Multiple subpial transection: a new approach to the surgical treatment of focal epilepsy

FRANK MORRELL, M.D., WALTER W. WHISLER, M.D., PH.D., AND THOMAS P. BLECK, M.D.

Departments of Neurological Sciences, Neurosurgery, and Internal Medicine, Rush-Presbyterian-St. Luke's Medical Center, Chicago, Illinois

A new operative approach has been designed for the relief of medically intractable focal epilepsy. It is intended particularly to be used in those cases where the epileptogenic lesion lies in “unresectable” cortex; that is, those cerebral regions subserving speech, memory, and primary motor and sensory function. The procedure is based upon experimental evidence indicating 1) that epileptogenic discharge requires substantial side-to-side or horizontal interaction of cortical neurons, and 2) that the major functional properties of cortical tissue depend upon the vertical fiber connections of the columnar units. The technique requires severing of tangential intracortical fibers while preserving the vertical fiber connections of both incoming and outgoing nerve pathways and of the penetrating blood vessels which also have a vertical orientation.

In this study, the effect of multiple subpial transection was assessed on both function and seizure control. The effect on function was reviewed in 32 cases; only 20 cases were evaluated with respect to seizure control, since a follow-up period of 5 years or more (5 to 22 years) is required before conclusions can be drawn. Multiple subpial transection was applied to the precentral gyrus in 16 cases, the postcentral gyrus in six, Broca’s area in five, and Wernicke’s area in five. With respect to function, the major finding was that none of the 32 patients has suffered a clinically significant behavioral deficit (although subtle deficits could be detected by careful neurological examination). Complete control of seizures has been obtained in 11 (55%) of the 20 cases evaluated. Nine patients developed recurrent seizures consequent to progressive disease unsuspected before operation (Rasmussen’s encephalitis in five, tumor in three, and subacute sclerosing panencephalitis in one). In none of these cases, however, did the recurrent seizures arise in the transected zone. Thus, the results indicate that multiple subpial transection is about as effective as standard excisional therapy, and can be successfully employed when epileptogenic lesions encroach upon cortical territories, the removal of which would be functionally incapacitating.

Key Words: epilepsy · intracortical connections · cortical columnar organization · epileptic discharge · surgical technique

A certain proportion of patients with medically intractable focal epilepsy, who are otherwise good candidates for excisional therapy, cannot be treated because their epileptogenic lesions lie in cortical territories controlling speech, movement, primary sensation, or memory. Standard ablation of these regions results in a grave and unacceptable functional deficit. For such cases, a new surgical approach has been devised. It has been applied selectively and has been systematically evaluated over the past two decades. This paper is a comprehensive report of the technique, the indications for its use, and the results of its application. Brief reports have appeared previously. 30–32

The procedure, multiple subpial transection (MST), is designed to sever horizontally coursing intracortical fibers longer than 5 mm while preserving vertically oriented incoming and outgoing neural elements as well as the penetrating blood vessels which also have a vertical orientation. The purpose of this orientation-selective lesion is to reduce the likelihood of occurrence of synchronized cell discharge and to do so in a manner which does not impair the major functional capacity of the tissue. In fact, MST does eliminate both the clinical and electrographic signs of epileptogenic discharge in virtually all cases. If properly performed, the procedure produces minimal impairment of the physiological capability of the tissue. Thus, there are two scales against which the effect of this procedure may be assessed. These are: 1) the functional result, and 2) the control of seizures. The effect of MST on the seizure disorder
reported herein is based on 20 patients in whom the follow-up period was 5 to 22 years. However, 32 cases are included in the evaluation of the effect of MST on function, since performance can be assessed almost immediately and the more recent cases can be included.

Rationale for the Procedure

Columnar Organization

In the early 1960's, at the time when the subpial transection procedure was conceived, a number of observations emerged from many physiological experiments suggesting that the vertical column was a master organizational principle for cerebral cortex.\(^3\)\(^,\)\(^4\)\(^,\)\(^2\)\(^,\)\(^3\)\(^,\)\(^4\)\(^,\)\(^5\)\(^,\)\(^6\)\(^,\)\(^7\)\(^,\)\(^8\)\(^,\)\(^9\)\(^,\)\(^1\) The most recent and comprehensive of these studies is that of Asanuma,\(^9\) who demonstrated that surgical cross-hatching of the visual cortex or implantation of mica plates or tantalum wire did not impair visual perception in the cat. Sperry\(^1\) concluded that these findings were difficult to reconcile with any form of electrical field theory or any hypothesis that regarded skilled behavior as dependent on "tangential intracortical conduction over the horizontal fiber systems of the cortex." Both groups of experiments suggested that the bulk of the functionally important connections of a cortical territory were arranged in vertical columns and that, if this columnar organization was respected and preserved, the horizontal fibers could be sectioned without causing serious disability.

Synchrony of Cell Discharge in Epilepsy

Electrophysiological explorations of cellular properties in a variety of animal models of focal epilepsy have revealed that a feature common to all models is the paroxysmal depolarization shift (PDS).\(^2\)\(^,\)\(^6\)\(^,\)\(^7\) This now well-known phenomenon is an intracellularly recorded prolonged depolarization accompanied by high-frequency firing leading to inactivation of the Na\(^+\) conductance. The PDS is believed to be the cellular substrate of the interictal spike or field potential seen in electroencephalographic (EEG) recordings. Indeed, many cells in the center of a focus exhibit the PDS in association with the EEG spike, indicating that extensive synchrony of cell activity is responsible for the epileptiform field potential.\(^9\)\(^,\)\(^1\) Although there continues to be uncertainty about the role of inhibition in such synchrony\(^1\)\(^,\)\(^6\)\(^,\)\(^7\) and with respect to a possible contribution of ephaptic mechanisms,\(^1\)\(^1\)\(^,\)\(^2\)\(^,\)\(^1\)\(^1\) there is little doubt about the essential role of cell synchrony. Several papers and extensive reviews have provided further details.\(^5\)\(^,\)\(^8\)\(^,\)\(^1\)\(^1\)\(^,\)\(^3\)\(^,\)\(^9\)\(^\)\(^,\)\(^1\)\(^0\)\(^,\)\(^1\)\(^1\)\(^,\)\(^2\)\(^1\)\(^,\)\(^3\)\(^,\)\(^4\)\(^,\)\(^5\)\(^,\)\(^6\)\(^,\)\(^7\)\(^,\)\(^8\)\(^,\)\(^9\)\(^,\)\(^1\)\(^0\)

Evidence assembled in the above reviews, particularly in those by Ayala, et al.,\(^5\)\(^,\)\(^8\)\(^,\)\(^1\)\(^0\) and Morrell,\(^2\) also indicates that "epileptic" neurons exhibit no abnormality of resting potential, input resistance, or any (resting) ionic conductance when measured at the level of the cell soma, where micro-electrode penetrations are normally made. However, the prominent occurrence of fractional spikes believed to be of dendritic origin\(^5\)\(^,\)\(^1\)\(^2\)\(^,\)\(^3\)\(^,\)\(^3\)\(^7\)\(^,\)\(^4\)\(^2\)\(^,\)\(^3\)\(^8\)\(^,\)\(^4\)\(^9\)\(^,\)\(^5\)\(^0\) suggests that some membrane anomaly may exist and that it may be mediated by side-to-side interactions among dendrites in superficial cortical laminae.\(^1\)

The "Critical Mass" of Cerebral Tissue

What is the extent of side-to-side or lateral interaction necessary to generate an epileptiform spike? Although it may be surmised that the larger the cortical island the more likely it is to support epileptiform activity, the minimum contiguous volume necessary to sustain synchronous spiking has been empirically determined to be 12.5 sq mm.\(^2\)\(^,\)\(^3\)\(^,\)\(^4\)\(^7\) Cortical islands greater than 5 mm in width, or horizontal connections of greater than 5 mm, can support paroxysmal discharge.\(^9\)\(^,\)\(^1\)\(^0\),\(^1\)\(^2\),\(^2\)\(^2\),\(^4\)\(^7\) If two experimental foci are placed 4 mm apart, the paroxysmal discharges generated tend to become synchronous; if the two foci are 6.7 mm apart, spike activity in the two regions remains independent.\(^2\) If "cross-talk" between cortical columns depends on synaptic mechanisms, it is likely to be limited to the trajectory of horizontal axonal ramifications (2.5 mm or less according to Szentagothai\(^4\)). Indeed, the electrical field of epileptiform events generated in isolated cortical slabs \textit{in vivo} has been estimated to extend only 1 to 2 mm,\(^4\)\(^7\) making it unlikely that even electrotonic influences could effectively subserve widespread synchronization. On the other hand, cortical slices as thin as 400 \(\mu\)m can sustain epileptiform bursting when bathed in penicillin, bicuculline, or picrotoxin (all antagonists of gamma-aminobutyric acid (GABA)-ergic inhibition) or with convulsant agents such as 4-aminopyridine.\(^1\)\(^,\)\(^4\),\(^1\)\(^4\),\(^1\)\(^8\),\(^5\)\(^1\),\(^5\)\(^2\) Except for these deafferented \textit{in vitro} preparations, however, the spontaneous generation of epileptiform potentials in intact brain appears to require several millimeters of contiguous tissue. Therefore, the transection interval described below is 5 mm.

Spread of Seizure Discharge

The most common pattern of spread when an interictal focus evolves into a clinical attack is that of local neighborhood propagation, best exemplified by the Jacksonian march. From this and from the foregoing considerations concerning cell synchrony, it seems reasonable to suggest that removal of a portion of the short intrinsic internuncial connections in cerebral cor-

F. Morrell, W. W. Whisler, and T. P. Bleck
Multiple subpial transection for focal epilepsy

tex should present an impediment to cell synchronization and at least to the initial phases of seizure spread.

Blood Supply Preservation and Prevention of Meningocerebral Scarring

Sperry, et al., carried out their transections from above, slicing the cortical gyri as one does a loaf of bread. However, those workers were not concerned with long-term survival or with potential epileptogenicity. Our requirement was to effect a similar dissolution of neural continuity while maintaining as intact a vascular supply as possible. Our goal was also to minimize the size of any breach of the pial surface in order to prevent fibroblastic invasion of brain tissue. Our purpose was best achieved by sectioning from below as described.

Surgical Technique

The device employed was an adaptation of an instrument originally designed for producing isolated cortical slabs in experimental animals. In a series of monkeys, the technique was modified to eliminate the undercutting and produce only intracortical interruption of horizontal fibers in the motor and inferotemporal cortices. A surprising preservation of function was noted after this procedure, and, in monkeys with alumina cream foci, epileptiform potentials disappeared when the focus was transected. These preliminary findings encouraged us to apply the method to the first human case.

The instrument consists of a heavy steel wire, the end of which is flattened and turned up at a right angle to the shaft for a distance of 4 mm (Fig. 1). The small, blunt, right-angled hook thus created is not sharpened but is smooth and rounded, and about 0.3 mm at its edge. The device is commercially fabricated out of a single piece of stainless steel. The critical feature of its construction is the balance between the springiness and the malleability of the wire, which must be such that the tip can be variously oriented with respect to the handle (to allow an approach to differently arranged gyri) without affecting its tensile strength. The 4-mm end segment of the wire is sufficiently short so that if the tip is held against the pia as it is pulled, the entire transection is confined to the gray matter, and all fibers exiting the cortex, even the U fibers, are spared.

Once the area to be transected has been electrocorticographically mapped, a small pinhole-sized nick is made in the pia with the point of a No. 11 blade in an area of the cortex that is relatively avascular. An attempt is made to reach as deep into the sulcus as possible, but access is often limited by the presence of large vessels. The instrument is introduced through the pial opening and then swept forward, dipping in an arc-like fashion underneath the gyrus (Fig. 2). The blade of the blunt hook is maintained in a strictly vertical orientation to avoid undercutting the cortex. The position of the blade is aligned with the flat side of the instrument handle to help maintain the correct orientation. The tip is raised at the far edge of the gyrus so that it is visible beneath and just elevates, but does not penetrate, the pia. The blade is then gently drawn straight back across the gyrus in the same plane as its forward movement, keeping its tip visible through the pia until the gyrus is transected. Care is taken not to snag any cortical vessels, especially from the opposite sulcus, in the hook of the blade. After the blade is removed, there is often some bleeding from capillaries on the surface at the point of original insertion. This is usually easily controlled by application of a very small piece of thrombin-soaked Gelfoam. The next transection is made parallel to the first and 5 mm away (Fig. 3). Transections are repeated as often as necessary to include the entire area of electrical abnormality and may encompass several gyri. The capillary bleeding associated with each traverse of the instrument results in a fine red line. The bleeding does not seem to cause damage, and the line is a useful reference against which to gauge the location of the next transection.

Clinical Application

Patient Selection

Patients in whom clinical and EEG features suggested
that the focus producing their seizures was located in a functionally critical area were candidates for MST. The nature of the procedure, its risks and benefits, and the option of a more traditional, limited resective procedure were explained to the patients and their families, and informed consent was obtained.

The overall surgical treatment was tailored to each patient; therefore, no case is exactly comparable to another. Electroconvulsive therapy was the main determinant of the boundaries of the epileptogenic lesion. In all cases, if there was a visible structural lesion coincident with the epileptiform electrical abnormality, it was removed. In the absence of a structural abnormality, or after its removal, the approach was predicated on the assumption that epileptogenic tissue should be removed where possible and that multiple subpial transection should be carried out in those regions where resection would have resulted in an unacceptable functional deficit. Thus, with two exceptions, every case had a variable mix of resected and transected tissue. Regions considered to be unacceptable for resection were the precentral and postcentral gyri of either hemisphere, Broca's area, and the posterior perisylvian speech zones (Wernicke's area, the angular gyrus, and the supramarginal gyrus) in the dominant hemisphere. In every case, the brain regions so described were physiologically identified by electrical stimulation of the exposed brain in the awake and consciously cooperating patient.

**Functional Localization**

The criteria used for physiological identification of local cerebral regions were not essentially different from the criteria employed in other centers. Our standard stimulation protocol required that a given effect be repeatedly reproduced at a threshold voltage at a particular brain site using appropriate controls for excessive patient cooperation (such as stimulation without warning, warning without stimulation). Effects of electrical stimulation are not considered to have localizing significance if afterdischarge occurs or if the symptoms outlast the application of current.

**Results With Respect to Function**

Outcome with respect to the function of the transected regions will be described in patient groups classified according to the anatomical region of the transection. There are four groups: 1) precentral gyrus; 2) postcentral gyrus; 3) Broca's area; and 4) the posterior temporoparietal complex of Wernicke's area, the angular gyrus, and the supramarginal gyrus. Several patients had transections that included more than one of these regions, such as Broca's area and the precentral gyrus or precentral and postcentral gyrus. Such patients will be described under each appropriate heading. Therefore, the sum of all patients entered into each group exceeds the total number of patients.

**Precentral Gyrus**

Multiple subpial transection of the precentral gyrus, including all of the face and hand areas but a variable proportion of the leg representation, was carried out in 16 patients. None of these patients developed a positive Babinski sign, hyperactive deep tendon reflexes, or increased muscle tone in the contralateral extremities. All could walk without a limp, all could use the arm and hand for eating, drawing, and writing. One patient continues his profession as a dance instructor. Postoperatively, some impairment of fine movement of the fingers was noted in eight of the 16 patients. The other eight had some impairment of skilled movement preoperatively, and in this group MST did not increase the deficit. One left-handed patient with a right precentral transection shifted to a right-hand preference, although she continued to be capable of using the left hand for such movements as writing, drawing, and eating. Interpretation of this latter case is complicated by the fact that a postcentral excision was also carried out. Thus, the shift in handedness may reflect the parietal ablation rather than the precentral transection. Moreover, in gaining appropriate access for the postcentral resection, the fibers emanating from the mesial aspect of the precentral gyrus (foot representation) were undercut by suction. The patient incurred a marked weakness of dorsiflexion at the ankle, hyperreflexia, and an upgoing toe sign in the left lower extremity. A comparison of the profound paresis of distal musculature in the leg with the intact (5/5) strength in the left arm, wrist, and fingers provided a contrast, within the same patient, of the consequence of undercutting of the foot area with that of MST of the arm, wrist, and finger representations. The proximal musculature of the leg retained good strength, so that the patient had no difficulty in bearing the weight of her body. Normal walking, however, was only possible with the aid of a foot brace. Now, 10 years after the surgery, she is
Multiple subpial transection for focal epilepsy

Case 1. Case presentations have been selected to illustrate various features of the clinical and electrographic outcome. The first case shows the common finding of epileptogenic discharge in the gyrus adjacent to the injured tissue, in this instance directly in the primary motor strip. This 17-year-old male high-school student had, at age 12 years, sustained a contusion of the right parietal cortex from the impact of a line drive in a baseball game. There was a dense cystic meningo-cerebral cicatrix in the parietal region. Electrical recordings disclosed active epileptiform discharge anterior and superior to the cyst. After complete removal of the cystic region, epileptiform activity persisted in the precentral gyrus and in a remaining margin of postcentral gyrus superior to the excision (Fig. 4). These discharges were associated with brief focal clinical attacks of his habitual type (Fig. 4 arrows). Multiple subpial transection of almost the entire lateral aspect of the precentral gyrus and a small portion of the postcentral arm area resulted in cessation of the electrical abnormality (Fig. 5). Postoperative neurological examination disclosed no motor deficit, although the parietal sensory loss expected from the postcentral excision was fully documented.

Case 2. The patient in the second case is one of two patients in whom no actual excision was made since the entire electrocorticographic abnormality lay in the pre- and postcentral gyri. There was virtually continuous epileptiform discharge at a postcentral electrode and at electrodes in the precentral gyrus of this 22-year-old woman. After MST that included the face and hand representations of the precentral gyrus and the entire face representation in the primary sensory receiving area, the electrodes were replaced. Subsequent recordings revealed no sign of epileptiform abnormality. The patient developed no paralysis and no sensory deficit.

Postcentral Gyrus

In six patients, MST of the postcentral gyrus (face, arm, and trunk representation) was carried out. None of the patients had any postoperative primary sensory loss or any deficit in stereogery, barognosis, or tactile reading. Two-point discrimination was symmetrical and no extinction occurred on double simultaneous stimulation in any patient. Fine, rapid skilled movements were impaired, however, and it was our impression that this difficulty was more pronounced in those with postcentral than with precentral transection. Nevertheless, in none of the six was the impairment suffi-
FIG. 5. Case 1. Electrocorticographic recordings obtained following multiple subpial transection (MST) of the precentral gyrus and a small portion of the postcentral gyrus superior to the ablation. The ablated region is stippled; the zone subjected to MST is shown by diagonal lines. Electrode positions are shown on the superimposed diagram. The electrical records from derivations overlying the transected zone (Channels 9 to 16) reveal no trace of the epileptiform abnormality so prominently shown in Fig. 4. Depression of background electrical activity seen in these same channels is a common finding immediately after MST. Usually cerebral rhythms resume over the ensuing 20 to 40 minutes.

Patient is a librarian, another a computer operator. One patient is a physician who has returned to work as a resident in internal medicine.

Case 3. The first patient on whom this procedure was used underwent transection of the perisylvian speech zones (Wernicke's area and the supramarginal and angular gyri) in July, 1967, at the age of 16 years. She had been well until the age of 7 years, when she was struck with a baseball in the left temporal region. Within a few months, she developed seizures characterized by an onset with "tingling" in the right side of the face followed by inability to understand speech, and then complex automatism. Each attack was followed by a period of pronounced receptive aphasia lasting 20 to 40 minutes. When the seizures increased to four to six each day in spite of the maximum tolerated doses of all anticonvulsant drugs, a left anterior temporal lobectomy was carried out without seizure control.
Multiple subpial transection for focal epilepsy

After another year of futile effort at medical control, surgical reexploration was carried out. Intraoperative recordings showed that the epileptogenic discharge was centered in the posterior temporal and inferior parietal cortex immediately posterior to the site of a tough, yellowed, and atrophic portion of the inferior postcentral gyrus. Electrical stimulation of the zone of electrical abnormality reproduced the habitual aura and the initial fragment of the seizure as well as the postictal aphasia. The atrophic portion of the postcentral gyrus was excised. Electrocorticographic tracings disclosed continued epileptiform discharge arising from the previously defined speech areas, most particularly from the angular gyrus. Following MST of the angular gyrus, the electrographic abnormality subsided. The patient has been seizure-free since the second operation.

Summary of Functional Results

The functional results demonstrate that MST is not associated with major dysfunction of the transected tissue. Careful neurological examination will, nevertheless, disclose the subtle deficits mentioned above in nearly all patients. Therefore, no claim is made that horizontal or tangential connections are functionally irrelevant — only that the price of severing them is small compared with that of ablation. Moreover, in many patients the net result, including elimination of seizures, yields an improvement of function of the transected tissue. For example, preoperatively, four of the patients with Wernicke’s area/angular gyrus transection and three of those with Broca’s area transection suffered severe aphasic symptoms for many hours each day. The minimal postoperative language deficit, such as minimal decrease in fluency, was regarded as preferable in every case. The patients with epileptogenic lesions of the motor cortex who were not already afflicted with some degree of permanent hemiparesis, were, nevertheless, functionally disabled by frequent clonic seizures. All of these individuals considered that the operation had improved their ability to utilize the involved hand and arm despite the diminution in fine movement skills.

Results With Respect to Seizures

As noted earlier, our assessment of the effect of MST on seizure control is limited to those patients in whom the follow-up period is 5 years or more (5 to 22 years).

Eleven (55%) of these 20 patients are seizure-free. All of the nine patients in whom seizures continued or recurred proved to have a progressive disease process, although in none of them was the progressive nature of the disorder known preoperatively. Five patients had the pathological findings of Rasmussen’s encephalitis; three had tumors, and one had subacute sclerosing panencephalitis.

In 18 of the 20 cases, transection resulted in immediate cessation of electrical abnormality in the transected zone. In two cases, both among the nine with progressive disease, the electrocorticographic abnormality persisted and, in these two, clinical seizures also persisted postoperatively (Table 1). In the other seven (of the nine), the transection eliminated the epileptiform discharge from the intraoperative record and resulted in relief of seizures for a variable period of time (several months to years). When both the epileptiform of electrical abnormality and clinical seizures eventually recurred in these seven patients, it was notable that the spike focus did not arise from the transected region and that the seizures had behavioral features different from those of the original attacks.

Case 4. The final case to be presented, a patient with the pathological findings of chronic encephalitis, demonstrates the late emergence of epileptogenic abnormality in the hemisphere opposite to that undergoing surgery. In that case, the EEG abnormality was associated with a clinical seizure pattern different from the original one and appropriate to the site of the new electrical disturbance. Following removal of the epileptogenic lesion in the left frontal cortex anterior to the precentral gyrus, there was persistent epileptiform discharge in the motor cortex. The inferior two-thirds of the precentral gyrus was then subpially transected. The patient was seizure-free for 2 years posttranssection, following which convulsive phenomena involving head and eye deviation to the left and clonic movement of the left extremities became apparent. An EEG recording obtained in January 1987, 6 years after the original surgery, revealed frequent epileptogenic discharges emanating from the right frontal lobe; no spikes arose from the territory of the previous removal and transection.

It is not intended that the “cure rate” of 55% in these transection cases be favorably (or unfavorably) compared with the usually cited statistics for ablative surgery (see Crandall’ for review). Almost all of our patients underwent partial removal of the epileptogenic site as well as multiple subpial transection. Nevertheless, in every case described, we believe that both electrocorticographic and clinical signs indicated that unresectable cortex was the primary site of disturbance and that the clinical outcome would not have been the same if the MST procedure had not been carried out. The increase in the percent of “cure” attributable to transection is

---

TABLE 1
Postoperative epileptiform electrical abnormality results in 20 cases

<table>
<thead>
<tr>
<th>Follow-Up Findings*</th>
<th>No. of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>cessation of electrical abnormality yes</td>
<td>18</td>
</tr>
<tr>
<td>no</td>
<td>2</td>
</tr>
<tr>
<td>recurrence of electrical abnormality elsewhere yes</td>
<td>7</td>
</tr>
<tr>
<td>no</td>
<td>13</td>
</tr>
</tbody>
</table>

* Follow-up period 5 to 22 years.
difficult to assess quantitatively, especially since only the most intractable of all possible cases were accepted for this experimental treatment.

Comment

Since multiple subpial transection is effective in abolishing epileptic seizures and is associated with minimal morbidity, we suggest that this operation may be a procedure of choice in patients with epileptogenic lesions situated in unresectable cortex. Furthermore, multiple subpial transection might be considered as a most desirable first step in the approach to any neocortical region where resection is not mandated by the presence of tumor or other gross pathology.

Acknowledgments

The authors thank Leyla deToledo-Morrell, Jerome Engel, Jr., and Mark Rayport for helpful discussion of these ideas and their presentation in this manuscript. We wish to especially thank John Hanbery who was the first to apply this technique in the human and who operated on the first three patients. Ray Clasen and Lucien Rubinstein examined the pathological material. We also thank the staff of the Photo Laboratory, Marine Biological Laboratory, Woods Hole, Massachusetts, for preparation of several figures, and Carolyn Kurt for typing the manuscript.

References

Multiple subpial transection for focal epilepsy


50. Wong RKS, Prince DA, Basbaum AI: Intradendritic recordings from hippocampal neurons. Proc Natl Acad Sci USA 76:986-990, 1979


Manuscript received April 25, 1988.
Address reprint requests to: Frank Morrell, M.D., Rush-Presbyterian-St. Luke’s Medical Center, 1753 West Congress Parkway, Chicago, Illinois 60612.