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Unmasking of presynaptic and postsynaptic high-frequency oscillations in epidural cervical somatosensory evoked potentials during voluntary movement

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Abstract

Objective: To investigate the effect of the voluntary movement on the amplitude of the somatosensory evoked potentials (SEPs) recorded by an epidural electrode at level of the cervical spinal cord (CSC).
Methods: Fourteen patients underwent an epidural electrode implant at CSC level for pain relief. After the median nerve stimulation, SEPs were recorded from the epidural electrode and from 4 surface electrodes (in frontal and parietal regions contralateral to the stimulated side, over the 6th cervical vertebra, and on the Erb's point). SEPs were recorded at rest and during a voluntary flexo-extension movement of the stimulated wrist. Beyond the low-frequency SEPs, also the high-frequency oscillations (HFOs) were analysed.
Results: The epidural electrode contacts recorded a triphasic potential (P1–N1–P2), whose negative peak showed the same latency as the cervical N13 response. The epidural potential amplitude was significantly decreased during the voluntary movement, as compared to the rest. Two main HFOs were identifiable: (1) the 1200 Hz HFO which was significantly lower in amplitude during movement than at rest, and (2) the 500 Hz HFO which was not modified by the voluntary movement.
Conclusions: The low-frequency cervical SEP component is subtended by HFOs probably generated by: (1) postsynaptic potentials in the dorsal horn neurones (1200 Hz), and (2) presynaptic ascending somatosensory inputs (500 Hz).
Significance: Our findings show that the voluntary movement may affect the somatosensory input processing also at CSC level.

Keywords: Somatosensory evoked potential; Gating; Dorsal horn; Dorsal columns; Neuromodulation

1. Introduction

Several studies have described amplitude reduction of the scalp somatosensory evoked potentials (SEPs) during the voluntary movement (Jones, 1981; Cheron and Borenstein, 1987, 1991; Cohen and Starr, 1987; Jones et al., 1989; Reisin et al., 1989; Rossini et al., 1990; Tinazzi et al., 1997; Touge et al., 1997; Valeriani et al., 1998, 1999, 2001). The phenomenon of SEP amplitude reduction by movement is commonly named as "gating". It is accepted that the gating effect occurs only at cerebral level since the amplitudes of the peripheral N9 potential and of the N13 spinal response are not decreased by movement. However, experimental studies in animals suggested that the gating effect occurs also in subcortical structures such as the cuneate nucleus (Ghez and Pisa, 1972), the medial lemniscus (Coulter, 1974) and the thalamus (Tsumoto et al., 1975; Yngling and Skinner, 1977; Chapman et al., 1988). More recently, Insola et al. (2004) reported a movement-induced decrease in amplitude of the subcortical SEPs recorded from basal

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ganglia in Parkinsonian patients implanted for chronic deep brain stimulation.

Since no gating effect has been described thus far at the cervical spinal cord level, we wondered whether this negative result may be due to the inadequacy of a surface posterior neck electrodes to record weak, but significant, N13 amplitude changes induced by movement.

To investigate this issue, we studied the effect of the voluntary movement on the low- and high-frequency SEPs recorded by a cervical epidural electrode in 14 patients suffering from chronic pain resistant to pharmacological treatment, implanted for neuromodulation. Spinal cord stimulation (SCS) represents an effective technique in management of painful syndromes (Meglio et al., 1989, 1994; Meglio, 2004; North et al., 2005; Gildenberg, 2006). In this procedure, a stimulating electrode is inserted percutaneously in the posterior surface of spinal cord and high-frequency stimuli are adjusted at appropriate frequency–intensity levels in order to reduce the painful symptoms without major side effects. During the trial screening period of therapeutic SCS, the epidural electrodes have externalised lead connections, thus they may be used to record electrical events evoked by peripheral nerve stimulation.

2. Materials and methods

2.1. Patients

Median nerve SEPs were recorded in 14 patients (10 men, 4 women, mean age: 57 ± 17 years) suffering from intractable dorso-lumbar pain, without any neurological deficit. Epidural leads were placed at C2 level in 6 patients, at C4 level in 6 patients, and at C6 level in 2 patients; 12 subjects were implanted with a quadripolar lead, 2 with an octopolar lead. In all patients, attempts of therapeutic stimulation began 4 days after the implant. All patients gave their informed consent to take part in the study.

2.2. Surgical procedure

The quadripolar electrode (Model Quad 3487A Medtronic; Minneapolis, USA, 4 contacts with a surface area of 2.54 mm^2 and equally spaced in a row spanning 30 mm) or octopolar electrode (Model Octad 3898 Medtronic; Minneapolis, USA, 8 contacts with a surface area of 3 mm^2 and equally spaced in a row spanning 66 mm) was implanted percutaneously under local analgesia in the posterior cervical epidural space and an X-ray of the cervical spine in antero-posterior and latero-lateral projections was made to verify the position of the electrode (Fig. 1). Spinal cord stimulation was performed by different types of bipolar or monopolar lead configurations, and different frequency/intensity combinations were tried out, in order to achieve the best therapeutic effect. Following this analysis, under general anaesthesia, a Synergy double generator (Medtronic, Minneapolis, USA, Neurological

Fig. 1. Latero-lateral X-ray projection showing the quadripolar epidural electrode position in one patient.

Division) was implanted, delivering bipolar stimulation with 1.5–3.5 V, 60–210 μs P.W. and 135 Hz in frequency.

2.3. SEP recording

SEPs were recorded in awake patients 2–3 days after implantation during the trial screening period when the electrode connections were externalised. For SEP recording, the patients lay on a couch in a warm and semidarkened room. A preliminary recording was performed to identify the stimulation side (right or left median nerve) producing the higher amplitude epidural SEPs; this side would be used for the experimental procedure. Electrical stimuli (0.2 ms duration) were delivered by skin electrodes at the wrist, and had an intensity slightly above the median nerve motor threshold. The stimulation rate was 1.5 Hz. In all our patients, SEPs were recorded in two different conditions: (i) at rest, and (ii) during a voluntary flexo-extension movement of the stimulated wrist (gating condition). In the gating condition, the absence of any modification in amplitude of the peripheral N9 potential, recorded at Erb's point ipsilateral to the stimulation, ensured us that the stimulating electrode contact was not affected by the hand movement. Disk recording electrodes (impedance below 5 kΩ) were placed at four locations: (i) Erb's point ipsilateral to