Averaged Evoked Potentials in Stereotaxic Surgery*

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THALAMIC nuclei and other subcortical structures can be identified during stereotaxic operations by recording potentials evoked by peripheral and depth stimulation. Recruiting and augmenting responses have been recorded by Housepian and Purpura and by Yoshida, et al.10 Evoked responses have been recorded from somatosensory relay nuclei by Ervin and Mark,9 from both neural populations and single cells by Albe-Fessard, et al.,1,2 and from single neurons by Jasper and Bertrand.9 Nevertheless, the recording of evoked potentials during stereotaxic operations does not appear to be widely used, probably because of the technical difficulties frequently encountered. The application of averaging computer techniques, however, permits the consistent retrieval of evoked responses in the presence of high amplitude background noise.

Material and Methods

The observations reported were made during nine stereotaxic amygdaloidotomies and 34 stereotaxic thalamotomies. Of the thalamotomies, 29 were done in patients with dyskinesia and five in patients with intractable pain from advanced cancer. Local anesthesia was used for the thalamotomies, but because the amygdaloidotomies were done in patients with behavior disorders, general anesthesia was necessary. Light nitrous oxide anesthesia was supplemented by thiopental sodium and muscle relaxants in these cases. The methods used for recording have been published8 and, therefore, will only be described briefly.

For somatosensory responses, stimuli at a frequency of either 1 or 4 c/s (cycles per second) were delivered transcutaneously to the median nerve at the wrist. An E & M Mark 3 photic stimulator was used for visual responses. Bipolar Teflon-insulated concentric stainless steel electrodes with an outer diameter of 1.4 mm, and 0.5 mm tip separation, were used for depth recording and stimulation. The composite waveforms picked up by the electrodes were fed into differential amplifiers with band pass from 0.5 to 1000 c/s, and then delivered to an averaging computer. An average of 50 to 100 sweeps was used when the evoked response was to be photographed. However, as the electrode tip advanced, fewer than 100 sweeps were averaged at each station, since a flat record after 10 to 20 sweeps indicated the absence of an evoked potential at that point. For depth stimulation, rectangular pulses of 0.3 msec (milliseconds) duration and 2.0 mA (milliamperes) amplitude were used.

A burr hole placed 2 to 3 cm anterior to the coronal suture and 1.5 to 2 cm lateral to the midline was used for the air ventriculogram and for the introduction of electrodes during the stereotaxic operation. Selection of coordinates was based on the Schaltenbrand and Bailey atlas.7

For the thalamotomies, the nuclei and tracts to be identified included the nuclei ventralis posterior lateralis (VPL), centre median (CM), ventralis anterior (VA), ventralis lateralis (VL), optic tract (OT), and the uncinate fasciculus. The lesions were made by a radiofrequency generator, with use of the thermistor tip electrodes of 1 mm outer diameter and tip exposure of either 3 or 5 mm. The lesion size was estimated from the data reported by Von Bonin, et al.8

Results

When the electrodes were directed toward VPL, responses with latencies of 12 to 18 msec were recorded from VPL or medial lemniscus (ML) and sometimes from both. Evoked potentials from ML were monophasic, and had a duration of approximately 10 msec, while those from VPL were more prolonged and had a more complex configuration (Figs.
Therefore, creased latency as electrode enters with could amplitudes electrode uted VPL, or thalamotomies or others of criteria cal findings maximum VPL response tonsil. Cortical response detected by scalp electrodes, 50 from 1 A. Evoked potentials from contralateral potentials could be retrieved as far away as 1 cm from the subcortical generator. The amplitude of the response rose sharply, however, as the electrode tip approached ML or VPL (Fig. 2). Therefore, it was necessary to set minimum amplitudes for the identification of target structures.

Based on histological and electrophysiological findings (Figs. 1 A and B, and 2), our criteria for electrode tip proximity to VPL and ML were averaged evoked potential amplitudes of at least 20 μV (microvolts) and 50 μV, respectively. With these criteria, VPL or ML or both were identified in 28 of 32 thalamotomies where the electrodes were directed toward VPL. In all cases, response could be obtained from VPL and ML only with contralateral stimulation. Complications were not encountered secondary to electrode penetration of VPL. The amplitudes of evoked potentials obtained from VPL were not as large as those observed in experimental animals, perhaps in part because the neuronal population density is less in the human thalamus than in that of monkeys and other experimental animals. A comparison of single-sweep evoked potentials with averaged responses failed to demonstrate significant amplitude attenuation introduced by averaging.

Compared with ML and VPL responses, the evoked potentials recorded from CM had latencies of 25 to 30 msec and could be obtained with contralateral and ipsilateral stimulation. However, the potentials recorded with contralateral stimulation had an earlier component, probably reflecting activity in ML (Fig. 3). When electrodes were directed toward CM, these responses to peripheral stimulation were obtained in but 9 of 18 cases. With electrical stimulation of presumed CM, at 6 to 8 c/s, potentials with a latency of 30 to
40 msec were recorded from the scalp electrodes in 6 of 16 operations.

When low frequency stimulation was carried out through the electrodes directed toward VL, two different types of response were recorded. One had characteristics similar to those described for stimulation of CM (Fig. 4), while the other resembled augmenting responses. The recruiting-like responses were presumably obtained from stimulation of VA, and were recorded in 9 of 23 thalamotomies. The augmenting-like responses were considered evidence of electrode tip position within VL, and were obtained in 10 of 23 cases. The sequence of a recruiting-like response followed by an augmenting-like response after the electrode had been advanced several millimeters was observed in 8 thalamotomies. Augmenting was never observed with the stimulation of VPL or ML.

In the patients operated upon for behavioral disorders, the medial and superior borders of the amygdala were localized by identifying the OT. To identify the OT without entering it with the electrode, the first penetration was made several millimeters lateral to the expected location of the OT. If an evoked response to photic stimulation was not obtained, the electrode was then redirected at a point 2 to 3 mm more medial. The electrode penetration was stopped when an evoked potential of approximately 50 μV amplitude was recorded (Fig. 5A). Because the OT runs posteriorly at an angle of 45° with the midline before turning into a sagittal plane at the caudal border of the amygdala, electrode penetrations were made at the caudal, central, and rostral portions of the amygdala (Fig. 5B). The OT was satisfactorily identified in each amygdaloidotomy. The electrode was then introduced at a point lateral to the location from which the OT responses were recorded. The area was stimulated through the depth electrode, and recordings were made from scalp electrode pairs placed over the frontal and occipital regions.

Responses were not obtained with stimulation of the amygdaloid area. When the electrode was moved more laterally, however,
Fig. 4. Evoked potential recorded from scalp electrodes over the frontal lobe with stimulation through an electrode directed toward VL at an angle of 45° with the intercommissural line and in a plane 10 mm lateral to the midline: Upper record with c/s stimulation and 6 mm above the target; middle record with c/s stimulation and 2 mm above the target; and lower record at 2 mm above and with stimulation at 7 c/s.

evoked potentials of short latency were recorded from the scalp electrodes over frontal cortex, but not from those over occipital cortex (Fig. 5 A and B), suggesting stimulation of the uncinate fasciculus. This response was obtained in 4 of 6 amygdaloidotomies. A series of radiofrequency lesions was made with the aggregate volume of the lesions estimated as 1.0 to 1.2 cm³ in each case. In each patient the visual fields were normal after surgery.

Discussion

The evoked potentials recorded with the use of averaging techniques are volume conductor records from a distributed source and, therefore, cannot be relied upon for the precise localization possible with unit recordings. However, for surgical purposes, averaged evoked potentials appear to be a reasonably reliable guide (Fig. 1). Latency and waveform determinations can be made consistently with averaging techniques. While satisfactory single-sweep evoked responses can be recorded in an electronically unshielded operating room, this is often difficult or even impossible unless electronic filters are used. Responses of low amplitude can be measured precisely with averaging techniques, a point of considerable importance when it is desirable to approach a subcortical structure without injuring it.

For example, in the identification of the optic tract during amygdaloidotomy, the slow waves associated with the general anesthetic agent sufficiently distort the baseline to preclude measurement of amplitude from a single sweep. Averaging does not greatly increase the time required for an operation, since it can be determined within a few seconds whether an evoked potential will be obtained. The time lost in averaging is made up by the greater increments of electrode advance made possible by the sensitivity of the method.

Because hand representation in VPL is in the rostral and ventral portion of the nucleus, identification of this area permits the localization rostrally of VL, and medially of VPM and CM. Since these are volume conductor records from a distributed source, the anterior edge of the VPL hand area is determined by moving the electrode rostrally until the amplitude of the response decreases. A similar procedure is followed for determination of the medial edge. The coordinates for the lesions shown in Fig. 1 B were selected on the basis of the series of evoked responses shown in Fig. 1 A and C.

The identification of CM by responses to peripheral and central stimulation was not
particularly successful, and therefore to save time and decrease the number of electrode penetrations, we no longer routinely direct the electrodes toward CM.

The evoked potentials recorded with depth stimulation as the electrodes were directed toward VL resemble those described by others. The failure to obtain these responses in more than half of our patients is disturbing, and the most likely explanation is inaccurate electrode placement. However, we have had comparable difficulty in recording augmenting responses in monkeys, even with histological confirmation that the electrode was within VL. Perhaps, as Ward has suggested, VL is not functionally homogeneous.

When an augmenting response was recorded, the lesion was placed in that location. If only a recruiting response could be obtained when the electrode was directed toward VL, the lesion was centered several millimeters below and posterior to the point from which stimulation provided the response. If neither recruiting nor augmenting responses could be recorded, the coordinates of the lesion were selected by dead reckoning from the VPL response, and were supplemented by noting the influence upon tremor of high-frequency
depth stimulation. Although the series is too small for definite conclusions, the clinical results were equally satisfactory when the lesions were placed by dead reckoning and when the coordinates were selected on the basis of recruiting and augmenting responses. This is not surprising if one considers the large size of the lesions relative to the structures involved.

The identification of the optic tract and presumably of the uncinate fasciculus provides a greater degree of assurance in the selection of coordinates for an amygdaloidotomy. Of even greater importance is the fact that the optic tract can thus be preserved from injury.

**Summary**

The use of averaging computer techniques facilitates the recording of evoked potentials during stereotaxic surgical procedures. In a series of 34 thalamotomies and 9 amygdaloidotomies, the subcortical structures most consistently identified by evoked potentials recordings were the medial lemniscus, the nucleus ventralis posterior lateralis, and the optic tract. The nuclei centre median, ventralis anterior, and ventralis lateralis were identified in less than half of the operations. Localization of these structures introduces a greater degree of safety during the creation of the lesion, and helps define the position of contiguous nuclei and pathways.
References