Clinical Neurophysiology 120 (2009) 770–775

Contents lists available at ScienceDirect

Clinical Neurophysiology

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

Magnetic lumbosacral motor root stimulation with a flat, large round coil

Hideyuki Matsumoto [a,*], Fitri Octaviana [b], Ritsuko Hanajima [a], Yasuo Terao [a], Akihiro Yugeta [a], Masashi Hamada [a], Satomi Inomata-Terada [a], Setsu Nakatani-Enomoto [c], Shoji Tsuji [a], Yoshikazu Ugawa [c]

[a] Department of Neurology, Division of Neuroscience, Graduate School of Medicine, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8655, Japan
[b] Department of Neurology, Faculty of Medicine, University of Indonesia, Indonesia
[c] Department of Neurology, School of Medicine, Fukushima Medical University, Japan

A R T I C L E I N F O

Article history:
Accepted 10 January 2009
Available online 23 February 2009

Keywords:
Magnetic stimulation
Compound muscle action potential
Motor-evoked potential
Peripheral nerve

A B S T R A C T

Objective: The aim of this paper is to develop a reliable method for supramaximal magnetic spinal motor root stimulation (MRS) for lower limb muscles using a specially devised coil.
Methods: For this study, 42 healthy subjects were recruited. A 20-cm diameter coil designated as a Magnetic Augmented Translumbosacral Stimulation (MATS) coil was used. Compound muscle action potentials (CMAPs) were recorded from the abductor hallucis muscle. Their CMAPs were compared with those obtained by MRS using a conventional round or double coil and with those obtained using high-voltage electrical stimulation.
Results: The MATS coil evoked CMAPs to supramaximal stimulation in 80 of 84 muscles, although round and double coils elicited supramaximal CMAPs in only 15 and 18 of 84 muscles, respectively. The CMAP size to the MATS coil stimulation was the same as that to high-voltage electrical motor root stimulation.
Conclusions: MATS coil achieved supramaximal stimulation of the lumbosacral spinal nerves.
Significance: The CMAPs to supramaximal stimulation are necessary for measurement of the amplitude and area for the detection of conduction blocks. The MATS coil stimulation of lumbosacral motor roots is a reliable method for measuring the CMAP size from lower limb muscles in spinal motor root stimulation.

1. Introduction

Magnetic stimulation placing a conventional round coil (ca. 10 cm diameter) over the cervical or lumbar spinal enlargements can activate spinal nerves (magnetic spinal motor root stimulation, MRS) (Ugawa et al., 1989, 1990). In clinical settings, the compound muscle action potentials (CMAPs) to MRS are often used for detecting proximal peripheral nerve lesions. In other words, MRS can give important physiological information that is unobtainable by conventional electrical nerve conduction examinations in distal extremities, rendering it useful, for instance, for detecting focal demyelinating lesions at some proximal sites of peripheral nerves (Ugawa, 2004; Matsumoto et al., 2005a). For hand muscles, our group has confirmed that supramaximal stimulation can be performed using magnetic cervical motor root stimulation in almost any healthy subject (Matsumoto et al., 2005b).

For leg muscles, however, MRS often fails to elicit CMAPs to supramaximal stimulation with a round coil (Chokroverty et al., 1989; Ugawa et al., 1989; Britton et al., 1990; Macdonell et al., 1992; Bischoff et al., 1993; Ertekin et al., 1994; Rossini et al., 1994; Hess, 2005) or a double coil (Epstein et al., 1991; Mills et al., 1993; Rossini et al., 1994; Hess, 2005). The deeper location of lumbosacral spinal nerves (the proposed site of activation) from the body surface compared to cervical spinal nerves might be the most important factor explaining this drawback of lumbosacral MRS.

In magnetic stimulation, eddy currents induced by rapidly flowing electrical currents in the winding of a coil can activate the nervous system in the body non-invasively and with little pain (Terao and Ugawa, 2002). A larger coil can induce greater eddy currents in deeper regions of the body (Cohen and Cuffin, 1991; Jalinous, 1991; Maccabee et al., 1996; Hsiao and Lin, 2001). Therefore, we devised a flat, round 20-cm diameter coil, which we designate as a Magnetic Augmented Translumbosacral Stimulation coil or 'MATS coil'. The aim of this study is to demonstrate that supramaximal stimulation can be accomplished reliably using MRS with the MATS coil. We demonstrate that the MATS coil usually accomplishes supramaximal stimulation, and show that larger CMAPs can be evoked by MRS with the MATS coil than with conventional round and double coils. Furthermore, to confirm the supramaximal stimulation, the sizes of CMAPs to MRS with a MATS coil are

* Corresponding author. Tel.: +81 3 5800 8672; fax: +81 3 5800 6548.
E-mail address: hideyukimatsumoto@mail.goo.ne.jp (H. Matsumoto).

1388-2457/$36.00
doi:10.1016/j.clinph.2009.01.004

compared with those obtained using high-voltage electrical stimulation: electrical spinal motor root stimulation (ERS).

2. Subjects and methods

2.1. Subjects

Subjects were 42 healthy volunteers (21 men and 21 women) with no history of peripheral neuropathies, neuromuscular diseases, or other medical problems including diabetes mellitus. The age and body height of the subjects were 40.7 ± 13.8 (mean ± standard deviation (SD); range 23–73) years and 163.5 ± 9.1 (147–182) cm, respectively.

Informed consent to participate in this study was obtained from all subjects. The protocol was approved by the Ethics Committee of The University of Tokyo, and was carried out in accordance with the ethical standards of the Declaration of Helsinki.

2.2. Recording

During the examination, subjects lay comfortably on a bed in a prone position. The CMAPs were recorded from the abductor hallucis (AH) muscle . This muscle was selected because of the negligible volume conduction from other muscles. Disposable silver–silver chloride disc electrodes of 9-mm diameter were placed in a belly tendon montage over AH. Signals were amplified by filters set at 20 Hz and 3 kHz and were recorded using a computer (Neuropack MEB-9100; Nihon Kohden Corp., Japan). The skin temperature was maintained at around 32 − 33 °C.

The following parameters were measured from each CMAP using a computer algorithm: peak-to-peak amplitude (mV), negative area (mV × ms) and onset latency (ms) (Fig. 1). Data for each parameter are shown as mean ± standard deviation (SD) unless otherwise described. For this paper, we abbreviate CMAP elicited by supramaximal stimulation as supramaximal CMAP.

2.3. Devices in MRS, ERS, and peripheral nerve stimulation

Magnetic stimulation was performed with a monophasic stimulator, Magstim 200 (The Magstim Co. Ltd., UK), connected to a MATS coil (diameter 20 cm, 0.98 T; The Magstim Co. Ltd., UK), a usual round coil (round coil, diameter 10 cm, 1.35 T; The Magstim Co. Ltd., UK), or a double branding iron coil (double coil, each diameter 8.5 cm, two windings combined with an angle of 170°, 1.40 T; The Magstim Co. Ltd., UK). The eddy current pulse induced by this stimulator was 1.0 ms in duration with a rising time of 0.1 ms. Herein, we use the following terms for MRS with each coil: MATS coil stimulation, round coil stimulation, and double-coil stimulation. Regarding ERS, high-voltage electrical stimulation was performed with an electrical stimulator (Digitimer D 180A; Digitimer Ltd., UK). This stimulator gave a spike pulse with a fast rise time and an exponential decay (nominal time constant of 100 μs). For peripheral nerve stimulation, a conventional electrical stimulator (Nihon Kohden Corp., Japan) was used. This stimulator gave a constant current square wave pulse of 0.2 ms duration.

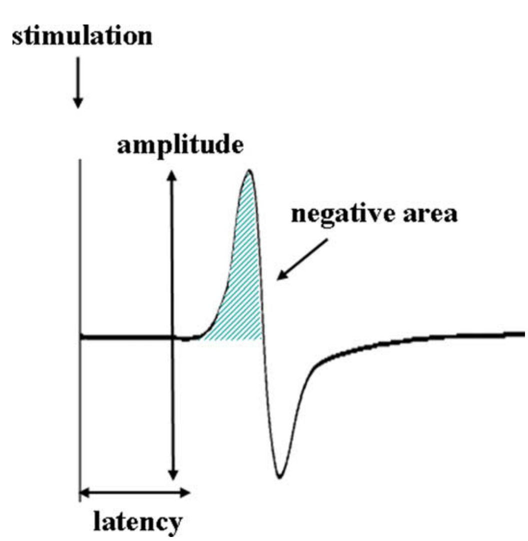

Fig. 1. Parameters of CMAPs analyzed in this study. Peak-to-peak amplitude (mV), negative area (mV × ms), and onset latency (ms) were analyzed as portrayed.

2.4. Experiment I. Optimal-induced current direction

Six subjects participated in this experiment. We first studied the best induced current direction for eliciting CMAPs from right AH in MATS coil stimulation. The induced current direction was defined as the tangential direction of the edge of coil placed over the activation site. The edge of MATS coil was positioned over the first sacral (S1) spinous process for inducing current to flow in 30° steps from 0° to 360° relative to the horizontal line (Fig. 2). The S1 spinous process was identified by palpation referring to Jacoby's line: the virtual line running along the upper edge of bilateral iliac crests; the line is the landmark of L4 spinous process. The MATS coil was always placed from the midline to the left side of body – opposite to the recorded muscle – to prevent non-target parts of the coil (the half wing of the coil opposite the recorded muscle: left half) from activating distal peripheral nerves for the target AH. The MATS coil was rotated on the left side of the body for inducing current in each direction. The stimulus intensity was adjusted to obtain CMAPs of about 10 mV at the most effective direction. With each current direction, three CMAPs were evoked and the mean CMAP amplitudes were compared among different directions of the induced currents. The optimal-induced current direction was defined as the angle where the largest CMAP amplitude was evoked.

We next studied the optimal-induced current direction for double-coil stimulation. The center of the junction region of the double coil was positioned over the S1 spinous process. The double coil was rotated in 30° steps from 0° to 360°. The stimulus intensity was adjusted to elicit CMAPs of about 10 mV at the most effective direction.

2.5. Experiment II. Comparison of CMAP size among three coil stimulations

In all, 42 subjects participated in this experiment. The CMAPs were recorded from the right AH. Magnetic stimulation was performed with MATS, round coils, and double coils. First, the MATS coil was placed using the optimal-induced current direction determined in Experiment I (240°, see Section 3). The optimal site for eliciting CMAPs (i.e., hot spot) was searched around the S1 spinous process from L5 to S2 spinous processes areas in each subject. We placed the coil in a usual manner at five positions (L5 spinous process, L5–S1 midpoint, S1 spinous process, S1–S2 midpoint, and S2 spinous process). A hot spot was defined as a position at which the largest amplitude of CMAP was evoked when giving the constant intensity stimulation. At the hot spot, the MATS coil was tightly pressed over the body so that the coil was as near as possible to the target lumbosacral spinal nerves (i.e., the spinal nerves just under a hot spot). The intensity was increased gradually to the maximal stimulator output (100%). We superimposed several CMAPs evoked by the stimulations at some different intensities to confirm supramaximal stimulation. We considered that supramaximal stimulation was achieved only when the size of superimposed