

GUIDELINES FOR SOMATOSENSORY EVOKED POTENTIALS

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Preface

The first guidelines for “Somatosensory Evoked Potentials” (SEPs) of the American Association of Electrodiagnostic Medicine (AAEM) were written in 1984. In the subsequent decade, numerous research and clinically based studies have expanded the knowledge, understanding, and utility of SEPs in clinical practice necessitating a revision of the guidelines.

To draft new SEP guidelines, the AAEM Board of Directors convened a panel of experts in SEPs - the AAEM Somatosensory Evoked Potentials Subcommittee. The guidelines drafted by this subcommittee were then reviewed by the AAEM Quality Assurance and Professional Practice Committees, and approved by the AAEM Board of Directors. A concerted effort was made to incorporate pertinent features of the 1991 guidelines of the American Electroencephalographic Society (now the American Clinical Neurophysiology Society). This document is intended to be a guideline and is not to be considered a standard of practice. Physicians may deviate from these guidelines when appropriate, provided the effects of any deviations are understood.

Originally developed by the 1984 AAEM Evoked Potentials Committee: Chair: Ernest A. Baran, MD; Members: Bernard M. Abrams, MD; Arminius Cassvan, MD; Roger Q. Cracco, MD; Andrew A. Eisen, MD; Jun Kimura, MD; W.T. Liberson, MD, PhD; and Walter C. Stolov, MD.

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These guidelines are based on guidelines for clinical evoked potentials originally prepared by the American Clinical Neurophysiology Society (ACNS) (formerly the American Electroencephalography Society) PO Box 30, Bloomfield, CT 06002-0030. Figures 1 and 2 are reproduced with permission from the ACNS. Modifications, deletions, or additions to the ACNS document were made to reflect the needs of the American Association of Electrodiagnostic Medicine’s (AAEM) membership.

CHAPTER 6

GUIDELINES FOR SOMATOSENSORY EVOKED POTENTIALS

Recommended Guidelines for the Clinical Practice of Somatosensory Evoked Potentials

Introduction

Somatosensory evoked potentials (SEPs) are recorded in different clinical contexts. They may be used to assess peripheral sensory function, to evaluate the functional integrity of sensory projection pathways in the central nervous system, or both. Collaboration among the different disciplines that utilize evoked potential measures must be fostered as much as possible. The following guidelines provide recommendations for recording and interpreting evoked potentials that are primarily aimed at evaluating the function of somatosensory pathways in the central nervous system with the intent of providing clinically relevant information. For further information regarding SEPs, please see Chapter 5, *Somatosensory Evoked Potentials: Clinical Uses*. More detailed explanations may be found in recent texts such as Chiappa's *Evoked Potentials in Clinical Medicine*.⁶

Qualifications for Practice

Recommended Qualifications for Practitioners of Clinical Evoked Potential Studies

Practitioners of clinical evoked potential studies should be physicians with a MD, DO, or foreign equivalent degree. Ideally, these physicians should also have specialized training in the interpretation of evoked potentials. The training of a qualified practitioner of clinical evoked potential studies should be designed to provide a thorough understanding of, and direct familiarity with, all aspects of evoked potential data acquisition, processing, and interpretation. Such training should include adequate educational experience in:

- a. The influences of stimulus parameters and other experimental variables on the responses that are recorded.
- b. Existing knowledge of the anatomic structures and neurophysiologic events underlying the generation of evoked potentials.
- c. The clinical significance and pathologic correlates of dysfunctional neural pathways demonstrated by evoked potentials alterations.
- d. Relevant normative data and statistics.

In addition, this learning experience should include the personal performance by the physician trainee (either with or without a technologist's assistance) of about 100 SEP examinations as well as the supervised interpretation of several hundred evoked potential studies, including responses to somatosensory stimuli in all age groups.

Optimally, the training to interpret evoked potential studies should be completed in a formal post-residency fellowship in clinical neurophysiology or during dedicated time within a residency. Fellowships are usually of 6-to12 months duration. During this time, general skills of clinical neurophysiology, in addition to those required for clinical evoked potential interpretation, should be provided. The American Association of Electrodiagnostic Medicine has a listing of fellowships. This is a voluntary listing and therefore does not include all fellowships available within the United States.

Becoming credentialed by a national examining organization that assesses accuracy of knowledge of evoked potentials is the only objective method of demonstrating competency in interpretation of evoked potential studies. The American Board of Electrodiagnostic Medicine offers an examination, with a portion devoted to clinically evoked potentials. Eligibility of acceptance for this examination requires completion of an accredited residency in neurology or physical medicine and rehabilitation (PM&R) with a minimum of 6 months of full-time equivalent formal clinical neurophysiology training and additional post-residency experience.

The American Board of Psychiatry and Neurology (ABPN) has established subspecialty certification in clinical neurophysiology. This written examination, first given in 1992, focuses on basic neurophysiology, electroencephalography (EEG), and electromyography (EMG), as well as evoked potentials, intraoperative monitoring, polysomnography, and autonomic testing. Eligibility for examination for subspecialty certification in clinical neurophysiology includes Board certification by the ABPN (neurology or psychiatry) or American Board of Physical Medicine and Rehabilitation (physiatry) and completion of a 1-year accredited fellowship in clinical neurophysiology.

Recommended Qualifications for Evoked Potential Technologists

An evoked potential technologist should receive training in the procedures for recording evoked potentials under the supervision of a qualified physician of clinical evoked potential studies. This training should include a supervised performance of at least several hundred evoked potential tests using somatosensory stimuli on patients in all age groups. It is desirable that some of these recordings be obtained in infant nurseries, intensive care units (ICUs), and the operating room, as well as in the evoked potential laboratory.

The qualifications for an evoked potential technologist derive from the tasks required to conduct SEP studies. These include the ability to explain the nature and purpose of the study to the patient, to allay any fears related to the study, to obtain high quality data, to annotate data sheets of all pertinent and appropriate information, to file and retrieve reports, and to trouble-shoot and maintain equipment. The background of such an individual in most instances requires the completion of a formal education program in clinical neurophysiology as well as direct training experience totaling at least 6 to 12 months but preferably more. Such skills constitute the qualifications of an entry-level evoked potential technologist.

More advanced qualifications or experience are needed to perform complex studies such as those obtained in neonatal and adult ICUs and in the operating room for intraoperative monitoring during surgery. Performing evoked potentials in these situations requires an evoked potential technologist with advanced training and experience, initiative, and capacity for independent judgment. Such a technologist would also provide training to junior staff, technologist trainees, and other medical personnel.

Guidelines for Clinical Evoked Potential Equipment

The guidelines given in this section represent the minimum necessary to obtain good-quality clinical evoked potentials. In many respects, analog and digital technology have advanced well beyond the minimum, and these advances are often incorporated in modern commercial equipment. This trend should be welcomed but does not imply obsolescence of older or noncommercial systems provided they comply with these guidelines.

Amplifier

Input signals with peak-to-peak amplitudes of 5 μ V to 50 mV should be amplified equal to the full range of the analog-to-digital (A-D) converter. Gain should be adjustable in steps of not more than 2.5 to 1. The differential input impedance of the amplifier must be at least 10 M Ω . The common mode rejection should

be at least 80 dB (10,000:1) at the highest sensitivity of the amplifier when the common mode signal is applied between both inputs and neutral. With filters wide open, the amplifier bandpass measured at the -3 dB points must be at least 0.1 to 5000 Hz. The rolloff slopes of the filters must be specified.

The noise level of the amplifier must not exceed 2 μ V rms with the inputs connected to neutral and with a bandpass of 0.1 to 5000 Hz. The amplifier must meet all specifications in the presence of a sustained 300-mV offset applied differentially between the input terminals 1 and 2 or commonly to inputs 1 and 2 (with respect to the patient "ground" or neutral lead).

Averager

Time (horizontal) resolution of the system should be 50 μ s/data point or less. The amplitude resolution of the A-D converter should be at least 8 bits, but preferably 12 bits. At least 500 addresses of memory should be available for each channel. The system should allow averaging at least 4000 trials. The onset of the averaging sweep should be easily and accurately synchronized to stimulus production. A mechanism whereby artifact-contaminated trials can be simply and quickly excluded from the averaging process is essential. This is most commonly achieved by rejecting those trials that exceed the limits of the A-D converter or some adjustable percentage thereof. At least 4 channels are the minimum necessary for most SEP studies.

Display and Writeout

A cathode ray tube (CRT) or equivalent display must be available to show the average waveforms and the ongoing unaveraged EEG. Such a display must have easily understandable voltage and time scales. A permanent hard copy of the evoked potentials must be available. Postacquisition data manipulations potentially affecting the reliability of the study (smoothing, additive transfers, etc.) should be routinely displayed on the hard copy as part of the data report.

Optional Features

Additional features may be useful in certain situations but are not essential. These include additional channels (as will be noted in the individual sections, 8 channels may often be used to advantage), lower amplifier noise, DC input capability, 10 to 12 bits of A-D conversion, electronic data transfer and storage, phase-shift-free digital filtering, data cursors, and continuous trend analysis. If electronic storage is used, it should always include the original data, and any electronic data manipulation performed after acquisition should automatically be detailed in the writeout. Ideally, the evoked potential instrument will be able to transfer acquired data using the American Society for Testing and Materials (ASTM) standards for electronic data transfer. Incorporation of such advanced features should not be at the cost of interpretable data outputs or user accessibility.

Guidelines for Clinical Evoked Potential Recording

Electrical Safety

In recording evoked potentials, steps must be taken to assure the patient's safety. The grounding and the chassis leakage current of all instruments connected to the patient or located in the same room as the patient must be tested periodically. Chassis leakage should be less than 100 μ A rms with ground open. Special caution must be exercised when recording evoked potentials with portable equipment at the patient's bedside, in the ICU, and in the operating room. Electronically sensitive patients, e.g., those with intracardiac lines, may have arrhythmias induced by even small currents leaking from the electrodiagnostic instrument. A direct connection from patient "ground" to chassis or power line ground should not be

present. An isolation amplifier or a solid-state current limiter must be incorporated to actively prevent such connections.

Equipment should be designed to prevent inadvertent shock during power-on, power-off, and power failures. For the operating room or ICU, current limiting must be present in every patient lead. In these areas the maximum leakage current through patient leads should be 10 μA rms to ground with 120 VAC applied. The maximum sink leakage current should be 10 μA rms at the input to the device of 20 μA rms at the patient end of the cable when attached to the device.⁴

Electrical stimulators for somatosensory evoked potentials should have all outputs isolated from ground, at an isolation voltage of 2500 V or more.³⁴ The selected output current should not be exceeded for any reason including system failure.

Filtering

Appropriate analog filtering is useful in rejecting frequencies of minimal or no clinical interest. As a result, evoked potentials are improved with less artifact and the desired level of signal-to-noise ratio improvement can be obtained with fewer stimuli. Excessive analog filtering (i.e., too narrow a bandpass) will alter the latency, amplitude, and morphology of evoked potential components.

Equipment made by different manufacturers may result in slightly different performance with identical filter settings. This is because the approximate break points of the filter (in Hz) do not describe the rolloff slopes (dB/octave). Differences in rolloff slopes can cause differences in amplitude, morphology, and most importantly latency.

Digital filtering and smoothing algorithms will affect amplitude and morphology but usually do not affect latency. Note that the term “digital filtering” is a general term and does not actually describe the construction of the filter. A digital filter could, for instance, emulate an analog RC filter.

Use of the 60- (or 50-) Hz notch filter is discouraged because it may ring when activated by a sudden transient such as an auditory or somatosensory stimulus artifact. As a result, a burst of 60-Hz activity of decreasing amplitude (interpeak interval of 16.66 ms or 20 ms for a 50-Hz filter) will contaminate the response. Under some circumstances this may falsely appear as a neural response when none is present or shift the latency of a true response.

The filter settings suggested in various portions of these guidelines were arrived at empirically and are known to have minimal clinically significant effect on obligate components.⁹

Polarity Convention

There is no universally accepted polarity convention, i.e. no agreement as to whether negativity of the electrode connected to the input terminal 1 of the amplifier relative to the input terminal 2 should be displayed as an upward or downward reflection. The former convention is the accepted standard in clinical EMG and EEG, whereas the latter standard prevails in other electrophysiologic fields.

The majority of commercially available evoked potential systems now employ an amplifier polarity convention with input terminals designated by “+” and “-”. A positive event occurring in the lead connected to the + terminal (or a negative event occurring in the lead connected to the - terminal) will result in an upward deflection. Downward deflections occur when a positive or negative event is applied to a terminal of opposite polarity. In a majority of current literature, negative events are displayed upward. The

choice of display is ultimately at the discretion of the individual; however, it is imperative that the polarity convention be understood and clearly labeled.

Calibration

The recording system must have the capacity to be calibrated periodically as needed to insure the integrity of analog and digital components. Generally, this is achieved by injecting into the input jacks of each channel rectangular pulses of appropriate amplitude, usually 0.5 to 100 μV , time-locked to the onset of the sweep. Calibration pulses should not be injected after a stage of amplification since the amplification system would not be fully checked. The calibration pulses must be amplified and averaged, and their amplitude measured in conditions identical to those to be employed for the recording of the evoked potential under study.

Impedance

The recording system must have the ability to measure and display the electrical impedance between each of the recording electrodes and the “ground” electrode. Impedance can be displayed either as a number or as a range (e.g., 2 to 5 $\text{k}\Omega$).

Replications

To replicate is to obtain 2 or more temporally independent averages. Replication of the response is imperative to demonstrate that clinical evoked responses are consistently repeatable and therefore are of neural and not artifactual origin. Nonsuppressed artifact can mimic biologic responses in a single average but usually not in subsequent replications. This can produce false components leading to incorrect assumptions regarding the normality or abnormality of a study.

Replication is demonstrated by the consistency of latency and amplitude measures as well as morphology of evoked potential components recorded in successive averages. Latency replication within 1% of the total sweep time and amplitude replication within 15% of the peak-to-peak amplitude can usually be achieved. Poor replication may be caused by (1) unusually low (but not necessarily abnormal) amplitude responses, (2) excessive artifact (frequently myogenic), and (3) insufficient number of responses in the average. Decreasing electrode impedance will often reduce noise by improving common mode rejection. Relaxation and sleep (sedation) will reduce various biologic artifacts. With low-amplitude responses, increasing the number of stimuli will improve the signal-to-noise ratio. However, there are practical limits since the signal-to-noise ratio is proportional to the square root of the number of averaged responses. In SEPs studies, increasing the intensity of the stimulus often increases the amplitude of the evoked potential components. Some clinical studies will have poor reproducibility not amenable to correction through any clinically practical technique. Poor reproducibility per se may not imply abnormality, but could reflect technical difficulties depending on the nerve and recording site being studied.

Guidelines for Documentation and Interpretation of Results

Documentation

All evoked potential records should bear the following information:

1. The patient's name, identifying number, age, and gender.
2. The date of the examination.
3. The technologist's name or initials as well as the interpreter's name or initials.

4. The derivation recorded in each channel in the form of abbreviated accepted designations of the electrode locations connected to the input terminals 1 and 2 of the amplifier, in that order.
5. The type, intensity, and rate of presentation of the stimuli, and the side and site of stimulation.
6. Other information relative to test results, including the nerve stimulated and the side.
7. The number of individual trials averaged.
8. The time calibration, corresponding to the epoch averaged, with subdivisions appropriate to the temporal dimensions of the evoked potential recorded. Whenever a prestimulus baseline or poststimulus delay is used, it should be clearly displayed.
9. The voltage calibration indicating the amplitude of deflection produced in terms of sensitivity (voltage/linear distance).
10. Modern evoked potential equipment will leave marks indicating the points at which "measurements" were taken. If such features are not available, the technologist or physician must mark by hand the peaks recognized and the sites at which they were measured.

Interpretation

A written and signed interpretation must be provided for each clinical evoked potential study. This should begin with the object of the examination and a concise summary of the clinical history available at the time of recording. The type of evoked potential recorded should be briefly outlined and information should be provided on any relevant medications received by the patient either as a treatment or in preparation for the test. If the recording was made while the patient was asleep, this should be stated (as latency values may be affected by sleep in normal subjects). The waveforms obtained should be described and the peak latencies, inter-peak intervals (when appropriate), and amplitudes of the significant components detailed. The results of relevant ancillary tests should be specified. The clinical significance of evoked potential alterations should be described, whenever possible. Copies of the recorded waveforms should be included or made available upon request.

Recommended Guidelines for Normative Studies of Evoked Potentials, Statistical Analysis of Results, and Criteria for Clinically Significant Abnormality

Introduction

The successful clinical application of evoked potentials depends, in large measure, on the availability of carefully collected and skillfully analyzed normative data. When differences exist in normative data values between different laboratories, there are a limited number of causes for such differences. These are (1) subject characteristics (age, gender, nonrandom sampling), (2) stimulation parameters, (3) recording parameters, and (4) data reduction algorithms ("peak picking" rules). In organizing new laboratories, it is acceptable to utilize as a reference the normative data published by another center provided the following requirements are satisfied:

1. Stimulus, recording, and other conditions are used that are *identical* to those of the reference laboratory as determined by appropriate calibration equipment and methods. Further, there must be detailed familiarity with the peak identification rules used by the reference laboratory.
2. At least 20 normal subjects are studied, spanning the age range of the patients to be examined in the particular laboratory, and it is determined that a specified proportion (such as 90% or 95%) of this subset of normal values falls within the limits derived from the subset studied in the reference laboratory. This exercise is imperative to verify the accuracy with which the conditions described in the above paragraphs are met.

Selection of Subjects

Appropriate selection of subjects for normative studies of evoked potentials is of critical importance.¹³ Persons contributing norms for SEPs should have no personal or family history of neurologic diseases and must be neurologically healthy. Any personal history of trauma, bone fractures and alterations of sensation must be carefully evaluated. Thorough inquiry should be made into the use of drugs by prospective normal subjects, including narcotics, stimulants, and neurotropic drugs. Individuals taking such medications should be excluded from normative studies.

Number, Age, Sex and Height of Subjects

Each control group analyzed separately should contain an equal number of age-matched individuals of the 2 sexes, with height and weight being considered as other relevant parameters. It would be ideal to have age-specific norms obtained by week in the perinatal period, by month in infants, and by year in children and by decade in adults if patients from all age ranges are studied. However, since it is desirable that each individual subgroup consist of a minimum of 20 subjects a very large number of subjects would need to be studied to cover the entire age range. *Regression analysis*^{5,16} of data collected on individuals evenly spread over a given age range permits more parsimonious use of subjects.

Paired Observations

Measures of responses to stimulation of right and left peripheral nerves should not be treated as independent observations, i.e. lumped together,¹⁵ since a high positive correlation exists between such paired evoked potential observations in normal subjects.

Description of Results and Criteria for Clinically Significant Abnormality

The first step to be taken in the statistical analysis of evoked potential measures obtained in a normative study is to examine the *shape of the distribution of the observations* in the particular sample examined. Should this distribution be or approximate a normal bell-shaped (Gaussian) curve, it is appropriate to describe the characteristics of the sample by computing standard measures of central tendency and dispersion, such as *the mean and the standard deviation*. It should be emphasized that these statistics assume normal distribution of values and have little validity unless this assumption is met. Unfortunately, the distribution of evoked potential measures obtained from the small samples generally studied, frequently exhibits deviations from normality including significant skewness (deviation of the curve from symmetry), kurtosis (relative peakedness or flatness of the curve), or both. Ratios (i.e. amplitude ratios), even when the numerator and denominator are both normally distributed, are usually markedly skewed even when large samples are utilized. In these instances, it is recommended that the *observed data be transformed*^{7,22,30} with the intent of obtaining a normal distribution or a distribution more closely approximating normalcy, before computing mean and standard deviation statistics. Taking the logarithm, the square root, negative inverse, or various other transformations of the values not conforming to normal distribution may be attempted. Some data sets cannot be transformed to a normal distribution. The original data and various transforms should be assessed for deviations of the distributions from normal. The distribution closest to normal should be used. Various statistics may be used, but for small sample sizes, the Shapiro-Wilk's goodness of fit (W) is sensitive to a wide range of deviations from normality.³² Once data are normalized, the mean and upper (or lower) limits are calculated from the normalized data and then transformed back to the original units.²⁰

Clinical diagnosis frequently requires that measures obtained in individual patients be compared to population norms with the intent of determining whether they are "normal" or "abnormal." Because a small sample from the normal population represents a very limited part of the entire set of relevant

observations, it cannot be identified with the population. Thus, statements that clinically observed values, such as the latency or amplitude of a given wave exceeding 2, 2.5, or 3 standard deviations of the mean of a normal control group, are “*abnormal*” are acceptable provided the following requirements are satisfied: (1) it is clearly specified that the values in question are regarded as abnormal compared to “*a control sample from the normal (healthy) population*” and (2) no precise probability is implied in predicting where these values are located relative to the normal population.

For any given limit (upper or lower) of normality, there is a certain probability of falsely interpreting values from healthy subjects as abnormal, i.e. of false-positive results and of conversely qualifying values from patients with disease as normal, i.e. of “false-negative” findings. Adopting more stringent normal limits (lowering the upper limits of absolute latency, interpeak latency (IPL), side-to-side comparison, etc.) has the advantage of decreasing the number of false-negative results (test more sensitive) but carries the penalty of increasing the proportion of false-positive (test less specific) decisions. The opposite is true when more liberal limits of normality are adopted. Setting normal limits is a decision to be made by each individual laboratory with full understanding of its statistical implications.

Further confounding these issues is the usual practice of applying multiple criteria of abnormality. It is common, particularly in brainstem auditory evoked potentials (BAEP) and SEPs, to consider several IPLs and side-to-side asymmetries of these IPLs in determining the normalcy of a given clinical study. If only a single criterion is being considered, 2 or 2.5 standard deviations may be appropriate, but when multiple criteria are being applied, a 3 standard deviation limit helps reduce the errors inherent in the overapplication of univariate statistics to multivariate problems.³⁵

Some of the statistical analyses alluded to, including the transformation of values not conforming to a normal distribution and the use of techniques such as regression analysis, among others, require extensive computational capabilities and advanced statistical skills. It is suggested that clinical laboratories undertaking the collection of normative data seek experienced advice on the design of their studies and support in the analysis of their results.

Ultimately, the adequacy of any given normal limit in discriminating between normal and diseased individuals must be supported by appropriate clinical and/or clinicopathologic correlations.

Recommended Guidelines for Short-Latency Somatosensory Evoked Potentials

Introduction

Short-latency SEPs (SSEPs) are early electrophysiologic responses of the somatosensory pathways to appropriate stimulation.³ Various types of stimuli can be applied to a number of body sites to elicit these potentials. However, brief electrical pulses delivered to major mixed nerve trunks at easily accessible locations generally are employed for their clinical study. In normal subjects, these responses mostly occur within 25 to 50 ms of the stimulus. The present recommended guidelines are limited to SSEPs to stimulation of the median nerve at the wrist for the upper extremity, and of the common peroneal nerve at the knee and posterior tibial nerve at the ankle for the lower extremity. Sensory nerve stimulation such as digital, sural, pudendal, and so forth, may also be used to obtain SSEPs; however, the guidelines below will not include these techniques. Dermatome SSEPs, i.e., stimulating the skin in a given dermatome area, are also not discussed.^{14,33}

Considerations Common to Upper and Lower Extremity Short-Latency Somatosensory Evoked Potentials

Stimulation and Grounding

Type and Placement of Stimulating Electrodes

EEG disc or needle or nerve conduction stimulating electrodes may be employed to elicit SSEPs. When EEG disc electrodes are used impedances of 10 k Ω or less is recommended to reduce discomfort and stimulus artifact. The placement of the stimulating electrodes varies according to the nerve trunk to be stimulated.

Stimulus Isolation and Subject Grounding

To contribute to the subject's safety and minimize stimulus artifact, the stimulator output must be isolated from ground by an appropriate stimulus isolation unit. A large band or plate electrode placed between stimulating and recording leads and connected to the preamplifier's ground will help reduce stimulus artifact and enhance safety in the event of isolator failure by restricting the flow of current to the subject's limb.

Stimulus Parameters

Monophasic rectangular pulses (square waves) of 100 to 300 μ s duration (or at least no longer than 500 μ s) are recommended. A stimulus rate of about 3 to 7 per second, not an integral of 60 Hz, is suggested. Stimulus rates as low as 0.5 Hz and stimulus durations as long as 1 ms may, however, be used in certain clinical conditions. Stimulus rate will influence amplitude and latency measures. Hence the same rate should be used as was used in the normal control population. Stimulus intensity should be sufficient to produce a visible muscle twitch. When no twitch can be elicited, as in cases of severe peripheral neuropathy, the stimulus should be delivered at least at an intensity known in the individual laboratory to produce a visible muscle twitch in the average subject. It is important that the extremity stimulated be visible to the technologist or physician at all times to permit observation of the twitch. Right and left nerve trunks should be stimulated independently.

Type of Stimulator

Either a constant current or a constant voltage stimulator may be used as a stimulator. Whether one type of stimulator is superior to the other is debatable. There are advantages and disadvantages to both types of stimulators and neither is superior in all applications. In situations in which it may be difficult to maintain sufficiently low and stable electrode impedances, such as in intraoperative recordings, a constant current stimulator is preferred.

Recording

Low recording electrode impedance is critical to obtaining satisfactory wave forms. If surface recording electrodes are used, the skin should be prepared with alcohol and scrubbed with a pumice or other abrasive compound. Impedance should be less than 5 k Ω for each of the recording electrodes. Needle recording electrodes can also be used, in which case specific skin preparation is not necessary. Universal precautions should be observed for both needle and surface electrodes.

Designation of Electrode Locations and Terminology

The system of nomenclature for SSEP waveforms uses N or P to designate the presumed polarity of the recorded signal (negative or positive), and an integer to denote the nominal poststimulus latency of the signal in normal adults. The reader is cautioned that these designations are used inconsistently in the

literature. The principal source of ambiguity is the failure of this system of nomenclature to encode recording montage along with polarity and nominal peak latency. For example, one author may speak of an “N19” recorded from contralateral scalp to noncephalic derivation, while another may use the same term to designate an entirely different signal recorded on a bipolar scalp to scalp derivation. Ambiguity can only be avoided by specifying the recording derivation in the clinical report. Some laboratories use the alternate designation of N1 or P1 for the first negative or positive peaks.

Upper Extremity Short-Latency Somatosensory Evoked Potentials

Designation of Components

SSEPs following median nerve stimulation include the following obligate components.

EP. EP is the propagated volley passing under Erb’s point.

N13. N13 is the stationary (nonpropagated) cervical potential, recorded referentially from the dorsal neck. It probably reflects mainly postsynaptic activity in the cervical cord.^{12,17,25}

P14. P14 is a subcortically generated far-field potential, recorded referentially from scalp electrodes. It has a widespread scalp distribution and probably reflects activity in the caudal medial lemniscus.^{10,11,17,27}

N18. N18 is a subcortically generated far-field potential, best recorded referentially from scalp electrodes ipsilateral to the stimulated nerve, away from the contralateral N20. It probably reflects postsynaptic activity from multiple generator sources in brainstem and perhaps thalamus.^{10,11,36}

N20. N20 reflects activation of the primary cortical somatosensory receiving area.^{1,2,11,18,26,28,29} N20 is recorded using a bipolar derivation to subtract the widespread far-field signals (e.g. P14 and N18) from the superimposed primary cortical activity recorded locally over the centroparietal region contralateral to the stimulated median nerve.¹¹

Electrodes

Median nerve stimulation at the wrist is recommended for standard testing to evaluate the integrity of central somatosensory pathways subserving the upper extremity. The cathode is placed between the tendons of the palmaris longus and flexor carpi radialis muscles, approximately 2 cm proximal to the wrist crease. The anode is then placed 2 to 3 cm distal to the cathode, or on the dorsum of the wrist. A ground electrode (metal plate electrode, circumferential band electrode, or “stickon” electrocardiographic-type electrode) is placed on the forearm.

Ulnar nerve stimulation at the wrist may also be used for testing, although reference values will be different. In this case, the cathode is placed lateral and adjacent to the flexor carpi ulnaris tendon, approximately 2 cm proximal to the wrist crease. The anode is then placed 2 to 3 cm distal to the cathode, or on the dorsum of the wrist. A ground electrode (metal plate electrode, circumferential band electrode, or “stickon” electrocardiographic-type electrode) is placed on the forearm.

Subject Grounding

A plate electrode on the palmar surface of the forearm or a band electrode around the forearm is suggested as a ground lead.

Motor Effects of Stimulation

Stimulation of the median nerve at the wrist should produce visual muscle twitch causing abduction of the thumb in the case of the median nerve, or adduction in the case of the ulnar nerve.

Recording

Recording Electrode Placement

It is recommended that recording electrodes be placed as follows:

Electrode #1: Over the midline frontal region of the scalp (Fz placement of the 10 to 20 International System).

Electrodes #2 and #3: Over the scalp on each side, 2 cm posterior to the C3 and C4 positions of the 10 to 20 International System. These electrodes should be referred to as C3' and C4', respectively.

Electrode #4: On the cervical spine over the C5 or C2 spinal processes, i.e. 2 or 5 spines respectively above C7. This last process is easily identified as the most prominent spine at the base of the neck when the neck is flexed. C5 and C2 spinal electrodes should be referred to as C5S and C2S, respectively.

Electrodes #5 and #6: An Erb's point on each side, i.e. within the angle formed by the posterior border of the clavicular head of the sternocleidomastoid muscle and the clavicle, 2 to 3 cm above the clavicle. The clavicular head of the muscle is readily visualized when the subject flexes the head against manual pressure on the forehead by the technologist or physician. Left and right Erb's point electrodes should be designated as EP1 and EP2, respectively.

Electrodes #7 and #8: Over the earlobe of each side (positions A1 and A2 of the 10 to 20 system). These 2 electrodes are optional. Mastoid electrodes may also be used.

Electrodes #9 and #10: A recording electrode placed over the median nerve just proximal to the antecubital fossa on the right and left sides. An active recording electrode should be placed distal and a reference electrode 4 cm proximal to the active electrode and parallel to the course of the median nerve. These 2 electrodes are optional.

Electrodes #11 and #12: A active recording electrode placed over the median nerve at the axilla on the left and right sides. A reference electrode should be placed over the acromion. These two electrodes are optional.

Montage

A montage consisting of the following derivations is suggested for a 4-channel system.

Channel 1: Contralateral scalp (C3' or C4') - scalp (Fz). Components P13-14 and N20 are recorded in this derivation.

Channel 2: Contralateral scalp (C3' or C4') – Erb's point (contralateral) or contralateral earlobe or mastoid. Waves P9, P11, P13-14, and N20 may be detected in this derivation.

Channel 3: Neck (C5S or C2S) - scalp (Fz). Components N9, N11, N13, and N14 may be seen in this derivation.

Channel 4: Erb's point ipsilateral to the side of stimulation – Erb's point contralateral to the side of stimulation.

Analysis Time

Analysis time should be 40 to 50 ms from stimulus onset, i.e. not including pre-stimulus baseline, if any. Whenever no scalp potentials are apparent during this time, it is recommended that longer analysis times be used, such as 60 and 100 ms, before inferring that the scalp components of the responses to median nerve stimulation are absent.

Number of Trials to be Averaged

Averaging about 200 to 500 individual trials is suggested, though the precise number will depend upon the signal-to-noise ratio. Two separate runs should be utilized to ensure reproducibility.

Analysis of Results

Components to be recognized

Records are analyzed to identify those potentials that are most consistently demonstrated in normal individuals. These include the following:

1. In ipsilateral-contralateral Erb's point derivation: Erb's point potential.
2. In neck-scalp derivation: Wave N13. (N9, N11, and N14 are not clearly identifiable in some normal subjects.)
3. In scalp-noncephalic reference (contralateral Erb's point) derivation: P9, P13-14, and N20. P11 is not consistently recorded in normal subjects.
4. In scalp-scalp: N20. In scalp-ear derivations: P13-14 and N20. (P13-14 are not clearly very well identifiable in normal subjects in scalp-scalp derivations.)

Measurements

A body measurement essential to assess peripheral nerve conduction and absolute latencies of median nerve SSEPs is the distance (in cm) from the stimulating cathode to Erb's point on each side. If the recording electrode is placed over the median nerve in the arm, distance should be measured from the cathode to the active electrode. IPLs will not be influenced by this measurement, however.

The following latency measurements, to be computed from the leading edge of stimulating pulse, are recommended to evaluate these responses:

1. Peak latency of Erb's point potential in the Erb's point derivation (negative or preceding positive, peak).
2. Peak latency waves of P9 and P13-14 in the scalp-noncephalic reference derivation.
3. Peak latency of the N13 component in the neck-scalp derivation.

4. Peak latency of the N20 wave in the scalp-ear or scalp-scalp derivation. If the peak of a potential cannot be identified with certainty, as is sometimes the case with the P13-14 component which may be bifid, lines can be drawn over the ascending and descending slopes of the potential and the intersection of the lines taken as the peak.

Criteria for Abnormality

1. *Absence of any obligate waveforms.* Absence of an obligate waveform, such as N9 in an ipsilateral-contralateral Erb's point derivation, or N13 in a neck-scalp derivation, or N20 in a scalp-scalp derivation, or P13-14 and N20 in a scalp-ear derivation may reflect either dysfunction of the corresponding generator or failure of that structure to receive ascending input. For example, loss of the N20 may reflect either a cortical lesion per se or a subcortical lesion of the ascending somatosensory pathways.

Implicit in this criterion is that the test must be technically adequate to permit recognition of a waveform if it is present. If, for example, a test demonstrates presence of Erb's point and N20 signals at normal latencies, but subcortical and cervical signals N13, P14, and N18 are not identified because referential channels are contaminated by artifact, the test cannot be interpreted as abnormal. Inability to record reproducible tracings in such an event represents a technical limitation rather than a patient abnormality.

2. *Prolongation of the interpeak latencies.* Prolongation of IPLs and interside IPLs beyond 2.5 or 3 standard deviations greater than the mean of an appropriate control population is interpreted as abnormal and reflecting delayed conduction between appropriate structures. A prolongation of the EP-P14 IPL is interpreted as indicating delayed conduction between the brachial plexus and the lower brainstem. Prolongation of the P14-N20 IPL is interpreted as indicating delayed conduction between the lower brainstem and the cortex. Because absolute latencies are directly influenced by arm length and temperature, they should not be used as a criterion for abnormality.

P14 sometimes appears as multiple inflections prior to N18 rather than a single positive peak. In such cases, there is uncertainty in the determination of the "true" P14 latency and caution is advised, particularly in the interpretation of small interside-IPL "abnormalities."

The implication of the choice of any given normal limit, the limitations inherent in the use of the standard deviation for comparing results of individual patients to population norms, and possible uses of alternative measures are discussed in a later section of this document.

3. *Other criteria for abnormality.* The most reliable criteria for clinically significant abnormalities of SSEPs are the absence of obligate waveforms and prolongation of IPLs as described above. It may be possible to extend the sensitivity of SSEP testing by further including abnormalities of waveform amplitude and asymmetry of amplitude. Care must be taken to (1) establish statistical criteria reflecting the nongaussian distribution of SSEP waveform amplitude in normal subjects and (2) control for the effects of stimulus intensity on waveform amplitude. In the absence of accompanying abnormalities of latency, abnormalities of amplitude should be interpreted with caution. There may be marked interside variability in amplitude in normal subjects, with even three or four-fold differences in some normal cases.

Morphologic peculiarities of waveforms, unaccompanied by latency prolongation, should not be interpreted as abnormalities. Under appropriate circumstances, however, the interpreting physician should feel free to report a test as within defined normal limits but demonstrating atypical features of uncertain clinical significance.

Short-Latency Somatosensory Evoked Potentials to Stimulation of the Lower Extremity

Whether the common peroneal nerve at the knee or the posterior tibial nerve at the ankle is to be stimulated may depend on the circumstances as well as on personal preference.

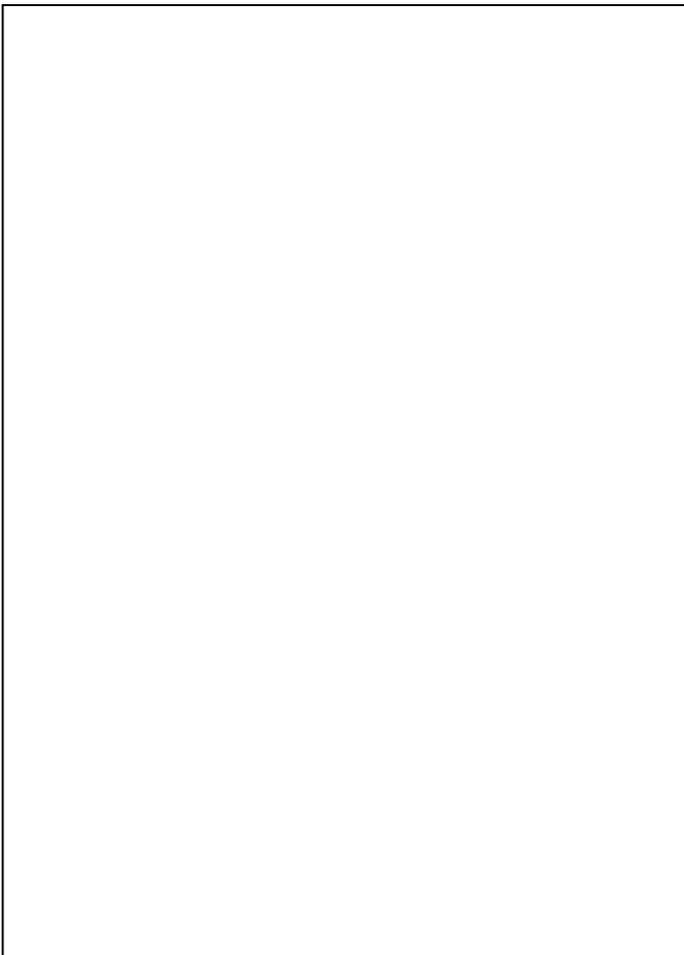
Stimulation of the Common Peroneal Nerve at the Knee

Terminology

Temporal features and abbreviation. SSEPs to stimulation of the common peroneal nerve at the knee^{8,31,37,38} occur within 40 ms of the stimulus in normal subjects. Recommended abbreviation is CPN-SSEPs.

Designation of components. It is suggested that the individual response components (Figure 1 [**old figure 2**]) be designated as follows:

1. Spine components: L3 and T12 spine potentials.
2. Scalp components: P27 and N35.



Stimulation

Placement of stimulating electrodes. With the subject in the prone position, the cathode should be placed over the lateral portion of the popliteal fossa, just medial to the tendon of the biceps femoris muscle and inferior to the leg crease. Alternately, the nerve may be stimulated posterior to the fibular head. The tendon of the biceps femoris and the fibular head is readily visualized when the subject flexes the leg against manual extension by the technologist or physician. The anode should be located 3 cm distal to the cathode.

Subject grounding. A plate electrode over the posterior aspect of the mid-thigh or a band electrode around the mid-thigh is recommended as a ground lead.

Motor effects of stimulation. Stimulation of the common peroneal nerve at the knee should produce a visible muscle twitch causing dorsiflexion or plantar flexion and eversion of the foot.

Recording

Analysis time. An analysis time of 50 to 100 ms from stimulus onset is recommended. If no scalp potentials are apparent during this time, a longer analysis time should be used, such as up to 200 ms, before inferring that the scalp components of the response are absent.

Number of trials averaged. At least 250 to 500 individual trials should be averaged, though the specific number will depend on the signal-to-noise ratio.

Recorded electrode placement. The electrodes for recording these responses should be placed as follows:

Electrode #1: Over the L3 spinous process, i.e., one spine above a line joining the iliac crests of the hip bones. This electrode should be referred to as L3S.

Electrode #2: 4 cm rostral to L3, or over the flank lateral to electrode #1.

Electrode #3: Over the T12 spinous process, i.e. three spines above the LS spine. This electrode should be designated T12S.

Electrode #4: 4 cm rostral to T12S, or over the flank lateral to electrode #3.

Electrode #5: Over the T6 spinous process, i.e. two spines above the line joining the lower border of the scapulae when the arms and shoulders are relaxed. This electrode should be termed T6S. This electrode is optional.

Electrode #6: 4 cm rostral to T6. This electrode is optional.

Electrode #7: Over the scalp on the midline, 2 cm posterior to the Cz position of the 10 to 20 system. This electrode should be referred to as Cz'. Some laboratories also record from C1' and C2' 10% lateral to Cz', since cortical potentials are sometimes more robust at those positions.

Electrode #8: Midway between positions Fpz and Fz of the 10 to 20 system. This electrode should be designated Fpz'.

Montage

A montage consisting of the following derivations is one possibility for a 4-channel system; however, other spine/scalp recording montages may be used for lower extremity SSEPs, such as spine (active)-iliac crest (reference), lower spine (active)-upper spine (reference).

Channel 1: Cz'-Fpz'

Channel 2: T6S - 4 cm rostral to T6S or flank; or C1'-Fpz'.

Channel 3: T12S - 4 cm rostral to T12S or flank; or C2'-Fpz'.

Channel 4: L3S - 4 cm rostral to L3S or flank.

Some laboratories also utilize a cervical spine recording electrode (e.g. C2 or C5 spine) referred to Fz, similar to that used for upper limb recordings. This is particularly useful for intraoperative monitoring.

Analysis of Results

Potentials to be recognized. Records are analyzed to identify those potentials that are most consistently demonstrated in normal subjects. These include the following:

1. In spine derivations: L3, T12, and T6 spine potentials.
2. In scalp-to-scalp derivations: components P27 and N35.

It should be noted that the spine potentials are not consistently recorded in normal subjects and their absence should not be considered an abnormality. The amplitude and latency of the N35 scalp component varies with the state of the subject.

Measurements. The following body measurements should be taken:

1. Distance from stimulating cathode on each leg to L3 spine electrode, and/or height.

The following latency measurements (to be computed from the leading edge of the stimulating pulse) are suggested to evaluate common peroneal nerve SSEPs:

1. Peak latencies of L3, T12, and T6 spine potentials.
2. Peak latency of the first major positive scalp potential (P27).

Using the above measurements, the following conduction velocities (in M/s) and latencies (in ms) can be computed:

1. Conduction velocity in peripheral afferent nerve fibers, which is determined by dividing the distance between the stimulating cathode and the L3 spine electrode by the latency of the L3 spine potential.
2. For conduction from spine to scalp, IPLs achieved by subtracting the latency of the L2, T12, and T6 spine potentials from the latency of the P27 scalp potentials are computed.

Criteria for Clinically Significant Abnormality

1. Absence of any of the obligate waveforms listed above (i.e., cortical potentials). Caution regarding technical adequacy, discussed with respect to the median SSEPs, applies similarly here. In cases in which the signal-to-noise ratio of the recording is not adequate to detect N35 were it present, failure to record it must not be interpreted as an abnormality. Similar considerations apply for P27.
2. Prolongation of the spine-N35 or spine-P27 interpeak latency. Prolongation of these IPLs beyond 2.5 or 3 standard deviations greater than the mean of an appropriate control population indicates a delay in conduction between the lumbar cord and somatosensory cortex.

Considerations (discussed with respect to median nerve SSEPs) regarding absolute latency measurements, interside-IPL measurements, and atypical features of uncertain significance apply here as well.

Stimulation of the Posterior Tibial Nerve at the Ankle

Terminology

Temporal features: Posterior tibial nerve-evoked short-latency somatosensory evoked potentials^{8,19,21,23,24} occur within 50 ms of the stimulus in normal subjects.

Stimulation

Placement of stimulating electrodes. The cathode should be placed midway between the medial border of the Achilles tendon and the posterior border of the medial malleolus. The Achilles tendon is readily visualized when the subject flexes the foot at the ankle against manual extension by the technologist or physician. The anode should be located 3 cm distal to the cathode.

Subject grounding. A band electrode around the calf or large disc electrode on the calf is recommended as a ground lead.

Motor effects of stimulation. Stimulation of the posterior tibial nerve nerve at the ankle should produce visible plantar flexion of the toes.

Recording

Analysis time. An analysis time of 60 to 100 ms from stimulus onset is suggested. If no scalp potentials are detected during this time, a longer analysis time should be used such as up to 200 ms, before inferring the scalp components of the response are absent.

Number of trials to be averaged. About 250 to 500 individual trials should be averaged, depending on the signal-to-noise ratio.

Recording electrode placement. The electrodes for recording these responses should be placed as follows; however, other recording montages, as indicated previously, may be used:

Electrode #1: Over the tibial nerve in the popliteal fossa, at or slightly above the popliteal crease, midway between the combined tendons of the semi-membranous and semi-tendinous muscles medially and the tendon of the biceps femoris laterally. These tendons are readily visualized when the subject flexes the knee against manual extension by the technologist or physician. (Stimulation of the tibial nerve in this location produces plantar flexion of foot and toes.) This popliteal fossa electrode should be designated PF.

Electrode #2: On the medial surface of the knee, 4 to 6 cm proximal to the location of Electrode #1.

Electrode #3: Over the L3 spinous process, i.e., 1 spine above the line joining the iliac crests of the hip bones. This electrode should be referred to as L3.

Electrode #4: 4 cm rostral to L3S or on the flank lateral to electrode #3.

Electrode #5: Over the T12 spinous process, i.e., 3 spines above the LS spine. This electrode should be referred to as T12S.

Electrode #6: 4 cm rostral to T12S or on the flank lateral to electrode #5.

Electrode #7: Over the scalp on the midline, 2 cm posterior to the Cz position of the 10 to 20 system. This electrode should be designated Cz'. Some laboratories also record from C1' and C2' 10% lateral to Cz', since cortical potentials are sometimes more robust at these locations.

Electrode #8: Midway between positions Fpz and Fz of the 10 to 20 system. This electrode should be referred to as Fpz'.

Montage. A montage consisting of the following derivations is suggested for a 4-channel system.

Channel 1: Cz' – Fpz'.

Channel 2: T12S - 4 cm rostral to T12S or flank; or C1'-Fpz.

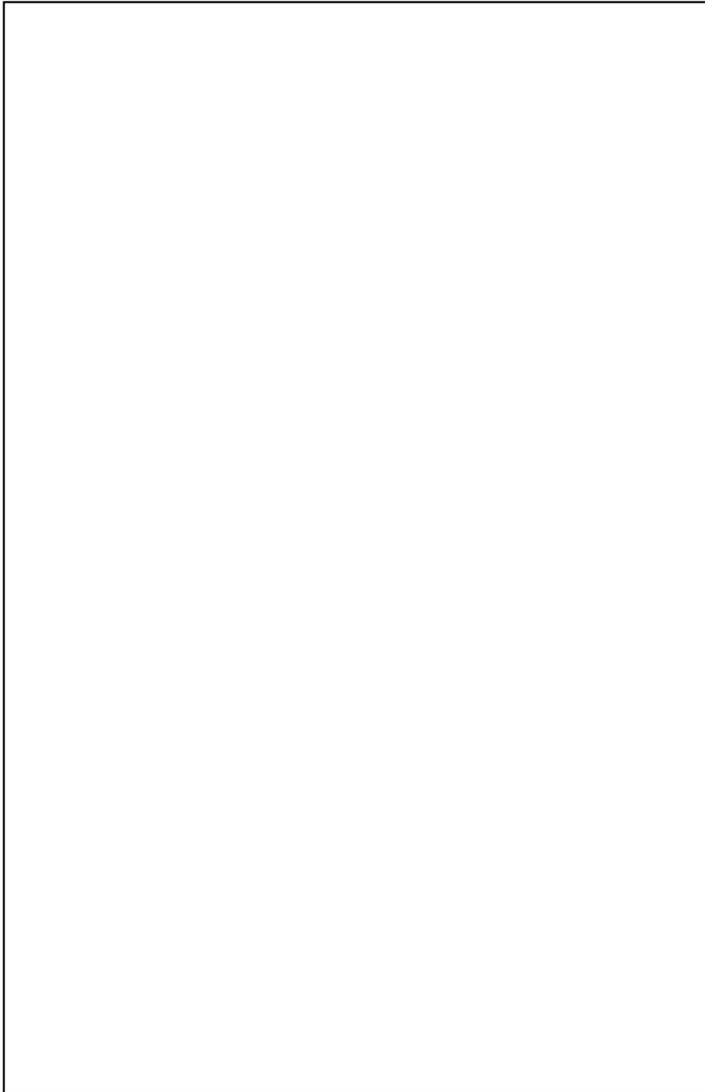
Channel 3: L3S - 4 cm rostral to L3S or flank; or C2'-Fpz.

Channel 4: PF - medial surface of knee.

Some laboratories also utilize a cervical spine recording electrode (e.g. C2 or C5 spine) referred to Fz, similar to that used for upper limb recordings. This is particularly useful for intraoperative monitoring.

Designation of components. Individual response components (Figure 2 [**old figure 3**]) should be designated as follows:

1. Nerve trunk (tibial nerve) component in the popliteal fossa: PF potential.
2. Spine components: T12 and L3 potentials.
3. Scalp components: P37 and N45 waves.



Analysis of Results

Potentials to be recognized. Records are analyzed to identify those potentials that are most consistently demonstrated in normal subjects. These include the following:

1. In the popliteal fossa derivations: PF potential.
2. In the spinal derivations: L3 and T12 potentials.
3. In scalp-to-scalp derivations: components P37 and N45.

It should be noted that the amplitude and latency of the N45 scalp component may be influenced by the state of the subject.

Measurements. The following body measurements should be taken:

1. Distance from stimulating cathode on each ankle to PF electrode.
2. Distance from stimulating cathode on each ankle to each L3 and T12 spine electrode.
3. Straight line distances from each L3 and T12 spine electrode to Cz' scalp lead.

The following latency measurements (to be computed from the leading edge of the stimulating pulse) are suggested to evaluate posterior tibial nerve SSEPs:

1. Peak latency of the popliteal fossa potential (initial negative or preceding positive, peak.)
2. Peak latency of the L3 and T12 spine potentials (negative peak).
3. Peak latency of the first major positive scalp potential (P37).

Using the above measurements, the following conduction velocities (in m/s) should be computed:

1. Conduction velocity in peripheral afferent nerve fibers, which is determined by dividing: (a) the distance between the stimulating cathode and the PF electrode by the latency of the PF potential, and (b) the distance between the stimulating cathode and the L3S electrode by the latency of the L3 spine potential.
2. For conduction from spine to scalp, IPLs achieved by subtracting the latency of the L3 and T12 spine potentials from the latency of the P37 scalp potentials are computed.

Criteria for Clinically Significant Abnormality

1. Absence of any of the obligate waveforms listed above (i.e., cortical potentials). Caution regarding technical adequacy, discussed with respect to the median SSEPs applies similarly here. In cases in which the signal-to-noise ratio of the recording is not adequate to detect P37 were it present, failure to record it must not be interpreted as an abnormality.
2. Prolongation of the spine-P37 interpeak latency. Prolongation of these IPLs beyond 2.5 or 3 standard deviations greater than the mean of an appropriate control population indicates a delay in conduction between the lumbar cord and somatosensory cortex.

Considerations (discussed with respect to median nerve SSEPs) regarding absolute latency measurements, interside-IPL measurements, and atypical features of uncertain significance apply here as well.

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