Localization of function in the excision of lesions from the sensorimotor region

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Since 1968, we have used the recording of averaged somatosensory evoked responses, in conjunction with cortical stimulation, to localize the sensorimotor cortex in the surgical management of epilepsy. Because this method permits quick localization of functional areas under general anesthesia, we have come to use it in the excision of brain tumors and other focal lesions located in the vicinity of the sensorimotor region. In this paper we describe this method and illustrate its utility.

Clinical Material and Methods

The patient population consisted of 31 patients. Twenty-six had a tumor; the remaining five had a tuberculoma, cysticercoid cyst, vascular malformation, astrocytic proliferation, and cystic infarct, respectively.

The method of functional localization under general anesthesia has been described previously in papers dealing with the surgery of epilepsy. Its description, with slight modification, is repeated here to emphasize those aspects related to the removal of tumors and other space-occupying lesions that reside in or near the sensorimotor region.

A craniotomy is performed under general endotracheal anesthesia. The patients are premedicated with atropine only. Induction of anesthesia is performed with halothane, and endotracheal intubation is carried out following administration of succinylcholine, a short-acting depolarizing muscle relaxant. Anesthesia is maintained with a combination of 50% N2O and O2, and halothane up to 2%, without neuromuscular paralysis. During cortical stimulation, halothane concentration is reduced to about 0.5% and it is usually possible to elicit movement. Upon completion of cortical stimulation, the patient is paralyzed with pancuronium, artificially ventilated, and carried on the narcotic, fentanyl, for the remainder of the procedure.

A horseshoe-shaped skin flap with its base toward the ear is fashioned. The medial free border of the flap is made 2 cm from the midline. It extends from the coronal suture posteriorly for approximately 9 cm. The anterior and posterior limbs of the flap are extended laterally from the medial border toward the base for approximately 8 cm. A bone flap of comparable size is fashioned. This assures exposure of the hand and face representation, and also sufficient “nonfunctional” adjacent cortex, which it is necessary to include in the recordings that localize the somatosensory area. As will be seen, one must compare records of evoked responses from nonfunctional areas, that yield either a small or no response, with the records from the somatosensory and motor cortex in order to identify the functional area. The liberal exposure also anticipates any displacement of the sensorimotor region by the lesion and associated edema. Depending on the findings in the
A Silastic template holding three rows of eight linearly oriented electrodes is placed on the cortical surface in a plane parallel to the midline and spanning the presumed location of the sensorimotor region. The inter-electrode distance is 1 cm, and each row is separated by 1.5 cm (Fig. 1). Simultaneous records are made from each adjacent pair of electrodes in the first row (that is, 1-2, 2-3, 3-4) while the contralateral median nerve is electrically stimulated transcutaneously (1/sec) at the wrist. Stimulus strength is adjusted to just above threshold for eliciting movement of the thumb. If an evoked response is not obtained, then recordings are made from the second row of electrodes, etc. A switching matrix controlled by a microprocessor is under keyboard command and it can select any row of recording sites in the brief time it takes to type in the command (such as “Matrix A”). A special-purpose computer is used to quickly expose the sensory evoked response by “averaging” 25 to 50 post-stimulus epochs (100 msec in duration) of electrical activity. If necessary, the face area is similarly identified using a solenoid to deliver a light tap to the upper or lower lip as the sensory stimulus.

computerized tomography (CT) scan, the position of the flap in the sagittal plane may be shifted anteriorly or posteriorly to assure that both the functional area and the lesion will be in the operative field.

After the brain is exposed, cortical sensory evoked responses are recorded to identify the sensorimotor region. Somatosensory evoked responses can be used to localize the sensorimotor region because, under our conditions of recording, a response occurs only in the primary somatosensory area, and variably in the motor cortex. The factors that determine whether or not a response is produced in the motor cortex are unknown. Obtaining a response is not related to the presence or absence of anesthesia, or to the side of recording (dominant versus nondominant hemisphere). Responses in association cortex, like those that occur in animals, are not seen in man.

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FIG. 1. Electrode array used to record somatosensory evoked responses for localizing the somatosensory area. It overlies the left cerebral hemisphere. The midline is at the bottom; anterior is to the reader's right. Under each number is an elliptical 1 x 2-mm pure platinum electrode disc. Teflon-coated wires from each electrode are assembled in the cable seen at top of the figure. The vertically oriented cottonoid strips at the bottom of the picture are used as markers which permit precise replacement of the array with a grid of numbered tickets. See Fig. 4 and related text for details.

FIG. 2. Somatosensory evoked responses identifying the somatosensory and motor hand areas. Vertical lines between traces indicate phase reversal of responses recorded bipolarly from adjacent areas (for details see text). Deflections at the beginning of each trace are shock artifacts. Time calibration is at bottom of figure. A: Recordings in a patient in whom only the somatosensory area yielded a response. Channel 1 (Ch. 1) is electrode combination 1-2, Ch. 2 is 2-3, etc. B: Recordings in a patient in whom both the somatosensory and motor hand areas yielded responses. (Reproduced from Goldring S, Gregorie EM: Surgical management of epilepsy using epidural recordings to localize the seizure focus. Review of 100 cases. J Neurosurg 60:457-466, 1984, with permission.)
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FIG. 3. Somatosensory evoked response identifying the sensorimotor area in Case 7. Cross-hatched circle indicates tumor site. Curved lines on the schematic brain identify the motor and somatosensory gyri. Black circles and associated numbers identify recording electrode sites. Numbers at top of each trace indicate the electrode sites from which the record was made.

When a response is evoked only in the somatosensory area, the tracings from the row of linearly oriented electrode sites usually show responses from only two adjacent pairs of electrode combinations, and these responses are reversed in polarity. For example, simultaneous recordings made from a row of electrodes, 1-2, 2-3, etc., show a response only from pairs 5-6 and 6-7, identified as channels 5 and 6, respectively, in Fig. 2A. Tracings from all other electrode sites show either no response or inconsequential deflections. Since electrode sites 5 and 7 show a response only when they are paired with electrode 6, and not when they are paired with the other electrodes to which they are adjacent, electrode site 6 is identified as overlying the somatosensory area. In some cases smaller responses are recorded from the areas immediately adjacent to the two sites which yield responses showing phase reversal. These are not locally generated; they reflect, instead, distant pick-up of the response generated in the somatosensory area. For carrying out more detailed cortical stimulation the electrode array is replaced with a mock array that consists of a grid of numbered tickets fused to a matrix of narrow Silastic stripping. The position of each ticket corresponds precisely to the electrode positions in the electrode array and the grid is oriented in the exact position that had been occupied by the electrode array to identify the somatosensory hand area (Fig. 4). The grid of numbered tickets permits more focal and extensive exploration with a bipolar electrode (inter-electrode distance = 0.5 mm).

Since it is possible to localize the sensorimotor region with cortical stimulation under general anesthesia that does not require neuromuscular paralysis, the use of somatosensory evoked responses for function localization may appear redundant and unnecessary. However, during general anesthesia the threshold for producing movement is raised, much time is spent varying stimulus intensities and exploring the cortical surface with the stimulating electrode, and (depending on the level of general anesthesia) the extent of the electrically excitable cortex may be constricted. By using somatosensory evoked responses prior to cortical stimulation, the spent time and frustration that are frequently ex-
performed in searching blindly for the domain of sensorimotor cortex are avoided.

**Illustrative Case Reports**

To illustrate the usefulness of the method of functional localization just described, we present brief descriptions of the following 10 cases.

**Case 1**

This 46-year-old man with known carcinoma of the lung presented with left focal motor seizures. They begin in the left abdomen and spread to the thorax and then to the arm and leg. At surgery, the arachnoid overlying the sulcus between two of the gyri was opaque in an area just adjacent to the medial edge of the craniotomy. The cortex seen through the arachnoid had a yellowish discoloration. In this area the tumor lay nestled in the depth of the sulcus which proved to be the central fissure, just medial to the arm and hand representation (Fig. 5-1). Working within the sulcus, the tumor, an adenocarcinoma 2½ cm in diameter, was removed.

Postoperatively, the patient had a left hemiparesis which progressively improved. When last examined 4 months after surgery his neurological examination was normal. He died 1 year after surgery.

**Case 2**

This 48-year-old woman had a left upper lobectomy for carcinoma of the lung in 1976. In 1978, she experienced focal seizures of her left hand; neurological examination was unremarkable. A CT scan showed an enhancing lesion in the posterior frontal lobe. During surgery the gyri in the posterior one-half of the field were seen to be swollen. There was no definite surface clue to indicate the subcortical site of the lesion. Functional localization showed the central fissure to be displaced anteriorly. It was located about one-half its usual distance from the coronal suture (that is, 2.5 cm instead of about 5 cm) when measured in a plane parallel to and near the midline. The gyrus just posterior to the somatosensory gyrus was entered a few millimeters behind the postcentral fissure at the level of the hand representation. This entry site was chosen because the somatosensory gyrus appeared somewhat more swollen than the motor gyrus, and the seizure pattern indicated that the focus was in or near the hand area (Fig. 5-2).

A subpial dissection was carried out to expose the hidden bank of the somatosensory gyrus; it was entered at that point and the tumor was encountered and removed. Care was taken not to disturb the anterior and superior cortical mantle, although underlying white matter probably incurred some injury. Postoperatively, the patient had a mild paresis of the left upper extremity. Two months after surgery her neurological examination was normal. There was no evidence of cortical sensory loss. She remains asymptomatic 6 years after surgery.

**Case 3**

This 42-year-old man developed focal seizures involving the left upper extremity. Neurological examination was normal. A CT scan showed an enhancing lesion in the right posterior frontal lobe. During surgery, the brain surface appeared normal except for focal...
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Case 4

This 20-year-old man had suffered focal seizures since he was 6 years of age. The ictus began with a feeling of numbness in the face and progressed to facial twitching that spread to involve the left arm. A CT scan showed a hypodense area in the posterior frontal region. At surgery, the inferior extent of the motor gyrus (toward the Sylvian fissure) was swollen and felt soft to palpation. Electrical stimulation of the precentral gyrus produced only hand movement; no facial responses could be obtained in the usual area of face representation. By contrast, sensory evoked responses could be obtained from face stimulation. At a point about 3 cm above the Sylvian fissure and just above the swollen segment, an evoked response could be obtained from either the hand or face stimulation, identifying the boundary between hand and face representation (Fig. 5-4). The motor gyrus below this point was entirely removed. It contained a mixed glioma. Postoperatively, the patient developed a left monoparesis and central facial weakness. These signs cleared entirely within a few days and neurological examination was normal at the time of discharge. He has been followed for 7 years without signs of recurrence.

Case 5

This 50-year-old woman with breast carcinoma developed focal seizures involving the left side of the face and left hand. A CT scan showed two lesions, one in the right posterior frontal lobe, the other in the posterior fossa. She received radiation therapy. Six months later she experienced focal seizures again. A CT scan showed persistence of the posterior frontal lesion; the posterior fossa tumor had disappeared (Fig. 5-5). During surgery, the lower one-half of the somatosensory gyrus which contained the face representation was observed to be swollen. The postcentral fissure was opened and the somatosensory gyrus was entered through its buried posterior bank. A well circumscribed tumor, an adenocarcinoma, was encountered and removed. Postoperatively, the patient had a mild left central facial weakness and cortical sensory deficit in her hand, which progressively disappeared during a 2-week period. When last seen 2 months postoperatively, her neurological examination was normal except for mild facial asymmetry.

Case 6

This 54-year-old woman had a 10-year history of focal seizures involving the left side of the face and left hand beginning with left facial tingling. A CT scan showed a frontoparietal lesion (Fig. 5-6). During surgery, the face somatosensory and motor areas were found to be swollen, with the somatosensory area showing the greatest change. The somatosensory gyrus was entered through its crest. A cyst 3.5 cm in diameter was encountered very superficially and removed intact. Histological examination showed it to be a cysticercoid cyst. Postoperatively, the patient had a mild left hemiparesis which progressively improved, and at the time of discharge she had only a mild left central facial weakness. Four years after surgery, her neurological examination is normal and she remains free of seizures.

Case 7

This 57-year-old woman presented with a mild right hemiparesis. A CT scan showed an enhancing left frontal lobe lesion, and a chest x-ray film showed a left apical lesion which proved to be an adenocarcinoma (Fig. 5-7). During surgery, the brain appeared normal except for a swollen gyrus, anteriorly adjacent to the precentral gyrus in the region of the hand representation. The swollen gyrus was entered through its crest. A tumor (adenocarcinoma) 2 cm in diameter, was encountered superficially and removed. Postoperatively, the patient's neurological examination was normal. She died 1 year after surgery.

Case 8

This 53-year-old man with renal cell carcinoma developed a right monoparesis in his upper extremity. A CT scan revealed a small posterior frontal mass about 2.5 cm below the cortical surface in the region of the presumed central fissure (Fig. 5-8). Because of the location of the lesion it was decided to treat him with irradiation rather than surgery. He was referred to us 5 months later because there had been no improvement. Computerized tomography showed the left posterior frontal lesion (Fig. 6). A nuclear magnetic resonance (NMR) scan showed the lesion to be at the base of a swollen gyrus (Fig. 7). During surgery the swollen gyrus was readily identified and proved to be the motor gyrus. The maximal swelling was in the area of hand representation. In this region the precentral fissure was opened, exposing the buried anterior bank of the motor gyrus which was entered near its base in the fissure. A 1.5-cm tumor nodule (metastatic carcinoma) was encountered and removed. Postoperatively, the patient had a right hemiparesis. This deficit has progressively improved. At present, 3 months postoperatively, he has
lesion in the left posterior inferior frontal lobe (Fig. 5-9). At surgery, the brain surface appeared normal. Palpation of the gyrus anteriorly adjacent to the motor gyrus, about 2 cm above the Sylvian fissure, gave the sensation of an underlying hard mass. The crest of the gyrus was entered at this point, and a well circumscribed tumor mass was encountered and removed. It proved to be a thrombosed arteriovenous malformation. Postoperatively, the patient's neurological examination, including language function, was normal except for mild right facial weakness which progressively disappeared over a 2-week period. She was lost to follow-up evaluation 4 years after surgery. During the time she was followed, the seizures remained controlled as long as she took her medication.

Case 10

This 37-year-old woman, who was 6 months pregnant, presented with a 2-week history of right-sided seizures that began with a focal sensory aura, sometimes associated with psychomotor phenomena. Neurological examination showed a very mild right hemiparesis and cortical sensory loss. A CT scan showed an enhancing lesion in the posterior frontal operculum (Fig. 5-10). During surgery the brain appeared normal except for a suggestive discoloration of the somatosensory gyrus adjacent to the Sylvian fissure. The gyrus was entered through its crest. A cystic tumor was encountered about 2 cm below the surface. A frozen section of the tumor tissue showed it to be a glioblastoma multiforme. A subtotal removal was carried out. Postoperatively, the patient had a right hemiparesis and dysphasia. She progressively improved. Two months postoperatively she exhibited only a mild expressive dysphasia and minimal right arm weakness. She died 11 months after surgery.

Summary of Remaining Cases

In the remaining 21 cases the lesions were located adjacent to the somatosensory and motor gyri, similar to those shown in Cases 7 and 9 (Fig. 5), or proved to be more diffuse in the frontal or parietal lobe, with or without extension into the sensorimotor area.

Discussion

Localization of functional areas is especially important when there is no surface clue to guide one to a subcortical lesion. Without localization of function such lesions are frequently approached obliquely, biasing the approach either anteriorly or posteriorly to avoid entry through the sensorimotor cortex. However, because lesions and their associated edema can displace adjacent brain tissue, oblique approaches based on the presumed location of the central fissure risk injury to the sensorimotor region. For example, in Case 2, where the central fissure was displaced anteriorly, had we elected to approach the lesion obliquely from a site anterior to the presumed location of the sensorimotor...
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region we would have traversed motor cortex and risked a hemiparesis.

Even when there is a surface clue about the location of a subcortical tumor, it is still important to know the spatial relationship of the subcortical lesion to the functional areas. For example, in Case 8 such information permitted us to approach the tumor through the precentral fissure rather than through either the crest of the motor gyrus or the central fissure. With the former approach there would have been more extensive injury to the motor gyrus, and with the latter we would have risked damage to the somatosensory as well as the motor gyrus. In this patient the NMR scan provided the necessary information for recognizing the surface landmark. Other recently introduced techniques, such as ultrasound and CT-guided stereotaxy, appear to have even greater potential for localizing the surface area overlying a subcortical lesion. Their use in combination with functional localization should further increase the safety of removing lesions from the vicinity of the sensorimotor region.

In Case 2, the patient exhibited weakness of the left upper extremity postoperatively, but then recovered normal neurological function, even though a portion of the somatosensory gyrus in the area of the hand representation had to be destroyed in gaining access to the tumor. This recovery might merely relate to the relatively small amount of the cortex that was damaged in removing the tumor. That is, the amount of damaged cortical tissue was perhaps less than the critical volume which must be destroyed before a neurological deficit becomes evident. Another possible explanation of the result, however, is found in recent studies which have demonstrated multiple representations of the body in the primary somatosensory cortex of subhuman primates. Within the S1 segment, there are two separate and complete cutaneous representations in areas 3b and 1, and two separate representations of deep body tissue in areas 3a and 2. Although there are probably differences in the sensory qualities subserved by the corresponding areas of the dual systems, it is possible that enough overlap of functional representation exists between each of the paired sensory representations to account for the preservation of the normal neurological function that occurred in Case 2? In that patient, the somatosensory gyrus was entered through its posterior buried bank. Assuming that a dual system of body representation exists in the human primary somatosensory area, the deep and cutaneous representation located anteriorly in areas 3a and 3b would have been left relatively undisturbed, and sufficient to subserve normal neurological function (at least, as determined by routine neurological examination). If such an interpretation is correct, it indicates the desirability of approaching lesions within the S1 gyrus through its buried posterior bank. Such an approach also diminishes the risk of injuring motor cortex. Furthermore, in behavioral studies in primates, discrete lesions in areas 1, 2, and 3b have shown that area 3b in the posterior bank of the central sulcus is the most critical area for the learning of somatosensory discrimination.

The motor cortex also has been shown to have a dual representation of the body, situated anteriorly and posteriorly in the precentral gyrus of subhuman primates. However, the sensory input to each of these regions is different, the anterior region having a deep sensory input and the posterior area having a cutaneous one. This finding makes it unlikely that a “redundancy” of functional representation exists in spatially separate systems of motor control. Thus, the recovery of motor function in Case 8, where the motor gyrus was entered through the hidden anterior bank of the gyrus, requires another explanation. In part, the recovery may be due to the relative sparing of the posterior region of the precentral gyrus. The apparent dominant role of this portion of the gyrus in effecting movement is suggested by the observation that the lowest stimulus threshold for producing motor responses is found in the region bordering the central fissure.

The recovery of function in patients who had lesions excised from the areas of sensory or motor facial representation (Cases 4, 5, 6, and 10) may have still another explanation — a greater bilateral cortical representation of the face than exists for the extremities. This possibility is especially supported by the complete recovery of facial movements in Case 4, where the entire inferior portion of the precentral gyrus was resected.

Our experience with localization of function in the anesthetized patient has convinced us that it is an important adjunct in cerebral surgery, and we are using it with increasing frequency. However, we are also convinced that we need to go further. We need a method that can identify in the anesthetized patient not only motor and primary sensory cortex, but also language cortex, distinguish primary sensory from association cortex, and ultimately identify the function with which the particular association cortex being manipulated is concerned. Such identification should be possible through craniotomies of sufficient size to deal only with the pathology. The method should be practical, and one that can be used routinely by all neurosurgeons who expose the brain.

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![Diagram](chart.png)
As an example of one approach to this problem, we are currently testing the following hypothesis. Is it possible that architectonically distinct areas might have specific electrophysiological markers? That this is possible is suggested by studies of the direct cortical response in animals. The direct cortical response is an electrical potential recorded in the immediate vicinity of a focal electrical stimulus applied to the cortical surface; the response dissipates within a few millimeters of the stimulus site. In the cat and rabbit, the response evoked in a primary sensory area is distinctly different from one evoked in an association area. We have made similar observations in the monkey (Fig. 8), and electrophysiological experiments by others have explained the configuration of these responses in terms of the specific synaptic organization being activated by the stimulus. Might exhaustive study of these responses specific to a focal electrical stimulus applied to the cortical surface; the response dissipates within a few millimeters of the stimulus site. In the cat and rabbit, the response evoked in a primary sensory area is distinctly different from one evoked in an association area. We have made similar observations in the monkey (Fig. 8), and electrophysiological experiments by others have explained the configuration of these responses in terms of the specific synaptic organization being activated by the stimulus.

Might exhaustive study of these responses in the human brain discover a profile of configurations in which the form of the response indicates the function with which the area being tested is concerned? If so, this knowledge could then be used to develop a practical method of functional localization. There are undoubtedly other ways of getting at this problem, and in these times of burgeoning technological development, we should be able to develop a method that will both expand our knowledge of the functional anatomy of the cerebral cortex and improve our surgical capabilities in dealing with cerebral lesions.

Acknowledgments

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