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# A methodological reappraisal of non invasive high voltage electrical stimulation of lumbosacral nerve roots

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HIGHLIGHTS

- A technique to achieve non invasive, well tolerated maximal stimulation of lumbosacral motor nerve roots.
- A method to obtain a simultaneous, bilateral and balanced maximal activation of several lumbosacral motor roots.
- A tool to detect conduction slowing and block in proximal tracts of peripheral motor nerves.

ABSTRACT

*Objective:* To describe a neurophysiological method to locate the optimal stimulation site (OSS) over the vertebral column, customized to the individual subject, to achieve maximal activation of lumbosacral roots by means of non-invasive high voltage electrical stimulation (HVES).
*Methods:* OSS was located in 30 volunteers by testing different stimulation points of a surface multi-electrode array placed over the dorso-lumbar junction of the vertebral column. The dorso-ventral stimulating montage was used (Troni et al., 1996). Motor responses to root stimulation (rCMAPs) were bilaterally recorded from Vastus Medialis (VM), Tibialis Anterior (TA), Soleus (SL) and Flexor Hallucis Brevis (FHB) muscles. The direct nature of rCMAPs was tested by delivering two maximal stimuli 50 ms apart.
*Results:* Except for a few subjects with large girth, maximal rCMAPs could be obtained from all muscles with a stimulating current intensity up to 550 V (1050 mA). Maximal double HVES excluded any reflex component in the recorded rCMAPs. The procedure was well tolerated and no side effects were observed.
*Conclusions:* A single maximal electric shock delivered at the proper vertebral level by means of the dorso-ventral montage is able to safely achieve synchronous, bilateral maximal activation of several roots, from L3 to S1.
*Significance:* Maximal activation of lumbosacral roots at their origin, unattainable with magnetic stimulation, is the essential requirement for direct detection of proximal nerve conduction slowing and block in lower limbs.


## 1. Introduction

Non invasive maximal stimulation of motor nerve roots at their origin from the spinal cord is a crucial need in clinical neurophysiology for a direct assessment of motor nerve pathology in the proximal tracts of peripheral nerves. There is general agreement that magnetic stimulation is unsuitable to achieve this goal (Troni et al., 1996; Menkes, 2006), because it provides submaximal and partly reflex motor responses (Ugawa et al., 1989; Cros et al., 1990; Evans et al., 1990; Oh, 1993), usually elicited near the intervertebral foramen or even more distally (Mills and Murray, 1986;

*Abbreviations:* CMAP, compound muscle action potential; EDSS, expanded disability status scale; FHB, Flexor Hallucis Brevis muscle; HVES, high voltage electrical stimulation; mA, milli-Ampere; MRI, magnetic resonance imaging; OSS, optimal stimulation site; pCMAP, compound muscle action potential to peripheral nerve stimulation; rCMAP, compound muscle action potential to radicular stimulation; SL, soleus muscle; TMS, transcranial magnetic stimulation; TA, Tibialis Anterior muscle; V, volt; VM, Vastus Medialis muscle.

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Cros et al., 1990; MacDonell et al., 1992). This bias is particularly severe for the deeply located lumbosacral roots which travel for a significant tract, up to 18 cm (Sunderland, 1976), inside the spinal canal before reaching the respective intervertebral formina (MacDonell et al., 1992). Root stimulation proximal to the neuroforamina, possibly at the conus medullaris, have been recently achieved by Matsumoto et al. (2009) by using a special, flat, large round coil; however, the recorded rCMAPs proved to be largely submaximal, which makes detection of conduction block impossible. Electrical stimulation has been attempted with non invasive, high voltage technique (Mills and Murray, 1986; Swash and Snooks, 1986; Maertens de Noordhut et al., 1988; Troni et al., 1996) or with invasive methods, by means of a monopolar needle deeply inserted over the transverse processes (Berger et al., 1987; Macdonell et al., 1992; Menkes et al., 1998). We have shown (Troni et al., 1996) that an effective activation of lumbosacral roots at a very proximal level can be obtained by non invasive high voltage electrical stimulation (HVES) through a dorso-ventral montage. Bühler et al. (2001) confirmed these results but, in their opinion, the excessive patient discomfort prevented the application of the dorso-ventral technique in routine examination. This negative remark may partly result from the use of a fixed stimulation site, i.e. the D12/L1 interspace, assumed as the "mean" projection level over the vertebral column of the emerging point from the spinal cord of L3 to S2 roots. This procedure does not consider the large inter-individual variability of the anatomical relationship between spinal cord and vertebral column in normal subjects (Reimann and Anson, 1944; Ievins, 1991; MacDonald et al., 1999).

The main purpose of our study is to describe a neurophysiological method to locate the lowest threshold, optimal stimulation site (OSS) over the vertebral column, customized to the individual subject. The use of OSS as a cathode allowed to achieve in most subjects a simultaneous, bilateral, balanced and maximal activation of several roots, from L3 to S2, close to their origin, with acceptable patient discomfort. Preliminary results of this paper have been presented elsewhere (Di Sapio et al., 2010; Troni et al., 2010).

## 2. Material and methods

### 2.1. Subjects

Experiments have been carried out, after obtaining full informed consent and approval of the study by the local Ethic Committee of the Hospital, in 15 healthy volunteers, 6 man and 9 women, aged 21–66 years (mean 39.9) and in 15 patients, 7 man and 8 women, aged 25–51 years (mean 42.1) with defined Multiple Sclerosis or Clinically Isolated Syndrome. All patients showed a negligible neurological disability (EDSS ranging from 0 to 1.5), and were included after clinical examination ruled out any signs and symptoms suggesting peripheral neuropathies. Moreover, a preliminary evaluation of motor conduction velocity of the peroneal and tibial nerves and sensory conduction velocity of sural nerve were normal in all cases.

All experiments were carried out at a room temperature not exceeding 20 °C. A 16 channel bipolar amplifier (BrainAmp ExG, Brain Products GmbH, Germany) was used for CMAP recording. Peripheral nerves stimulation was performed using a Digitimer DS7 stimulator (Digitimer Ltd., UK) and HVES by using an high voltage electrical stimulator Digitimer D 185-Mark IIa (Digitimer Ltd., UK), with a maximum output up to 1000 V and currents up to 1000 mA, which produces a rectangular (50 μs) pulse shape with extremely rapid rise and fall times.

### 2.2. Recording sites

CMAPs to peripheral nerve stimulation (pCMAP) and to HVES of lumbosacral roots (rCMAP) were bilaterally recorded from symmetrical sites of the VM, TA, SL and FHB muscles with a pair of surface electrodes (diameter 0.8 cm) placed over the muscle belly, 5 cm apart in a belly-tendon arrangement (Fig. 1B). VM pCMAPs were evoked by stimulation (1 ms) of the femoral nerve at the groin by using an antero-posterior montage, the cathode being a surface electrode (diameter 1 cm) placed just lateral of the femoral artery and the anode a larger (diameter 4 cm) surface electrode taped over the gluteal fold. TA, SL and FHB pCMAPs were elicited by stimulation of the peroneal nerve at the fibular head and of the tibial nerve respectively at the popliteal fossa and at the ankle.

The optimum recording sites (cathode) giving maximal CMAPs with a regular triphasic shape and a sharp initial negative deflection was first located.

TA and FHB F-waves with minimal latency were chosen within the sample of responses elicited by 30 consecutive stimuli. The peripheral motor conduction time was calculated from the usual formula $(F + M - 1)/2$ (Kimura, 1974) and the resulting values were compared with the corresponding rCMAP latencies.

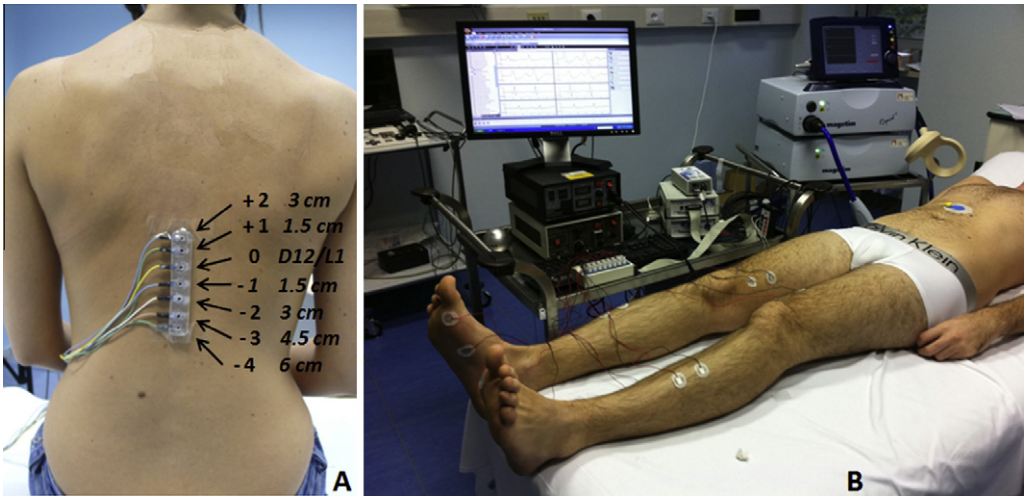


**Fig. 1.** The multi-electrode stimulating array, including 7 surface silver–silver chloride electrodes, 1.5 cm apart, is shown in A. Two of the electrodes were rostral (+1 and +2) and four caudal (−1 to −4) to electrode 0, positioned at the D12/L1 vertebral interspace, located by the Tuffier's line. The recording sites from VM, TA, SL and FHB muscles of both sides are shown in B. Note the large stimulating anode positioned midline between the umbilicus and the tip of the xiphoid process.