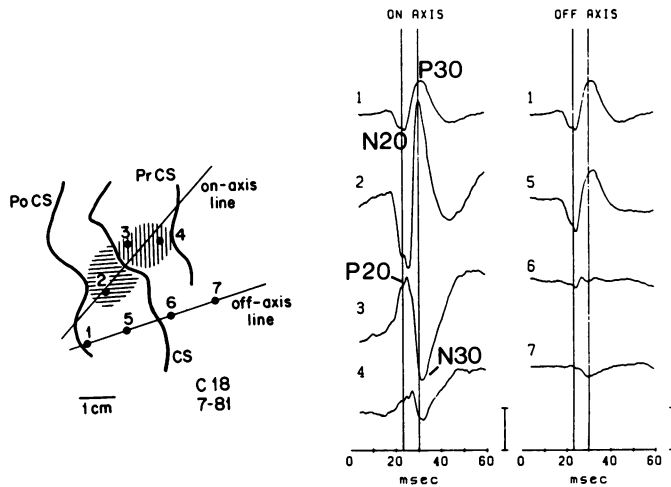


FIG. 6. SEPs in relation to the orientation of the CS. *Left:* Right hemisphere, general anesthesia. Regions of large amplitude 20- and 30-msec potentials illustrated as in Fig. 5. *Right:* Locations near the on-axis line showed large N20 and P30 postcentral potentials (locations 1 and 2) and P20 and N30 precentral potentials (locations 3 and 4), whereas an array perpendicular to the CS in that region (*off-axis line*) recorded virtually no precentral potentials. Isolatency lines are at the approximate peak of P20 and N20 (23 msec) and N30 and P30 (30 msec).

as determined by SEP recording. Thus the SEP method of localization is valid in the sense that it provides the same identification of motor and somatosensory cortex as does cortical stimulation, but it is not subject to the ambiguity of localization occasionally experienced using the latter method.

#### ANESTHETIC CONDITIONS FOR LOCALIZATION

The SEP method of localization works equally well under local anesthesia or under general endotracheal anesthesia using 40–60 percent nitrous oxide in oxygen supplemented with 0.25–0.5 percent isoflurane or a similar halogenated anesthetic. Circumstantial evidence suggests that higher concentrations (1.0–2.0 percent) of the halogenated agents may depress or abolish SEPs. Fifteen minutes prior to SEP recording, the anesthetic level is reduced to about 50 percent nitrous oxide and about 0.5 percent isoflurane or similar agent. If desirable, a muscle relaxant is administered.

#### FAILURE OF LOCALIZATION

In three of the 52 patients recorded to date we were unable to record SEPs in surgery. All three had tumors (two astrocytomas, one metastatic adenocarcinoma) in or abutting sensorimotor cortex, with resultant edema and avascular regions. Pre-operative scalp recordings were obtained in two of the three patients; in neither case were SEPs recordable over the affected hemisphere, although normal potentials were recorded, over the normal hemisphere, to stimulation of the corresponding contralateral median nerve. This result suggests that pre-operative failure to record SEPs from the affected hemisphere predicts intra-operative failure to record them as well.

## OTHER POSSIBLE METHODS OF LOCALIZATION

Depending on the location of the craniotomy and proposed resection, it may be desirable to localize the sensorimotor face and leg areas instead of, or in addition to, the hand area. Morrell et al. [11] noted that SEP recording allowed localization of the primary receiving areas of hand, leg, or face. Goldring and Gregorie [12] stated that the face area could be identified by SEP recording using a light tap to the lip as the stimulus. However, neither group has as yet published recordings of such activity. We have attempted to record SEPs evoked by electrical stimulation of the lips (six cases), or of the posterior tibial or peroneal nerve (five cases). Reliable potentials were recorded in a few cases, but their topographic relationship to the CS (as determined by hand area recording and cortical stimulation) has not as yet been consistent enough to provide localizing criteria.

As would be expected, inspection of the cortical surface was not helpful in localizing the sensorimotor area. The well-known variability in the configuration of fissures and overlying vasculature prevented their use as landmarks. This finding was especially true in the case of large mass lesions and consequent displacement of tissue; in one such case the initial estimate of the location of the CS was incorrect by two sulci. While it is true that the CS often makes a characteristic bend in the region of the hand area (Fig. 5), similar bends were also seen in the precentral and postcentral sulci, and the configuration of the CS was often apparent only on retrospective analysis of photographs made in surgery. Similar retrospective analysis of the appearance and location of draining veins in relation to the CS revealed no relationships useful for localization.

## SUMMARY

The following criteria are useful for localization of the hand area of sensorimotor cortex:

Polarity inversion of N20-P30 to P20-N20 occurs as electrode locations cross the CS from somatosensory to motor cortex. Aside from the exceptions mentioned above (inadequate exposure of the hand area or complete failure to record SEPs), the polarity inversion of these potentials was a consistent feature of all recordings, as concluded also by Broughton et al. [4] and Lueders et al. [6].

P25 (and N35, if present) is largest in a small region of the postcentral gyrus about 1 cm medial to the region of largest N20-P30 potentials. Depending on their relative amplitudes and latencies, the postcentral P25 and N35 potentials may be confused with the precentral P20 and N30 potentials.

An initial negativity in the 18–24 msec latency range is always indicative of a postcentral location.

The largest amplitude potentials are recorded from the somatosensory cortex just posterior to the CS.

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