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Descending spinal cord evoked potentials in cervical spondylotic myelopathy: Characteristic waveform changes seen at the lesion site

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HIGHLIGHTS

- We characterized the type of D-wave changes seen at the lesion site in cervical spondylotic myelopathy with MRI evidence of single-level cord compression.
- An abrupt reduction of the negative peak accompanied by an enhancement of the initial-positive peak helps identify the site of conduction block.
- The enhancement of the positive peak tended to diminish with a more caudal compression, which may be explained by progressive loss of the descending motor volleys at the synapses in the cervical enlargement.

ABSTRACT

Objectives: To characterize waveform changes of descending spinal cord evoked potentials (D-SCEPs) seen in cervical spondylotic myelopathy (CSM).
Methods: Intraoperative D-SCEP recording from serial intervertebral discs after transcranial electrical stimulation in 19 CSM patients with cord compression at a single level.
Results: Compared to the baseline (100%) obtained one level rostrally, the D-SCEP recorded at the compression site showed a significantly ($p < 0.001$) decreased amplitude (48%) and area (48%) of negative peak and increased amplitude (171%) and area (279%) of initial-positive peak. The degree in reduction of negative peak remained the same irrespective of the cord level involved, whereas enhancement of the positive peak tended to diminish with a more caudal compression.
Conclusions: In intraoperative electrophysiological studies of CSM with D-SCEP, an abrupt reduction of the negative peak accompanied by an enhancement of the initial-positive peak helps identify the site of conduction block. We speculate that progressive loss of the descending motor volleys at the synapses in the cervical enlargement may account for limited or absent enhancement of positive peak seen caudally.
Significance: The current finding helps us understand the pros and cons of various electrophysiologic techniques for intraoperative localization of maximal cord involvement in CSM.
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1. Introduction

Electrophysiologic techniques used to localize the site of the spinal cord lesion have made steady progress since earlier studies conducted under the term "electrospinogram" in animal models (Morrison et al., 1975; Rossini et al., 1980) and humans (Shimoji et al., 1971). As previously reported in cervical spondylotic myelopathy (CSM) (Tani et al., 1998, 1999, 2002), multisegmental recording of ascending spinal cord evoked potentials (A-SCEPs) can precisely localize the site of conduction abnormalities before decompression procedures. This method utilizes monopolar recording electrodes placed in the structures adjacent to the spinal cord and bipolar stimulating electrodes inserted in the lumbar epi-

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dural space. An abrupt reduction in size of the negative peak accompanied by an augmentation of the initial-positive peak over a short segment serves as strong evidence of a focal conduction block. The study provided a useful addition to MRI in localizing the level of maximal cord involvement, particularly in elderly patients with clinically silent cord compression at multiple levels (Tani et al., 1999, 2002). This technique, however, has the inherent limitation of only detecting the most caudal conduction block, which precludes the evaluation of more rostral segments.

An assessment of descending spinal cord evoked potentials (D-SCEPs) after transcranial electrical stimulation (TES) of the brain, if added to A-SCEP studies, may circumvent this problem. Descending volleys in corticospinal tract axons terminate at various levels of the cord to synapse with spinal motoneurons or interneurons. This, in turn, would cause a progressive decline of motor volleys reaching the caudal recording sites, resulting in a greater diminution of the D-SCEPs than predicted from physiological temporal dispersion where the recorded potentials become smaller in amplitude and longer in duration with increasing distance between stimulating and pickup electrodes. To further clarify this relationship, we have now studied waveform changes of the D-SCEP associated with single-level cord compression. In particular, we wished to determine if the same principles of waveform changes hold for analyses of A-SCEP and D-SCEP in identifying focal conduction abnormalities.

2. Materials and methods

2.1. Patients

From January 2004 to April 2010, a total of 140 CSM patients underwent intraoperative D-SCEP studies. We selected 19 patients (11 men) ranging in age from 35 to 90 years (average, 62 years) based on MRI evidence of single-level cord compression. None had history of seizures or implanted devices such as cardiac pacemaker or cochlear implant. All agreed in writing to participate in the study after reading an informed consent form approved by the hospital ethics committee. Myelopathy resulted from cervical disc herniation in 11 and cervical spondylosis in 8 patients. All had a single-level anterior operation, 6 at C3–4 (C3–4 group), 8 at C4–5 (C4–5 group) and 5 at C5–6 (C5–6 group).

2.2. Clinical findings

The functional scale developed by the Japanese Orthopaedic Association (JOA) (Jpn Othop Assoc., 1994) scores the motor function from 0 to 4 points for both upper and lower limbs. For the upper limb, 1 patient had normal finger dexterity (4 points); 6 showed clumsy but functional writing (3 points); 8 could write but not functionally (2 points); and 4 managed to feed themselves but displayed no other function (1 point). For the lower limb, 2 patients had normal walking ability (4 points); 2 had some difficulty but were capable of fast walking unaided (3 points); 9 needed supports when going up and down the stairs (2 points); and 6 required walking aids (1 point). The combined JOA motor scores averaged 4.0 ± 1.7 (mean ± SD) for the total 19 patients and 2.4 ± 1.1 for C3–4, 4.1 ± 1.1 for C4–5, and 5.8 ± 1.3 for C5–6 group, showing a significant ($p < 0.01$) difference between C3–4 and C5–6 groups.

Muscle stretch reflexes, though generally hyperactive, showed a diminution of biceps responses in 3 patients, and of gastrocnemius–soleus in 5. Of the 5 patients with a diminished response in the gastrocnemius–soleus, 3 patients had moderate to severe radiological changes of the lumbar spine suggestive of spinal stenosis and the remaining 2 patients, either diabetes or chronic renal failure treated with regular hemodialysis. Extensor plantar responses were found in 4 patients.

2.3. MRI evaluation

All patients underwent surface coil MR examination of cervical cord preoperatively with the superconducting system (1.5 T Signa HDx; GE Healthcare, Waukesha, WI, USA). The spin echo pulse sequences were 350–600/9–12 (TR ms/TE ms) for T1- and 2600–4000/90–110 for T2-weighted images.

Cord measurements at each intervertebral level from C2–3 to C6–7 included: (1) AP-diameter on midsagittal T1-weighted images and (2) cross-sectional area on axial T1-weighted images. The values were converted into the actual diameter and area with a magnification factor. Sagittal T2-weighted images served best to detect increased signal intensity resulting from cord compression.

2.4. Stimuli

All recordings were made in the operating room of Kochi Medical School during surgery before decompression procedures. Following preoperative general anesthesia with sevoflurane, two subdermal stimulating corkscrew-like electrodes (CS001-220, A-Gram, Glenn Rock, New Jersey) were placed into the scalp 2 cm anteriorly and 5 cm laterally to the vertex on both sides (Kondo et al., 1985; Matsuda and Shimazu, 1989; Kaneko et al., 2001; Fukuoka et al., 2004; Nakanishi et al., 2006). A capacitively coupled pulse of 50 μs in duration and up to 400 V in intensity was delivered from a high-voltage electrical stimulator (Digitimer D185, Welwyn Garden City, UK) at a rate of 1/s, stimulating both sides alternately with reversed electrode polarity. Stimulus intensity was increased until a distinct D-SCEP of lowest threshold was identified.

2.5. Recording

After exposure of the anterior aspect of the vertebral bodies, a series of monopolar needle electrodes, 0.7 mm in diameter and about 4 kΩ in impedance at 1 kHz (OA210-006, Unique Medical Corp, Tokyo, Japan), were inserted into the intervertebral discs in the midline. They were then advanced posteriorly to cover the distance of the disc diameter calculated from measurement on the plain lateral radiograph. A needle electrode inserted into the skin at the caudal end of the operative field served as the common reference. This location of the reference electrode was chosen to minimize stimulus artifact. Accumulated evidence supports the validity of using a common distant reference when recording SCEPs from active leads placed equidistant to the spinal cord (Cracco and Evans, 1978; Schramm et al., 1983; Halter et al., 1989; Matsuda and Shimazu, 1989; Nakanishi et al., 2006). Also, a traveling impulse within the cervical spinal cord does not encounter a sudden geometric change of the volume conductor, which may register far-field potentials complicating recording with a referential montage. A pair of alligator clips was attached to the skin at the operative site as the ground electrode. A muscle relaxant (vecuronium, 0.015–0.110 mg/kg bolus) administered intravenously immediately before recording D-SCEP abolished interference from the twitch of paraspinal muscles near the electrodes.

The recording sites included three to five serial vertebral levels between C2–3 and C6–7 to cover the extent of vertebral exposure required for the respective decompression; three levels in 5 patients, four levels in 11 and five levels in 3. Each test set comprised an average of 50 summated potentials, sampled at 50 kHz, with a frequency response of 20 Hz–3 kHz.

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