Clinical Neurophysiology 121 (2010) 921–929

Contents lists available at ScienceDirect

Clinical Neurophysiology

journal homepage: www.elsevier.com/locate/clinph

Effect of movement on SEPs generated by dorsal column nuclei

Angelo Insola [a,*], Luca Padua [b], Paolo Mazzone [c], Massimiliano Valeriani [d]

[a] Unità Operativa di Neurofisiopatologia, CTO, Via S. Nemesio 21, 00145 Rome, Italy
[b] Fondazione Don Gnocchi, ONLUS, Italy
[c] Unità Operativa di Neurochirurgia funzionale e stereotassica, CTO, Via S. Nemesio 21, 00145 Rome, Italy
[d] Divisione di Neurologia, Ospedale Pediatrico Bambino Gesú, IRCCS, Piazza Sant'Onofrio 4, 00165 Rome, Italy

ARTICLE INFO

Article history:
Accepted 8 January 2010
Available online 12 February 2010

Keywords:
Somatosensory evoked potential
Gating
Dorsal column nuclei
High-frequency oscillations
Neuromodulation

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 dorsal column nuclei (DCN).
Methods: Five patients, suffering from chronic pain resistant to pharmacological treatment, underwent an epidural electrode implant at high cervical spinal cord level (C2) for neuromodulation. After tibial nerve stimulation, SEPs were recorded from the epidural electrode contacts, from a Cz lead, and from two electrodes placed over the 12th dorsal vertebra and 4th lumbar vertebra, respectively. SEPs were recorded at rest and during a voluntary flexo-extension movement of the stimulated foot. Beyond the low-frequency SEPs, also the high-frequency oscillations (HFOs), obtained by filtering the recorded traces by means of a 1000–2000 Hz bandpass offline, were analysed.
Results: The epidural electrode contacts recorded a triphasic potential (P1–N1–P2), whose negative peak showed a latency similar to that of the P30 far-field response obtained from the scalp. The epidural potential amplitude was significantly decreased by the voluntary movement, as compared to the rest ($p < 0.01$). A main HFO peak, identifiable at around 1200 Hz, was significantly lower in amplitude during movement than at rest ($p = 0.008$).
Conclusions: Our findings suggest that the epidural C2 triphasic wave is a potential arising from DCN. The low-frequency epidural SEP component is subtended by a 1200 Hz HFO, probably generated by post-synaptic events.
Significance: The amplitude reduction of the DCN response during movement is possibly due to decreased excitability of the DCN neurons receiving the somatosensory ascending input.

1. Introduction

Previous studies in humans have shown that the amplitude of the somatosensory evoked potentials (SEPs) is diminished during voluntary movement of the stimulated limb (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). This phenomenon, known as "gating", is due to either centrifugal or centripetal mechanisms or both (Cohen and Starr, 1987; Jones et al., 1989). It has been thought that the gating effect occurs only at cerebral level since the amplitudes of the peripheral and spinal responses are not decreased by movement. However, experimental studies in animals suggested that the gating effect takes place 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, we showed in humans that the amplitude of the subcortical SEPs, recorded from the basal ganglia and from the cervical spinal cord, is reduced by the voluntary movement (Insola et al., 2004, 2008). Our findings suggest that the transmission of the sensory input is gated by movement before reaching the primary somatosensory cortex. However, SEP components recorded at the basal ganglia level may be influenced by cortical–subcortical loops, so that the amplitude decrement of these responses during movement could depend on a primarily cortical phenomenon (Insola et al., 2004). The spinal N13 potential is likely to be due to the activation the dorsal horn neurons by collateral branches of the somatosensory ascending pathways (Desmedt and Cheron, 1981; Jeanmonod et al., 1989) and it does not represent a relay nucleus response. Therefore, the N13 amplitude decrease during movement (Insola et al., 2008) does not give us an evidence that movement gates the somatosensory pathways also under the cerebral cortex. The aim of the present study is to investigate whether the

* Corresponding author. Tel.: +39 06 5100 3794; fax: +39 06 5100 3537.
E-mail addresses: angelo.insola@virgilio.it (A. Insola), m.valeriani@tiscali.it (M. Valeriani).

1388-2457/$36.00 © 2010 International Federation of Clinical Neurophysiology. Published by Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.clinph.2010.01.006

gating phenomenon occurs only within the cerebral cortex or at multiple levels of the human somatosensory system. We have studied the effect of the voluntary movement on the low- and high-frequency SEPs recorded by a cervical epidural lead in 5 patients, suffering from chronic pain resistant to pharmacological treatment and implanted at 2nd cervical vertebra (C2) for neuromodulation. After median nerve stimulation, the SEP component recorded by the C2 epidural electrode is likely to represent a mixture of both the spinal N13 potential (lower N13) and the dorsal column nuclei (DCN) potential (upper N13) (Kaji and Sumner, 1987; Sonoo et al., 1990; Zanette et al., 1995; Araki et al., 1997). Thus, a possible movement-induced gating effect on the DCN SEP component would be difficult to be demonstrated. In order to overcome this problem, in our patients the tibial nerve SEPs were recorded, thus allowing us to obtain a genuine DCN potential from the epidural C2 lead without any spinal response contamination (Jones and Small, 1978; Desmedt and Cheron, 1983b; Riffel et al.,1984; Seyal et al., 1987; Møller et al., 1990; Morioka et al., 1991).

2. Materials and methods

2.1. Patients

Tibial nerve SEPs were recorded in 5 patients (4 men, 1 women, mean age: 57 ± 17 years) suffering from intractable dorso-lumbar pain, without any neurological deficit. Epidural leads were placed at C2 level in all patients. The epidural lead was a quadripolar electrode. 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 approved by the local Ethics Committee.

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) 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 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 tibial 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 ankle, and had an intensity slightly above the 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 foot (gating condition). Subjects were asked to move their stimulated foot randomly, thus the flexion–extension movement of the ankle did not have a fixed frequency. The scalp recording electrode (impedance below 5 kΩ) was placed at the Cz vertex, referred to the earlobe ipsilateral to the stimulation. SEPs were also recorded from the 4th lumbar vertebra, referred to 2nd lumbar vertebra, and from the 12th dorsal vertebra, referred to abdomen. Lastly, SEPs were also obtained from the 4 contacts of the epidural electrode, referred to the shoulder contralateral to the stimulation. The ground electrode was at the stimulated lower limb. The analysis time was 100 ms, with a sampling rate of 10.000 Hz. The amplifier bandpass was 3–3000 Hz (12 dB roll-off). Two averages of 1000 trials each were obtained for each condition, and printed out. In the gating condition, the absence of any modification in amplitude of the cauda equina potential, recorded at the 4th lumbar vertebra, ensured us that the stimulating electrode contact was not affected by the foot movement.

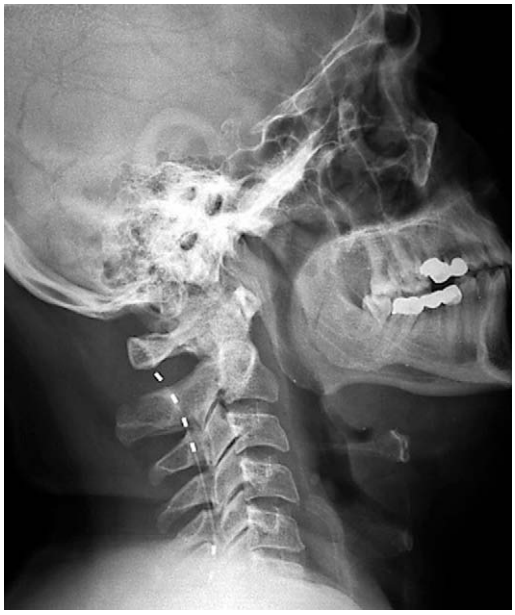

Fig. 1. Latero-lateral X-ray projection showing the quadripolar epidural electrode position in one patient. The tip of the lead (contact 0) is located between C1 and C2 vertebra (upper part of C2 soma).

2.3.1. Low-frequency SEPs

SEPs were identified on the basis of latency and polarity. After setting the low-pass filter at 500 Hz, amplitudes and peak latencies were measured on the average of the 2 runs obtained for each condition (rest and gating). For the surface SEP components amplitudes were measured from the baseline. In the epidural traces, the peak-to-peak amplitudes of the P1–N1 potentials was measured.

2.3.2. High-frequency SEPs

In order to study the high-frequency responses selectively, in all the patients the epidural traces were submitted to time–frequency analysis based on a Morlet wavelet transformation (AutoSignal 3.1, Systat Software, Inc.). After identification and evaluation of standard SEPs, frequency spectrum was estimated by means of autoregressive (AR) modeling. The algorithm we used was the SVD (singular value decomposition) least-squares method. AR frequency spectra within the whole latency window (0–100 ms) revealed a main peak at around 1200 Hz (Fig. 2), which was also confirmed by the frequency power maps (Fig. 3A). Therefore, the epidural traces of the patients were filtered by a 1000–2000 Hz bandpass. Although the high-frequency oscillations (HFOs) were measured at all contacts of the epidural electrode, only the HFOs