Descending spinal cord evoked potentials in cervical spondylotic myelopathy: Characteristic waveform changes seen at the lesion site
（頸椎症性脊髄症の下行性脊髄誘発電位：障害高位で観察される特徴的波形変化の検討）

Nobuaki Tadokoro¹, Toshikazu Tani¹, Masahiko Ikeuchi¹, Ryuichi Takemasa¹, Kazunobu Kida¹, Tatsunori Ikemoto², Takahiro Ushida³, Shinichirou Taniguchi⁴, Jun Kimura⁵

1) Department of Orthopaedic Surgery, Kochi Medical School
2) Department of Orthopaedic Surgery, Kuroshio Hospital
3) Multidisciplinary Pain Center, Aichi Medical School
4) Department of Orthopaedic Surgery, Kansai Medical University Takii Hospital
5) Department of Neurology, University of Iowa

Purpose
We reported the results of level diagnosis in compressive myelopathy using ascending spinal cord evoked potentials (A-SCEP): monopolar recording electrode placed near the spinal cord and bipolar stimulating electrode inserted in the lumbar epidural 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. A-SCEP were a useful addition to MRI in terms of localizing the level of maximal cord involvement, particularly in elderly patients with clinically silent cord compression at multiple levels (Tani et al., 1999, 2002). However, a limitation of A-SCEP recordings is that evaluation of segments more rostral than the conduction block are precluded. 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 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.

Materials & Methods
19 cervical spondylotic myelopathy (CSM) patients (11 males, 8 females) with single level cord...
compression were included in this study. The mean age of patients was 62 years old. 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).

The functional scale developed by the Japanese orthopaedic association (JOA) (Jpn Orthop Assoc. 1994) scores motor function from 0 to 4 points for both upper and lower limbs. 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.

Following inhalational general anesthesia, two stimulating corkscrew-like electrodes were placed into the scalp 2 cm anteriorly and 5 cm laterally to the vertex on both sides. 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. 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. A needle electrode inserted into the skin at the caudal end of the operative field served as the common reference.

The recording sites included more than three serial vertebral levels. The MRI-based site of cord compression, designated as ‘0’, served as the point of reference for the remaining levels numbered in order of increasing distance, assigning a minus sign caudally.

Measurements of D-SCEP included: (1) amplitudes from the baseline to the initial-positive and the negative peaks; and (2) areas (voltage–time integral) of the initial-positive and the negative phases. Cord measurements at each intervertebral level from C2–3 to C6–7 in MRI included: (1) anteroposterior-diameter (APD) on midsagittal T1-weighted images and (2) cross-sectional areas (CSA) on axial T1-weighted images.

Results

Compared to the baseline (100%) obtained one level rostrally, the D-SCEP recorded at ‘0’ level showed a significantly (p < 0.001) decreased amplitude (48 ± 18%), area (48 ± 24%) of negative peak and increased amplitude (171 ± 96%) and area (279 ± 201%) of initial-positive peak. The degree of 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. This tendency of rostrally prominent enhancement showed a significant (P<0.05) difference in area between C3–4 and C5–6. Sagittal and axial T1-weighted MRI at ‘0’ level showed a
significantly ($p \leq 0.001$) smaller APD ($3.8 \pm 1.1\text{mm}$) and CSA($42.4 \pm 9.7\text{mm}^2$) than the remaining more caudal and rostral levels.

**Discussion & Conclusions**

D-SCEP can be recorded under inhalational general anesthesia with single shocks which probably activates descending motor pathways to both upper and lower limbs bilaterally. This stimulation technique evoked a relatively large, synchronous D-SCEP showing a short latency ($3.3 \pm 0.1\text{ ms at C4–5}$) and fast conduction velocity ($60.9\text{ m/s}$), similar to those estimated for the D-wave in humans. Recording a short-latency D-SCEP using a referential derivation poses the technical challenge of eliminating amplifier overload caused by a high-voltage TES. We employed a low amplifier sensitivity for the initial averaging with alternate stimulation of the right and left scalp to minimize baseline shifts caused by surface spread of stimulus current. Subsequent amplification optimal to evoke maximal D-SCEPs allowed accurate analyses of both positive and negative peaks. A bolus injection of a muscle relaxant (vecuronium, $0.015–0.110\text{ mg/kg}$) immediately before the recording also helped eliminate contamination from paraspinal muscles near the recording electrodes.

The D-SCEP showed an abrupt reduction in size of the negative peak accompanied by an enlargement of the initial positive peak at the compression site. These waveform changes can be explained by the concept of phase cancellation. The combination of the opposing changes seen in the negative and positive peaks characterizes the D-SCEP at the compression sites, as shown in previous studies of A-SCEP in CSM patients. The long descending axons originating in the brain terminate at various levels of the cord and most abundantly at the cervical enlargement, which contains numerous motoneurons innervating the upper limbs. Thus, progressively fewer descending axons remain caudally leading to a decreasing size of the D-SCEP. At a caudal level of conduction block, therefore, this physiological reduction of the D-SCEP adds a further decrease in size of the negative peak, at the same time countering the positive peak enhancement. Patients in the C5–6 group also had a relatively mild myelopathy as indicated by a significantly higher JOA motor score compared with the C3–4 group. Therefore, a smaller degree of conduction block in the C5–6 group may have contributed to a smaller change of the positive and negative peaks of the D-SCEP compared to the C3–4 group. We conclude that the D-SCEP serves as a useful measure in detecting the most rostral conduction block in the motor pathways, complementing the A-SCEP used to localize the most caudal conduction block in the sensory pathways. A change in negative peak, irrespective of the level of involvement, provides a better indication of compression site at more caudal levels, where partial conduction block may not alter the initial positive peak.