Computerized brain-surface voltage topographic mapping for localization of intracranial spikes from electrocorticography

Technical note

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The purpose of this paper is to describe the use of computerized brain-surface voltage topographic mapping to localize and identify epileptic discharges recorded on electrocorticographic (ECoG) studies in which a subdural grid was used during intracranial video electroencephalographic (IVEEG) monitoring. The authors studied 12 children who underwent surgery for intractable extrahippocampal epilepsy. Cortical surfaces and subdural grid electrodes were photographed during the initial surgery to create an electrode map that could be superimposed onto a picture of the brain surface. Spikes were selected from ictal discharges recorded at the beginning of clinically confirmed seizures and from interictal discharges seen on ECoG studies during IVEEG recording. A computer program was used to calculate the sequential amplitude of the spikes by using squared interpolation, and they were then superimposed onto the electrode map. Interictal discharges and high-amplitude spike complexes at seizure onset were plotted on the map. This mapping procedure depicted the ictal zone in nine patients and the interictal zone in 12, and proved to be an accurate and useful source of information for planning corrective surgery.

Key Words • epilepsy • voltage topographic mapping • electrocorticography • intracranial spike

Mapping Procedures

Functional Mapping and IVEEG Monitoring

We studied 12 children who had extrahippocampal epilepsy refractory to multiple antiepileptic medications by using IVEEG monitoring with placement of a subdural grid. Time-locked video EEG telemetry (System 5000; Nicolet, Madison, WI) was used to run computer programs for automatic seizure and spike detection, recording of manually triggering events, and storage of all the data collected (sampling rate 200 Hz). Color video monitoring was used to depict the clinical features of the seizures. Functional mapping of the primary motor, sensory, and language cortices was accomplished using electrical stimulation and somatosensory evoked potentials through contralateral median nerve stimulation.

Subdural Grid Implantation and Digital Images

After a craniotomy was made to expose the region of interest, a custom-designed subdural grid (up to 128 channels, 5-mm diameter electrodes, 1-cm electrode spacing,
Brain-surface voltage topographic mapping was performed on the gyrus next to the eloquent cortex (except for part of the inferior frontal gyrus. Multiple subpial transections were identified on the basis of the ECoG recordings (Fig. 1G). Because the grid position may have shifted after the first operation, plain views of the subdural grids on the brain surfaces were obtained before delineation of the cortical excision area, thus permitting slight adjustments to the surgical plan according to gyral formation.

Voltage Topographic Mapping of Spikes

The mapping software created a template of the brain surface with electrodes in place, it showed a section of the selected spike waveform and the time course of voltage distribution of the spike discharge. Voltages were mapped onto a $100 \times 100$ rectangular grid that covered the photograph of the brain surface. Inverse-square interpolation was used to calculate voltage values on the rectangular grid from the irregularly placed electrodes. A referential montage was used (Fig. 1E). Propagation plots were used to show the time course of the voltage distribution. The voltage topographic color gradient was transparent to enable the underlying brain surface and veins to be recognized on the high-resolution monitor screen (Fig. 1F).

Excision of Epileptic Region

After both clinical and ECoG findings had been recorded for several days, patients were returned to the operating room for removal of grids and excision of epileptic zones. The section of brain excised or subjected to multiple subpial transaction was identified on the basis of IVEEG recordings (Fig. 1G). Because the grid position may have shifted after the first operation, plain views of the subdural grids on the brain surfaces were obtained before delineation of the cortical excision area, thus permitting slight adjustments to the surgical plan according to gyral formation.

Results

Voltage topographic mapping showed the extent of the interictal discharges in all 12 patients, which enabled us to recognize the interictal zone. We were able to map the ictal zone, as defined by selected initial spike complexes at the clinically confirmed seizure onset followed by low-amplitude fast waves, in nine patients (Fig. 2).

Discussion

Voltage topographic mapping of intracranial spikes can depict the epileptogenic zones on a 2D combined ECoG electrode map and brain-surface image. Quantitative EEG data recorded with fast sampling rates provide high temporal resolution to help us understand the migration of seizures and interictal discharges from one area of the brain to another. This procedure allows surgeons to plan the maximum extent of excision needed to control seizures and preserve the functional cortex in pediatric patients with extrahippocampal epilepsy.

In children with intractable extrahippocampal epilepsy, this method shows, objectively and accurately, the am-

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**Fig. 1.** A: Intraoperative photograph showing the brain surface before subdural grid placement. B: Intraoperative photograph showing placement of a custom-designed subdural grid to cover the right hemisphere (108 channels, slits between rows to take into account the convexity of the brain surface). C: Tracing showing interictal and ictal spikes that were selected and marked as required for use in other situations. D: An electrode map created on the template that permitted manual placement of selected electrodes onto the main cortical surface picture (A), according to the ECoG electrode location (B). E and F: The resultant voltage topographic map (D) showed the distribution of amplitude every 5 msec, from top left to bottom right (F), and the distribution (F) of spike discharges. G: The surgical plan was based on the positions of the ictal and interictal zones and the functional cortices. Areas of function are labeled as follows: dark blue dots designate motor cortex (Fa = face; Fi = finger; H = hand; L = lip; Sh = shoulder; T = tongue; Th = throat), and green dots designate somatosensory (S) cortex. The area to be excised is outlined with a white line, and includes the middle to posterior portion of the right frontal region except for part of the inferior frontal gyrus. Multiple subpial transaction was performed on the gyrus next to the eloquent cortex (yellow dots, electrodes 26, 40, and 54).
Fig. 2. Upper: An EEG tracing showing ictal epileptic discharges including 56 channels from the subdural grid (referential montage, reference electrode no. 104 not shown on topography; high-frequency filter 70 Hz, notch filter 60 Hz; time constant 0.032 sec). Center and Lower: Voltage topographic maps (81 channels selected, squared interpolation; blue, positive polarity; red, negative polarity) showing the initial ictal spike complexes at times of cursors A and B in the tracing. Two different patterns of ictal spikes—spike A and spike B, anterior to middle portion of frontal region—delineated the extent of the ictal zone.
Brain-surface voltage topographic mapping

plitude distribution of discharges on an electrode map superimposed on a brain-surface digital photograph. In routine EEG analysis, adequate bipolar montage design can define phase reversals to demonstrate that the generators of spike complexes are close to the electrode position, with negative maxima, or between negative and positive maxima. In the method we describe, however, differences in amplitude among the electrodes of interest are promptly demonstrated with gradient colors, with no change in the EEG montage to observe phase reversal. This method distinctly displays the veins and gyrus formations beneath the topographic mapping on the electrocorticogram. Even taking into account the limitation of a 2D picture of a three-dimensional convexity, the computer program provided accurate enough information to delineate the marginal electrode positions on the sulci within the epileptic zone on a high-resolution monitor screen. The distance between the electrodes on the convex surface ranged from 10 to 13 mm, a variation small enough to keep the errors inherent in the 2D photograph within reasonable limits.

When spike complexes occur at the beginning of clinically confirmed seizures, amplitude distribution of the spikes can be used to depict the ictal zone. Analysis of short segments (a few milliseconds) within these complexes shows the dynamics of neuronal activities. Mathematical methods, such as spectral analysis, fractal analysis, and power spectrum, have been used to show longer periods of seizure spread seen on intracranial EEG recordings. Computerized pictures of intracranial spikes from depth electrodes provide a three-dimensional EEG energy field. Various ictal rhythmic discharges occur in association with ictal onset lobes, seizure profiles, and pathophysiological conditions in the extratemporal lobe epilepsies. Some seizures therefore do not demonstrate enough intracranial spikes during the ictal period to enable use of the method we have described. Therefore, the procedure cannot be universally applied; however, when initial spike complexes occur at the clinically confirmed seizure onset, voltage plotting of the spikes can show part of the ictal zone.

In all intracranial ECoG recordings, topographic mapping displays the various interictal spike discharges on the brain surface and is thus able to show the interictal zones. In nonlesional extrahippocampal seizures, the epileptogenic area in the interictal zone has to be removed or disconnected by multiple subpial transection to ensure a good surgical outcome. Persistent postexcisional epileptiform activity distant from the resection border in frontal lobe epilepsy is an unfavorable prognostic indicator. We selectively mapped the zone of interictal spikes covering more than six neighboring electrodes, an area approximately 5 to 6 cm square, for consideration of the cortical source of epileptogenic activity. We believe that topographical analysis of these spike clusters is essential to define the extent of this epileptogenic zone. Superimposing the epileptic regions onto the digitized anatomical images, including the primary motor, sensory, and language cortices, contributes to a better surgical plan.

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References


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