Analysis of Dermatomal Spinal Somatosensory Evoked Potentials in Lumbar Nerve Root Transection
Or-The Diagnostic Value of Dermatomal Somatosensory Evoked Potentials in Acute Nerve Root Injury: An Experimental Study with Special Reference on Stimulus Intensity
in lumbar nerve root Transection

Abstract

Study design

DSSEPs (dermatomal somatosensory evoked potentials) were recorded at spinal level to stimulation of the skin at L2, L4 and L5 dermatomes and of sciatic nerve. This study was completed to evaluate the normal DSSEP by various stimulating parameters and comparison with MSSEP; then investigate the diagnostic utility for detecting single nerve root injury by comparing the change of DSSEP elicited by submaximal and supramaximal stimulus after transection of L4 or 5 nerve root at immediate, one-hour, and one-week after surgery.

Objective

The present study was designed to investigate the characteristics and normatic value of the DSSEP elicited from lower limb dermatomes, and to determine the specificity and sensitivity of D-SSEP in detecting single nerve root injury, and whether stimulus intensity demonstrate significantly effect on the change of D-SSEP to determine the optimal stimulating parameter.

Summary of background data

The application of DSSEP has enabled clinicians to assess single nerve root-specific pathway, and been used in the electrodiagnosis of lumbosacral radiculopathy and intraoperative neuromonitoring. However, unacceptable low sensitivity and specificity have been reported and the value of such electrophysiological test is controversial. Furthermore, the normal variability, the basic characteristics, sensitivity, and the specificity of D-SSEP are not well documented. Without investigation of these basic
parameters and constitutions of a normal D-SSEP, determination of the diagnostic value of DSSEP is difficult; therefore, detail experimental research on D-SSEP is needed.

**Methods.** Twenty-four rats were used. Eight rats were used to specify a standard waveform, characters and the influencing factors and to evolve the stimulating and recording techniques. Then, two groups with eight rats in each group received (I) left L4, and (II) L5 nerve root transected. D-SSEP were recorded at the thoracolumbar junction following submaximal and supramaximal stimulation at the L2, L4, and L5 dermatomal field. Potentials recorded before and immediate, one-hour, and one week after a single nerve root transection were compared.

**Results.** Electrical stimulation on various dermatomes (L2, L4, and L5) yielded reproducible spinal response in all rats and tests, the amplitude is affected by stimulating intensity, but not rates. The reduction of the relative amplitude of the D-SSEP of the transected root were larger by submaximal than supramaximal stimulating intensity in both groups; 0 vs 31.3 and 3.8 vs 22.5 % in the immediate post-transection recordings of group I and II respectively. Using the same electromonitoring criteria, supramaximal stimulus showed a significantly higher false negative rate statistically than submaximal stimulus in both groups. The false positive rate was also lower in D-SSEP elicited by submaximal stimulating intensity than supramaximal intensity.

**Conclusions.** The present animal experiment demonstrated that D-SSEP is a valuable aid to detect acute single nerve root injury, proper stimulating and recording settings are requisite in high accuracy of the intraoperative neuromonitoring with D-SSEP. Verified submaximal dermatomal stimulation in the clinical domain will identify conduction abnormalities more consistency in acute nerve root injury than supramaximal stimulation, therefore, submaximal stimulation is recommended to avoid false results due to admixture of the contamination of the contiguous dermatomal stimulation.

[Key words: normative data somatosensory evoked potential, compound muscle action potentials, intraoperative neuromonitoring, lumbosacral nerve roots, simultaneous monitoring]
• SSEP (D-SSEPs by L2, L4, and L5 dermatomes plus M-SSEP by sciatic nerve stimulation) were elicited from 24 rats. First eight rats were used to investigate the waveform, descriptive statistics for amplitude, latency, left to right comparisons, and level to level comparison. These results suggested D-SSEP can be recorded very consistently with the stimulating and recording parameters for D-SSEP were carefully controlled.

• The remaining 16 rats were used to determine the effectiveness of D-SSEP in predicting acute nerve root injury by comparing the potentials before and after different lumbosacral nerve root transection. The results indicated that D-SSEP was sensitive and specific to acute lumbosacral nerve root injury.

• The results also showed that with same electromonitoring criteria used across sub- and supramaximal stimulating intensity, the submaximal produced a significantly lower false-negative rate than the supramaximal stimulating.

Mini Abstract

This study demonstrated the value of using interspinous electrode recording of DSSEP in detecting single nerve root injury in intraoperative monitoring of acute lumbosacral nerve root injury. The present results also provide answers to some of the questions pertaining to the DSSEP as a useful intraoperative neuromonitoring technique. Accurate DSSEP interpretation is depended on a precise knowledge of the segmental anatomy (innervation patterns) and proper setting of the stimulating and recording techniques. The stimulating intensity is an important factor that can influence interpretation, and using the submaximal stimulating intensity can enhance the sensitivity and specificity significantly and supramaximal stimulus should be avoid.

Introduction

Intraoperative neuromonitoring with various techniques are now widely used during invasive spinal surgery as they offer a non-invasive way to measure the functional integrity of the spinal cord. Most of the current methods do not give the information
on the functional state of a single nerve root; the concerns of the failure to detect specific spinal nerve root lesion or deficit has led to attempts selectively to monitor the conduction of the single nerve root. There are few techniques for intraoperative neuromonitoring of a single nerve root, actually, no reliable method has been established.\textsuperscript{5-14,18,19} D-SSEP obtained from stimulation of different dermatome has been advocated as a useful alternative route because such potentials seemed reflected the specific conduction of the supplying nerve root. Although this technique has been used extensively in electrodiagnosis of lumbosacral root disease and with abundant reports, but the effectiveness is in great diversity.\textsuperscript{15,16} Meanwhile, the clinical application with D-SSEP in intraoperative neuromonitoring of a single nerve root is limited because of the major problems of difficulties in obtaining the stable, and consistent signal during general anesthesia of subject, and the lack of the validation of the warning criteria for such potential. To elucidate the conflicting clinical results and overcome those limitations, the understanding of the D-SSEP, such as the basic electrophysiologic characteristics, normal variability, sensitivity and specificity in diagnosis is crucial. Animal model are of useful in elucidation of these questions,\textsuperscript{16} unfortunately, unlike the extensive studies on spinal cord monitoring using various animals, there is surprisingly little experimental literature on DSSEP.\textsuperscript{14,17,20} In a previous study of comparing the effect of single lumbosacral nerve root transection on M-SSEP, D-SSEP and CMAP, it was observed that D-SSEP was specific to single nerve root injury, but with less sensitivity. In L5 transection group, the L5 D-SSEP showed 66.5% decrease in amplitude, the true positive rate is 25 and 62.5 % when using 50% and 30% reduction as critical criteria.\textsuperscript{14} These observations also raised the question whether the unexpected low sensitivity could be related to the monitoring technique and procedure.

The first purpose of this experiment is to systemically investigate the typical waveform, analyze the normal magnitude of latency and amplitude variation in different stimulation and recording parameters of DSSEP in rat. This rather fundamental aspect of DSSEP has not previously been performed. The second purpose is to determine the sensitivity and specificity of DSSEP in detecting the single nerve root conductivity after sectioning various lumbar nerve roots by monitoring different DSSEP, with special references to the stimulation zone and intensity of the evoking of the DSSEP. It is hoped that these comparative analyses will reveal the inherent normal variation for DSSEP techniques and provide insight as to how sequential DSSEP trials should be analyzed and interpreted in intraoperative electrodiagnosis.
Materials and Methods

The experimental protocol was reviewed and approved by the Institutional Animal Care and Use Committee, NCKU. In total, twenty-four rats weighing between 390 and 490 grams were used in this study. Each rat was housed individually in a room with a 12/12 hr light/dark cycle with free access to food and water.

Animal preparation and surgical procedures

All surgical procedures were performed with intraperitoneal sodium pentobarbital anesthesia (Nembutal; 50 mg/kg; Abbott, North Chicago, IL). The depth of anesthesia was determined by noting the withdrawal reflex upon tail pinch. The animals were premedicated with gentamycin (8 mg/kg, intramuscular; Yung Shin Pharmaceutical Industrial Co., Ltd., Taichung, Taiwan). Core temperature was monitored with probes in the rectum and connected to a multichannel thermometer (Portable Hybrid Recorder, model 3087; Yokogawa Hokushin Electric, Tokyo, Japan) and maintained by heating pad and lamp within 37°C to 38°C. Preoperative X-rays were taken with a metal marker to determine the level of the spine. The rat was then placed in prone position with hips extended. The surgical procedures were performed under aseptic conditions and using 1.5× loupe magnification. A midline, posterior longitudinal incision was made from the mid-thoracic spine to the sacrum, and the paravertebral muscles were retracted. The left lamina and transverse process from L1 to sacrum was then exposed to identify the extraforaminal portion of left L1- 6, and S1 roots. Because of the limited area of the back of rat, and to prevent bleeding and leaking of the cerebrospinal fluid, the lamina was preserved and the nerve roots were dissected proximally to the bony boundary.

Standardization of D-SSEP

To determine the basic characteristics of D-SSEP, its relation with M-SSEP elicited by sciatic nerve stimulation, and the effect of stimulation intensity and frequency, in first eight rats, D-SSEP was elicited by one or two constant zones of dermatomal fields, tested at various stimulation parameters. At final we performed neurectomy to verify the proximal transmission of the conductive volley after dermatomal stimulation.

Setup of Stimulation and Recording Preparation

Spinal somatosensory evoked potentials (SSEP) were recorded by bipolar needle electrodes. The cathode was placed in the thoraco-lumbar interspinous ligament and the anode 1 cm proximal to it. Stimulation was delivered from different sites to
acquire (or obtain)- (i) Mixed-nerve-elicited SSEP (M-SSEP): Stimulation was delivered by similar electrodes placed under the bilateral sciatic nerves just proximal to the bifurcation of the peroneal branch, with the cathode 3 mm proximal to the anode after dorsal incisions in both thighs and exposure of a 1.5-centimeter segment of both sciatic nerves. (ii) Dermatomal SSEPs (DSSEP): Stimulation was elicited from a pair of subcutaneous needle electrodes with an interelectrode distance of 2 mm at the various dermatomes. DSSEP was performed by locating the electrodes on a consistent area for the L2, 4, and 5 dermatomes, the appropriate placement was based on the composite dermatome charts published by Takahashi and Nakajima. Specifically, the electrodes were located on the most posterior portion of abdomen, groin, and the base of the hindlimb for L2 D-SSEP. The site of stimulation for L4 was ventral aspect of the mid-portion of the hindpaw, and for L5 in the lateral aspect of the proximal-portion of the hindpaw. Square pulse impulses 0.2 msec in duration with various intensities and stimulation rate was first used to test the difference. The recording was filtered for data from 10 to 5000 Hz; recording time was 20 msec. Stimulation on two zones with two pairs of electrodes inserted within the well-documented regions for L4 and L5 were also excited to determine the conduction velocity. Finally, to determine the pathway of propagation of D-SSEPs, the potentials were recorded before and after peroneal or tibial neurectomy in each four rats of these eight rats, and then, sciatic neurectomy in all rat.

Experimental protocol of nerve root transection

The remaining 16 rats were divided into two groups of eight, which were then assigned to two different transection groups: (I) left L4 transection; (II) left L5 transection; each with two groups undergoing different stimulation intensities (submaximal and supramaximal stimulus- the electric stimulus of approximately 20% less currents than required for the maximal stimulus as submaximal and 20% greater
as supramaximal stimulation.) The current threshold that producing the maximal
amplitude was established for each stimulation zone (left L2, 4, 5, and right L4 and 5)
by electrical current increasing from the baseline (0 mA); then a current intensity of
submaximal and supramaximal stimulation were delivered and responsive evoked
potentials were recorded. After the measurement of baseline D-SSEPs at sub- and
supra-maximal stimulation, the rats underwent nerve root transection by microscissors.
After completion of various transections, the D-SSEP were recorded immediately and
one hour after transection. The animals were allowed to recover and then kept
separately for one week. On one week later, the D-SSEP were recorded with the
similar anesthesia, and the electrophysiological monitoring setup.
The electrophysiological data were collected, stored, and analyzed on an
electrodiagnostic device (Neuropack Z; Nihon Koden, Tokyo, Japan). The amplitude
of the major peaks in these recordings was expressed as a percentage of the
pre-transection values. The animals were then deeply anesthetized, after which an
intracardiac perfusion with warm lactated Ringer's saline solution and glutaraldehyde
was performed. After perfusion and careful posterior dissection of the lumbar
vertebrae, gross examination of the transected nerve root and the innervation pattern
of the nerve roots were made; and verified with intended grouping.
Results

Characterization of the D-SSEP

In first eight rats, a search was made to investigate the basic features of D-SSEP in comparing with M-SSEP elicited by direct sciatic nerve stimulation. Electrical stimulation on various dermatomes (L2, L4, and 5) yielded reproducible spinal response (D-SSEP) in all rats (every tests). The D-SSEP consisted of a consistent, major component of a broad, monophasic, negative wave. The configuration of the D-SSEP was similar to M-SSEP except the M-SSEP presented as a larger, and in a sharp, peak morphology. There was no obvious difference in the morphology after either dermatomal stimulation. The mean latency ranged between 0.95 to 1.25 msec, 1.75 to 2.05 msec, and 1.55 to 1.70 msec in L2, L4, and L5 dermatome elicited D-SSEP. The latency increased as the distance between stimulating and recording electrodes increased instead of the stimulating of different dermatome. Latencies of SSEP to each dermatome increased as a function of increasing distance of the stimulation site from the recording site. There is no significant difference between right and left extremities in latency and amplitude of all animals (Fig. 1). Conduction velocities from the site of stimulation to the spinal recording site were computed from two different sites of the same dermatome, each of the dermatome studied showed very consistent and no inter-dermatomal difference. The mean conduction velocity across both sites of the same dermatome velocity (mean = 52.6+ 8.9) is significantly slower than the value for conduction velocity of mixed nerve elicited SSEP (mean = 95.2+ 23.5 m/sec) by stimulating two sites at the sciatic nerve (p<0.001) in this current study. These data indicated that the MSSEP composed of faster conducting fibers than DSSEP.

Relationship between stimulus intensity, frequency and amplitude

Figure 2 illustrates the effect of stimulus intensity and the relationship between stimulus intensity and amplitude on D-SSEP elicited by stimulation on various dermatomes. No substantial differences in morphology of D-SSEPs were seen at various stimulus intensities. As the intensity increasing above threshold stimulus, there was a progressive increase in the amplitude until the maximal stimulus reached, and the latency decreased. The shortening in the latency, thereby implied local spreading of current than a further elicitation of nerve fibers with different threshold. Stimulating presentation frequency at a rate range from 5 to 50 Hz caused no change in the amplitude and the latency of the potential, indicating that the major component of potential is synapse-independent.

The amplitude of L4 and L5 D-SSEPs were reduced to 21.2 and 51.8% after common peroneal nerve, and 56.9 and 5.5% after tibial nerve transection respectively; all followed by abolishment of L4 and L5-DSSEPs after additional transection of sciatic
nerve. Meanwhile, the contralateral L4, L5 and ipsilateral L2 D-SSEPs remained consistent without any obvious change (Fig. 3). These results indicated that the L4 and L5 D-SSEP conducted mainly along the sciatic nerve.

Effect of nerve root transection on D-SSEP

Nerve root transection typically decreased or abolished the amplitude with a variable shift of latency of the corresponding D-SSEP immediately, one hour and one week after the operation is the characteristic change (Fig. 4). Table I presents the relative values (mean and SD) of peak amplitude with percentage of pre-transection amplitude, the relative value of the amplitude was defined as 0 % in the case of complete abolishment of the wave. In such cases, latency data were excluded.

For both groups, either with submaximal or supramaximal stimulus the right L4, and L5 D-SSEP (not operated side) remained essentially constant during the whole test period. The time-course change of the left L2 D-SSEP (same side but not contiguous to the cut nerve root territory) also showed no statistically significant difference. In group 1 (L4 transection; n=8), L4 transection caused a significant reduction of amplitude of L4 D-SSEP elicited by submaximal and supramaximal stimulus immediate, one hour and one week after the operation. Moreover, the percentage of decreasement is significantly pronounced in tests with submaximal stimulus than supramaximal stimulus of L4 DSSEP ($P<0.001$ in the recording immediately and one-hour after transection, =$0.001$ onw week after the transection). The left L5 D-SSEP, elicited from the ipsilateral dermatome in contiguity to L4 dermatome by submaximal stimulus, demonstrated a slight reduction in amplitude, but at no time were the response lost nor were significant changes in amplitude was noted. However, the reduction were more obvious and became significantly different in the immediate and one-hour post-transectional recordings when using supramaximal stimulus.

Similarly, transection of L5 (group 2, n=8) caused significant reduction of amplitude of L5 D-SSEP than other DSSEPs, furthermore, the percentage of reduction by submaximal stimulus was significantly substantial than by supramaximal stimulation ($p=0.025$, 0.015, and 0.031 for the immediate, one hour and one week after transection respectively). Meanwhile, the L4 D-SSEP also demonstrated a less decrease of amplitude but with statistically significant difference than the cocontralateral L4 and 5 DSSEP and L2 DSSEP. In all these recordings, the change in latency is unremarkable and inconsistent from immediately, one hour and one week after the operation in all animals.

The sensitivity and specificity of D-SSEP and the its (those) relationship with stimulus intensity

While complete transection of nerve root represents a rare form of injury or disease of nerve root, it appears to a well-controlled model in testing the sensitivity and
specificity of DSSEP. The amplitude percentages in each recording after operation were divided into three groups: absence of potential, deterioration of amplitude greater than 50%, and deterioration of amplitude less than 50% (Table 2 A and B). In group 1, of eight rat underwent left L4 transection, 23 (95.8%) and only 2 (8.3%) of 24 tests of submaximal and supramaximal stimulation completely loss the potential respectively in immediate, one hour, and one week after operation. There is significant difference in the sensitivity (p<0.001). However, using more than 50% attenuation of amplitude as positive criteria, the sensitivity became 100% in both stimulus intensities. However, since specific DSSEP is assumed to reflect the sole conductivity of the elicited dermatome, thereby, using >50% reduction (the general accepted criteria of Intraoperative spinal cord electrodiagnosis) as a critical sign in such controlled complete transection of the responsible nerve root seems to be less logical. Similarly, in transection of L5 root (Group 2, n = 8), the different warning criteria revealed a sensitivity of 22 (91.6%) and 8 (33.3%) (significant difference in the sensitivity (p<0.001)) as complete lost; and 100% and 87.5% as >50% loss of amplitude in submaximal and supramaximal stimulus. The contralateral side D-SSEP (right L4 and 5) and the ipsilateral DSSEP not in conjunctive vicinity of L4 or L5 (ie, left L2) were well maintained, and there is no false positive case in those total 144 recordings in all time-point during the whole experimental period. However, in addition to the significant reduction of the amplitude in average of the near-by D-SSEP to the cut root, there is only one immediate recording of false positive (complete loss of amplitude) in left L4 D-SSEP immediate after the transection of the left L5 root, however, the potential reappeared but returned to less than 50% of the baseline one hour later. Therefore, the specificity is very high (only one false positive) when using abolishment of amplitude as criteria, whereas, using the 50% reduction as warning criteria, the false positive rate were 18.8% and 29.2% in submaximal and supramaximal stimulation respectively. The sensitivity and specificity rate were showed in Table 3 A and B.
Discussion

Rationale of this study and study design or Intraoperative neuromonitoring of lumbosacral nerve root

Intraoperative monitoring of spinal cord function using mixed nerve elicited somatosensory evoked potentials (M-SSEP) recorded from cortex or spinal cord has become a standard of care during invasive spinal surgery and has achieved significant success at reducing the incidence of iatrogenic spinal cord injury. However, a useful monitoring modality for detecting the postoperative lumbosacral root injury is much less well-established. The ability to monitor the single nerve root is desirable because different nerve root travel along separate tracts, each enter the spinal canal and join to the cauda equina separately. Because M-SSEP are typically mediated by several spinal nerve roots, lesser sensitivity and lack of specificity for a single radicular lesion or injury may be because the conductional abnormality of a single nerve root may be masked by the normal signals mediated by the unaffected nerve roots. Therefore, injury to one nerve root will not necessarily be detected by monitoring the SSEP elicited by major or specific nerves. Continuous monitoring the free-running or triggered electromyographic (EMG) activity from appropriate myotomes, or D-SSEP elicited by dermatome seems to be reasonable solutions to assess single nerve root function.

There were great disparity in the usefulness of DSSEP in electrodiagnosis of radiculopathy and intraoperative neuromonitoring. Since the method of using DSSEP for the diagnosis herniated lumbar disc in 1980, this technique became a popular and was thought to be a necessary tool in the evaluation of suspected radiculopathy by many researchers. However, the reported accuracy rate ranged from 7.2% to 93%, which suggests DSSEP might provide reliable information about nerve root function and might be a complementary study; but the ultimate diagnostic value is questionable needs further investigations. In Intraoperative neuromonitoring of lumbosacral surgery, DSSEP was found to be helpful in assessing the adequacy of neural decompression and predicting of new postoperative neurologic deficits in surgical correction of spondylolisthesis. A series study of 108 case of elective lumbar surgery used DSSEP to monitor the pedicle screw insertion verified DSSEP was an excellent method to verify intraoperative neurological status. However, Toleikis et al have used the DSSEP during the intrapedicular fixation procedures and found the repeatable DSSEP were recorded able in 80 of 81 patients, but they summarized that the D-SSEP may not be a sensitive enough tool for detecting compromise of a single nerve root function. Tsai et al also concluded that intraoperative dermatomal evoked potential monitoring fails to predict outcome from lumbar decompression surgery. In addition to the opinions differ concerning the
preferability (preference) of D-SSEP in diagnosing radiculopathy and the intraoperative monitoring, there exists no comprehensive, fundamental experimental work and data regarding standardized method for acquiring DSSEP and the appropriate interpretation (defining the consensus regarding of the boundaries that suggest pathology) of this potential. This study was designed to elucidate the transmitting of the axonal volleys of D-SSEP, the variables affecting the potential, and the warning criterion in intraoperative use of the D-SSEP in experimental animals.

**Methodologic Aspects of stimulation and recording of D-SSEP**

A critical analysis of the standard waveform, characters, and influencing factors, particularly, the stimulating conditions (intensity, presentation rate, and site of stimulation) and recording condition, as well as a standardized criteria in interpretation of data, must be undertaken before determining what constitutes a pathologic response in electrodiagnosis or intraoperative neuromonitoring. Toleikis et al advocated that the waveforms of D-SSEP was poorly defined and lower in amplitude during general anesthesia, particularly for the L2, L3, and L4 D-SSEP, which were assumed to be because of a lower density of somatic innervation than L5 and S1 in human. Besides from the technical standpoint and anatomical basis, such scalp-recorded D-SSEP is difficulty to obtain, especially the dermatomes of lower extremity and with inhalation anesthesia. In our recent report of experimental work and this study, D-SSEP by stimulation of lower limb dermatome and M-SSEP by sciatic nerve stimulation can be recorded continuously and consistently by needle electrodes within interspinous space. The invasiveness and obstruct to the operation are the major disadvantages that ever criticized, however, the interspinous needle is extrathecal setting thus cause no fear to the neural damage, and clinical practice has verified that setup of the electrode in the operative field cause minimally inconvenient, and the electrodes caused no interfere to the surgical manipulation during operation. In addition, alteration of stimulation techniques was made to improve the reliability and quality of the potentials, e.g. using low stimulation rates, increasing the averaging numbers, using larger stimulation electrode, and increasing the stimulation intensity. In this study, subdermal needle electrodes were very easily to evoked a well-defined response in L2, L4, and L5- including dermatome of low and high somatic innervation, there was obvious difference in amplitude of D-SSEP elicited from different dermatome was also verified. Furthermore, the thresholds of normal animal using this technique are low- between 2 to 5 mA, which indicate the stimulation is very effective. It maybe particular valuable when stimulation on the dermatome which the supplied nerve root has been significant injured and that it had undergone Wallerian degeneration, because the stimulus threshold required to activate was markedly elevated. However, in clinical practice, human’s field of dermatome is
much large, the interelectrode distance should be increased accordingly. The operation
time will prolong and the response time after identifying the abnormal signal will
shorten if the number of averaging is increased, or the stimulation rate is lowered. We
have found that consistent D-SSEP could be obtained by using high stimulation rate
(up to 30 Hz) and showed no difference in latency and amplitude with low rate. In this
study, a well-defined waveform was always obtainable after averaging 200 repetitons,
the signal acquisition time is usually less than 30 secs when using 10 Hz stimulating
rate, thus can provide more timely information intraoperatively.

**Value of D-SSEP in Intraoperative Neuromonitoring of Acute Single Nerve Root
Injury- or Effect of Stimulating Zone and Intensity in Reliability of Specificity and Sensitivity**

The D-SSEP is theoretically thought to be absolute segment-specific and reflect the
conductivity of the stimulated dermatome to root and recording site finally. However,
substantial clinical experiences from electrodiagnosis of radiculopathy in awake
patients\textsuperscript{16,25,31} or intraoperative neuromonitoring\textsuperscript{8,9,13}, and our previous experimental
work\textsuperscript{14} against this hypothesis. Such unexpected low and limited diagnostic utility of
DSSEP is likely due to several factors. First, there is noted to be a high degree of
biologic variation; considerable variation exists in the dermatomal charts published
by different investigators, but comparison of these maps permits the definition of
certain areas that are generally agreed to lie within the territory of particular
dermatomes.\textsuperscript{17,32} The data in this study clearly demonstrated that irrespective of which
zone within the specific dermatome is chosen, the high sensitivity (change of the
amplitude) to the transection of the corresponding nerve root showed no significant
difference. Second, stimulating intensity of the DSSEP procedure that contributed
significantly to overall variability. In awaked patients, electrical stimulation in target
dermatome at an intensity of two to three times the sensory threshold was used to
elicit responses that can be recorded with facility over the spine and scalp\textsuperscript{30,33}. In
intraoperative neuromonitoring, the intensity was always increased to overcome the
suppression of the inhalative anesthetics; however, the intensity was arbitrary, (e.g.
0.3 ms duration of constant current of 20-30 mA\textsuperscript{9}), and no common agreed standard
for the stimulating intensity. Also, because of the compact nature of the electrical
spreading, it is conceivable that a so-called specific D-SSEP evoked by electrical
stimulation on dermatome may contaminated by the simultaneous activation of the
neighbored dermatome, the specific peripheral nerve adjacent to the dermatomal
stimulation, or any combination of these; the appropriate stimulating intensity should
be also investigated extensively to avoid the bias. It is clear from this study that the
use of supramaximal stimulating do yield more false negative result indicating a lower
diagnostic specificity of DSSEP than submaximal stimulating intensity in acute nerve
root injury. Furthermore, when using the supramaximal stimulation, the false positive increased too. As evidenced here, if supramaximal stimulation is utilized for comparison, there is a risk of false positive and could thus potentially mimic a pathologic response of an uninjured dermatome and corresponding nerve root. These findings mean of submaximal stimulation intensity in elicitation of DSSEP increases the specificity, and it is preferable to supramaximal stimulation. Third, The warning criteria is not well-established in intraoperative neuromonitoring of utilizing DSSEP. Absent or asymmetric level-by-level response, prolonged latency and/or reduced amplitude have been used as the diagnostic criterion in electrodiagnosis of chronic compressive radiculopathy.\textsuperscript{15,16,21-26,28,31} However, because most chronic compressive lesion cause low-grade, insidious compression and do not compromise all or most of the viable nerve root tissue, it should not surprising that diagnostic criteria of DSSEP used in such lesion are not exceedingly sensitive (or suitable) in defining acute nerve root injury occurs intraoperatively which is always massive and sudden injury. In the intraoperative nerve root monitoring of acute nerve root damage, such as in this study, we recorded the serial DSSEP while performing acute nerve root transection. As a result, the method allow us to compare the change of DSSEP elicited from bilateral, multiple dermatomes of hindlimbs after transection of nerve root, and verified the obvious, and significant reduction of the amplitude, rather than the latency, which occurred immediate and persisted for at least one week.

General Conclusions and outlook

To our knowledge, this is the first systematic, basic study of DSSEP following acute nerve root transection. On the basis of these results, it may be concluded that DSSEP to lower limb dermatomal stimulation are useful in the early detecting of single nerve root injury. While rootlet rhizotomy in this study represents a different form of damage to the nerve root than does chronic compression or acute completely resection of a nerve root is rarely occurred clinically, it appears that the DSSEP are sensitive to reflect the functional integrity of the entire root and therefore, should be sensitive to the adequacy of nerve root decompression or detecting of acute single nerve root damage intraoperatively. More importantly, the conductive integrity of a single lumbosacral nerve root do not reliably ascertain except that adequate dermatome stimulation has taken place and that submaximal dermatomal stimulation is recommended to avoid false results due to unintentional admixture of adjacent dermatome(s) to the intentioned- stimulating dermatome. Furthermore, caution must be exercised in diagnosing acute nerve root by the close observation of the change of the serial recording and comparison bilaterally, particularly with respect to amplitude criteria.
References


24. Pape E. Sensory nerve somatosensory evoked potentials (SEP) in the evaluation of patients with sciatica: false P1 latency prolongation may be due to admixture of dermatomal SEP. Electromyogr Clin Neurophysiol. 2001 Sep;41(6):337-44.


Legends for Figures

**Figure 1.** Example of typical dermatomal spinal somatosensory evoked potential (DSSEP) and setup of recording system and stimulation site of L2-, and two different L4- and L5-DSSEP according to the composite dermatome charts published by Takahashi and Nakajima; location of stimulating needles are indicated by paired of dots and bars. L4(d), 4(p), 5(d), and 5(p) indicate L4 distal, L4 proximal site, L5 distal, and L5 proximal site.

**Figure 2.** Relationship between stimulus intensity and amplitudes of DSSEP.

**Figure 3.** Various DSSEPs recorded before and after transection of the left peroneal and then left tibial nerves.

**Figure 4.** Characteristic change of DSSEP in group I (left L4 transection). Upper two columns are left L4 DSSEP of sub- (top) and supra-maximal (second top) stimulus; lower two columns are left L5 DSSEP of sub- (second bottom) and supra-maximal stimulus (bottom).
### Table 1. Comparison of amplitude change between Groups I and II

<table>
<thead>
<tr>
<th>Time Point (min)</th>
<th>Group I (Lt L4 transection)</th>
<th>Group II (Lt L5 transection)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lt L4</td>
<td>Rt L4</td>
</tr>
<tr>
<td>Lt L2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immediate</td>
<td>$0 \pm 0^{a\dagger}$</td>
<td>$85.8 \pm 13.1^b$</td>
</tr>
<tr>
<td></td>
<td>$(31.3 \pm 17.1)^{\dagger}$</td>
<td>$(110.1 \pm 16.0)^{c}$</td>
</tr>
<tr>
<td>1 hr</td>
<td>$0 \pm 0^{a\dagger}$</td>
<td>$91.7 \pm 14.1^b$</td>
</tr>
<tr>
<td></td>
<td>$(35.3 \pm 13.6)^{a\dagger}$</td>
<td>$(119.4 \pm 31.1)^{c}$</td>
</tr>
<tr>
<td>1 wk</td>
<td>$3.1 \pm 8.9^{a\dagger}$</td>
<td>$97.9 \pm 4.2^b$</td>
</tr>
<tr>
<td></td>
<td>$(25.1 \pm 12.2)^{a\dagger}$</td>
<td>$(88.6 \pm 24.8)^b$</td>
</tr>
</tbody>
</table>

\[\text{Group II (Lt L5 transection)}\]

<p>| Immediate        | $45.6 \pm 42.4^{a\dagger}$ | $85.6 \pm 10.9^c$ | $3.8 \pm 10.6^{a^b}$ | $100.4 \pm 20.7^c$ | $86.6 \pm 20.5^{a^c}$ | &lt;0.001 |
|                  | $(51.0 \pm 18.9)^{a\dagger}$ | $(83.1 \pm 18.8)^c$ | $(22.5 \pm 18.1)^b$ | $(85.1 \pm 4.0)^c$ | $(107.6 \pm 24.6)^c$ | &lt;0.001 |
| 1 hr             | $63.5 \pm 17.7^{a\dagger}$ | $90.3 \pm 18.1^c$ | $0 \pm 0^{a^b}$ | $95.7 \pm 21.9^c$ | $112.5 \pm 23.3^{a^c}$ | &lt;0.001 |
|                  | $(57.4 \pm 22.2)^{a\dagger}$ | $(94.0 \pm 21.6)^c$ | $(24.9 \pm 25.5)^b$ | $(90.5 \pm 11.3)^c$ | $(99.2 \pm 18.5)^c$ | &lt;0.001 |</p>
<table>
<thead>
<tr>
<th></th>
<th>Relative Values</th>
<th>Percentage of Pre-transaction Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 wk</td>
<td>67.9 ± 21.7(a^\dagger)</td>
<td>103.1 ± 21.6(c)</td>
</tr>
<tr>
<td></td>
<td>(48.7 ± 25.0)(a^\dagger)</td>
<td>(83.0 ± 32.8)(b)</td>
</tr>
</tbody>
</table>

Relative values (mean ± S.D.) of peak amplitude with percentage of pre-transaction amplitude of the same D-SSEP. \(\dagger\) data in these rows are with submaximal stimulus; \(\dagger\) the data in these rows (in ( )) are with supramaximal stimulus. \(a,b,c\) Different superscript letters indicate a significant difference across these three groups (ANOVA).
Table 2A. Comparison of amplitude of L4 and 5 D-SSEPs after L4 transection in Groups I

<table>
<thead>
<tr>
<th>Time Point</th>
<th>immediate</th>
<th>1 hr</th>
<th>1 wk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Complete loss</td>
<td>Loss&gt;50%</td>
<td>Loss&lt;50%</td>
</tr>
<tr>
<td>Lt L4 (sub)</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lt L4 (supra)</td>
<td>0 (1)</td>
<td>(7)</td>
<td>(0)</td>
</tr>
<tr>
<td>Lt L5 (sub)</td>
<td>0</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Lt L5 (supra)</td>
<td>0 (2)</td>
<td>(6)</td>
<td>(0)</td>
</tr>
</tbody>
</table>

Table 2B. Comparison of amplitude of L4 and 5 D-SSEPs after L5 transection in Groups II

<table>
<thead>
<tr>
<th>Time Point</th>
<th>immediate</th>
<th>1 hr</th>
<th>1 wk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>\Complete loss</td>
<td>Loss&gt;50%</td>
<td>Loss&lt;50%</td>
</tr>
<tr>
<td>Lt L4 (sub)</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Lt L4 (supra)</td>
<td>0 (4)</td>
<td>(4)</td>
<td>(0)</td>
</tr>
<tr>
<td>Lt L5 (sub)</td>
<td>7</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Lt L5 (supra)</td>
<td>2 (6)</td>
<td>(0)</td>
<td>(3)</td>
</tr>
</tbody>
</table>

\[ data in these rows are with submaximal stimulus; ‡ the data in ( ) in these rows are with supramaximal stimulus]
Table 3A. The accuracy of SSEP using two different warning criteria (complete loss and 50 %) after nerve transection in group I

<table>
<thead>
<tr>
<th>SSEP Change</th>
<th>L4 D-SSEP change</th>
<th>L5 D-SSEP change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Submax</td>
<td>Supramax</td>
</tr>
<tr>
<td>+ (complete loss)</td>
<td>23/24</td>
<td>2/24 (TP)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- )</td>
<td>1/24</td>
<td>22/24 (FN)</td>
</tr>
<tr>
<td>+ (&gt; 50% loss)</td>
<td>24/24</td>
<td>23/24 (TP)</td>
</tr>
<tr>
<td>-</td>
<td>0/24</td>
<td>1/24 (FN)</td>
</tr>
</tbody>
</table>

*Asterisks indicate a significant difference between the left (operated) and right (uninjured) sides (paired t-test). Sn = sensitivity, Sp = specificity

Table 3B. The accuracy of SSEP using two different warning criteria (complete loss and 50 %) after nerve transection in group II

<table>
<thead>
<tr>
<th>SSEP Change</th>
<th>L5 D-SSEP change</th>
<th>L4 D-SSEP change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Submax</td>
<td>Supramax</td>
</tr>
<tr>
<td>+ (complete loss)</td>
<td>22/24d</td>
<td>8/24 (TP)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- )</td>
<td>2/24</td>
<td>16/24 (FN)</td>
</tr>
<tr>
<td>+ (&gt; 50% loss)</td>
<td>24/24</td>
<td>21/24 (TP)</td>
</tr>
<tr>
<td>-</td>
<td>0/24</td>
<td>3/24 (FN)</td>
</tr>
</tbody>
</table>

* Asterisks indicate a significant difference between the left (operated) and right (uninjured) sides (paired t-test). Sn = sensitivity, Sp = specificity
Spinal SEP and Pedicle Screw Placement

before
after Pero. N. cutting
and Tib. N. Cutting

left L2
left L4
left L5
right L5

2 ms