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Clinical Study

Phase reversal technique decreases cortical stimulation time during motor mapping

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ABSTRACT

Neurophysiologic mapping of the primary motor cortex (PMC) is commonly used in supratentorial surgery. Electrical cortical stimulation is guided by anatomic landmarks towards the precentral gyrus, with recording of the triggered primary motor responses (TPMR) in the contralateral hemibody. Thus, factors such as distortion of the pericentral anatomy, small surgical fields, brain shifts and miscalibrated neuronavigational systems may lengthen the process and result in unnecessary stimulations, increasing the probability of triggering seizures. We hypothesized that central sulcus localization via the median somatosensory evoked potentials phase reversal technique (MSSEP PRT) accurately guides the surgeon, resulting in prompt identification of the PMC with minimal electrical stimulation. Multivariate Cox regression was used to study the impact of MSSEP PRT on time spent performing electrical cortical stimulation to TPMR. The analysis was adjusted for presence of increased cortical excitability, high motor thresholds, lesions close to PMC and fMRI data, in 100 consecutive standardized motor mapping procedures for brain tumor resection and epilepsy surgery. Phase reversal and change morphology of the recorded somatosensory evoked potentials quadrupled (hazard ratio [HR] 4.13, $p < 0.0001$) and doubled (HR 2.14, $p = 0.02$) the rate of obtaining TPMR, respectively. A 1 mA increase in motor threshold decreased the rate by 9% (HR 0.91, $p = 0.0002$). Afterdischarges triggered before TPMR and lesions in close proximity to PMC decreased the rate of TPMR by 76% (HR 0.23, $p < 0.0001$) and 48% (HR 0.52, $p = 0.04$), respectively. Informative PRT decreases stimulation time. Afterdischarges triggered before TPMR, high motor thresholds and lesions close to the PMC increase it.

1. Introduction

Maximal resection of supratentorial brain lesions improves survival and quality of life [1–7]. However, this may be difficult to achieve due to the close proximity of eloquent cortex [8–9]. To date, the gold standard for intraoperative identification of the primary motor cortex (PMC) remains neurophysiologic mapping via direct cortical stimulation with recording of triggered motor responses [10–13]. Based on anatomic landmarks, this stimulation is initiated in presumed precentral locations. However, accurate identification of the precentral gyrus based strictly on visual inspection is often inaccurate, particularly in cases of distorted pericentral anatomy.

Along these lines, neurophysiologic localization of the central sulcus (CS) has been successfully employed using the somatosensory evoked potentials (SSEP) phase reversal technique (PRT) [14,15]. This consists of electrical stimulation of the contralateral median nerve and recording of the SSEP directly from the cortical surface. Some authors even advocate it as the primary method of motor mapping, with further employment of direct cortical stimulation only in cases where this fails [16].

Unfortunately, there are many circumstances when a definite identification of the CS based on SSEP PRT fails on the initial attempts due low signal to noise ratio, a consequence of inadequate placement of the recording strip, environmental noise, pericentral pathology or anesthetic effects [16]. Additionally, presence of the lesion in close proximity to eloquent cortex induces acute and chronic plasticity [17–20]. This can result in a "mismatch" between the location of CS and that of the PMC, when identification of the

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former cannot eliminate the need for cortical stimulation. For these reasons, a successful SSEP PRT, while lengthy, may not be sufficient. Thus, while some use it exclusively, others skip it altogether, relying only on direct electrical cortical stimulation as a neurophysiologic mapping tool. However, cortical stimulation can trigger afterdischarges (AD) and seizures. These pose a direct safety risk to the patient and increase the likelihood of erroneous mapping, more so with longer stimulations and higher current densities.

Hence, any tool that can topographically "guide" stimulation will also restrict its unnecessarily extensive use, while increasing its safety and efficiency. The latter concern is also influenced by lesion location and its pathology [21–29], depth of anesthesia [13], abnormally increased cortical excitability, and availability of additional mapping data (such as fMRI).

Our goal was to assess the utility of PRT in guiding cortical stimulation while adjusting for the effect of lesion location, mapping threshold, presence of stimulation triggered AD and fMRI data. We hypothesized that informative PRT would independently reduce the time spent performing direct cortical electrical stimulation for successful identification of the PMC.

2. Methods

2.1. Patient selection

One hundred fifty five consecutive motor mapping procedures performed between January 2005 and December 2010 at a tertiary care center were reviewed. The patients included in the study met the following inclusion criteria.

(1) Mapping was conducted intraoperatively.

(2) CS localization via standardized median somatosensory evoked potentials (MSSEP) PRT was performed before the initiation of the electrical cortical stimulation. The contralateral median nerve was stimulated at the wrist, using repetitive pulses at 3.17 Hz, 0.3 ms pulse duration applied with the smallest intensity (mA) that resulted in a good thumb twitch. Averaged SSEP were recorded directly from the cortical surface, using an eight contact subdural strip (reference on contralateral mastoid), placed perpendicular to and across the presumed location and direction of the CS. If no phase reversal was obtained, the neurosurgeon repositioned the strip. New recordings were done with the strip in the new position. The process was repeated until informative results were obtained – that is, phase reversal or changes in morphology (Fig. 1) or until the decision to proceed with the cortical stimulation was made in consensus by the surgeon, neurophysiologist and anesthesiologist, depending upon the specifics of each case. For example, active bleeding, adherent dura or small surgical field were circumstances when the PRT may have been stopped earlier than in other cases when no such challenges were present. The time spent on CS localization was recorded in each patient.

(3) Electrocorticogram (ECoG) was performed during stimulation via the strip first used for SSEP PRT to identify AD. We defined AD as focal epileptiform discharges triggered by electrical cortical stimulation.

(4) High frequency anodal stimulation [11,12,30,31] with repetitive trains at 2 Hz, five pulses/train, pulse frequency 250 Hz, pulse width 0.5 ms, applied using a monopolar hand held stimulator (anode) and a sterile subdermal needle electrode (cathode), placed at the margin of the surgical field was carried out.

(5) Triggered muscle motor evoked potentials (mMEP) recorded via subdermal needle electrodes from the following contralateral (to the stimulated hemisphere) hemibody muscles: orbicularis oculi, orbicularis oris, masseter, trapezius, deltoid, triceps, brachioradialis, abductor pollicis brevis, abductor digiti minimi, quadriceps, anterior tibialis and abductor hallucis. Each channel recorded the activity in two muscles, with the exception of the face, where two needles were used per muscle.

(6) Stimulation of all regions of interest in a step-wise fashion, starting at 1 mA and gradually increasing in stimulus intensity by 0.5 to 2 mA, as considered appropriate. Maximum current intensity applied was 25 mA. The mapping was considered successful if reliably triggered mMEP were obtained at PMC threshold (triggered primary motor responses [TPMR]). We defined a reliable triggered mMEP as a compound muscle action potential time-locked to the stimulation, of at least 50 uV (longest peak to peak distance) and reproducibly elicited on repeated stimulations of the same cortical region, in the absence of AD.

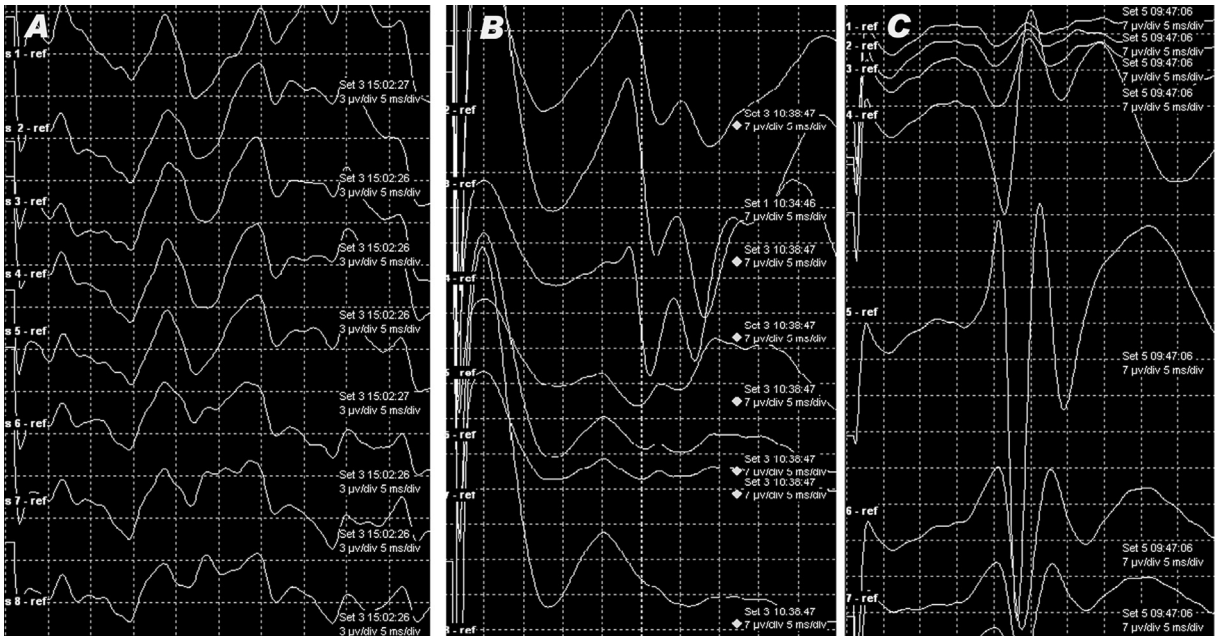

Fig. 1. Median somatosensory phase reversal technique for central sulcus localization. (A) No reliable somatosensory evoked potentials (SSEP) are recorded. (B) Recorded SSEP, with a definite change in morphology between contacts 4 and 5. (C) Recorded SSEP, with a clear phase reversal between contacts 4 and 5.