PRACTICE PARAMETER FOR ELECTRODIAGNOSTIC STUDIES IN CARPAL TUNNEL SYNDROME: SUMMARY STATEMENT*

AMERICAN ASSOCIATION OF ELECTRODIAGNOSTIC MEDICINE, AMERICAN ACADEMY OF NEUROLOGY, and AMERICAN ACADEMY OF PHYSICAL MEDICINE AND REHABILITATION

Carpal tunnel syndrome (CTS) is a common clinical problem and frequently requires surgical therapy. The results of electrodiagnostic (EDX) studies have been found to be highly sensitive and specific for the diagnosis of CTS. This document defines the standards, guidelines, and options for EDX studies of CTS based on a critical review of the literature published in 1993 and recently updated by a review of the literature through the year 2000. The reader is referred to the updated review for a detailed discussion of the literature and the EDX techniques for the assessment of CTS which are summarized here. Both reviews addressed the following key clinical questions:

1. In patients clinically suspected of having CTS, what are the best EDX studies to confirm the diagnosis?
2. How can future clinical research studies be improved to evaluate the usefulness of laboratory studies, including EDX studies, to confirm the diagnosis of CTS?

DESCRIPTION OF THE REVIEW PROCESS

The source of the articles for the first CTS Literature Review published in 1993 was a Medline search for literature in English from January 1, 1986, through May 1991. The Medical Subject Headings (MeSH) searched were (1) wrist injuries or wrist joint, (2) nerve compression syndrome, and (3) carpal tunnel syndrome. The search identified 488 articles. Based on a review of the abstracts, 81 articles describing EDX studies were chosen for review. An additional 78 reports were identified from the bibliographies of the 81 articles, and AAEM consultants recommended 6 others for a total of 165 articles. Of the 165 articles reviewed, 20 were classified as background references. The source of the articles for the second CTS Literature Review was a Medline search for literature in English through December 2000. The MeSH searched...
were (1) carpal tunnel syndrome and diagnosis or (2) carpal tunnel syndrome and neural conduction. The search generated 497 article titles with abstracts published since 1990. Based on a review of the abstracts, the AAEM CTS Task Force chose 92 articles for review. An additional 5 articles were identified from the bibliographies of the articles, and 16 from AAEM members who have current research interests in CTS, for a total of 113 articles. Of the 113 articles reviewed, 24 were classified as background references.

DESCRIPTION OF THE REVIEWERS
In 1997, the AAEM President appointed Dr. Charles K. Jablecki to Chair the AAEM CTS Task Force. The Chair selected the members of the AAEM CTS Task Force from the AAEM membership with the assistance of the AAEM staff and the AAEM President to include neurologists (Floeter, Jablecki, Wilson) and physiatrists (Andary, Quartly, Vennix) in both academic (Andary, Floeter, Quartly, Vennix) and clinical practice (Jablecki, Wilson) with interests in the use of EDX studies in CTS. The AAEM CTS Task Force included three members who authored the first CTS Literature Review published in 1993 (Jablecki, Andary, Wilson). In 1999, the AAEM President appointed Dr. Robert G. Miller to the AAEM CTS Task Force to provide an interface and full collaboration with the AAN Quality Standards Subcommittee in the development of the second CTS Literature Review and the Summary Statement.

LITERATURE INCLUSION CRITERIA
In the fall of 1991, the AAEM Quality Assurance Committee adopted six literature inclusion criteria (LIC) of scientific methodology to evaluate CTS literature describing EDX procedures. The AAEM CTS Task Force used the same six AAEM CTS LIC when reviewing the literature. The first two criteria apply to all studies of diagnostic tests and deal with the quality of evidence and reducing bias; the remaining four criteria deal with technical and analytic issues that are critical to the use of nerve conduction studies (NCSs) to document nerve pathology. All of these criteria are important for a study to determine whether or not a NCS is useful to diagnose CTS. The six LIC used were as follows:

1. Prospective study design.
2. Diagnosis of CTS in patient population based on clinical criteria independent of the EDX procedure under evaluation.
3. EDX procedure described in sufficient detail to permit replication of the procedure.
4. Limb temperature monitored (measured continuously) during nerve conduction procedures and minimum (or range) of limb temperatures reported for both CTS patients and the reference population.
5. Reference values for the EDX test obtained either:
   a) with concomitant studies of a reference population, or
   b) with previous studies of a reference population in the same laboratory.
6. Criteria for abnormal findings clearly stated and, if the measurement is a quantitative one, the abnormal value is defined in statistically computed terms, e.g., range and mean ± 2 standard deviations, from data derived from the reference population.

REVIEW OF ELECTRODIAGNOSTIC STUDIES
A total of 22 of the 278 articles reviewed met all 6 AAEM CTS LIC. There were nine additional articles (eight using surface electrodes and one using needle electrodes) that studied median motor and sensory nerve conduction across the carpal tunnel (amplitude, latency, and velocity) in normal subjects only and otherwise fulfilled the AAEM CTS LIC.

Table 1 provides a summary of pooled sensitivities and specificities from studies that met all six AAEM CTS LIC for EDX techniques used to diagnose CTS. In these studies, hand temperatures were monitored continuously and the majority of the studies maintained the hand temperature at 32°C or greater. Details of techniques and the specific studies pooled are provided in the second CTS Literature review.

DEFINITION OF PRACTICE RECOMMENDATION STRENGTHS
The strength of a recommendation or conclusion is
based on the quality and consistency of supporting evidence. The following rating system is used:

**Practice standards:** generally accepted principles for patient management that reflects a high degree of clinical certainty.

**Practice guidelines:** recommendations for patient management that reflect moderate clinical certainty.

**Practice options:** other strategies for patient management for which the clinical utility is uncertain.
Table 1. Comparison of pooled sensitivities and specificities of EDX techniques to diagnose CTS.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pooled sensitivity*</th>
<th>Pooled specificity*</th>
</tr>
</thead>
<tbody>
<tr>
<td>A  Median sensory and mixed nerve conduction: wrist and palm segment</td>
<td>0.85†</td>
<td>0.98†</td>
</tr>
<tr>
<td>compared to forearm or digit segment</td>
<td>(0.83, 0.88)</td>
<td>(0.94, 1.00)</td>
</tr>
<tr>
<td>B  Comparison of median and ulnar sensory conduction between wrist and</td>
<td>0.85</td>
<td>0.97</td>
</tr>
<tr>
<td>ring finger</td>
<td>(0.80, 0.90)</td>
<td>(0.91, 0.99)</td>
</tr>
<tr>
<td>C  Median sensory and mixed nerve conduction between wrist and palm</td>
<td>0.74†</td>
<td>0.97†</td>
</tr>
<tr>
<td></td>
<td>(0.71, 0.76)</td>
<td>(0.95, 0.99)</td>
</tr>
<tr>
<td>D  Comparison of median and ulnar mixed nerve conduction between wrist</td>
<td>0.71</td>
<td>0.97</td>
</tr>
<tr>
<td>and palm</td>
<td>(0.65, 0.77)</td>
<td>(0.91, 0.99)</td>
</tr>
<tr>
<td>E  Median motor nerve conduction between wrist and palm</td>
<td>0.69†</td>
<td>0.98†</td>
</tr>
<tr>
<td></td>
<td>(0.64, 0.74)</td>
<td>(0.93, 0.99)</td>
</tr>
<tr>
<td>F  Comparison of median and radial sensory conduction between wrist and</td>
<td>0.65</td>
<td>0.99</td>
</tr>
<tr>
<td>thumb</td>
<td>(0.60, 0.71)</td>
<td>(0.96, 1.00)</td>
</tr>
<tr>
<td>G  Median sensory nerve conduction between wrist and digit</td>
<td>0.65†</td>
<td>0.98†</td>
</tr>
<tr>
<td></td>
<td>(0.63, 0.67)</td>
<td>(0.97, 0.99)</td>
</tr>
<tr>
<td>H  Median motor nerve distal latency</td>
<td>0.63†</td>
<td>0.98†</td>
</tr>
<tr>
<td></td>
<td>(0.61, 0.65)</td>
<td>(0.96, 0.99)</td>
</tr>
<tr>
<td>I  Median motor nerve terminal latency index</td>
<td>0.62†</td>
<td>0.94†</td>
</tr>
<tr>
<td></td>
<td>(0.54, 0.70)</td>
<td>(0.87, 0.97)</td>
</tr>
<tr>
<td>J  Comparison of median motor nerve distal latency (second lumbrical) to</td>
<td>0.56‡</td>
<td>0.98‡</td>
</tr>
<tr>
<td>the ulnar motor nerve distal latency (second interossei)</td>
<td>(0.46, 0.66)</td>
<td>(0.90, 1.00)</td>
</tr>
<tr>
<td>K  Sympathetic skin response</td>
<td>0.04</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>(0.00, 0.08)</td>
<td>(0.44, 0.61)</td>
</tr>
</tbody>
</table>

*For each EDX technique to summarize results across studies, sensitivities were pooled from individual studies by calculating a weighted average. In calculating the weighted average, studies enrolling more patients received more weight than studies enrolling fewer patients. Specificities were similarly pooled by calculating the weighted average. The data in the parentheses below the sensitivity and specificity values represent the lower and upper 95% confidence limits of the weighted average, respectively. Data analysis courtesy of Dr. Gary Gronseth. †There was heterogeneity between some of the studies (the 95% confidence intervals of the sensitivities and specificities do not overlap). This disparity may be related to differences in case definition of CTS, the use of different cut-points to define an abnormal value, and differences in the average severity of the CTS patients in the different studies. ‡Results based on a single study.

RECOMMENDATIONS REGARDING EDX STUDIES TO CONFIRM A CLINICAL DIAGNOSIS OF CTS

The recommendations below are identical to those made and endorsed in 1993 by the American Academy of Neurology, the American Academy of Physical Medicine and Rehabilitation, and the American Association of Electrodiagnostic Medicine with the clarification of recommendation 1 and 2a and the addition of 2c based on new evidence reviewed in the second CTS Literature Review.²

In patients suspected of CTS, the following EDX studies are recommended (See Table I for sensitivity and specificity of Techniques A–K):

1. Perform a median sensory NCS across the wrist with a conduction distance of 13 cm to 14 cm (Technique G). If the result is abnormal, comparison of the result of the median sensory NCS to the result of a sensory NCS of one other adjacent sensory nerve in the symptomatic limb (Standard).

2. If the initial median sensory NCS across the wrist has a conduction distance greater than 8 cm and the result is normal, one of the following additional studies is recommended:
   a. comparison of median sensory or mixed nerve conduction across the wrist over a short (7 cm to 8 cm) conduction distance (Technique C) with ulnar sensory nerve conduction across the wrist over the same short (7 cm to 8 cm) conduction distance (Technique D) (Standard), or
   b. comparison of median sensory conduction across the wrist with radial or ulnar sensory conduction across the wrist in the same limb (Techniques B and F) (Standard), or
   c. comparison of median sensory or mixed nerve conduction through the carpal tunnel to sensory or mixed NCSs of proximal (forearm) or distal (digit)
segments of the median nerve in the same limb (Technique A) (Standard).

3. Motor NCS of the median nerve recording from the thenar muscle (Technique H) and of one other nerve in the symptomatic limb to include measurement of distal latency (Guideline).

4. Supplementary NCS: comparison of the median motor nerve distal latency (second lumbrical) to the ulnar motor nerve distal latency (second interossei) (Technique J); median motor terminal latency index (Technique I); median motor nerve conduction between wrist and palm (Technique E); median motor nerve compound muscle action potential (CMAP) wrist-to-palm amplitude ratio to detect conduction block; median sensory nerve action potential (SNAP) wrist-to-palm amplitude ratio to detect conduction block; short segment (1 cm) incremental median sensory nerve conduction across the carpal tunnel (Option).

5. Needle electromyography (EMG) of a sample of muscles innervated by the C5 to T1 spinal roots, including a thenar muscle innervated by the median nerve of the symptomatic limb (Option).

Based on the second AAEM CTS Literature Review,² the following EDX studies are not recommended to confirm a clinical diagnosis of CTS either because the EDX studies recommended above have greater sensitivity and specificity or the test is best described as investigational at this time.

1. Low sensitivity and specificity compared to other EDX studies: multiple median F-wave parameters, median motor nerve residual latency, and sympathetic skin response (Technique K).

2. Investigational studies: evaluation of the effect on median NCS of limb ischemia, dynamic hand exercises, and brief or sustained wrist positioning.

**RECOMMENDATIONS FOR FUTURE RESEARCH STUDIES IN CTS**

The AAEM recommends that future clinical research studies of the usefulness of EDX studies to confirm the diagnosis of CTS meet three clinical study criteria:

1. Prospective study.

2. Clinical diagnosis of CTS independent of EDX studies. For example, a diagnosis of probable CTS as defined in the second CTS Literature Review² which is based on a consensus recommendation by Rempel and colleagues.⁶

3. A uniform protocol for data collection and measurement with the physicians performing and interpreting the EDX studies under investigation blinded to the clinical diagnosis of all the human subjects (normal, CTS, disease control) in the study at least until the data collection and measurements are completed.

The AAEM recommends that future clinical research studies of the usefulness of EDX studies to confirm the diagnosis of CTS meet four additional methodological study criteria:

1. Description of EDX technique sufficient to permit replication of the study.

2. Monitor limb temperature continuously during the EDX study.

3. Normal values for EDX technique obtained with concomitant studies or with previous studies in the same laboratory.

4. Criteria of EDX abnormality obtained from normal population and defined in statistical terms.

The first and second AAEM CTS Literature Reviews¹,² used six CTS LIC. The second CTS Literature Review² recommends (1) the addition of criterion 3, and (2) that future AAEM CTS Literature Reviews use all seven CTS LIC to review reports of the usefulness of EDX studies in the evaluation of CTS patients. The second AAEM CTS Literature Review² also provides a set of specific criteria to make a clinical diagnosis of CTS based on expert opinion.

Both the first and second AAEM CTS Literature Reviews recommend that outcome studies should be performed to assess the harms, benefits, and costs of performing NCSs and needle EMG in patients with symptoms suggestive of CTS.

The AAEM CTS Task Force has addressed future research principles over future research topics (except for outcome studies) because the Task Force concluded that future research studies need to meet these principles (1) to provide reliable and
reproducible data to evaluate the usefulness of EDX studies to confirm the clinical diagnosis of CTS, and (2) to permit comparison of the relative utility of different EDX studies for that purpose.

DISCLAIMER
This report is provided as an educational service of the AAEM, AAN, and AAPM&R. It is based on an assessment of the current scientific and clinical information. It is not intended to include all possible methods of care of a particular clinical problem, or all legitimate criteria for choosing to use a specific procedure. Neither is it intended to exclude any reasonable alternative methodologies. The AAEM recognizes that specific patient care decisions are the prerogative of the patient and his/her physician and are based on all of the circumstances involved.

REFERENCES
ABSTRACT: The first AAEM Carpal Tunnel Syndrome (CTS) Literature Review (1993) evaluated the sensitivity and specificity of nerve conduction studies (NCSs) and needle electromyography (EMG) to confirm a clinical diagnosis of CTS based upon a critical review of 165 articles from the literature through May 1991. This new report includes all of the information from the first review and 113 additional articles from the literature through December 2000. The authors concluded that median sensory and motor NCSs are valid and reproducible clinical laboratory studies that confirm the clinical diagnosis of CTS with a high degree of sensitivity (>85%) and specificity (>95%) and that the clinical practice recommendations published in 1993 remain valid. Needle EMG studies were not as sensitive or specific as NCSs to diagnose CTS although they are useful to document axonal nerve pathology. In future research studies to evaluate the usefulness of NCSs and needle EMGs to diagnose CTS, the authors recommend that (1) the physician performing and interpreting the NCS and needle EMGs be blinded to the diagnosis of the subjects (normal, CTS patient, or disease control) to avoid observer bias and (2) the clinical diagnosis of CTS be made according to a new set of consensus clinical diagnostic criteria presented in this report to provide a more uniform population of CTS patients.

Second AAEM Literature Review of the Usefulness of Nerve Conduction Studies and Needle Electromyography for the Evaluation of Patients With Carpal Tunnel Syndrome

Charles K. Jablecki MD, Michael T. Andary, MD, MS, Mary Kay Floeter, MD, PhD, Robert G. Miller, MD, Caroline A. Quartly, MD, FRCP(C) Michael J. Vennix, MD, John R. Wilson, MD

INTRODUCTION

Carpal tunnel syndrome (CTS) is a common clinical problem and a frequent diagnosis of patients referred for evaluation in electrodagnostic medicine (EDX) laboratories. In Rochester, MN, the prevalence of CTS was estimated at 88 per 100,000 in 1961 to 1965 and at 125 per 100,000 in 1976 to 1980. In 1988, there were 51 cases per 100,000 in Santa Clara County, California, of which 47% were work-related. Most physicians agree that the accuracy of the diagnoses and the care and management of patients with symptoms and signs of CTS are improved by the performance of EDX studies which increases the likelihood of the correct diagnosis of CTS.1-3,10,11,20,21,23-25 Those physicians believe that a definite diagnosis of CTS cannot be based solely on subjective complaints (e.g., pain, paresthesia), subjective findings, (e.g., Tinel’s sign, Phalen’s sign, sensory deficit) and voluntary effort (e.g., weakness) because there are other common disorders (e.g., cervical radiculopathy, tendonitis) which have similar signs and symptoms or that may coexist with CTS. In addition, there is a high incidence (20% or greater) of Tinel’s sign and Phalen’s sign in normal subjects.227,230,246 The accuracy of the diagnosis of CTS is important because the diagnosis often leads to surgical release of the carpal ligament in patients whose symptoms are refractory to non-operative therapy. If the symptoms are not due to CTS, then the patient is unlikely to benefit from surgery.

The sensitivity and specificity of nerve conduction studies (NCSs) and needle electromyography (EMG) for the diagnosis of CTS were evaluated by a critical review of the medical literature published in 1993.19 The 1993 CTS Literature Review provided the evidence base for the Practice Parameters for Electrodiagnostic Studies in CTS which was endorsed by the American Association of Electrodagnostic Medicine (AAEM), the American Academy of Neurology (AAN), and the American Academy of Physical Medicine and Rehabilitation (AAPMR). Furthermore, the recommendation that future clinical research studies should meet the 6 AAEM CTS literature classification criteria (hereafter referred to as the literature inclusion criteria (LIC)) published in 1993 has been described as a goal of several subsequent studies of EDX tests in CTS.59,75,91,140,188,189,221,237,254

In the 1993 report, it was recommended that the report be reviewed and updated periodically. The AAEM formed a
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second CTS Task Force in 2000 to update the 1993 report and to provide a single reference for EDX studies in CTS by including the information from the 1993 publication along with the additional information from a systematic review of articles published in English through December 2000.

Based on a systematic review of the literature, this document addresses the following key clinical questions:

1. In patients clinically suspected of having CTS, what are the best EDX studies to confirm the diagnosis?
2. What improvements can be made to future clinical research studies to evaluate the usefulness of laboratory studies, including EDX studies, to confirm the diagnosis of CTS?

AAEM CTS LITERATURE INCLUSION CRITERIA

In the fall of 1991, the AAEM Quality Assurance (QA) Committee adopted 6 criteria of scientific methodology to evaluate CTS literature describing EDX procedures. The AAEM CTS Task Force used the same 6 AAEM CTS LIC to update this report. The first 2 criteria apply to all studies of diagnostic tests and deal with the quality of evidence and reducing bias; the remaining 4 criteria deal with technical and analytic issues that are critical to the use of NCS to document nerve pathology. All of these criteria are important for a study to determine whether or not an NCS is useful to diagnose CTS.

1. Prospective study design. A prospective study design permits uniform collection and analysis of data.
2. Diagnosis of CTS in patient population based on clinical criteria independent of the EDX procedure under evaluation. Use of clinical criteria for the diagnosis of CTS permits identification of a defined population in which to test the sensitivity of the EDX procedure to confirm the diagnosis of CTS. The clinical criteria include a history of nocturnal and activity-related pain and paresthesia in the affected hand, reproduction of the paresthesia with maneuvers that stress the median nerve in the carpal tunnel (Phalen’s sign/wrist flexion, reverse Phalen’s sign/wrist extension, Tinel’s sign/percussion of the wrist, carpal tunnel compression test), sensory deficit limited to the distribution of the median nerve passing through the carpal tunnel, and weakness and/or atrophy limited to the median innervated muscles in the thenar eminence.1,12,244
3. EDX procedure described in sufficient detail to permit replication of the procedure. Specific details of the EDX procedure are necessary (1) to verify the results and (2) to use the procedure in other clinical laboratories.
4. Limb temperature monitored (measured continuously) during nerve conduction procedures and minimum (or range) of limb temperatures reported for both CTS patients and the reference population. The speed of sensory and motor nerve conduction is temperature dependent. The use of temperature correction factors to adjust nerve conduction velocity (CV) measurements made in cool limbs of CTS patients to a reference temperature is controversial and not recommended.10,14,18
5. Reference values for the EDX test obtained either
   a. with concomitant studies of a reference population, or
   b. with previous studies of a reference population in the same laboratory.
   The results of the EDX procedure in a reference population are necessary to determine the specificity of the results of the EDX procedure in CTS patients.
6. Criteria for abnormal findings clearly stated and, if the measurement is a quantitative one, the abnormal value is defined in statistically computed terms, e.g., range and mean ± 2 standard deviations, from data derived from the reference population. Use of standard statistical terms permits computation of the sensitivity and specificity of the EDX procedure and comparison of the procedure to other EDX and non-EDX tests for CTS.

Description of the Review Process

The 6 AAEM CTS LIC were listed on a review sheet followed by “yes” or “no” answers to be circled by the reviewer to indicate whether or not an article fulfilled each criterion; each article was reviewed independently by 2 reviewers and the results were discussed until a consensus was reached if there was a difference in scoring. The articles were then ranked by the number of criteria met. Table 1 lists those articles meeting 4, 5, or 6 of the AAEM CTS LIC.

EDX studies of only normal subjects could meet a maximum of 5 of the 6 AAEM CTS LIC because these studies do not contain CTS patients (criterion 2).
### Table 1. Literature Classification of EDX Studies.

#### Normal Subjects and Patients With CTS

<table>
<thead>
<tr>
<th>Surface Electrodes</th>
<th>Subdermal Electrodes</th>
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<tbody>
<tr>
<td>6 of 6 Literature Inclusion Criteria Met</td>
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<tr>
<td>Carroll38</td>
<td>Kimura130</td>
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<td>Casey and LeQuene97</td>
<td>Kunter90</td>
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<td>Cioni and colleagues17</td>
<td>Nathan and colleagues181</td>
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<td>Clifford and Isaels48</td>
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<td>DeLean74</td>
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<td>4 of 6 Literature Inclusion Criteria Met</td>
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<td>Chang and colleagues44</td>
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<td>Gunnarsson and colleagues91</td>
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<td>Joym117</td>
<td>Monga and Laidlow173</td>
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<td>Kabiraj and colleagues119</td>
<td>Pease and colleagues192</td>
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<tr>
<td>Kemble131</td>
<td>Pease and colleagues194</td>
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<tr>
<td>5 of 6 Literature Inclusion Criteria Met (criteria met: 1,3,4,5,6; criterion 2 relates to CTS patients only)</td>
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<td>Buschbacher23</td>
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<td>Buschbacher23</td>
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<td>Wiederholt65</td>
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<td>Buschbacher24</td>
<td>Di Benedetto and colleagues58</td>
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</tbody>
</table>

* Surface electrodes for motor studies, subdermal needle electrodes for sensory studies.

The source of the articles reviewed in the 1993 report was a Medline search for literature in English from January 1, 1986, through May 1991. The Medical Subject Headings (MeSH) searched were (1) wrist injuries or wrist joint, (2) nerve compression syndrome, and (3) CTS. The search generated 488 article titles with abstracts. Two AAEM 1991 to 1993 QA Committee members reviewed the abstracts. Of the 488 articles, 81 reports referred to electrodiagnosis and other laboratory studies to evaluate CTS; these were...
reviewed. The bibliographies of the 81 reports were examined and an additional 78 reports published prior to 1986 were identified and reviewed. The AAEM QA Committee members and 12 additional AAEM members, who have current research interests in CTS, were contacted to provide bibliographies of EDX studies in CTS. Six additional references were identified from these AAEM consultants. Of the total of 165 (81+78+6) articles reviewed, 20 were classified as background references.

The source of the articles for this second report was a Medline search for literature in English through December 2000. The MeSH searched were CTS and diagnosis or carpal tunnel and neural conduction. The search generated 497 article titles with abstracts published since 1990. Based on a review of the abstracts, the AAEM CTS Task Force chose 92 articles for review. An additional 5 articles were identified from the bibliographies of the articles and 16 from AAEM members who have current research interests in CTS. Of the total of 113 (92+5+16) articles reviewed, 24 were classified as background references.

At the start of the second review process, the AAEM CTS LIC for limb temperature monitoring during an NCS was clarified: the published paper must report the limb temperature was measured continuously during the NCS. To be certain that all of the papers reported in the second CTS Literature Review met this criterion, the papers reviewed for the first CTS Literature Review were re-examined. As a result of the re-examination, there was no change in the classification of papers that previously met 5/6 AAEM CTS LIC; several papers that previously met 4/6 (9), 5/6 (6), 3/6 (4), and 1/6(111) were reclassified as not meeting the AAEM CTS LIC for limb temperature monitoring.

DESCRIPTION OF DATA PRESENTATION

Tables were constructed to display the data from the articles that met all 6 AAEM CTS LIC unless the studies used subdermal (needle) stimulating and/or recording electrodes for the NCS or the studies were considered to be investigational. Abstracts of articles that met 4, 5, or 6 AAEM CTS LIC or had historical interest are included in the references.

The tables describing the results of NCSs with surface recording and stimulating electrodes were to include the following information:

1. Author:
   a. Publication date.

2. Control subjects:
   a. Number of control hands (number of control subjects).
   b. Mean (range) age of control subjects.

3. CTS Patients:
   a. Number of CTS hands (number of CTS patients).
   b. Mean (range) age of CTS patients.

4. Test parameters:
   a. Conduction distance in centimeters.
   b. Stimulation site.
   c. Recording site.

5. Range or minimum hand temperature.
6. Mean ± standard deviation of test results in normal hands.
7. Criteria for abnormal value, e.g., mean ± 2 standard deviations.
8. Abnormal value.
9. Specificity of the test defined as the percentage of normal hands with normal test results (calculated or actual).
10. Sensitivity of the test defined as the percentage of CTS hands with abnormal test results.

If an article chosen for a table did not contain all the data required for the table, the author(s) of the article were contacted to provide the missing information and the data was added to the table with a notation of the source as being written communication.

REVIEWER OBSERVATIONS

Although the amplitudes of median sensory nerve action potentials (SNAPs) are frequently reduced in CTS, this is not always the case. Furthermore, damage to the median nerve fibers in the brachial plexus or proximal portions of the median nerve can produce changes in the amplitude of median nerve responses in the hand similar to changes caused by damage to the median nerve fibers in the carpal tunnel. On the other hand, focal slowing or block of nerve conduction across the carpal tunnel has localizing pathologic significance. For this reason, the 1991 to 1993 AAEM QA Committee agreed to focus on the results of EDX techniques to measure the speed of median nerve conduction across the carpal tunnel in CTS rather than the results of techniques to measure the amplitude of median sensory and motor responses. Since 1991, additional articles have been published which support that decision. This current report is more inclusive and contains new tables with data on median sensory and motor nerve amplitude changes in CTS patients from the 1991 to 2000 literature search to permit the reader to verify the conclusions of the AAEM CTS Task Force.

While reviewing the articles, it became clear that the selection criteria for the clinical diagnosis of CTS was not always described in sufficient detail to determine whether the patient group was representative of the CTS population. In 1989, Jackson and Clifford demonstrated that the incidence of EDX abnormalities increased according to the severity of the median nerve compression as determined by the clinical history of persistent sensory symptoms and the
clinical findings of thenar muscle weakness and atrophy. Thus, selection of more advanced cases would increase the yield of EDX abnormalities. A report by Buchthal and colleagues in 1974 illustrated this point because they reported a 91% incidence of abnormal findings on the needle EMG examination of the abductor pollicis brevis (APB) muscle in CTS patients. Subsequent studies of needle EMG findings in CTS and the consensus of members of the 1991 to 1993 AAEM QA Committee and the AAEM CTS Task Force was that the incidence of abnormal needle EMG findings in the thenar muscles of CTS patients is much less than were reported by Buchthal and colleagues whose studies were conducted at a national clinical research center.

To balance the authority of a publication meeting the 6 AAEM CTS LIC in a controlled academic setting with the reality of clinical experience, the 1991 to 1993 QA Committee decided to report data in tables only if the maximum incidence of any EDX abnormality in all the CTS patients in the study was less than 90%. If over 90% of the patients with a clinical diagnosis of CTS demonstrate a test abnormality, the results suggest that the patient population was heavily screened and, therefore, biased with patients with advanced CTS. For this reason, the studies of Casey and LeQuesne and Cioni and colleagues, which met the 6 literature classification criteria, were not included in the table data of the 1993 publication. This convention was eliminated from the current review. Data from all studies that met 6 AAEM CTS LIC are displayed in tables regardless of how high or low the sensitivity and specificity of the test results so readers can draw their own conclusions.

The AAEM CTS Task Force identified 2 possible sources of investigator bias in the CTS literature: selection bias and observer bias.

Selection bias might increase the incidence of EDX test abnormalities due to inclusion of CTS patients with more severe CTS than usually encountered in a clinical practice. To address prospectively the issue of selection bias in CTS research studies as described above, the AAEM CTS Task Force developed a set of criteria for the clinical diagnosis of CTS to provide a more uniform population of CTS patients for use in future research studies of the usefulness of EDX studies to diagnose CTS (see Table 2).

Observer bias might increase the incidence of EDX test abnormalities due to the desire of the researcher to document the usefulness of the EDX test. To address prospectively the issue of observer bias, Sackett and colleagues have recommended that clinical research studies of diagnostic tests be performed with the physician performing and interpreting the diagnostic tests blinded to the diagnosis of the subject. At the recommendation of the AAN, the AAEM recently endorsed that principle and recommends that physicians performing and interpreting the EDX test as part of a clinical research study be blinded to the clinical classification of the research subjects (normal, CTS, disease control).

**REVIEW OF EDX STUDIES**

The identification of the clinical manifestations and operative treatment for symptoms due to compression of the median nerve in the carpal tunnel are generally credited to Phalen although there were earlier reports of successful surgical treatment of median nerve compression in the carpal tunnel. In 1953, Kremer published the salient clinical feature of CTS.

In 1949, Dawson and Scott reported the reproducible recording of nerve action potentials with surface electrodes in arms of healthy human subjects after electric stimulation of the nerves and suggested that the technique may be useful in detecting nerve damage. In 1956, Simpson reported the observation that the median motor distal latency was prolonged across the carpal tunnel in CTS and this was confirmed by other investigators: Thomas in 1960 and Lambert in 1962. In 1956, Dawson described a technique for measuring median sensory nerve conduction across the carpal tunnel. In 1958, Gilliatt and Sears demonstrated slow median sensory nerve conduction across the carpal tunnel in patients with CTS. Casey and LeQuesne confirmed the finding of Buchthal and Rosenfalck that the median nerve conduction abnormalities in CTS were focal and localized to the segment of the median nerve in the carpal tunnel. Brown confirmed the localization of the median nerve conduction abnormalities in CTS patients to be under the carpal ligament with intraoperative NCSs. Other studies have verified these reports and median sensory and motor NCSs have become the mainstay for the laboratory evaluation of CTS.

Over the past 40 years, clinical research efforts have refined the techniques of median sensory and motor NCSs across the carpal tunnel to make the tests more sensitive and specific for the detection of compression of the median nerve in the carpal tunnel. To make the NCSs more sensitive, investigators have developed techniques to exclude the normal segment of the median nerve distal to the flexor retinaculum of the carpal tunnel, compared the speed of median nerve conduction to the speed of ulnar or radial nerve conduction from the same hand, performed sequential short segment (1 cm) sensory and motor NCSs, and compared the median nerve conduction across the carpal tunnel to median nerve conduction in the forearm or digit.
Table 2. Clinical Diagnostic Criteria for CTS Research.

To assist in the research evaluation of EDX studies to confirm the clinical diagnosis of CTS, the following criteria are provided to make a clinical diagnosis of CTS. The criteria are based on symptoms alone; the findings on the physical examination are not necessary for the clinical diagnosis of CTS. The findings on the physical examination should be used with the medical history to diagnose (1) alternative causes of the sensory symptoms in the hand(s) and (2) concomitant disorders that may confound the laboratory diagnosis of CTS. This document incorporates criteria originally proposed by the AAN Quality Standards Subcommittee in 1993. Note that the first inclusion criterion is based on the presence of numbness and tingling, not pain, because numbness and tingling are more specific for nerve injury whereas pain is commonly found in soft-tissue injuries and musculoskeletal disorders in addition to CTS. The terms “numbness and tingling” were chosen over the term “paresthesia” because the terms “numbness and tingling” are generally understood by patients and the term “paresthesia” is foreign to most patients.

INCLUSION CRITERIA

1. Sensory symptoms (numbness and/or tingling) in at least 2 of digits 1, 2, 3, and 4 for at least 1 month. The sensory symptoms may be intermittent or constant, but if constant, there must have been a period of time during which the symptoms were intermittent. The numbness and tingling may be accompanied by pain, but pain alone is not sufficient to meet this first inclusion criteria.
2. Sensory symptoms (numbness and/or tingling) aggravated by at least 1 of the following: sleep, sustained hand or arm positioning, or repetitive actions of the hand.
3. Sensory symptoms (numbness and/or tingling) mitigated by at least 1 of the following: changes in hand posture, shaking the hand, or use of a wrist splint.
4. If pain is present, the wrist, hand, and finger pain is greater than elbow, shoulder, or neck pain if there is pain in any or all of those locations.

EXCLUSION CRITERIA

1. Sensory symptoms exclusive or predominantly in the D5 (little finger) (ulnar neuropathy).
2. Neck pain or shoulder pain preceded the paresthesia in the digits (cervical radiculopathy and/or brachial plexopathy).
3. Numbness and/or tingling in the feet which preceded or accompanied the sensory symptoms in the hands (polyneuropathy).
4. Findings on the problem focused history and physical examination which indicate an explanation for the sensory symptoms which is more probable than CTS, for example, digital neuropathy, median nerve pathology proximal to the carpal tunnel, ulnar neuropathy, radial neuropathy, cervical radiculopathy, spinal cord, brainstem or brain pathology, or a polyneuropathy.

CERTAINTY DIAGNOSIS OF CTS FOR RESEARCH STUDIES

It is recommended that clinical research studies use a combination of clinical and EDX findings to define the highest level of certainty (definite) of the diagnosis of carpal tunnel syndrome, while clinical criteria alone are used to define probable and possible CTS as follows:

**Definite CTS:** Patients (1) satisfy all inclusion and exclusion criteria, and (2) have nerve conduction abnormalities consistent with pathology exclusive to the median nerve and localized in the carpal tunnel segment of the median nerve.

**Probable CTS:** Patients satisfy all clinical inclusion and exclusion criteria.

USE OF CLINICAL DIAGNOSTIC CRITERIA FOR CTS RESEARCH

1. It is recommended that clinical studies of CTS include patients who meet the criteria for the diagnosis of probable CTS based on clinical findings alone as test subjects for studies to evaluate the usefulness of EDX studies to confirm the clinical diagnosis of CTS. The use of a uniform set of diagnostic criteria will permit clinical research studies to focus on a well-defined CTS patient population and will simplify comparison of different EDX techniques as well as EDX data from different clinical laboratories.
2. It is acknowledged that a diagnosis of CTS based solely on clinical criteria alone has limited sensitivity and specificity (Rempel). Therefore, for clinical research purposes, a diagnosis of definite CTS requires the demonstration of abnormalities of median nerve conduction in the carpal tunnel segment of the median nerve in addition to meeting the clinical inclusion and exclusion criteria. These diagnostic criteria for CTS are proposed for clinical research studies to provide a uniform population of CTS patients with a “gold standard” diagnosis and representing a broad spectrum of disease.
3. It is acknowledged that there are CTS patients who meet only the criteria for probable and possible CTS but who still may deserve clinical treatment of their condition. Furthermore, there are CTS patients with concomitant polyneuropathy, ulnar neuropathy, and cervical radiculopathy who might be excluded from clinical research studies of CTS based on the exclusion criteria but who may still deserve appropriate clinical treatment of their condition.
To evaluate the specificity of NCSs for the diagnosis of CTS, investigators have used clinical criteria for the diagnosis of CTS independent of EDX findings, performed prospective studies, and included concomitant evaluation of normal control subjects. The results of these clinical research efforts have found rapid application in the clinical laboratory. Physicians in several specialties, including neurology, physical medicine and rehabilitation, orthopaedics, neurosurgery, plastic surgery, rheumatology, and occupational medicine have concluded that NCSs and needle EMG are of value for the laboratory diagnosis of CTS. In a multidiscipline consensus forum, Rempel and colleagues concluded that NCSs, combined with the clinical history and clinical findings, provide a better basis for the diagnosis of CTS than the clinical history and clinical finding alone.

Several investigators have studied the relationship between the abnormalities on NCSs and the duration and severity of symptoms and signs of CTS. Patients with weakness and/or sensory deficits frequently have low amplitude motor and/or sensory potentials, respectively. Although the incidence of abnormalities of median sensory and motor conduction is greater when the duration of the symptoms of CTS is longer, there are definite exceptions. Furthermore, in 1963, Fullerton demonstrated that the susceptibility of median motor nerve conduction across the wrist to ischemia correlated with the frequency and severity of intermittent attacks of pain and paresthesias in the affected hand; slowing of motor nerve conduction (prolonged distal latency) did not correlate with pain and paresthesias. Fullerton suggested that there were 2 mechanisms responsible for the symptoms and signs of CTS: (1) a rapidly reversible change in the nerve fibers associated with ischemic attacks, and (2) a slowly developing structural change in the nerve fibers resulting from pressure on the nerve under the flexor retinaculum. In 1980, Gilliatt reviewed additional evidence to support Fullerton’s hypothesis which provides an explanation for the prompt relief of some symptoms of CTS with surgical decompression of the carpal tunnel.

Motor and sensory NCSs can be performed in the clinical laboratory setting with surface stimulating and recording electrodes. The technical factors that influence the results of these studies have been identified to include the following: amplifier gain and filter settings; electrode size, shape, and material; distance between stimulating and recording electrodes; distance between recording electrodes; and limb temperature. Pathologic conditions which cause nerve damage also alter the results of NCSs by slowing or blocking nerve conduction. NCSs provide a unique and reliable method for assessing directly the integrity of sensory and motor nerve fibers.

Needle EMG is performed by inserting a sterile needle electrode through the skin into the belly of a muscle and evaluating the spontaneous and voluntary electrical activity in the muscle. The technical factors that influence the results of these studies have been identified and include amplifier gain and filter settings and electrode size, shape, and material. After injury of a nerve to a muscle, abnormal electrical activity can be recorded in the muscle, which serves to provide objective evidence of motor nerve injury.

NCSs and needle EMG are complementary but distinctly different EDX techniques although they are often performed sequentially for the evaluation of clinical problems. Because the use of NCSs and needle EMG requires (1) the formulation of a differential diagnosis based on the clinical history and physical examination, (2) interpretation of the data during the examination, and (3) a change in the direction of the examination during the study based upon that interpretation integrated with clinical information, NCSs and EMG are the practice of medicine and should be performed by a physician qualified by education, training, and experience.

RESULTS

The article review process was designed to ensure that all of the articles cited used comparable scientific methods to evaluate the proposed EDX study. Some variation is to be expected in the results even with identical techniques because the percentage of abnormal values depends on several factors including (1) the number of and selection process for the normal subjects, (2) the number of and selection process for the CTS patients—few articles described in detail the clinical criteria for the diagnosis of CTS or the severity of the CTS in the patients entered in the study, and (3) the numeric value chosen as the upper limit of normal for the NCS.

A total of 22 of the 320 articles and abstracts reviewed met all 6 AAEM CTS LIC (see Table 1) and 16 of these 22 articles were selected as the source of the data displayed in Tables 3 through 22. The 16 articles selected for the tables: (1) met all 6 CTS LIC, (2) used surface recording electrodes for NCSs, (3) used a technique that evaluated median nerve conduction with the wrist in a neutral position and the hand in a rested state, and (4) reported median nerve conduction abnormalities in a total of 1812 CTS patients and a total of 678 normal subjects. The data from the remaining 6 articles are discussed in the text but were not used as a source of Table because: (1) 3 investigators used subdermal needle electrodes for stimulating and/or recording electrodes for all of the NCSs (1 used needle recording electrodes for the median sensory NCS and surface electrodes for the median motor NCS), and needle electrodes are not generally used for NCS, and (2) 3 additional articles reported the effect of wrist positioning and/or hand movements on median NCS and these studies are best viewed as investigational techniques.
since there is conflicting information on their usefulness to diagnose CTS.

There were 9 additional articles listed in Table 1 (8 using surface electrodes and 1 using needle electrodes) that studied median motor and sensory nerve conduction across the carpal tunnel (amplitude, latency, and velocity) in normal subjects only and otherwise fulfilled the AAEM CTS LIC. The 9 articles are referenced in the text that accompanies the appropriate numbered tables. The 8 articles that used surface electrodes provide measurements of median nerve conduction in a total of 425 normal subjects.

**Median Motor Nerve Conduction Studies**

**Median Motor Nerve Distal Latency.** Table 3 presents the results of 6 studies of median motor conduction over a 6 to 8 cm length of the median nerve passing through the carpal tunnel that met all 6 AAEM CTS LIC; the median motor distal latency is prolonged in 44% to 74% of CTS patients. The more recent studies in Table 3 reported sensitivities of 44% to 55% with specificities of 97% to 99%. The abnormal value (>4.0 ms) chosen for the median motor distal latency in the report by Padua was almost identical to the abnormal value reported in an independent study of 105 control subjects by Stetson. However, the criteria for an abnormal value in the report by Kuntzer (>4.5 ms) was closer to the abnormal value (>4.7 ms) reported in a larger independent study of 249 control subjects by Buschbacher.

There were 21 studies of the median motor distal latency in CTS that met 4 or 5 of the 6 AAEM CTS LIC with the following incidence of prolonged median motor distal latency measurements in CTS: Rosen (1993), 20%; Macleod (1987), 29%; Mills (1985), 33%; Kothari (1995), 33%; Gunnarsson (1997), 37%; White and colleagues (1988), 46%; Preston and Logigian (1992), 54%; Seror (1994), 55%, Kimura and Ayyar (1985), 56%; Trojaborg and colleagues (1996), 60%; Preswick (1963), 62%; Thomas (1960), 63%; Bhula and Thoppi (1981), 67%; Merchant and colleagues (1990), 68%; Kemble (1968), 69%; Marinacci (1964), 69%; Fitz (1990), 72%; Shean and colleagues (1995), 78%; Melvin and colleagues (1973), 79%; Schwartz and colleagues (1980), 80%; Monga and colleagues (1985), 81%. Interestingly, the median motor conduction may be slightly slowed in the forearm segment above the carpal tunnel in CTS patients. Chang provided evidence that the slowing is due to the block of conduction of the faster conducting fibers at the wrist.

**Median Motor Nerve Conduction between Wrist and Palm.** Table 4 presents the results of 2 studies that met 6 AAEM CTS LIC and calculated the median motor CV over a short conduction distance (5 cm to 6 cm) between the wrist and palm stimulation sites. Compared to the studies in Table 3 of median distal motor latency, the calculated median motor CV across the carpal tunnel was a more sensitive test for CTS.

**Median Motor Nerve Compound Muscle Action Potential Amplitude.** Table 5 presents the results of a study of median motor nerve compound muscle action potential (CMAP) amplitude changes in CTS by Kuntzer that met all 6 AAEM CTS LIC. The study demonstrated that measurements of median motor distal latency is more often abnormal in CTS patients than the measurement of median motor CMAP amplitude; 47% versus 15% (compare Table 3 and Table 5). The criterion of abnormality (mean \(-2\) standard deviation [SD]) chosen by Kuntzer (1994) of the CMAP \(<5\) mV lies between the mean \(-2\) SD of 2 studies of normal subjects that met 5 of the 6 AAEM CTS LIC: the mean \(\pm\) SD for the thenar CMAP was 10.2 \(\pm\) 3.6 mV, mean \(-2\) SD = 3.0 mV (Buschbacher and 12.5 \(\pm\) 3.1 mV, mean \(-2\) SD = 6.3 mV (Stetson). The ratio of the amplitude of the median motor CMAP recorded over the APB with (1) stimulation of the median nerve at the wrist and (2) stimulation in the palm makes it possible to identify median motor nerve conduction block across the carpal tunnel. The technique is technically difficult because it is necessary to take steps to avoid simultaneous stimulation of the ulnar nerve in the palm which, if undetected, results in a factitious increase in the ABP CMAP with palm stimulation compared to the APB CMAP with wrist stimulation (Di Guglielmo). Pease and Gordon evaluated this technique for the diagnosis of CTS and the results were inconclusive.

Table 6 presents the results of the study by Di Guglielmo that met all 6 AAEM CTS LIC; the incidence of motor conduction block was low (7%) with the criteria of a greater than 30% reduction in CMAP amplitude with less than a 15% increase in the duration of the proximal CMAP, criteria which take into account temporal dispersion and phase cancellation. Lesser and colleagues, in a study that met 5 of the 6 AAEM CTS LIC, reported that a higher incidence of abnormalities (39% of CTS patients showed evidence of motor conduction block across the carpal tunnel) but did not provide data on temporal dispersion and phase cancellation which would give the appearance of conduction block (Di Guglielmo).
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Number of Normal Hands (subjects)</th>
<th>Normal Subject's Age: Mean (range)</th>
<th>Number of CTS Hands (patients)</th>
<th>CTS Subjects Age: Mean (range)</th>
<th>Technique: Conduction Distance</th>
<th>Stimulation Site</th>
<th>Recording Site</th>
<th>Minimum Hand Temperature</th>
<th>Median Motor Distal Latency ± SD</th>
<th>Criteria for Abnormal Value</th>
<th>Abnormal Value</th>
<th>Specificity of Abnormal Value</th>
<th>Sensitivity of Abnormal Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DeLean</td>
<td>1988</td>
<td>80 (43)</td>
<td>33 (20 to 73)</td>
<td>253 (150)</td>
<td>47 (20 to 84)</td>
<td>6 cm to 8 cm</td>
<td>Wrist</td>
<td>APB</td>
<td>32°C</td>
<td>3.2 ± 0.4 ms</td>
<td>Mean + 2 SD</td>
<td>&gt;4.2 ms</td>
<td>99% (estimate)</td>
<td>60%</td>
</tr>
<tr>
<td>Jackson and Clifford</td>
<td>1989</td>
<td>38 (38)</td>
<td>42 (21 to 69)</td>
<td>131 (123)</td>
<td>53 (21 to 85)</td>
<td>8 cm</td>
<td>Wrist</td>
<td>APB</td>
<td>31°C</td>
<td>3.18 ± 0.27 ms</td>
<td>Mean + 2 SD</td>
<td>&gt;3.71 ms</td>
<td>95% (estimate)</td>
<td>74%†</td>
</tr>
<tr>
<td>Kimura</td>
<td>1979</td>
<td>122 (61)</td>
<td>43 (15 to 60)</td>
<td>172 (105)</td>
<td>48 (20 to 78)</td>
<td>Anatomical landmarks</td>
<td>3 cm proximal to wrist crease</td>
<td>APB</td>
<td>34°C</td>
<td>3.60 ± 0.36 ms</td>
<td>Mean + 2 SD</td>
<td>&gt;4.4 ms</td>
<td>97.5% (estimate)</td>
<td>61%</td>
</tr>
<tr>
<td>Padua and colleagues</td>
<td>1996</td>
<td>40 (36)</td>
<td>44 (19 to 79)</td>
<td>50 (43)</td>
<td>45 (23 to 80)</td>
<td>Anatomical landmarks</td>
<td>Wrist</td>
<td>APB</td>
<td>31°C</td>
<td>3.66 ± 0.38 ms</td>
<td>Mean + 2 SD</td>
<td>&gt;4.5 ms</td>
<td>97.5% (estimate)</td>
<td>44%</td>
</tr>
<tr>
<td>Padua and colleagues</td>
<td>1997*</td>
<td>70 (70)†</td>
<td>43 (25 to 70)</td>
<td>500 (379)</td>
<td>51 (20 to 88)</td>
<td>Anatomical landmarks</td>
<td>Distal wrist crease</td>
<td>APB</td>
<td>32°C</td>
<td>3.3 ± 0.5 ms</td>
<td>Mean + 2 SD</td>
<td>&gt;4.3 ms</td>
<td>98.6% (actual)</td>
<td>55%</td>
</tr>
<tr>
<td>Kuntzer</td>
<td>1994</td>
<td>56 (54)</td>
<td>38 (18 to 68)</td>
<td>100 (100)†</td>
<td>51 (26 to 85)</td>
<td>6 cm</td>
<td>Wrist</td>
<td>APB</td>
<td>33°C</td>
<td>3.3 ± 0.5 ms</td>
<td>Mean + 2 SD</td>
<td>&gt;4.3 ms</td>
<td>97.5% (estimate)</td>
<td>47%</td>
</tr>
<tr>
<td>Cioni and colleagues</td>
<td>1989</td>
<td>375 (370)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80%</td>
</tr>
</tbody>
</table>

The median nerve motor conduction studies cited in Table 3 were performed by fastening surface recording electrodes over the thenar eminence (G1 or E1) and thumb (G2 or E2) and supramaximal stimulation of the median nerve with surface electrodes above the wrist crease. With these anatomic landmarks, the conduction distance is usually 6 to 8 cm in normal adults. The time (latency) from the stimulus artifact to the initial negative deflection of the compound muscle action potential (CMAP) was measured in ms and recorded as the median motor distal latency (MDL). Slowing of median motor nerve conduction in the carpal tunnel with nerve injury will result in prolongation of the median MDL. Because cooling of the nerve fibers and increasing the conduction distance also result in prolongation of the median nerve MDL, it is important that the limb temperature and the conduction distance be controlled.

* 1997 Padua and colleagues paper cites reference population studies performed in the same laboratory in 1996.
† For each reference subject, only one hand was tested; for each CTS patient, only the most symptomatic hand was tested.
‡ Written communication.
§ Written communication: the SD of the normal value was misprinted in the 1996 paper, Table 1 (page 50), 3.2 ± 0.8 ms, and should have been 0.4 ms. The abnormal value (4.0 ms) was published correctly.

**Specificity** equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of test data from the reference population.

**Sensitivity** equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population.

**APB** = Abductor Pollicis Brevis  **CTS** = Carpal Tunnel Syndrome  **SD** = Standard Deviation
### Table 4. Median Motor Nerve Conduction Between Wrist and Palm in CTS.

<table>
<thead>
<tr>
<th>Author</th>
<th>Kimura&lt;sup&gt;130&lt;/sup&gt;</th>
<th>Di Guglielmo and colleagues&lt;sup&gt;59&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>1979</td>
<td>1997</td>
</tr>
<tr>
<td>Number of Normal Hands (subjects)</td>
<td>122 (61)</td>
<td>88 (69)</td>
</tr>
<tr>
<td>Normal Subject’s Age: Mean (range)</td>
<td>43 (15 to 60)</td>
<td>40 (20 to 86)</td>
</tr>
<tr>
<td>Number of CTS Hands (patients)</td>
<td>172 (105)</td>
<td>294 (198)</td>
</tr>
<tr>
<td>CTS Subjects Age: Mean (range)</td>
<td>48 (20 to 78)</td>
<td>46 (13 to 84)</td>
</tr>
<tr>
<td>Technique</td>
<td>Anatomical landmarks</td>
<td>Anatomical landmarks</td>
</tr>
<tr>
<td>Proximal Stimulation Site</td>
<td>Wrist crease</td>
<td>1-2 cm proximal to wrist crease</td>
</tr>
<tr>
<td>Distal Stimulation Site</td>
<td>Palm</td>
<td>3 cm distal to wrist crease</td>
</tr>
<tr>
<td>Recording Site</td>
<td>APB</td>
<td>APB</td>
</tr>
<tr>
<td>Minimum Hand Temperature</td>
<td>34°C</td>
<td>32°C</td>
</tr>
<tr>
<td>Median Motor CV ± SD</td>
<td>49.0 ± 5.7</td>
<td>46.7 ± 5.8</td>
</tr>
<tr>
<td>Criteria for Abnormal Value</td>
<td>Mean – 2 SD</td>
<td>Mean – 2 SD</td>
</tr>
<tr>
<td>Abnormal Value</td>
<td>&lt;38 m/s</td>
<td>&lt;35 m/s</td>
</tr>
<tr>
<td>Specificity of Abnormal Value</td>
<td>97.5% (estimate)</td>
<td>97.5% (estimate)</td>
</tr>
<tr>
<td>Sensitivity of Abnormal Value</td>
<td>84%</td>
<td>23% (61%)*</td>
</tr>
</tbody>
</table>

* In the Di Guglielmo and colleagues paper,<sup>59</sup> measurement of median motor conduction in the carpal tunnel segment was performed only in 146 CTS hands with normal median sensory conduction from wrist to D2 (SCV >45 m/s) and normal median motor distal latency (<4.2 ms). Therefore, the percentage (33/146 = 23%) of abnormal median motor conduction across the carpal tunnel segment was reported for a subset of all the CTS hands. From the data in the paper, the maximum possible percentage of abnormal median motor conduction in the carpal tunnel segment for all the CTS hands was calculated to be 61%.

**Specificity** equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of test data from the reference population.

**Sensitivity** equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population.

**APB** = Abductor Pollicis Brevis  
**CTS** = Carpal Tunnel Syndrome  
**CMAP** = Compound Muscle Action Potential  
**CV** = Conduction Velocity  
**SD** = Standard Deviation  
**SCV** = Sensory Conduction Velocity

### Table 5. Median Motor Nerve CMAP Amplitude in CTS.

<table>
<thead>
<tr>
<th>Author</th>
<th>Kuntzer&lt;sup&gt;140&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>1994</td>
</tr>
<tr>
<td>Number of Normal Hands (subjects)</td>
<td>70 (70)*</td>
</tr>
<tr>
<td>Normal Subject’s Age: Mean (range)</td>
<td>43 (25 to 70)</td>
</tr>
<tr>
<td>Number of CTS hands (patients)</td>
<td>100 (100)*</td>
</tr>
<tr>
<td>Normal Subject’s Age: Mean (range)</td>
<td>51 (26 to 85)</td>
</tr>
<tr>
<td>Stimulation Site</td>
<td>Wrist</td>
</tr>
<tr>
<td>Recording Site</td>
<td>APB</td>
</tr>
<tr>
<td>Minimum Hand Temperature</td>
<td>32°C</td>
</tr>
<tr>
<td>Normal CMAP amplitude ± SD</td>
<td>7.8 ± 1.4 mV</td>
</tr>
<tr>
<td>Criteria for Abnormal Value</td>
<td>Mean – 2 SD</td>
</tr>
<tr>
<td>Abnormal Value</td>
<td>&lt;5 mV</td>
</tr>
<tr>
<td>Specificity of Abnormal Value</td>
<td>100% (actual)</td>
</tr>
<tr>
<td>Sensitivity of Abnormal Value</td>
<td>15%</td>
</tr>
</tbody>
</table>

* For each reference subject, only 1 hand was tested; for each CTS patient, only the most symptomatic hand was tested.

**Specificity** equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of test data from the reference population.

**Sensitivity** equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population.

**APB** = Abductor Pollicis Brevis  
**CTS** = Carpal Tunnel Syndrome  
**CMAP** = Compound Muscle Action Potential  
**SD** = Standard Deviation

**Median Motor Short-segment Incremental Studies.** Kimura<sup>128,130</sup> performed short-segment incremental stimulation of the median nerve across the carpal tunnel at 1-cm intervals and noted that, unlike the median sensory nerve fibers (see below), the median motor nerve fibers are difficult to activate sequentially in steps of 1 cm because of the recurrent course of the motor branch of the median nerve to the thenar muscle and the proximity of the stimulating electrodes to the thenar muscle. The technique can be time consuming because it is often difficult to eliminate the stimulus artifact from the
in 1988 reported a very high test sensitivity (89% in mild CTS), the same authors reported a very high incidence (72%) of abnormalities in asymptomatic hands, which positive results. For these reasons, the technique of recording,\(^{128,130,243}\) in addition, it is difficult to choose a limit for normal results that provide both sensitivity and specificity. For example, although White and colleagues\(^{204}\) in 1988 reported a very high test sensitivity (89% in mild CTS), the same authors reported a very high incidence (72%) of abnormalities in asymptomatic hands, which suggests that this test has an unacceptable high rate of false positive results. For these reasons, the technique of segmental (1 cm) median motor nerve stimulation has not been widely accepted for evaluation of patients with CTS.

**Martin-Gruber Anastomosis.** The Martin-Gruber anastomosis describes the anomalous communication in the forearm of nerve fibers from the median nerve to the ulnar nerve, and its presence may affect the results of median motor NCSs in CTS. Stimulation of the median nerve at the elbow ordinarily results in the selective activation of median innervated intrinsic hand muscles. In the presence of a Martin-Gruber anomaly, however, ulnar and median innervated hand muscles are simultaneously activated by stimulation of the median nerve at the elbow.\(^{93,107,129,141}\)

The Martin-Gruber anomaly does not affect the measurement of the median motor distal latency with stimulation of the median nerve at the wrist.\(^{243}\) If the median nerve conduction in the carpal tunnel is sufficiently slower than the ulnar nerve conduction at the wrist, then stimulation of the median nerve at the elbow in the presence of the Martin-Gruber median to ulnar anastomosis in the forearm may result in 2 temporally separate CMAPs recorded over the thenar muscle, the normal ulnar response and delayed median response.\(^{92,93,129}\) More often the occurrence of CTS in a patient with an underlying Martin-Gruber anastomosis results in (1) a change in the waveform of the thenar muscle action potential with proximal median nerve stimulation (initial positive deflection and increased amplitude) compared to distal median nerve stimulation (initial negative deflection)\(^{93}\) and (2) an erroneously fast median nerve forearm CV measurement.\(^{129,267}\) Gutmann\(^{92,93}\) suggested that the presence of an initial positive deflection of the CMAP recorded over the thenar muscle with stimulation of the median nerve at the elbow which was not present with stimulation of the median nerve at the wrist was evidence of median nerve pathology at the wrist. However, more proximal median nerve pathology in the forearm could result in the same phenomenon.

**Comparison of Distal Median Nerve Conduction to Proximal Median Nerve Conduction.** Investigators have recommended formulae (residual latency [RL] and terminal latency index [TLI]) to permit comparison of distal median nerve conduction through the carpal tunnel to more proximal median nerve conduction through the forearm with the goal of eliminating intersubject variability of motor nerve conduction and thereby improving the diagnostic usefulness of motor NCSs to diagnose CTS.\(^{137,222}\)

**Median Motor Nerve RL.** Kraft and Halvorson\(^{137}\) proposed the concept and formula for RL measurements. The RL is equal to the difference between the measured distal latency and the predicted distal latency, the latter computed as the quotient of the distal conduction distance and the proximal CV of the same nerve. Kuntzer,\(^{140}\) in a report that met 6 AAEM CTS LIC, confirmed that the measurements of median motor RL is more often abnormal in CTS patients than the measurement of median motor distal latency, 64%

---

**Table 6. Median Motor Nerve CMAP Wrist to Palm Amplitude Ratio in CTS.**

<table>
<thead>
<tr>
<th>Author</th>
<th>Di Guglielmo and colleagues(^{59})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>1997</td>
</tr>
<tr>
<td>Number of Normal Hands (subjects)</td>
<td>88 (69)</td>
</tr>
<tr>
<td>Normal Subject’s Age: Mean (range)</td>
<td>40 (20 to 86)</td>
</tr>
<tr>
<td>Number of CTS Hands (subjects)</td>
<td>294 (198)</td>
</tr>
<tr>
<td>CTS Subjects Age: Mean (range)</td>
<td>46 (13 to 84)</td>
</tr>
<tr>
<td>Technique: Conduction Distance</td>
<td>Anatomical landmarks</td>
</tr>
<tr>
<td>Wrist Stimulation Site</td>
<td>1 cm to 2 cm proximal to wrist crease</td>
</tr>
<tr>
<td>Palm Stimulation Site</td>
<td>3 cm distal to wrist crease</td>
</tr>
<tr>
<td>Recording Site</td>
<td>APB</td>
</tr>
<tr>
<td>Minimum Temperature</td>
<td>32°C</td>
</tr>
<tr>
<td>Amplitude (wrist) ± SD</td>
<td>10.2 ± 2.9 mV</td>
</tr>
<tr>
<td>Amplitude (palm) ± SD</td>
<td>10.5 ± 2.9 mV</td>
</tr>
<tr>
<td>Wrist to palm amplitude ratio ± SD</td>
<td>0.9 ± 0.1</td>
</tr>
<tr>
<td>Abnormal Value</td>
<td>&lt;0.7</td>
</tr>
<tr>
<td>Criteria for Abnormal Value</td>
<td>Lowest value of range of normal values*</td>
</tr>
<tr>
<td>Specificity of Abnormal Value</td>
<td>100% (actual)</td>
</tr>
<tr>
<td>Sensitivity of Abnormal Value</td>
<td>7%</td>
</tr>
</tbody>
</table>

* Written communication.

**Specificity** equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of test data from the reference population.

**Sensitivity** equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population.

ABP = Abductor Pollicis Brevis  CMAP = Compound Muscle Action Potential  CTS = Carpal Tunnel Syndrome  SD = Standard Deviation
versus 47%, but with lower specificity, 89% versus 99% 
(Table 7 and Table 3). The latter results suggest that if the 
criteria for an abnormal RL were adjusted for comparable 
specificity, that the increased incidence of abnormalities 
would fall. Evidence to support this conclusion is found in 
the study by Trojaborg,\textsuperscript{233} which met 5 of the 6 AAEM CTS 
LIC. Trojaborg\textsuperscript{233} noted a lower incidence of abnormal RL 
values (48%) compared to abnormal distal latency values 
(60%) in CTS patients with comparable specificity and that 
the RL was normal in CTS patients with normal median 
motor distal latencies. The interested reader is also referred 
to studies of median motor nerve RL previously reviewed in 
the 1993 AAEM CTS Literature Review.

**Median Nerve Terminal Latency Index.** Simovic and 
Weinberg\textsuperscript{220,253} provide a summary of the reported studies 
on the usefulness of the median motor TLI to diagnose CTS. 
In 1979, Shahani described the potential usefulness of the 
TLI ratio to diagnose CTS. In 1988, Lissens reported similar 
findings in the Dutch literature. The TLI is calculated from 
the conventional median motor NCS measurements that 
adjusts the median motor distal latency for the terminal 
motor conduction distance and the proximal median motor 
nerve CV. The TLI is calculated as follows: terminal 
conduction distance / [proximal CV × distal latency]. The 
ratio decreases as the conduction time increases across the 
carpal tunnel.

Table 8 presents the results of 2 studies of the TLI that met 6 
AAEM CTS LIC. The study by Simovic and Weinberg\textsuperscript{220,253} 
concluded that 81.5% of CTS patients demonstrate a TLI 
less than 0.34. However, Donahue and colleagues\textsuperscript{60} noted 
that the presence of the Martin-Gruber anastomosis in CTS 
patients could create an artificially high median motor 
forearm CV measurement. The study by Kuntzer\textsuperscript{140} noted 
that 10% of the control group and 7% of the CTS group 
showed a median-to-ulnar crossover. Kuntzer\textsuperscript{140} excluded 
those normal subjects and CTS patients from his analysis of 
the value of the TLI to identify CTS and noted that only 
50% of the CTS group showed a TLI less than 0.34 with a 
specificity of 91%. Simovic and Weinberg\textsuperscript{237} provided a 
summary of the published normative data on 242 hands and 
noted that only 6 had a TLI under 0.34 to yield a specificity 
of 97.5%. These interesting findings need to be confirmed in 
other laboratories to determine the usefulness of the TLI to 
diagnose CTS.

**Comparison of Median Motor Nerve Conduction to Ulnar 
Motor Nerve Conduction in the Same Limb.** There are 3 
different published methods to confirm the diagnosis of 
CTS by calculating the difference between the median and 
ulnar nerve distal motor latencies: the median-thenan to 
ulnar-hypothenar latency difference (THLD),\textsuperscript{167} the median-
thenan to ulnar-thenan latency difference (TTLD),\textsuperscript{220} and the 
median-lumbrical to ulnar-interosseus latency difference 
(LILD).\textsuperscript{146} These studies approach the sensitivity of median 
sensory NCSs in the diagnosis of CTS and may also be useful 
in localizing median nerve pathology to the wrist (1) when the 
median sensory response is absent and (2) when CTS occurs 
in the presence of a polyneuropathy.\textsuperscript{220,255}

**Median-Thenar to Ulnar-Hypothenar Latency Difference.** 
The THLD method is straightforward and calculates the 
difference (THLD) between (1) the distal latency of the 
CMAP recorded over the APB with median nerve 
stimulation at the wrist (thenar latency) and (2) the distal 
latency of the CMAP recorded over the abductor digitii 
minimi (ADM) with ulnar nerve stimulation at the wrist 
(hypothenar latency).\textsuperscript{167,220} There are no studies of this 
method that meet all 6 AAEM CTS LIC. In a study that met 
5 of the 6 AAEM CTS LIC, Sander\textsuperscript{220} noted the sensitivity

<table>
<thead>
<tr>
<th>Table 7. Median Motor Nerve RL in CTS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author</td>
</tr>
<tr>
<td>Year</td>
</tr>
<tr>
<td>Number of Normal Hands (subjects)</td>
</tr>
<tr>
<td>Normal Subject’s Age: Mean (range)</td>
</tr>
<tr>
<td>Number CTS hands (patients)</td>
</tr>
<tr>
<td>CTS Subject Age</td>
</tr>
<tr>
<td>Technique: Conduction Distance</td>
</tr>
<tr>
<td>Stimulation Site</td>
</tr>
<tr>
<td>Recording Site</td>
</tr>
<tr>
<td>Minimum Hand Temperature</td>
</tr>
<tr>
<td>Normal RL ± SD</td>
</tr>
<tr>
<td>Criteria for Abnormal Value</td>
</tr>
<tr>
<td>Abnormal Values</td>
</tr>
<tr>
<td>Specificity of Abnormal Value</td>
</tr>
<tr>
<td>Sensitivity of Abnormal Value</td>
</tr>
</tbody>
</table>

* For each reference subject, only 1 hand was tested: for each CTS patient, only the most symptomatic hand was tested.

Specificity equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of test data from the reference population. 

Sensitivity equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population. 

APB = Abductor Pollicis Brevis  CTS = Carpal Tunnel Syndrome  RL = Residual Latency  SD = Standard Deviation
Table 8. Median Motor Nerve Terminal Latency Index in CTS.

<table>
<thead>
<tr>
<th>Author</th>
<th>Simovic and colleagues$^{237}$</th>
<th>Kuntzer$^{40}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>1999</td>
<td>1994</td>
</tr>
<tr>
<td>Number of Normal Hands (subjects)</td>
<td>38 (19)</td>
<td>63 (63)*</td>
</tr>
<tr>
<td>Normal Subject’s Age: Mean (range)</td>
<td>40 (25 to 68)</td>
<td>45 (32 to 72)*</td>
</tr>
<tr>
<td>Number of CTS Hands (patients)</td>
<td>54 (54)</td>
<td>93 (93)*</td>
</tr>
<tr>
<td>CTS Subjects Age: Mean (range)</td>
<td>50 (18 to 86)</td>
<td>50 (35 to 85)*</td>
</tr>
<tr>
<td>Technique</td>
<td>Motor conduction study</td>
<td>Motor conduction study</td>
</tr>
<tr>
<td>Stimulation Site</td>
<td>Wrist</td>
<td>Wrist</td>
</tr>
<tr>
<td>Stimulation Site</td>
<td>Elbow</td>
<td>Elbow</td>
</tr>
<tr>
<td>Recording Site</td>
<td>APB</td>
<td>APB</td>
</tr>
<tr>
<td>Minimum Hand Temperature</td>
<td>32°C</td>
<td>32°C</td>
</tr>
<tr>
<td>Terminal Latency Index ± SD</td>
<td>0.43 ± 0.045</td>
<td>0.427 ± 0.043</td>
</tr>
<tr>
<td>Criteria for Abnormal Value</td>
<td>Mean – 2 SD</td>
<td>Mean – 2 SD</td>
</tr>
<tr>
<td>Abnormal Value</td>
<td>&lt;0.34</td>
<td>&lt;0.34</td>
</tr>
<tr>
<td>Specificity of Abnormal Value</td>
<td>97.5% (estimate)</td>
<td>91.4% (actual)</td>
</tr>
<tr>
<td>Sensitivity of Abnormal Value</td>
<td>82%</td>
<td>50%</td>
</tr>
</tbody>
</table>

* For each reference subject, only 1 hand was tested; for each CTS patient, only the most symptomatic hand was tested. Terminal latency index data from 7 (10%) of 70 normal subjects and 7 (7%) of the 100 CTS subjects were excluded because of the presence of a median to ulnar crossover in the forearm and median nerve conduction velocity calculations may not be accurate in those cases. The crossover was identified by a compound muscle action potential with an initial negative (upgoing) deflection recorded over the abductor digiti minimi (gain 200 µV/div) with median nerve stimulation at the elbow. The mean and range of the ages of the remaining 63 normal subjects and 93 CTS patients were provided by the author by written communication.

Specificity equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of test data from the reference population.

Sensitivity equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population.

APB = Abductor Pollicis Brevis  CTS = Carpal Tunnel Syndrome  SD = Standard Deviation

of the THLD study approached the sensitivity of median mixed nerve palmar studies for the diagnosis of CTS because 85% of CTS patients with abnormal median mixed nerve palmar studies showed abnormal THLD. In a study that met 4 of the 6 AAEM CTS LIC, Rosen$^{214}$ also noted that median mixed nerve palmar conduction studies (100%) were much more sensitive than THLD studies (36%).

Median-Thenar to Ulnar-Thenar Latency Difference. The TTLD method was unusual because the CMAP is recorded over the thenar eminence (active electrode over the APB) with sequential stimulation at the wrist of first the median and then the ulnar nerves and one calculates the difference (TTLD) between the distal latency with median and ulnar nerve stimulation. The CMAP recorded over the thenar eminence with ulnar nerve stimulation at the wrist begin with an initial positive deflection because the CMAP was in part volume conducted from the hypothenar muscles (Sander$^{220}$). There are no studies of this method that meet all 6 AAEM CTS LIC. In a study that met 5 of the 6 AAEM CTS LIC, Sander$^{220}$ noted the sensitivity of the TTLD study approached the sensitivity of median mixed nerve palmar studies because 95% of CTS patients with abnormal median mixed nerve palmar studies showed abnormal TTLD.

Median-Lumbrical to Ulnar-Interossei Latency Difference. The LILD method is also unusual because the CMAP is recorded over the distal medial palm (active electrode
placed slightly lateral to the midpoint of the third metacarpal) with stimulation at the wrist for both the median and ulnar nerves. The median nerve CMAP is recorded from the second lumbral and the ulnar nerve CMAP is recorded from the dorsal interosseus deep to the second lumbral in the palm with the same set of recording electrodes. In contrast to the TTLD methodology described above, both CMAPs have an initial negative deflection.

In a study that met all 6 AAEM CTS LIC, Uncini demonstrated that the LILD identified a small number of additional CTS patients with normal median motor distal latency values (Table 9). Because Uncini did not simultaneously evaluate median mixed nerve palmar conduction studies in CTS patients, his results are not inconsistent with the results of Sander which showed the median mixed nerve palmar conduction studies to be more sensitive than the THLD and TTLD studies to identify CTS patients.

There were 4 studies of the LILD in CTS that met 4 or 5 of the 6 AAEM CTS LIC with the following incidence of abnormal LILD measurements in CTS: Sheean and colleagues (1995), 73%; Trojaborg (1996), 84%; Preston and Logigian (1992), 95%; and Resende (2000), 100%. Sheean and colleagues noted that the computation of the LILD was identical in sensitivity to computation of the difference in median and ulnar mixed nerve palmar CV to confirm the diagnosis of CTS; in 48 of 66 hands with suspected CTS, 48 (72%) showed abnormalities with each test and there was a close correlation between the 2 tests.

**Median F-Wave Latency Studies.** Table 10 presents the results of a study of 7 different F-wave parameters in CTS. The study by Kuntzer met 6 AAEM CTS LIC and demonstrated that none of the F-wave parameters achieved the specificity and sensitivity for the diagnosis of CTS of direct measurements of distal median motor conduction across the carpal tunnel segment of the median nerve. Sander and colleagues, in a study that met 5 of the 6 AAEM CTS LIC, evaluated the calculated difference (FWLD: F-wave latency difference) between the minimum median F-wave latency recorded from the APB and the minimum ulnar F-wave latency recorded from the ADM to identify CTS patients. In the Sander and colleagues study, the sensitivity of the FWLD to identify CTS was less than (1) comparison of median and ulnar distal motor latencies across the carpal tunnel and (2) comparison of median and ulnar mixed nerve latencies across the carpal tunnel. Macleod, in a study that met 4 of the 6 AAEM CTS LIC, noted that there was a high percentage of repeater F waves in CTS, which are identical recurring F waves with the same latency, configuration, and amplitude. However, abnormalities of median F-wave parameters can be caused by pathology not only in the carpal tunnel segment of the

| Table 9. Comparison of the Median Motor Nerve Distal Latency (2nd Lumbral) to the Ulnar Motor Nerve Distal Latency (Interossei) in CTS. |
|---|---|
| Author | Uncini and colleagues |
| Year | 1993 |
| Number of Normal Hands (subjects) | 72 (47) |
| Normal Subject’s Age: Mean (range) | 45 (18 to 78) |
| Number of CTS Hands (patients) | 95 (70) |
| CTS Subject’s Age: Mean (range) | 49 (26 to 78) |
| Technique: Conduction Distance | Anatomical landmarks |
| Stimulation Site (median) | Wrist crease |
| Stimulation Site (ulnar) | Wrist crease |
| Recording Site | Palm* |
| Minimum Hand Temperature | 32°C |
| Difference Median-Ulnar Onset Latency ± SD | 0.10 ± 0.19 ms |
| Criteria for Abnormal Value | Mean ± 2 SD |
| Abnormal Value Difference in Median and Ulnar Latency | >0.5 ms |
| Specificity of Abnormal Value | 97.5% (estimate) |
| Sensitivity of Abnormal Value | 10% (56%)† |

* Lateral to midpoint 3rd metacarpal bone
† In the Uncini and colleagues paper, comparison of median motor conduction (lumbral) and ulnar motor conduction (interossei) was done only in the CTS patients with (1) normal median sensory conduction from D2 to wrist (SCV >45 ms) and (2) normal median motor conduction from wrist to APB (MDL <4.3 ms) so that the percentage (10%) of abnormal comparison studies of median/ulnar motor conduction was reported for a subset of the CTS patient population; from the data in the paper, the maximum possible percentage of abnormal comparison studies of median/ulnar motor conduction for the whole CTS patient population was calculated to be 56%.

**Specificity** equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of test data from the reference population. **Sensitivity** equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population. **APB** = Abductor Pollicis Brevis **MDL** = Motor Distal Latency **SCV** = Sensory Conduction Velocity
median nerve, but also by pathology along the length of the median motor nerve fibers to the APB from the spinal cord to the wrist. For all these reasons, measurements of F-wave latencies and other F-wave parameters are not recommended for the diagnosis of CTS.

Buschbacher, in a study that met 5 of the 6 AAEM LIC, reported the results of F-wave parameter in 195 reference subjects. Fisher (1997) used CTS as a model for analyzing the effects of focal nerve injury on F-wave parameters.

**Median Sensory NCSs**

*Median Sensory Nerve Conduction from Digit to Wrist.* Table 11 presents the results of 6 studies of median sensory NCSs of a 13 to 14 cm length of the median nerve with the proximal portion passing through the carpal tunnel (digit-wrist studies). These 6 studies that met all 6 AAEM CTS LIC determined that between 40% and 74% of patients with CTS demonstrate either a prolonged median sensory peak latency or the median SNAP was absent. In a 1972 study that met the 6 AAEM CTS LIC, Casey and LeQuese
colleagues (1997) reported a 94% incidence of abnormal median digit-wrist sensory conduction: 15 out of 16 CTS patient studies abnormal with 9 out of 16 absent SNAP and 6 out of 16 reduced CV.

There are 4 studies listed in Table 1 that provide median sensory nerve conduction data in normal subjects which support the choice of abnormal values in the 6 studies in Table 11 for median sensory peak latency, median sensory onset latency, and median sensory CV (calculated from the onset latency and conduction distance).

There were 19 other median sensory NCSs of the peak latency, onset latency, and CV with conduction between the wrist and a digit (conduction distance of 13 to 14 cm) that met 4 or 5 of the AAEM CTS LIC with the following incidence of abnormal findings (absent response, prolonged peak or onset latency, or reduced CV) in patients with CTS: Andary and colleagues (1996), 27%; Kothari and colleagues (1995), D2 42% and D3 54%; White and colleagues (1988), 44%, if a response could be elicited; Rosen (1993), 48%; Mills (1985), 53%; Sheean and colleagues (1995), 55%; Stevens (1987), 64%; Seror (1994), peak latency 61%, CV 66%; Preston and Logigian (1992), 67%; Felsenthal (1979), 70%; Trojaborg (1996), D2 70% and D3 72%; Gunnarsson (1997), 77%; Melvin and colleagues (1973), 79%; Marinacci (1964), 83%; Monga and colleagues (1985), 86%; Kimura and Ayyar (1985), 92%; Kemble (1968), 93%; Plaja (1971), 98%; Merchut and colleagues (1990), 100%.

While most authors used the index finger (Digit 2 or D2) for stimulation or recording, some prefer to use the middle finger (Digit 3 or D3) instead of the index finger to evaluate median sensory conduction in CTS. The studies that evaluated median digit-wrist sensory conduction with several digits noted abnormalities in CTS patients more often with evaluation of the middle finger compared to the index finger, and evaluation of the thumb and sometimes the ring finger studies were more often abnormal than both the index and middle finger studies.

There are 2 studies of median sensory conduction from digit to wrist in normal subjects that met 5 of the 6 AAEM CTS LIC: Stetson (1994) D2 onset latency (3.0 ± 0.2 ms) and D2 sensory CV (SCV) (60.2 ± 4.9 m/s); Buschbacher (1996) onset (D2 = 2.6 ± 0.3 ms, D3 = 2.7 ± 0.3 ms) and peak (D2 and D3 = 3.4 ± 0.3 ms) latencies, the Buschbacher data presents mean + 2 SD values higher than most of the reference values in the 7 studies in Table 11.

**Median Sensory Nerve Conduction from the Palm to the Wrist.** Table 12 presents the results of 7 studies of median sensory and/or mixed NCSs of an 8-cm length of the median nerve passing through the carpal tunnel. These 7 studies that met all 6 AAEM CTS LIC determined that between 67% and 84% of patients with CTS demonstrate a prolonged median peak latency, onset latency, or CV with a conduction distance of 8 cm.

In Table 1, there are 4 studies of median sensory and/or mixed nerve conduction between the wrist and palm in normal subjects. Using a technique to study the conduction of the wrist-palm median nerve segment similar to Kimura, Di Benedetto and colleagues reported a difference in peak latency in healthy subjects of less than 2.2 ms, and a difference in onset latency in healthy subjects of less than 1.8 ms, the latter value almost identical to the finding of Kimura in Table 12. Cruz Martinez and colleagues calculated the CV in palm-to-wrist segments of the median nerve from the onset latency in 47 normal subjects, aged 21 to 77 Under the age of 50, the median sensory CV was 55 ± 5 m/s, and over the age of 50, the median sensory CV was 51 ± 5 m/s. Stetson (1994) in a study of 105 normal subjects noted an onset latency of 1.8 ± 0.2 ms. Buschbacher (1994) in a study of 248 normal subjects reported an onset latency of 1.6 ± 0.2 ms and a peak latency of 2.1 ± 0.2 ms.

There were 15 additional studies that report median mixed nerve conduction over a 7 cm to 8 cm distance across the carpal tunnel that met 4 or 5 of the 6 AAEM CTS LIC with the following incidence of abnormal findings in patients with CTS: Kimura (1978), 45%; Andary and colleagues (1996), 57%; White and colleagues (1988), 65%, a study that ignored cases with absent responses; Mills (1985), 67%; Robinson and colleagues (1998) 70%; Sheean and colleagues (1995), 73%; Seror (1994), 76%; Preston and Logigian (1992), 82%; Stevens (1987), 87%; Monga and colleagues (1985), 88%; Felsenthal and Spindler (1979), 100%; Wongsam (1983), 100%;
Table 10. Median Motor Nerve F-Wave Studies in CTS.

<table>
<thead>
<tr>
<th>Author</th>
<th>Kuntzer&lt;sup&gt;140&lt;/sup&gt;</th>
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<tbody>
<tr>
<td><strong>Year</strong></td>
<td>1994</td>
</tr>
<tr>
<td><strong>Number of Normal Hands (subjects)</strong></td>
<td>70 (70)*</td>
</tr>
<tr>
<td><strong>Normal Subject’s Age:</strong></td>
<td>Mean (range) 43 (25 to 70)</td>
</tr>
<tr>
<td><strong>Number of CTS Hands (patients)</strong></td>
<td>100 (100)*</td>
</tr>
<tr>
<td><strong>CTS Subjects Age:</strong></td>
<td>Mean (range) 51 (26 to 85)</td>
</tr>
<tr>
<td><strong>Stimulation Site</strong></td>
<td>Wrist</td>
</tr>
<tr>
<td><strong>Recording Site</strong></td>
<td>APB</td>
</tr>
<tr>
<td><strong>Minimum Hand Temperature</strong></td>
<td>32°C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>F-Wave Parameter</th>
<th>Persistence</th>
<th>Chronodispersion</th>
<th>Minimal latency</th>
<th>Minimal ulnar-median F-wave latency difference</th>
<th>Mean duration</th>
<th>Mean amplitude</th>
<th>Mean amplitude ratio†</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Normal ± SD</strong></td>
<td>92.8 ± 9.2%</td>
<td>1.42 ± 0.37 ms</td>
<td>27.6 ± 2.1 ms</td>
<td>0.59 ± 0.91 ms</td>
<td>10.67 ± 1.62 ms</td>
<td>0.297 ± 0.124 mV</td>
<td>2.97 ± 1.21</td>
</tr>
<tr>
<td><strong>Criteria for Abnormal Value</strong></td>
<td>Mean – 2 SD</td>
<td>Mean + 2 SD</td>
<td>Formula + 2 SD‡</td>
<td>Mean + 2 SD</td>
<td>Mean + 2 SD</td>
<td>Mean + 2 SD</td>
<td>Mean + 2 SD</td>
</tr>
<tr>
<td><strong>Abnormal Value</strong></td>
<td>&lt;70%</td>
<td>&gt;2.2 ms</td>
<td>SD = 1.4</td>
<td>72.4</td>
<td>&gt;14 ms</td>
<td>&gt;0.545 mV</td>
<td>&gt;5.39</td>
</tr>
<tr>
<td><strong>Specificity of Abnormal Value</strong></td>
<td>91% (actual)</td>
<td>80% (actual)</td>
<td>86% (actual)</td>
<td>90% (actual)</td>
<td>10% (actual)</td>
<td>10% (actual)</td>
<td>70% (actual)</td>
</tr>
<tr>
<td><strong>Sensitivity of Abnormal Value</strong></td>
<td>35%</td>
<td>69%</td>
<td>16%</td>
<td>48%</td>
<td>2%</td>
<td>2%</td>
<td>15%</td>
</tr>
</tbody>
</table>

* For each reference subject, only 1 hand was tested; for each CTS patient, only the most symptomatic hand was tested.
† Mean F-wave amplitude as a percentage of the median CMAP.
‡ Formula: minimum F-wave latency (ms) equals 0.12 × height (cm) + 6.8.

**Specificity** equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of test data from the reference population.

**Sensitivity** equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population.

CTS = Carpal Tunnel Syndrome  SD = Standard Deviation  APB = Abductor Pollicis Brevis  CMAP = Compound Muscle Action Potential
## Table 11. Median Sensory Nerve Conduction Between Wrist and Digit in CTS.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Number of Normal Hands (subjects)</th>
<th>Normal Subject' s Age: Mean (range)</th>
<th>Number of CTS Hands (patients)</th>
<th>CTS Subject' s Age: Mean (range)</th>
<th>Technique: Conduction Distance</th>
<th>Recording Site</th>
<th>Minimum Hand Temperature</th>
<th>Median Sensory Peak Latency ± SD</th>
<th>Median Sensory Onset Latency ± SD</th>
<th>Median Sensory Conduction Velocity (calculated from onset latency) ± SD</th>
<th>Criteria for Abnormal Value</th>
<th>Abnormal Value</th>
<th>Specificity of Abnormal Value</th>
<th>Sensitivity of Abnormal Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casey and LeQuesne39</td>
<td>1972</td>
<td>75 (75)</td>
<td>51 (30 to 70)</td>
<td>16 (16)</td>
<td>56 (35 to 70)</td>
<td>Anatomical landmarks</td>
<td>Wrist</td>
<td>35°C</td>
<td>Not reported</td>
<td>Not reported</td>
<td>54.8 ± 7.3 m/s</td>
<td>Mean - 2 SD</td>
<td>&lt;40 m/s</td>
<td>97.5% (estimate)</td>
<td>43%</td>
</tr>
<tr>
<td>Kimura130</td>
<td>1979</td>
<td>122 (61)</td>
<td>43 (15 to 50)</td>
<td>172 (105)</td>
<td>48 (20 to 78)</td>
<td>Anatomical landmarks</td>
<td>Index finger (D2)</td>
<td>34°C</td>
<td>Not reported</td>
<td>Not reported</td>
<td>2.91 ± 0.24 ms (age 40 to 59)</td>
<td>Mean + 2 SD</td>
<td>Sensory latency &gt;3.4 ms</td>
<td>97.5% (estimate)</td>
<td>63%</td>
</tr>
<tr>
<td>Carroll18</td>
<td>1987</td>
<td>100 (50)</td>
<td>47 (16 to 82)</td>
<td>161 (101)</td>
<td>45 (22 to 82)</td>
<td>13 cm (anatomical landmarks)</td>
<td>Wrist</td>
<td>30°C</td>
<td>3.16 ± 0.16 ms (age 16 to 39)</td>
<td>2.82 ± 0.28 ms (age 40 to 59)</td>
<td>3.5 ms (age 60 to 82)</td>
<td>Mean + 2 SD</td>
<td>&lt;30 m/s</td>
<td>100% (actual)</td>
<td>49%</td>
</tr>
<tr>
<td>Jackson and Clifford18</td>
<td>1989</td>
<td>38 (38)</td>
<td>42 (21 to 69)</td>
<td>131 (123)</td>
<td>53 (21 to 85)</td>
<td>14 cm (anatomical landmarks)</td>
<td>Index finger (D2)</td>
<td>31°C</td>
<td>Not reported</td>
<td>Not reported</td>
<td>2.71 ± 0.23 ms (age 16 to 39)</td>
<td>Mean - 2 SD</td>
<td>Sensory latency &gt;3.4 ms</td>
<td>97.5% (estimate)</td>
<td>66%</td>
</tr>
<tr>
<td>Cioni and colleagues47</td>
<td>1989</td>
<td>56 (54)</td>
<td>38 (18 to 68)</td>
<td>375 (370)</td>
<td>46 (20 to 72)</td>
<td>14 cm (anatomical landmarks)</td>
<td>Index finger (D2)</td>
<td>32°C</td>
<td>Not reported</td>
<td>Not reported</td>
<td>3.03 ± 0.23 ms (age 40 to 59)</td>
<td>Mean + 2 SD</td>
<td>Sensory latency &gt;3.4 ms</td>
<td>97.5% (estimate)</td>
<td>80% (96%)§</td>
</tr>
<tr>
<td>Kuntzer140</td>
<td>1994</td>
<td>70 (70)†</td>
<td>43 (25 to 70)</td>
<td>100 (100)†</td>
<td>46 (20 to 85)</td>
<td>14 cm (anatomical landmarks)</td>
<td>Middle finger (D3)</td>
<td>32°C</td>
<td>Not reported</td>
<td>Not reported</td>
<td>3.16 ± 0.16 ms (age 16 to 39)</td>
<td>Mean + 2 SD</td>
<td>Sensory latency &gt;3.4 ms</td>
<td>100% (actual)</td>
<td>49%</td>
</tr>
<tr>
<td>Padua and colleagues188</td>
<td>1996</td>
<td>40 (36)</td>
<td>44 (19 to 79)</td>
<td>50 (43)</td>
<td>51 (26 to 85)</td>
<td>14 cm (anatomical landmarks)</td>
<td>Wrist</td>
<td>37°C</td>
<td>Not reported</td>
<td>Not reported</td>
<td>2.47 ± 0.12 ms (age 16 to 39)</td>
<td>Mean + 2 SD</td>
<td>Sensory latency &gt;3.4 ms</td>
<td>97.5% (estimate)</td>
<td>49%</td>
</tr>
<tr>
<td>Padua and colleagues189</td>
<td>1997*</td>
<td>30 (25)</td>
<td>42 (23 to 63)</td>
<td>500 (379)</td>
<td>45 (23 to 80)</td>
<td>14 cm (anatomical landmarks)</td>
<td>Wrist</td>
<td>31°C</td>
<td>Not reported</td>
<td>Not reported</td>
<td>3.5 ms (age 60 to 82)</td>
<td>Mean + 2 SD</td>
<td>Sensory latency &gt;3.4 ms</td>
<td>97.5% (actual)</td>
<td>40%</td>
</tr>
<tr>
<td>Scelsa and colleagues221</td>
<td>1998</td>
<td></td>
<td></td>
<td></td>
<td>51 (20 to 88)</td>
<td>14 cm (anatomical landmarks)</td>
<td>Wrist</td>
<td>31°C</td>
<td>Not reported</td>
<td>Not reported</td>
<td>3.16 ± 0.16 ms (age 16 to 39)</td>
<td>Mean + 2 SD</td>
<td>Sensory latency &gt;3.4 ms</td>
<td>97.5% (estimate)</td>
<td>49%</td>
</tr>
</tbody>
</table>

The antidromic median nerve conduction studies cited in Table 9 were performed by securing surface recording ring electrodes on the index or middle finger and stimulating the median nerve in the wrist proximal to the carpal tunnel. With these anatomic landmarks, the conduction distance is usually 13 to 14 cm in normal adults. The time (latency) from the stimulus artifact to the onset or peak of the negative deflection of the biphasic or triphasic waveform was measured in milliseconds and recorded as the median sensory peak latency. Studies have shown that the orthodromic median nerve sensory conduction study can be performed by stimulating the digit and recording from the wrist and the latency measurements results are essentially identical though the amplitude of the sensory nerve action potential (SNAP) is less.147 Slowing of median nerve sensory conduction in the carpal tunnel with nerve injury will result in prolongation of the median sensory peak latency and slowing of the conduction velocity.

* 1997 paper cites reference population studies performed in the same laboratory published in 1996.
† For each reference subject, only 1 hand was tested; for each CTS patient, only the most symptomatic hand was tested. § Written communication. ¶ In the Cioni and colleagues paper,47 measurement of the median SNCV from digit to wrist was done only in a CTS patient’s hand with normal median motor distal latency (≤ 4.3 ms) so that the percentage (80%) of abnormal median SNCV was reported for a subset of the CTS population; from the data in the paper, the maximum possible percentage of abnormal median SNCVs for the whole CTS population was calculated to be 96%. # Written communication: calculated form the onset latency.

**Specificity** equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of test data from the reference population.
**Sensitivity** equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population.

**CTS** = Carpal Tunnel Syndrome  
**SD** = Standard Deviation  
**SNCV** = Sensory Nerve Conduction Velocity
### Table 12. Median Sensory and Mixed Nerve Conduction Between Wrist and Palm in CTS.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Number of Normal Hands (subjects)</th>
<th>Normal Subject’s Age: Mean (range)</th>
<th>Number of CTS Hands (patients)</th>
<th>CTS Subject’s Age: Mean (range)</th>
<th>Technique: Conduction Distance</th>
<th>Stimulation Site</th>
<th>Recording Site(s)</th>
<th>Minimum Hand Temperature</th>
<th>Median Sensory Onset Latency ± SD</th>
<th>Median Sensory Peak Latency ± SD</th>
<th>Difference Median Sensory Onset Latency ± SD</th>
<th>Median Sensory Conduction Velocity ± SD</th>
<th>Criteria for Abnormal Value</th>
<th>Abnormal Value</th>
<th>Specificity of Abnormal Value</th>
<th>Sensitivity of Abnormal Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jackson and Clifford</td>
<td>1989</td>
<td>38 (38)</td>
<td>131 (123)</td>
<td>172 (105)¥</td>
<td>53 (21 to 85)</td>
<td>8 cm</td>
<td>Palm</td>
<td>D2</td>
<td>31°C</td>
<td>1.54 ± 0.12 ms</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Mean + 2 SD</td>
<td>Onset &gt;1.78 ms, Peak &gt;2.27 ms</td>
<td>97% (actual)</td>
<td>69%</td>
<td></td>
</tr>
<tr>
<td>Clifford</td>
<td>1979</td>
<td>122 (61)</td>
<td>122 (61)</td>
<td>172 (105)¥</td>
<td>53 (21 to 85)</td>
<td>8 cm</td>
<td>Wrist crease: 3 cm proximal, 5 cm distal</td>
<td>Palm</td>
<td>Wrist</td>
<td>34°C</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Mean + 2 SD</td>
<td>Onset &gt;1.78 ms, Peak &gt;2.27 ms</td>
<td>97.5% (estimate)</td>
<td>84%</td>
</tr>
<tr>
<td>Kuntzer</td>
<td>1998</td>
<td>30 (25)</td>
<td>30 (25)</td>
<td>67 (42)</td>
<td>50 (25 to 85)</td>
<td>8 cm</td>
<td>Palm</td>
<td>Palm</td>
<td>32°C</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Mean + 2 SD</td>
<td>Difference &gt;1.8 ms</td>
<td>98% (actual)</td>
<td>67%</td>
<td></td>
</tr>
<tr>
<td>Scelsa and colleagues</td>
<td>1994</td>
<td>70 (70)†</td>
<td>70 (70)†</td>
<td>100 (100)†</td>
<td>51 (26 to 85)</td>
<td>8 cm</td>
<td>Palm</td>
<td>Palm</td>
<td>32°C</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Mean + 2 SD</td>
<td>&lt;46 m/s</td>
<td>97% (estimate)</td>
<td>83%</td>
<td></td>
</tr>
<tr>
<td>Di Guglielmo and colleagues</td>
<td>1997</td>
<td>88 (69)</td>
<td>88 (69)</td>
<td>294 (198)</td>
<td>46 (13 to 84)</td>
<td>8 cm</td>
<td>Palm</td>
<td>D3</td>
<td>32°C</td>
<td>58.5 ± 5.2 m/s§</td>
<td>54.2 ± 3.1 m/s</td>
<td>59.5 ± 5.2 m/s§ (written communication)</td>
<td>Mean + 2 SD</td>
<td>&lt;45 m/s</td>
<td>97.5% (estimate)</td>
<td>13% (56%)#</td>
<td></td>
</tr>
<tr>
<td>Padua and colleagues</td>
<td>1996</td>
<td>40 (36)</td>
<td>40 (20 to 86)</td>
<td>294 (198)</td>
<td>45 (23 to 80)</td>
<td>8 cm</td>
<td>Palm and wrist</td>
<td>Wrist</td>
<td>31°C</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Mean + 2 SD</td>
<td>&lt;45 m/s</td>
<td>97.5% (estimate)</td>
<td>76%</td>
<td></td>
</tr>
<tr>
<td>Padua and colleagues</td>
<td>1997*</td>
<td>50 (43)</td>
<td>44 (19 to 79)</td>
<td>294 (198)</td>
<td>51 (20 to 88)</td>
<td>8 cm</td>
<td>Palm and wrist</td>
<td>D3</td>
<td>32°C</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Not reported</td>
<td>Mean + 2 SD</td>
<td>&lt;45 m/s</td>
<td>97.5% (estimate)</td>
<td>20% (81%)*</td>
<td></td>
</tr>
</tbody>
</table>

The nerve conduction studies of the carpal tunnel segment of the median nerve described in Table 8 were obtained in 3 different ways. (1) To study median mixed nerve conduction, Jackson and Clifford, Kuntzer,140 and Scelsa and colleagues,221 placed recording disc electrodes over the median nerve above the wrist and stimulated the median nerve in the palm between the 2nd and 3rd metacarpal heads with measurement of the conduction distance. Measurements of the time (ms) from the stimulus artifact to the onset and negative peak of the potential were recorded as the onset and peak latencies, respectively. (2) To study median sensory nerve conduction, Kimura130 and Di Guglielmo and colleagues59 placed recording ring electrodes on the index finger and stimulated the median nerve in 2 locations, 3 cm proximal to the wrist crease and 5 cm distal to the wrist crease. Measurements of the time (ms) from the stimulus artifact to the onset of the sensory nerve action potential or SNAP (onset latency) were made for each site and the difference calculated and (a) reported as the conduction time of the sensory fibers in the median nerve segment in the carpal tunnel or (b) used to calculate the sensory conduction velocity (SCV) of the carpal tunnel segment. (3) To study median nerve sensory conduction, Padua and colleagues188,189 placed stimulating ring electrodes on the middle finger and a bipolar bar electrodes on the palm and wrist. The palm-wrist conduction velocity was calculated as (palm-wrist distance / [(digit-wrist onset latency) - (digit palm onset latency)]).

* The 1997 Padua and colleagues paper189 referenced studies of normal subjects published in the 1996 Padua and colleagues paper.188 In the 1997 Padua and colleagues paper,189 measurement of median sensory conduction in the carpal tunnel segment was done only in CTS patients with normal (1) median sensory conduction from D1 to wrist (SCV >42 m/s), (2) normal median sensory conduction from D3 to wrist (SCV >44 m/s), and (3) normal median motor distal latency (<4 ms) so that the percentage (20%) of abnormal median sensory conduction across the wrist was reported for a subset of the CTS population; from the data in the paper, the maximum possible percentage of abnormal median sensory conduction in the carpal tunnel segment for the whole CTS patient population was calculated to be 81%.

† For each reference subject, only 1 hand was tested for each CTS patient, only the most symptomatic hand was tested. ‡ Written communication. § Calculated from onset latency (written communication).

CTS = Carpal Tunnel Syndrome  SD = Standard Deviation

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**Practice Parameter: Carpal Tunnel Syndrome**

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**S942 CTS Literature Review**

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Rosen (1993), 100%; Rossi and colleagues (1994), 100%.

In a study that met 4 of the 6 AAEM CTS LIC, Rossi reported a variation on the orthodromic median and ulnar palmar conduction studies with a slightly longer conduction distance (about 10 cm) to enable selective stimulation of the palmar branches to the adjacent surfaces of the digits at the metacarpophalangeal joints. Rossi concluded that stimulation of the palmar branch to the adjacent surfaces of the middle and ring fingers demonstrated a measurable abnormal response when the orthodromic median sensory response with stimulation of the fourth digit was absent and when the response with stimulation of the palmar branch of the median nerve to the adjacent surfaces of the index and middle fingers was normal.

**Median SNAP Amplitude Studies.** Kuntzer, in a report that met all 6 AAEM CTS LIC, confirmed that the measurements of median sensory conduction from digit to wrist is more often abnormal in CTS patients than the measurement of median SNAP amplitude, 49% versus 30% (Table 13). In a study that met 5 of the 6 AAEM CTS LIC, Sander noted that median sensory conduction from digit to wrist is more abnormal in CTS than measurement of median SNAP amplitude, 64% versus 48%. In a study that met 4 of the 6 AAEM CTS LIC, Sheean and colleagues (1995) also noted that median sensory conduction from digit to wrist is more often abnormal in CTS patients than median SNAP amplitude, 55% versus 41%. Two recent studies (Seror and Nesathurai) and several earlier studies that compared the diagnostic sensitivity of median sensory conduction from digit to wrist to measurements of median SNAP amplitudes reached the same conclusion with the exception of Loong and Seah, who computed the ratio of the median SNAP amplitude to the ulnar SNAP amplitude in the same hand.

Two studies of normal subjects that met 5 of the 6 AAEM CTS LIC noted values slightly greater than the values reported by Kuntzer in Table 13 for normal subjects for the mean and SD of the median SNAP amplitude: 32.7 ± 11.4 μV by Stetson (1995) and 41 ± 20 μV by Buschbacher. In a study of 258 normal subjects listed in Table 1, Buschbacher noted up to a 50% to 55% increase in the conduction block was low (13%) with the criteria of a greater than 50% reduction in SNAP amplitude. Lesser and colleagues, in a study that met 5 of the 6 AAEM CTS LIC, reported that 36% of CTS patients showed evidence of sensory conduction block across the carpal tunnel but did not provide data on temporal dispersion and phase cancellation which would give the appearance of conduction block as did Di Guglielmo.

<table>
<thead>
<tr>
<th>Table 13. Median SNAP Amplitude in CTS.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author</strong></td>
</tr>
<tr>
<td><strong>Year</strong></td>
</tr>
<tr>
<td><strong>Number of Normal Hands (subjects)</strong></td>
</tr>
<tr>
<td><strong>Normal Subject's Age: Mean (range)</strong></td>
</tr>
<tr>
<td><strong>Number CTS Hands (patients)</strong></td>
</tr>
<tr>
<td><strong>CTS Subject Age</strong></td>
</tr>
<tr>
<td><strong>Stimulation Site</strong></td>
</tr>
<tr>
<td><strong>Recording Site</strong></td>
</tr>
<tr>
<td><strong>Minimum Hand Temperature</strong></td>
</tr>
<tr>
<td><strong>Normal SNAP Amplitude ± SD</strong></td>
</tr>
<tr>
<td><strong>Criteria for Abnormal Value</strong></td>
</tr>
<tr>
<td><strong>Abnormal Values</strong></td>
</tr>
<tr>
<td><strong>Specificity of Abnormal Value</strong></td>
</tr>
<tr>
<td><strong>Sensitivity of Abnormal Value†</strong></td>
</tr>
</tbody>
</table>

* For each reference subject, only 1 hand was tested; for each CTS patient, only the most symptomatic hand was tested.
† Stimulation of the most symptomatic finger or third digit.

**Specificity** equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of test data from the reference population.

**Sensitivity** equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population.

**CTS** = Carpal Tunnel Syndrome, **SD** = Standard Deviation, **SNAP** = Sensory Nerve Action Potential.
Table 14. Median SNAP Wrist to Palm Amplitude Ratio in CTS.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Number of Normal Hands (subjects)</th>
<th>Normal Subject’s Age: Mean (range)</th>
<th>Number of CTS Hands (subjects)</th>
<th>CTS Subject’s Age: Mean (range)</th>
<th>Technique: Conduction Distance</th>
<th>Wrist Stimulation Site</th>
<th>Palm Stimulation Site</th>
<th>Recording Site</th>
<th>Minimum Temperature</th>
<th>Amplitude (wrist) ± SD</th>
<th>Amplitude (palm) ± SD</th>
<th>Wrist to Palm Amplitude Ratio ± SD</th>
<th>Criteria for Abnormal Value</th>
<th>Abnormal Value</th>
<th>Specificity of Abnormal Value</th>
<th>Sensitivity of Abnormal Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Di Guglielmo and colleagues</td>
<td>1997</td>
<td>88 (69)</td>
<td>40 (20 to 86)</td>
<td>294 (198)</td>
<td>46 (13 to 84)</td>
<td>Anatomical landmarks</td>
<td>1 cm to 2 cm proximal to wrist crease</td>
<td>3 cm distal to wrist crease</td>
<td>D2</td>
<td>32°C</td>
<td>42 ± 19 µV</td>
<td>45 ± 21 µV</td>
<td>0.8 ± 0.2</td>
<td>Lowest value of range of normal values*</td>
<td>&lt;0.5</td>
<td>100% (actual)</td>
<td>13%</td>
<td>Written communication.</td>
</tr>
</tbody>
</table>

SNAP amplitude between wrist and palm stimulation in normal subjects, a finding similar to that reported by Di Guglielmo.59

Median Sensory Short-segment Incremental Studies. Table 15 presents the results of sequential antidromic stimulation of the median sensory nerve at 1-cm intervals across the carpal tunnel recording from the middle finger.

Table 15. Short-segment Incremental Median Sensory Nerve Conduction Across the Carpal Tunnel in CTS.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Number of Normal Hands (subjects)</th>
<th>Normal Subject’s Age: Mean (range)</th>
<th>Number of CTS Hands (patients)</th>
<th>CTS Subject’s Age: Mean (range)</th>
<th>Technique: Conduction Distance</th>
<th>Stimulation Site</th>
<th>Referenced to the Wrist Crease</th>
<th>Recording Site</th>
<th>Minimum Hand Temperature</th>
<th>Maximum Difference between Consecutive Segments ± SD</th>
<th>Criteria for Abnormal Value</th>
<th>Abnormal Value</th>
<th>Specificity of Abnormal Value</th>
<th>Sensitivity of Abnormal Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nathan and colleagues</td>
<td>1988</td>
<td>70 (38)</td>
<td>38 (16 to 69)*</td>
<td>54 (30)</td>
<td>43 (23 to 70)*</td>
<td>1-cm intervals</td>
<td>9 points</td>
<td>Start 2 cm proximal End 6 cm distal</td>
<td>Middle finger</td>
<td>30°C</td>
<td>0.29 ± 0.8 ms</td>
<td>Calculated range of normal 0.1 to 0.3 ms</td>
<td>&gt;0.4 ms / &gt;0.5 ms</td>
<td>81% / 97% (actual)</td>
<td>81% / 54%</td>
<td>Written communication.</td>
</tr>
</tbody>
</table>

The median sensory conduction study was performed by placing the recording ring electrodes on the middle finger and stimulating the median nerve at 9 points separated by 1-cm intervals beginning 2 cm proximal to the wrist crease and ending 6 cm distal to the wrist crease. The time (ms) from the stimulus artifact to the peak of the SNAP was measured for each stimulation site and the difference between the peak latency for successive SNAPs was calculated. Two years later, Nathan and colleagues,182 in a study that also met 6/6 AAEM CTS LIC, localized the slowing of conduction most commonly to the an area 3 to 4 cm distal to the wrist crease.

Specificity equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of test data from the reference population. Sensitivity equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population.

CTS = Carpal Tunnel Syndrome  SD = Standard Deviation  SNAP = Sensory Nerve Action Potential by Nathan and colleagues,181 a short-segment incremental stimulation technique (antidromic inching test or AIT) initially described by Kimura.130 Though time consuming, the landmark studies by Kimura128,130 localized the...
abnormality of median sensory conduction in most CTS patients to the distal edge of the carpal ligament, and this finding has been confirmed by Nathan and colleagues,182 White and colleagues,204 Imaoka and colleagues,206 and Seror.226 Because a frequency distribution of the segmental latency differences in the normal subjects showed a skewed distribution of data, Nathan181 used a contingency table to evaluate the sensitivity and specificity of 2 different criteria of abnormality (0.4 ms and 0.5 ms). Although Nathan181 recommends use of the 0.4 ms criterion of abnormality, only the 0.5 ms criterion provides specificity (97%) comparable to the other tests presented in this review.

Imaoka and colleagues106 in a study that met 5 of the 6 AAEM CTS LIC, used a special linear grid of 9 surface electrodes at 15 mm intervals (a total of 8 neighboring pairs of electrodes) to record the median SNAP simultaneously across the wrist with stimulation of the median nerve at the elbow. With a criterion of deviation by 0.6 ms or more from a predicted peak latency value based on measurements of peak latencies recorded proximal to the wrist crease, Imaoka106 and colleagues (1992) reported a specificity of 99% compared to normal subjects (mean ± 3 SD) and a high test sensitivity (87% in mild CTS).

Seror,226 in a study that met 4 of the 6 AAEM CTS LIC, used an orthodromic inching test (OIT) with stimulation of the third digit and measuring the peak latency of the SNAP recorded with a bipolar fixed distance (22 mm) surface electrode moved centimeter by centimeter from a point 4 cm proximal to the distal wrist crease to a point 6 cm distal to the distal wrist crease to provide 11 measurements; an abnormality was defined as a conduction delay greater than 0.36 ms based on control studies with a range of 0.20 to 0.34 ms. Seror226 concluded that most CTS patients can be diagnosed with other methods and that the more time consuming “inching” technique is needed to confirm the diagnosis in only about 5% of all CTS patients.

Seror,224 in a study that met 4 of the 6 AAEM CTS LIC, concluded that the OIT was superior to the AIT because the OIT was more sensitive than the AIT, the stimulation site and intensity was unchanged during the study which ensures that the same nerve fibers are evaluated, and the stimulation intensity is less and better tolerated by the patient compared to AIT.

Comparison of Carpal Tunnel Segment Median Mixed Nerve Conduction to More Proximal (Forearm) Mixed Nerve Conduction or Distal (palm to digit) Median Sensory Nerve Conduction. The possible usefulness of comparing CVs of different segments of the same nerve to demonstrate focal conduction slowing to minimize intersubject variability has been evaluated with median sensory and mixed nerve conduction in CTS patients. The results of 2 studies that met all 6 AAEM CTS LIC are presented in Table 16. The first by Scelsa concluded that comparison of the median palm to index finger sensory CV to the median carpal tunnel mixed nerve CV demonstrated a sensitivity to detect CTS (87%) that was significantly greater than the sensitivity (61%) of comparison of the median forearm CV to the median carpal tunnel CV with similar specificities (98% and 96%, respectively). The second by Kuntzer presented an intermediate sensitivity (69%) with similar specificity (99%) by comparison of the peak latency of the mixed nerve median palm to wrist segment to the peak latency of the median sensory palm to D2 segment. There are also 2 studies that meet all 6 AAEM CTS LIC by Padua and colleagues that described the usefulness of a ratio of the orthodromic sensory CV for 2 segments of the median sensory nerve (D3 to palm/palm to wrist) to diagnose CTS with high sensitivity: 1996, 98% and 1997, 97%.

In 1985, Kimura and Ayyar111 reported a 100% incidence of abnormalities in CTS patients if the ratio of the median antidromic sensory CV across the wrist to the median sensory CV across the forearm was calculated. However, in a study that met 4 of the 6 AAEM CTS LIC, Rosen noted that the quotient of the median antidromic mixed nerve CV in the carpal tunnel segment to the antidromic median sensory CV in the forearm segment (70%) was less sensitive than median mixed nerve palm to wrist conduction (100%).

Buschbacher,35 in a study of 258 normal subjects listed in Table 1, noted that 50% of the wrist to digit median sensory peak latency is attributable to the wrist-palm segment, a finding that agrees well with the ratio of the peak latency for the 2 segments reported by Kuntzer,140 0.98 ± 0.17 in Table 16.

Comparison of Median Sensory Nerve Conduction to Ulnar or Radial Sensory Nerve Conduction in the Same Limb. In theory, the biologic variation in speed of nerve conduction from person to person due to age and genetic differences can be controlled by comparison of the speed of nerve conduction in 1 nerve to another nerve in the same limb.99,243 This comparison principle underlies the basis for development of the sensory NCSs reported in Tables 17, 18, 19, and 20.

Comparison of Median and Ulnar Sensory Nerve Conduction Between Wrist and Digit. Table 17 presents the results of a study that met all 6 AAEM CTS LIC by Kuntzer who determined the difference between the median and ulnar nerve peak latency measurements with orthodromic stimulation (14-cm conduction distance) in CTS patients and normal control subjects and found the percentage of CTS patients with abnormal values was 61%. Stetson242 in a
Table 16. Median Sensory and Mixed Nerve Conduction in CTS: Wrist and Palm Segment Compared to Forearm or Digit Segment.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Number of Normal Hands (subjects)</th>
<th>Normal Subject’s Age: Mean (range)</th>
<th>Number of CTS Hands (patients)</th>
<th>CTS Subject’s Age: Mean (range)</th>
<th>Technique: Conduction Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scelsa and colleagues</td>
<td>1998</td>
<td>30 (25)</td>
<td>42 (23 to 63)</td>
<td>67 (42)</td>
<td>50 (25 to 85)</td>
<td>Anatomical landmarks</td>
</tr>
<tr>
<td>Kuntzer</td>
<td>1994</td>
<td>70 (70);</td>
<td>43 (25 to 70)</td>
<td>100 (100);</td>
<td>51 (26 to 85)</td>
<td>Anatomical landmarks</td>
</tr>
<tr>
<td>Padua and colleagues</td>
<td>1996</td>
<td>40 (36)</td>
<td>44 (19 to 79)</td>
<td>50 (43)</td>
<td>45 (23 to 80)</td>
<td>Anatomical landmarks</td>
</tr>
<tr>
<td>Padua and colleagues</td>
<td>1997*</td>
<td></td>
<td></td>
<td>500 (379)</td>
<td>51 (20 to 88)</td>
<td>Anatomical landmarks</td>
</tr>
</tbody>
</table>

**Carpal Tunnel Segment**

- **Stimulation Site**: Palm
- **Recording Site**: Wrist

**Other Segment**

- **Stimulation Site**: Palm
- **Recording Site**: Wrist

<table>
<thead>
<tr>
<th>Technique: Conduction Distance</th>
<th>Author</th>
<th>Year</th>
<th>Number of Normal Hands (subjects)</th>
<th>Normal Subject’s Age: Mean (range)</th>
<th>Number of CTS Hands (patients)</th>
<th>CTS Subject’s Age: Mean (range)</th>
<th>Technique: Conduction Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anatomical landmarks</td>
<td>Scelsa and colleagues</td>
<td>1998</td>
<td>30 (25)</td>
<td>42 (23 to 63)</td>
<td>67 (42)</td>
<td>50 (25 to 85)</td>
<td>Anatomical landmarks</td>
</tr>
<tr>
<td>Anatomical landmarks</td>
<td>Kuntzer</td>
<td>1994</td>
<td>70 (70)</td>
<td>43 (25 to 70)</td>
<td>100 (100);</td>
<td>51 (26 to 85)</td>
<td>Anatomical landmarks</td>
</tr>
<tr>
<td>Anatomical landmarks</td>
<td>Padua and colleagues</td>
<td>1996</td>
<td>40 (36)</td>
<td>44 (19 to 79)</td>
<td>50 (43)</td>
<td>45 (23 to 80)</td>
<td>Anatomical landmarks</td>
</tr>
<tr>
<td>Anatomical landmarks</td>
<td>Padua and colleagues</td>
<td>1997*</td>
<td></td>
<td></td>
<td>500 (379)</td>
<td>51 (20 to 88)</td>
<td>Anatomical landmarks</td>
</tr>
</tbody>
</table>

**Carpal Tunnel Segment**

- **Stimulation Site**: Palm
- **Recording Site**: Wrist

**Other Segment**

- **Stimulation Site**: Palm
- **Recording Site**: Wrist

**Technique: Conduction Distance**

- **Anatomical landmarks**

**Specificity** equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of test data from the reference population.

**Sensitivity** equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population.

**CTS** = Carpal Tunnel Syndrome  **SD** = Standard Deviation  **SNCV** = Sensory Nerve Conduction Velocity  **SCV** = Sensory Conduction Velocity
study of 105 normal subjects listed in Table 1, noted a value (mean + 2 SD = 0.5ms) identical to that reported by Kuntzer.\textsuperscript{140} A study that met 5 of the 6 AAEM CTS LIC showed a slightly lower sensitivity for the same test in CTS patients: Andary\textsuperscript{9} (1996), 42%.

 Comparison of Median and Ulnar Sensory (Mixed) Nerve Conduction between Wrist and Palm. Table 18 presents the results of 2 studies that met all 6 AAEM CTS LIC. Both Jackson and Clifford\textsuperscript{110} and Uncini\textsuperscript{254} determined the difference between the median and ulnar nerve latency measurements with palmar stimulation (8 cm conduction distance to recording electrodes over the wrist) in CTS patients and normal subjects. Jackson and Clifford\textsuperscript{110} found the percentage of CTS patients with abnormal values was 66% and Uncini\textsuperscript{254} reported abnormalities in 56% of CTS patients with normal median sensory conduction from D2 to wrist (SCV >45 m/s). Jackson and Clifford\textsuperscript{110} and Uncini\textsuperscript{254} reported values for the median-ulnar palmar latency difference for normal hands (96% <0.4 ms) and (97% <0.4 ms), respectively, similar to the findings of 3 independent studies of normal hands: Redmond and Rivner\textsuperscript{204} (92% <0.5 ms), Stetson and colleagues\textsuperscript{242} (95% <0.5 ms) and Buschbacher\textsuperscript{36} (97% <0.5 ms). Six studies that met 4 or 5 of the 6 AAEM CTS LIC showed similar sensitivity of the comparison study of median and ulnar mixed NCSs between wrist and palm in CTS patients: Kim\textsuperscript{127} (1983), 57%; Mills\textsuperscript{171} (1985), 60%; Andary\textsuperscript{9} (1996), 61%; Robinson\textsuperscript{211} (1998) 70%; Sheean and colleagues\textsuperscript{233} (1995) 73%; and Preston and Logigian\textsuperscript{200} (1994), 94%.

 Comparison of Median and Ulnar Sensory Conduction between Wrist and Ring Finger. Table 19 presents the results of 2 studies which compared the speed of sensory conduction in the branches of the median and ulnar nerves to the ring finger and found between 77% to 82% showed abnormalities. Stetson,\textsuperscript{242} in a study of normal hands, noted a similar mean and slightly greater standard deviation for the median-ulnar difference (0.1 ± 0.25 ms) than the 2 studies in Table 19. Cioni and colleagues,\textsuperscript{47} in a study that met all 6 AAEM CTS LIC, found 100% of CTS patients showed abnormal median sensory conduction compared to ulnar sensory conduction in the ring finger. These findings are similar to the findings of 7 studies that met 4 or 5 of the 6 AAEM CTS LIC Robinson and colleagues\textsuperscript{211} (1998), 74%; Uncini and colleagues\textsuperscript{255} (1989), 78%; Lauritzen and colleagues\textsuperscript{143} (1991), 87%; Monga and Laidlow\textsuperscript{173} (1982), 93%; Seror\textsuperscript{228} (1994), 97%; Johnson and colleagues\textsuperscript{66} (1981), 100%; Charles and colleagues\textsuperscript{48} (1990), 100%.

### Table 17. Comparison of Median and Ulnar Sensory Nerve Conduction Between Wrist and Digit in CTS.

<table>
<thead>
<tr>
<th>Author</th>
<th>Kuntzer\textsuperscript{140}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>1994</td>
</tr>
<tr>
<td>Number of Normal Hands (subjects)</td>
<td>70 (70)*</td>
</tr>
<tr>
<td>Normal Subject’s Age: Mean (range)</td>
<td>43 (25 to 70)</td>
</tr>
<tr>
<td>Number of CTS Hands (patients)</td>
<td>100 (100)*</td>
</tr>
<tr>
<td>CTS Subject’s Age: Mean (range)</td>
<td>51 (26 to 85)</td>
</tr>
<tr>
<td>Technique: Conduction Distance</td>
<td>14 cm</td>
</tr>
<tr>
<td>Stimulation Site</td>
<td>Median: Digit 3\textsuperscript{†} Ulnar: Digit 5</td>
</tr>
<tr>
<td>Recording Site</td>
<td>Wrist</td>
</tr>
<tr>
<td>Minimum Hand Temperature</td>
<td>32°C</td>
</tr>
<tr>
<td>Difference Median-Ulnar Peak Latency ± SD</td>
<td>0.14 ± 0.16 ms</td>
</tr>
<tr>
<td>Criteria for Abnormal Value</td>
<td>Mean + 2 SD</td>
</tr>
<tr>
<td>Abnormal Value Difference in Median and Ulnar Peak Latency</td>
<td>&gt;0.50 ms</td>
</tr>
<tr>
<td>Specificity of Abnormal Value</td>
<td>100% (actual)</td>
</tr>
<tr>
<td>Sensitivity of Abnormal Value</td>
<td>61% (actual)</td>
</tr>
</tbody>
</table>

* For each reference subject, only 1 hand was tested and for each CTS patient, the most symptomatic hand was tested.
† D3 or the most symptomatic digit was tested.

Specificity equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of test data from the reference population.

Sensitivity equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population.

CTS = Carpal Tunnel Syndrome  SD = Standard Deviation
When performing the antidromic median and ulnar sensory conduction study from wrist to D4 (conduction distance of 14 cm), Laroy\textsuperscript{142} recommended simultaneous recording of SNAPs from another median (D3) and ulnar (D5) innervated digit to detect inadvertent co-stimulation of the median and ulnar nerves in the wrist. In the same study, Laroy\textsuperscript{142} found no evidence of mononeural (median or ulnar) innervation of D4 in 2047 hands of 1260 patients.

**Comparison of Median and Radial Sensory Conduction Between Wrist and Thumb.** Table 20 presents the results of 3 studies which met all 6 AAEM CTS LIC and evaluated sensory conduction in the branches of the median and radial nerves to the thumb over equal conduction distances. Both Carroll\textsuperscript{38} and Jackson and Clifford\textsuperscript{110} determined the difference between the median and radial nerve latency measurements; the findings in the normal control subjects in both studies were similar (less than 0.3 to 0.4 ms difference was normal). Carroll\textsuperscript{38} compared the median and radial nerve latency measurements to the thumb in the CTS patients in his study if the median sensory response was normal over the wrist-digit segment (see Table 11) and estimated a total incidence of abnormal median-radial sensory comparison studies in symptomatic hands of CTS patients to be 60%. Carroll’s estimate is similar to the finding of Jackson and Clifford\textsuperscript{110} (69%) who compared the median and radial sensory latency in all of their CTS patients (Table 20). Padua\textsuperscript{188,189} computed the ratio of the radial to median sensory conduction velocity measured from the thumb to the wrist and found 76% of CTS patients showed abnormalities. Cioni and colleagues,\textsuperscript{47} in a study that met 6 AAEM CTS LIC found 96% of CTS patients showed abnormal median-radial comparison conduction studies. These findings are similar to the findings of 5 other studies that met 4 or 5 of the 6 AAEM CTS LIC: White and colleagues\textsuperscript{254} (1988), 58% (of mild CTS); Robinson and colleagues\textsuperscript{211} (1998) 76%; Pease and colleagues\textsuperscript{192} (1989), 87% (of mild CTS); Andary\textsuperscript{9} (1996), 90%; Johnson and colleagues\textsuperscript{114} (1987), 100%.

### Needle EMG of the Thenar Muscle in CTS

About 30 years ago, Buchthal and colleagues\textsuperscript{30} reported a 91% incidence of abnormal findings on the needle EMG examination of the APB muscle in patients with CTS: 50% fibrillation activity, 50% decreased recruitment, 66% abnormalities of motor unit action potential (MUAP) configuration. These findings were similar to an earlier study by Marinacci,\textsuperscript{159} which also reported a very high (96%) incidence of APB needle EMG abnormalities. The high incidence of needle EMG abnormalities in the APB noted by Buchthal and colleagues\textsuperscript{31} and by Marinacci,\textsuperscript{159} may be related to a combination of patient selection,\textsuperscript{31,159} the

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**Table 18. Comparison of Median and Ulnar Mixed Nerve Conduction Between Wrist and Palm in CTS.**

<table>
<thead>
<tr>
<th>Author</th>
<th>Number of Normal Hands (subjects)</th>
<th>Normal Subject’s Age: Mean (range)</th>
<th>Number of CTS Hands (patients)</th>
<th>CTS Subject’s Age: Mean (range)</th>
<th>Technique: Conduction Distance</th>
<th>Stimulation Site</th>
<th>Recording Site</th>
<th>Minimum Hand Temperature</th>
<th>Difference Median-Ulnar Onset Latency ± SD</th>
<th>Difference Median-Ulnar Peak Latency ± SD</th>
<th>Criteria for Abnormal Value</th>
<th>Abnormal Value Difference in Median and Ulnar Latency</th>
<th>Specificity of Abnormal Value</th>
<th>Sensitivity of Abnormal Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jackson and Clifford\textsuperscript{110}</td>
<td>38 (38)</td>
<td>42 (21 to 69)</td>
<td>131 (123)</td>
<td>53 (21 to 85)</td>
<td>8 cm</td>
<td>Palm</td>
<td>Wrist</td>
<td>31°C</td>
<td>0.08 ± 0.12 ms</td>
<td>0.10 ± 0.14 ms</td>
<td>Mean + 2 SD</td>
<td>Onset &gt;0.32 ms, Peak &gt;0.31 ms</td>
<td>95% (actual)</td>
<td>66%</td>
</tr>
<tr>
<td>Uncini and colleagues\textsuperscript{254}</td>
<td>72 (47)</td>
<td>45 (18 to 78)</td>
<td>95 (70)</td>
<td>49 (26 to 78)</td>
<td>8 cm</td>
<td>Palm</td>
<td>Wrist</td>
<td>32°C</td>
<td>0.10 ± 0.11 ms</td>
<td>Not reported</td>
<td>Mean + 2 SD</td>
<td>Onset &gt;0.4 ms (not reported)</td>
<td>97.5% (estimate)</td>
<td>56% (78%)*</td>
</tr>
</tbody>
</table>

The technique for palmar stimulation of the median nerve described by Jackson and colleagues\textsuperscript{110} in Table 8 was adapted to study the ulnar nerve by placement of the recording electrodes over the ulnar nerve at the wrist and stimulating in the palm between the 4th and 5th metacarpal heads (see Table 4). The difference in the latency of the median and ulnar mixed nerve latencies was evaluated.

* In the Uncini and colleagues paper,\textsuperscript{254} comparison of median and ulnar sensory conduction across the palm-wrist segment was done only in the CTS patients with (1) normal median sensory conduction from D2 to wrist (SCV >45 ms) and (2) normal median motor conduction (MDL <4.3 ms) from wrist to APB so that the percentage (56%) of median-ulnar sensory conduction abnormalities was reported for a subset of the CTS patient population; from the data in the paper, the maximum possible percentage of median-ulnar sensory conduction abnormalities for the whole CTS patient population was calculated to be 78%.

**Specificity** equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of test data from the reference population.

**Sensitivity** equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population.

APB = Abductor Pollicis Brevis

CTS = Carpal Tunnel Syndrome

MDL = Motor Distal Latency

SD = Standard Deviation

SCV = Sensory Conduction Velocity
Table 19.
Comparison of Median and Ulnar Sensory Conduction Between Wrist and Ring Finger in CTS.

<table>
<thead>
<tr>
<th>Author</th>
<th>Jackson and Clifford(^{110})</th>
<th>Uncini and colleagues(^{254})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>1989</td>
<td>1993</td>
</tr>
<tr>
<td>Number of Normal Hands (subjects)</td>
<td>38 (38)</td>
<td>72 (47)</td>
</tr>
<tr>
<td>Normal Subject’s Age: Mean (range)</td>
<td>42 (21 to 69)</td>
<td>45 (18 to 78)</td>
</tr>
<tr>
<td>Number of CTS Hands (patients)</td>
<td>131 (123)</td>
<td>95 (70)</td>
</tr>
<tr>
<td>CTS Subject’s Age: Mean (range)</td>
<td>53 (21 to 85)</td>
<td>49 (26 to 78)</td>
</tr>
<tr>
<td>Technique: Conduction Distance</td>
<td>14 cm</td>
<td>Identical for each subject Range: 12 cm to 14 cm</td>
</tr>
<tr>
<td>Stimulation Site</td>
<td>Wrist</td>
<td>Ring finger</td>
</tr>
<tr>
<td>Recording Site</td>
<td>Ring finger</td>
<td>Wrist</td>
</tr>
<tr>
<td>Minimum Hand Temperature</td>
<td>31°C</td>
<td>32°C</td>
</tr>
<tr>
<td>Difference Median and Ulnar Onset Latency ± SD</td>
<td>0.13 ± 0.15 ms</td>
<td>0.14 ± 0.13 ms</td>
</tr>
<tr>
<td>Difference Median and Ulnar Peak Latency ± SD</td>
<td>0.09 ± 0.13 ms</td>
<td>Not reported</td>
</tr>
<tr>
<td>Criteria for Abnormal Value</td>
<td>Mean + 2 SD</td>
<td>Mean + 2 SD</td>
</tr>
<tr>
<td>Abnormal Value</td>
<td>Onset &gt;0.43 ms</td>
<td>Onset &gt;0.4 ms</td>
</tr>
<tr>
<td></td>
<td>Peak &gt;0.35 ms</td>
<td>Peak (not reported)</td>
</tr>
<tr>
<td>Specificity of Abnormal Value</td>
<td>95% (actual)</td>
<td>97.5% (estimate)</td>
</tr>
<tr>
<td>Sensitivity of Abnormal Value</td>
<td>82%</td>
<td>77% (89%)*</td>
</tr>
</tbody>
</table>

Nerve conduction of the branches of the median and ulnar nerves to the ring finger can be measured by securing surface ring electrodes on the ring finger and surface disc electrodes over both the median and ulnar nerves proximal to the wrist crease with identical conduction distances (14 cm). The conduction time (ms) from the stimulus artifact to the onset (onset latency) or peak (peak latency) of the SNAP is determined and the median-ulnar latency difference calculated.

* In the Uncini and colleagues paper,\(^{254}\) comparison of orthodromic median and ulnar sensory conduction from D4 along an identical distance to the wrist (range 12-14 cm for all tests) was done only in the CTS patients with (1) normal median sensory conduction from D2 to wrist (SCV >45 ms) and (2) normal median motor conduction (MDL <4.3 ms) from wrist to APB so that the percentage (77%) of median/ulnar sensory conduction abnormalities was reported for a subset of the CTS patient population; from the data in the paper, the maximum possible percentage of median/ulnar sensory conduction abnormalities for the whole CTS patient population was calculated to be 89%.

Specificity equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of test data from the reference population.

Sensitivity equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population.

APB = Abductor Pollicis Brevis  CTS = Carpal Tunnel Syndrome Potential  MDL = Motor Distal Latency  SD = Standard Deviation  SCV = Sensory Conduction Velocity  SNAP = Sensory Nerve Action
Table 20. Comparison of Median and Radial Sensory Conduction Between Wrist and Thumb in CTS.

| Author                              | Year | Number of Normal Hands (subjects) | Normal Subject’s Age: Mean (range) | Number of CTS Hands (patients) | CTS Subject’s Age: Mean (range) | Technique: Conduction Distance (range) | Stimulation Site | Recording Site | Minimum Hand Temperature | Difference Median and Radial Onset Latency ± SD | Difference Median and Radial Peak Latency ± SD | Ratio of Radial to Median SCV | Criteria for Abnormal Value | Abnormal Value | Sensitivity of Abnormal Value | Specificity of Abnormal Value | Sensitivity of Abnormal Value |
|-------------------------------------|------|----------------------------------|-----------------------------------|--------------------------------|--------------------------------|--------------------------------------|-----------------|----------------|--------------------------|---------------------------------------------|---------------------------------------------|--------------------------------|--------------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Carroll18                         | 1987 | 100 (50)                         | 47 (16 to 82)                     | 161 (101)                      | 45 (22 to 82)                  | 8.7 (6.7 to 10.5) cm                | Thumb           | Wrist         | 30°C                      | Not reported                        | 0.09 ± 0.10 ms aged 16 to 39 or 0.15 ± 0.12 ms aged 40 to 59 | Not reported | Mean + 2 SD                     | Difference in latencies age 16 to 39 >0.3 ms age 40 to 59 >0.4 ms age 60 to 82 >0.3 ms | 21% (60%)*                     | 69%                         | 99% (actual)                   | 97.5% (estimate) |
| Jackson and Clifford110           | 1989 | 38 (38)                          | 42 (21 to 69)                     | 131 (123)                      | 53 (21 to 85)                  | 10 cm                               | Wrist           | Thumb         | 31°C                      | 0.08 ± 0.12 ms                                      | 0.13 ± 0.08 ms aged 60 to 82           | Not reported | Mean + 2 SD                     | Difference in latencies Onset >0.32 ms Peak >0.37 ms | 100% (actual)                  | —                           | 100% (actual)                  | —                           |
| Padua and colleagues188          | 1996 | 40 (36)                          | 44 (19 to 79)                     | 50 (43)                        | 45 (23 to 80)                  | Anatomic landmarks                  | Thumb           | Wrist         | 31°C                      | Not reported                        | Not reported                                | 1.01 ± 0.09 | Mean + 2 SD                     | Ratio of SVC >1.2             | —                           | —                           | —                           |

Nerve conduction of the branches of the median and radial nerves to the thumb can be measured by securing surface ring electrodes on the thumb and surface disk electrodes over both the median and radial nerves proximal to the wrist crease with identical conduction distances (10 cm). The conduction time (ms) from the stimulus artifact to the onset (onset latency) or peak (peak latency) of the SNAP is determined and reported as the onset or peak latency. Carroll18 and Jackson and Clifford110 calculated the difference between the median and radial latencies. Padua and colleagues188 computed the SCV for the median and radial nerve segments and calculated the ratio of the radial SCV to the median SCV.

* In the Carroll18 paper, comparison of median and radial sensory conduction was done only in the CTS patients with normal median sensory conduction from D2 to wrist (13 cm conduction distance in Table 3) so that the percentage of abnormal median/radial sensory conduction abnormalities was reported for a subset of the CTS patient population; from the data in the paper, the maximum possible percentage of abnormal median/radial sensory comparison studies for the whole CTS patient population was calculated to be 60%.

Specificity equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of test data from the reference population.

Sensitivity equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population.

CTS = Carpal Tunnel Syndrome  SD = Standard Deviation  SNAP = Sensory Nerve Action Potential  SCV = Sensory Conduction Velocity

number of different sites examined in the APB,31 and the use of quantitative measurements of MUAP parameters.31

In more recent studies that met all 6 AAEM CTS LIC, a much lower incidence of fibrillation activity has been described in the APB muscle of CTS patients: Jackson and Clifford110 (1989), 131 APB, 25%; and Kuntzer140 (1994), 100 APB, 29%. Two other recent studies that met 4 or 5 of the 6 AAEM CTS LIC report similar findings: Kimura and Ayyar,131 APB, 40% abnormal: 22% fibrillation activity and/or 31% decreased recruitment of abnormalities of MUAP configuration; and Seror228 (1994) 150 APB, 42% abnormal with a “neurogenic pattern,” Sander220 (1999) 79 APB, 12% abnormal with either fibrillation activity or MUAPs of increased duration. It is the consensus of the AAEM CTS Task Force that the reports by Kimura and Ayyar,131 Jackson and Clifford,110 Kuntzer,140 Seror,228 and Sander220 are more representative of the percentage (12% to 42%) of abnormal results of qualitative needle EMG studies in CTS patients than the earlier studies of Buchthal and colleagues31 and by Marinacci.159

In a retrospective review of 480 CTS patients, Werner and Albers261 (1995) reported that the median motor and sensory latencies were the most important predictors of an abnormal needle examination of the APB muscle of 480 CTS patients: 48% abnormalities of MUAP configuration and/or fibrillation activity and 21% fibrillation activity. Vennix258

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noted that 95% of CTS with evidence of denervation on needle EMG had APB CMAP amplitudes less than 7 mV but agreed with Werner and Albers that these models are not applicable in the clinical setting to predict denervation in individual CTS patients.

In 1999, Gnatz and Conway debated the issue of the performing needle EMG of the APB muscle and other hand and limb muscles in CTS patients. Gnatz concluded that the needle EMG is important in all CTS suspects because the discomfort and expense of the exam was outweighed by the diagnostic information obtained. Conway recommended that needle EMG be performed only when pathology proximal to the carpal tunnel was suspected. Sener and Conway agreed that more studies are needed to evaluate the question of performing needle EMG in every patient suspected of CTS. There are a few other studies which address this issue.

**Sympathetic Skin Response in CTS**

Kuntzer, in a study that met all 6 AAEM CTS LIC, reported a low (10%) incidence of abnormalities with an EDX test of the sympathetic skin response (SSR) in the CTS patients (Table 21). Verghese, in a study that met 5 of 6 AAEM CTS LIC, reported that 24% (33/139) of symptomatic hands of CTS patients had a prolonged SSR latency (>1.72 s). However, Sener, in a study that met all 6 AAEM CTS LIC, reported that none of the 44 symptomatic limbs in CTS patients showed a SSR latency greater than limbs of 20 normal subjects (Table 21). Sener noted over half of the CTS patients complained of at least 1 symptoms in the affected hand that may indicate autonomic dysfunction: swelling of the hand or fingers, dryness, excessive perspiration, pallor, red or purple discoloration, and coolness. However, for the reasons noted above, SSR studies are not recommended as an EDX study to diagnose CTS patients.

**The Effect of Limb Ischemia, Dynamic Hand Exercises, and Brief and Sustained Wrist Positioning on Median NCSs in CTS**

**Effect of Limb Ischemia on Median Nerve Conduction in Carpal Tunnel Syndrome.** In 1953, Gilliatt and Wilson described the production of paresthesia in limbs of CTS patients with a pneumatic tourniquet. As noted above, in 1963, Fullerton evaluated the effect of upper extremity ischemia on median motor conduction in the forearm and hand and suggested that transient nocturnal symptoms were due to median nerve ischemia. Limb ischemia caused the median thenar CMAP amplitude to fall to less than 40% of the initial value after 25 minutes in 7 out of 15 CTS patients whereas the median thenar CMAP amplitude in normal subjects remained above 50% of the initial value after 30 minutes of ischemia.

**Effect of Dynamic Hand Exercise on Median Nerve Conduction in CTS.** In 1994, Clifford, in a study that met all 6 AAEM CTS LIC, evaluated the effect of 4 minutes of repetitive wrist and finger movements on median sensory nerve conduction to D4 and found a significant difference between a group of CTS patients and normal subjects. However, the difference was of insufficient magnitude to discriminate individual CTS patients from control subjects. Therefore, the effects of repetitive wrist and finger movements on median NCS in CTS patients are classified as investigational at this time.

**Effect of Sustained Wrist Positioning on Median Nerve Conduction in CTS.** The effect of sustained (1 minute or greater) active or passive wrist and finger positioning (maximal flexion or extension) on median sensory and motor nerve conduction in normal subjects and CTS patients has been evaluated by several investigators: Schwartz, Marin, Dunnan, Werner, Hansson and Nilsson, Rosecrance, and Kiernan. Initial studies which focused on the effect of sustained wrist positioning on the median distal sensory latency and the median motor distal latency produced conflicting results: Schwartz, Marin, and Dunnan. More recent studies have focused on the effect of prolonged positioning on the amplitude of the median SNAP and reported more promising results: Hansson and Nilsson, Rosecrance, and Kiernan. Hansson and Nilsson, in a study that met 5 of the 6 AAEM CTS LIC, evaluated the effect of prolonged (up to 45 minutes) passive wrist flexion on the median SNAP amplitude and determined the time (T50) it takes for the SNAP amplitude to fall to one-half the baseline value. Rosecrance and colleagues, in a study that met all 6 AAEM CTS LIC, evaluated the recovery time for the SNAP amplitude to return to baseline after 5 minutes of active extreme wrist and fingers flexion. In both reports, the changes in the SNAP amplitude during (Hansson and Nilsson) or after (Rosecrance and colleagues) sustained wrist positioning distinguished CTS patients from normal subjects. Because others have not yet confirmed these results, the effects of sustained wrist positioning on median nerve conduction in CTS patients are classified as investigational at this time.

Hansson and Nilsson also provided evidence that the effect of prolonged extreme wrist flexion was due to ischemia and not to compression of the nerve. The results of the recent studies by Hansson and Nilsson and Rosecrance and colleagues are consistent with the effect
Table 21. Sympathetic Skin Response in CTS.

<table>
<thead>
<tr>
<th>Author</th>
<th>Kuntzer(^{140})</th>
<th>Sener(^{223})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>1994</td>
<td>2000</td>
</tr>
<tr>
<td>Number of Normal Hands (subjects)</td>
<td>30 (30)*</td>
<td>42 (21)</td>
</tr>
<tr>
<td>Normal Subject’s Age: Mean (range)</td>
<td>45 (25 to 70)</td>
<td>38 (18 to 60)</td>
</tr>
<tr>
<td>Number of CTS hands (patients)</td>
<td>30 (30)*</td>
<td>46 (31)</td>
</tr>
<tr>
<td>CTS Subject’s Age: Mean (range)</td>
<td>48 (32 to 72)</td>
<td>46 (26 to 70)</td>
</tr>
<tr>
<td>Stimulation Site</td>
<td>Opposite wrist</td>
<td>Sternum</td>
</tr>
<tr>
<td>Recording Site</td>
<td>D2 and D5</td>
<td>D2 and D5</td>
</tr>
<tr>
<td>Minimum Hand Temperature</td>
<td>32°C</td>
<td>32°C</td>
</tr>
<tr>
<td>Calculation</td>
<td>D2/D5 amplitude ratio (\times 100) +</td>
<td>Onset latency</td>
</tr>
<tr>
<td>Normal ± SD</td>
<td>69.8 ± 16.9</td>
<td>D2: 1.42 ± 0.13 s $\pm$</td>
</tr>
<tr>
<td>Criteria for Abnormal Value</td>
<td>Mean – 2 SD</td>
<td>Mean + 2 SD</td>
</tr>
<tr>
<td>Abnormal Value</td>
<td>&lt;36</td>
<td>D2: &gt;1.68 s</td>
</tr>
<tr>
<td>Specificity of Abnormal Value</td>
<td>100% (actual)</td>
<td>D2: 98% (actual) +</td>
</tr>
<tr>
<td>Sensitivity of Abnormal Value</td>
<td>10%</td>
<td>D2: 0%</td>
</tr>
</tbody>
</table>

* For each reference subject, only 1 hand was tested; for each CTS patient, only the most symptomatic hand was tested.
† Written communication.
\( + \) Written communication: the data in Table 3 of the published paper was mislabeled “ms” (the correct units were “s”) and the D2 and D5 SSR studies yield values greater than the abnormal values in 1 of the 42 control subjects and none of the CTS patients.

Specificity equals the percentage of reference subjects’ hands with normal results and was either “actual” based on analysis of the test data from the reference population or an “estimate” based on the statistical distribution of data from the reference population.

Sensitivity equals the percentage of CTS patients’ hands with abnormal results calculated from the test data on the CTS population.

CTS = Carpal Tunnel Syndrome  SD = Standard Deviation  SSR = Sympathetic Skin Response

Effect of Brief Wrist Positioning on Median Nerve Conduction in CTS. A phenomenon that takes place during wrist flexion and extension with limb positioning is longitudinal sliding of the median nerve in the carpal tunnel. In 1976, McLellan\(^{78}\) first reported sliding of the median nerve based on observations of the effect of limb movements on the orientation of a needle placed in the median nerve proximal to the wrist. Because the nerve slides in the carpal tunnel, the length of median nerve between the stimulating electrodes proximal to the wrist and the recording electrodes over the thenar muscle (motor study) or the digit (sensory study) is least with wrist flexion, intermediate in the neutral position, and greatest with wrist extension. The effect of longitudinal sliding on median SNAP latency measurements in normal subjects was first described by McLellan and Swash\(^{164}\) and subsequently confirmed by Valls-Solé and colleagues.\(^{257}\) Valls-Solé and colleagues\(^{257}\) also noted that the latency differences between flexion and extension wrist positions were significantly less of wrist positioning on intracarpal tunnel pressures and median nerve conduction; increased intracarpal tunnel pressures have a greater effect on the amplitude of the median sensory and motor response than on the CV (distal latency). In 1982, Lundborg and colleagues\(^{152}\) demonstrated that compression of the median nerve in the carpal tunnel to pressures over 50 mm Hg caused a rapidly reversible block of median sensory and motor conduction. In 1981, Gelberman and colleagues\(^{78}\) made direct measurements of the intracarpal tunnel pressure with a wick catheter and noted that (1) intracarpal tunnel pressure with the wrist in the neutral position is increased in patients with CTS compared to control subjects (2) intracarpal tunnel pressure increases in CTS and control subjects with wrist flexion and extension and (3) intracarpal pressure changes in CTS patients (greater than 50 mm Hg for several minutes) were sufficient to cause rapidly reversible (ischemic) nerve conduction block. Gelberman\(^{79}\) recently reviewed these findings and subsequent supporting literature on intracarpal tunnel measurements.
in CTS patients compared to control subjects consistent with limited sliding of the median nerve in the carpal tunnel of CTS patients. Nakamichi and Tachibana provided independent confirmation of the limited sliding of the median nerve in CTS patients with ultrasound measurements. Because the effect of brief positioning on median nerve latency measurements in CTS is less than that of normal subjects, it is unlikely that these studies would be of value to distinguish CTS patients from normal subjects although there is 1 disputed report and a commentary to the contrary. For these reasons, studies on the effect of brief wrist positioning on median nerve conduction in CTS are considered investigational.

**Other EDX Studies in CTS**

Several other variations on median sensory and motor NCSs have been reported to be useful for the evaluation of patients with CTS. The review of the literature through 2000 indicated that the value of these tests for the clinical EDX evaluation of patients with CTS still remains to be established and these studies are considered investigational. These EDX studies include the following: (1) measurement of the refractory period of the median nerve, (2) anterior interosseous latency measurements, (3) anterior interosseous/median nerve latency ratio, (4) temporal dispersion of the SNAP, and (5) distal stimulation of the “pulp” of digits.

Several investigators have used CTS patients to evaluate EDX studies, not from the standpoint of using the EDX test to diagnose CTS, but from the standpoint that CTS is a model of focal nerve compression.

**Statistical Considerations: Normal Values, Normal Distributions, Use of Multiple Tests, Receiver-Operating Curves**

Studies have shown that several demographic and anthropometric factors influence the results of NCS amplitude and latency values. Therefore the normal values used for NCSs should take into account these factors. Age, height, and body mass index affect latency values and finger circumference affect amplitude values. Both latency and amplitude values are affected by comorbid conditions: diabetes, thyroid disease, and connective tissue diseases. The effect of all of these factors may be reduced by comparison of median NCS results to the results of NCSs of adjacent nerve segments.

Dorfman and Robinson reviewed the important principles governing the acquisition and use of normative data in electrodiagnostic medicine and the authors made several points worth restating: (1) EDX data from the disease-free population may be skewed rather than having a Gaussian distribution and setting the abnormal value by calculating the mean ± 2 standard deviations may result in misclassification of data from the patients, (2) there are several alternative statistical strategies for dealing with sample distributions which are non-Gaussian to permit identification of an abnormal value to maximize sensitivity and specificity of the test results, and (3) if multiple independent EDX tests are performed on a single patient, the likelihood of finding an abnormal value on the basis of chance is significant.

Robinson and colleagues reported the use of a single summary variable (combined sensory index or CSI) based on the results of 3 different NCSs to assess median sensory conduction across the carpal tunnel: median-ulnar midpalmar orthodromic difference at 8 cm (palmdiff), medial-ulnar ring finger antidromic differences at 14 cm (ringdiff), and median-radial thumb antidromic difference at 10 cm (thumbdiff). The CSI = palmdiff + ringdiff + thumbdiff. Theoretically random (nonsystematic) technical errors would be canceled out as more observations are collected and reliability would be enhanced. The possibility of making a false-positive diagnosis by chance alone (i.e., chance observation of a single extreme value) is reduced when multiple observations are combined because it is unlikely that all observations in a healthy subject will have chance extreme values in the same directions. Lew and colleagues confirmed that test-retest reliability of the CSI was superior to a single NCS and, in addition, the CSI was less affected by temperature changes than absolute latency values of individual NCSs. Finally, combining measurements into a single variable avoids the additive risk of false positive results when making a diagnosis based on any 1 of many tests being “abnormal.” Based on results in 53 CTS patients and 46 control subjects, Robinson and colleagues reported a CSI score greater than or equal to 1.0 yields a sensitivity of 83% and a specificity of 95%. The study also confirmed that doing more tests and requiring that only 1 of many of the tests be abnormal for a diagnosis of CTS produced an excess of false-positive results (nearly 8%). Interestingly, the most recent report by Robinson and colleagues noted that there were endpoints for the 3 individual tests that confidently predicted the results of the CSI without loss of specificity so that it was not necessary to do all 3 tests: palmdiff >0.3 ms, ringdiff >0.4 ms, or the thumbdiff >0.7 ms.

McNeil recommended the use of receiver-operating curve (ROC) analysis as a method to use the results of laboratory studies to calculate the percentage risk of patients having a disease. Two papers have used ROC analysis to determine the optimal cut-off value for NCS abnormalities in patients with CTS. Limitation of ROC analysis for evaluating EDX studies in CTS patients include the absence of a highly specific diagnostic test for CTS independent of EDX studies (such as biopsy or autopsy), the need for an estimate of the true prevalence of CTS, and difficulty in generalizing findings from 1 laboratory to another.
Comparison of Sensitivity of Different EDX Studies

Based on the data reviewed in the Results, median sensory and motor nerve CV studies including comparison of median sensory conduction to ulnar and radial sensory conduction in the same hand are more sensitive and specific for the diagnosis of CTS than measurements of (1) median SNAP amplitudes and amplitude ratios, (2) motor CMAP amplitudes and amplitude ratios, (3) F-wave parameters, and (4) sympathetic skin responses.

Several studies that met 4 or more of the 6 AAEM CTS LIC compared the relative sensitivity of different tests of median sensory conduction, median motor conduction, and needle EMG in CTS patients.

In 4 of 4 recent (after 1980) studies of patients with CTS, NCSs showed abnormalities more often than needle EMG of the APB muscle (Kimura and Ayyar,131 Jackson and Clifford,110 Seror,226 and Kuntzer.140) In 23 of 29 studies of CTS patients, median sensory NCSs were abnormal more frequently than motor NCSs.

In 20 of 20 studies of patients with CTS, comparison of median sensory/mixed nerve conduction to ulnar sensory/mixed nerve conduction or radial sensory nerve conduction in the same limb of CTS patients were abnormal more frequently than evaluation of median sensory NCSs from wrist to digit alone.9,38,45,47,57,63,110,116,140,143,148,171,173,174,188,189,220,222,223,226,254,255 These 20 studies included the 6 reports that met 6 AAEM CTS LIC by Carroll,38 Jackson and Clifford,110 Kuntzer,140 Padua and colleagues,188,189 and Uncini and colleagues254 which are summarized in Tables 9, 17, 18, 19, and 20.

The pooled sensitivity of the several tests evaluated is shown in Table 22 (data analysis by Gary Gronseth, MD). The data in the appropriate table for each study were subjected to a meta-analysis with 95% confidence limits to take into account the fact that some of the studies included more CTS patients than other studies. CONCLUSIONS

This report provides convincing scientific evidence that median sensory and motor NCSs:

1. Are valid and reproducible clinical laboratory studies.
2. Confirm a clinical diagnosis of CTS with a high degree of sensitivity (>85%) and specificity (>95%).

The sensitivities of the several different median NCSs were compared. The comparison demonstrated that:

1. Median sensory NCSs confirm the clinical diagnosis of CTS more often than median motor NCSs (63% to 69% versus 65% to 85%; Tables 3, 11, 12, 18, 19, 20, and 22).

2. The median sensory or mixed nerve conduction from wrist to digit (conduction distance 13 to 14 cm) is less sensitive (65%; Tables 11 and 22) for confirmation of the clinical diagnosis of CTS compared to:
   a. Techniques which evaluate median sensory or mixed nerve conduction over a short (7 to 8 cm) conduction distance across the carpal tunnel (e.g., palmar studies 74%; Tables 12 and 22);
   b. Techniques which compare sensory or mixed nerve conduction of the median nerve through the carpal tunnel to sensory or mixed nerve conduction of the ulnar nerve (85%; Tables 18, 19, and 22) or radial nerve (65%; Tables 20 and 22) in the same hand;
   c. Techniques which compare sensory or mixed nerve conduction of the median nerve through the carpal tunnel to sensory or mixed NCSs of proximal (forearm) and distal (digit) segments of the median nerve in the same limb (85%; Tables 16 and 22).

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Table 22. Comparison of Pooled Sensitivities and Specificities of EDX Techniques to Diagnose CTS.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pooled Sensitivity*</th>
<th>Pooled Specificity*</th>
</tr>
</thead>
<tbody>
<tr>
<td>A  Median sensory and mixed nerve conduction: wrist and palm segment compared to forearm or digit segment</td>
<td>0.85† (0.83,0.88)</td>
<td>0.98† (0.94,1.00)</td>
</tr>
<tr>
<td>B  Comparison of median and ulnar sensory conduction between wrist and ring finger</td>
<td>0.85 (0.80,0.90)</td>
<td>0.97 (0.91,0.99)</td>
</tr>
<tr>
<td>C  Median sensory and mixed nerve conduction between wrist and palm</td>
<td>0.74† (0.71,0.76)</td>
<td>0.97† (0.95,0.99)</td>
</tr>
<tr>
<td>D  Comparison of median and ulnar mixed nerve conduction between wrist and palm</td>
<td>0.71 (0.65,0.77)</td>
<td>0.97 (0.91,0.99)</td>
</tr>
<tr>
<td>E  Median motor nerve conduction between wrist and palm</td>
<td>0.69† (0.64,0.74)</td>
<td>0.98† (0.93,0.99)</td>
</tr>
<tr>
<td>F  Comparison of median and radial sensory conduction between wrist and thumb</td>
<td>0.65 (0.60,0.71)</td>
<td>0.99 (0.96,1.00)</td>
</tr>
<tr>
<td>G  Median sensory nerve conduction between wrist and digit</td>
<td>0.65† (0.63,0.67)</td>
<td>0.98† (0.97,0.99)</td>
</tr>
<tr>
<td>H  Median motor nerve distal latency</td>
<td>0.63† (0.61,0.65)</td>
<td>0.98† (0.96,0.99)</td>
</tr>
<tr>
<td>I  Median motor nerve terminal latency index</td>
<td>0.62† (0.54,0.70)</td>
<td>0.94† (0.87,0.97)</td>
</tr>
<tr>
<td>J  Comparison of median motor nerve distal latency (second lumbral) to the ulnar motor nerve distal latency (second interossei)</td>
<td>0.56‡ (0.46,0.66)</td>
<td>0.98‡ (0.90,1.00)</td>
</tr>
<tr>
<td>K  Sympathetic skin response</td>
<td>0.04 (0.00,0.08)</td>
<td>0.52 (0.44,0.61)</td>
</tr>
</tbody>
</table>

* For each EDX technique to summarize results across studies, sensitivities were pooled from individual studies by calculating a weighted average. In calculating the weighted average, studies enrolling more patients received more weight than studies enrolling fewer patients. Specificities were similarly pooled by calculating the weighted average. The data in the parentheses below the sensitivity and specificity values represent the lower and upper 95% confidence limits of the weighted average, respectively. Data analysis courtesy of Dr. Gary Gronseth.

† There was heterogeneity between some of the studies (the 95% confidence intervals of the sensitivities and specificities do not overlap). This disparity may be related to differences in case definition of CTS, the use of different cut-points to define an abnormal value, and differences in the average severity of the CTS patients in the different studies.

‡ Results based on a single study.

RECOMMENDATIONS REGARDING EDX STUDIES TO CONFIRM A CLINICAL DIAGNOSIS OF CTS

The recommendations below are identical to those made and endorsed in 1993 by the AAN, the AAPMR, and the AAEM with the clarification of recommendation 1 and 2a and the addition of 2c based on new evidence reviewed in the second CTS Literature Review. In patients suspected of positive CTS, the following EDX studies are recommended (see Table 22 for sensitivity and specificity of Techniques A – K):

1. Median sensory NCS across the wrist with a conduction distance of 13 to 14 cm (Technique G). If the result is abnormal, comparison of the result of the median sensory NCS to the result of a sensory NCS of 1 other adjacent sensory nerve in the symptomatic limb (Standard).

2. If the initial median sensory NCS across the wrist has a conduction distance greater than 8 cm and the result is normal, 1 of the following additional studies is recommended:
   a. Comparison of median sensory or mixed nerve conduction across the wrist over a short (7 to 8 cm) conduction distance (Technique C) with ulnar sensory nerve conduction across the wrist over the same short (7 to 8 cm)
Practice Parameter: Carpal Tunnel Syndrome

conduction distance (Technique D) (Standard), or

b. Comparison of median sensory conduction across the wrist with radial or ulnar sensory conduction across the wrist in the same limb (Techniques B and F) (Standard), or

c. Comparison of median sensory or mixed nerve conduction through the carpal tunnel to sensory or mixed NCSs of proximal (forearm) or distal (digit) segments of the median nerve in the same limb (Technique A) (Standard).

3. Motor conduction study of the median nerve recording from the thenar muscle (Technique H) and of 1 other nerve in the symptomatic limb to include measurement of distal latency (Guideline).

4. Supplementary NCS: Comparison of the median motor nerve distal latency (second lumbrical) to the ulnar motor nerve distal latency (second interosseus) (Technique J), median motor terminal latency index (Technique I), median motor nerve conduction between wrist and palm (Technique E), median motor nerve CMAP wrist to palm amplitude ratio to detect conduction block, median SNAP wrist to palm amplitude ratio to detect conduction block, short-segment (1 cm) incremental median sensory nerve conduction across the carpal tunnel (Option).

5. Needle electromyography of a sample of muscles innervated by the C5 to T1 spinal roots, including a thenar muscle innervated by the median nerve of the symptomatic limb (Option).

Based on the second AAEM CTS Literature Review\(^2\), the following EDX studies are not recommended to confirm a clinical diagnosis of CTS either because the EDX studies recommended above have greater sensitivity and specificity or the test is best described as investigational at this time.

1. Low sensitivity and specificity compared to other EDX studies: multiple median F-wave parameters, median motor nerve RL, and sympathetic skin response (Technique K).

2. Investigational studies: evaluation of the effect on median NCS of limb ischemia, dynamic hand exercises, and brief or sustained wrist positioning.

Definition Of Practice Recommendation Strengths

The strength of a recommendation or conclusion is based on the quality and consistency of supporting evidence. The following rating system is used:

- **Practice standards**: generally accepted principles for patient management that reflects a high degree of clinical certainty.
- **Practice guidelines**: recommendations for patient management that reflect moderate clinical certainty.
- **Practice options**: other strategies for patient management for which the clinical utility is uncertain.

RECOMMENDATIONS FOR FUTURE RESEARCH STUDIES IN CTS

The AAEM recommends that future clinical research studies of the usefulness of EDX studies to confirm the diagnosis of CTS meet 3 clinical study criteria:

1. Prospective study.

2. Clinical diagnosis of CTS independent of EDX studies: For example, a diagnosis of probable CTS as defined in the second CTS Literature Review\(^2\) which is based on a consensus recommendation by Rempel and colleagues.\(^{205}\)

3. A uniform protocol for data collection and measurement with the physicians performing and interpreting the EDX studies under investigation blinded to the clinical diagnosis of all the human subjects (normal, CTS, disease control) in the study at least until the data collection and measurements are completed.

The AAEM recommends that future clinical research studies of the usefulness of EDX studies to confirm the diagnosis of CTS meet 4 additional methodological study criteria:

1. Description of EDX technique sufficient to permit replication of the study.

2. Monitor limb temperature continuously during the EDX study.

3. Normal values for EDX technique obtained with concomitant studies or with previous studies in the same laboratory.

4. Criteria of EDX abnormality obtained from normal population and defined in statistical terms.

The first and second AAEM CTS Literature Reviews\(^1,2\) used 6 CTS LIC. The second CTS Literature Review\(^2\) recommended (1) the addition of criterion 3 and (2) that future AAEM CTS Literature Reviews use all 7 CTS LIC to review reports of the usefulness of EDX studies in the evaluation of CTS patients. The second AAEM CTS Literature Review\(^2\) also provided a set of specific criteria to make a clinical diagnosis of CTS based on expert opinion
The AAEM recommends that studies which compare the sensitivity and specificity studies of NCSs and needle EMG to the sensitivity and specificity of other tests proposed for the diagnosis of CTS use the clinical diagnosis of probable CTS as defined in Table 2. These alternative diagnostic studies include the following: quantitative cutaneous sensory testing of perception threshold for vibration, 2-point discrimination, touch, warmth, cold, and electric current;\textsuperscript{1,2,22,120,153,160,168,247} hand symptom diagrams;\textsuperscript{122,123,124} magnetic resonance imaging and computed tomographic studies of the carpal tunnel;\textsuperscript{16,17,99,169} thermography;\textsuperscript{100,170,240} wrist ratio;\textsuperscript{90} provocation of symptoms by ultrasound;\textsuperscript{172} and carpal tunnel pressure measurements.\textsuperscript{78,212}

Both the first and second AAEM CTS Literature Reviews recommended that outcome studies should be performed to assess the harms, benefits, and costs of performing NCSs and needle EMG in patients with symptoms suggestive of CTS.

The AAEM recommends that future outcome studies of treatment of CTS use the clinical diagnoses of definite CTS (as defined in Table 2) with EDX studies of high sensitivity and specificity for the diagnosis of CTS performed by a specially trained physician, i.e., median mixed nerve palmar studies and/or comparison of median to ulnar and/or radial sensory NCS in the same hand.

The AAEM CTS Task Force has addressed future research principles over future research topics (except for outcome studies) because the Task Force concluded that future research studies need to meet these principles (1) to provide reliable and reproducible data to evaluate the usefulness of EDX studies to confirm the clinical diagnosis of CTS and (2) permit comparison of the relative utility of different EDX studies for that purpose.

It is recommended that the AAEM review this report every 5 years and update the report as necessary.

DISCUSSION

This report includes 2 recommendations in addition to those in the 1993 CTS Literature Review to improve future clinical research studies of the usefulness of EDX studies to confirm the clinical diagnosis of CTS.

1. This report provides a new consensus based set of inclusion and exclusion criteria for the clinical diagnosis of CTS according to the certainty of the diagnosis: possible CTS, probable CTS, and definite CTS (Table 2). We recommend the criteria for the diagnosis of probable CTS be used in future studies of EDX tests to reduce the possibility of selection bias, to provide a more uniform population of CTS patients, and to provide a valid scientific basis for comparison of the results of future studies from different laboratories. This suggestion is a refinement on the original recommendation made in the 1993 CTS Literature Review.

2. Sackett and colleagues\textsuperscript{217} and others have recommended that clinical research studies of diagnostic tests (including EDX studies) be performed with the physician performing and interpreting the diagnostic tests blinded to the diagnosis of the subject with the goal of eliminating observer bias. There is a solid body of clinical evidence and experience which indicates that NCSs are useful to confirm the diagnosis of CTS, a body of evidence similar in weight to the clinical evidence that radiographs are useful to identify fractures of the limb bones and electrocardiograms are useful to identify myocardial ischemia and infarction. Nevertheless, it is worth performing future evaluations of EDX studies in CTS with the examiner blinded to the clinical diagnosis of the subject as the next step to establishing the validity of these conclusions beyond a reasonable doubt. In fact, some clinical investigators have already begun to perform evaluations of NCSs in CTS in a blinded fashion (Salerno and colleagues\textsuperscript{218,219} and Werner and colleagues\textsuperscript{263}).

In the 1993 AAEM CTS Literature Review, it was recommended that an outcome study be performed to assess the harms, benefits, and costs of performing NCSs and nerve EMG in patients with symptoms suggestive of CTS. In 1994, Boniface and colleagues\textsuperscript{20} published a prospective study from England which demonstrated that NCS/EMG studies were useful and cost effective in management of patients suspected of CTS.\textsuperscript{20} In addition, the AAEM has encouraged additional outcome studies including the publication of guidelines for outcome studies in neuromuscular diseases including CTS.\textsuperscript{108} The AAEM Research and Education Foundation has recently funded a prospective outcome study of 400 patients to evaluate the usefulness of EDX studies in the evaluation and management of patients with symptoms suggestive of CTS. It is recommended that outcome studies continue to be a priority for future clinical research in the diagnosis and management of CTS and other neuromuscular diseases.

INTERFACE WITH AAEM GUIDELINES

In 1999, the AAEM republished guidelines based upon expert opinion and first published in 1992 for the evaluation of CTS patients.\textsuperscript{2,4} The AAEM Guidelines recommend the following EDX studies: (1) median sensory or mixed NCS to include determination of (a) the amplitude and (b) peak latency or onset latency or CV of the segment of the median nerve passing through the carpal tunnel; (2) median motor
NCS to include determination of the amplitude, distal latency, and CV in the forearm; (3) ulnar (or radial) sensory and motor conduction studies in the same limb to exclude a peripheral neuropathy; (4) needle EMG examination of the APB to determine the severity of the median motor nerve pathology; and (5) needle EMG examination of limb muscles innervated by the C5/6–T1 spinal nerve roots to exclude a cervical radiculopathy, brachial plexopathy, and a proximal median neuropathy.\textsuperscript{2,4} The first and second \textit{AAEM CTS Literature Reviews} both cite published studies that provide an evidence basis for AAEM Guidelines 1, 2, and 4, but do not address Guidelines 3 and 5 for EDX evaluation of patients suspected of CTS.

**SUMMARY OF HARMs, BENEFITS, AND COSTS FOR INTERVENTIONS CONSIDERED**

The AAEM has prepared a document that describes the risks in electrodiagnostic medicine.\textsuperscript{3} Briefly, the risks to the patient of needle EMG include transient discomfort, bruise, hematoma, and infection from the needle insertion required to perform needle EMG. The risks of NCS to the patient include transient discomfort of the electric shocks. The risk of needle EMG to the EDX consultant includes inadvertent needle puncture of the EDX consultant by the needle used to evaluate the patient and infection by hepatitis, human immuno-deficiency virus, or other communicable disease.

The AAEM has prepared a document that describes the benefits of electrodiagnostic medicine.\textsuperscript{4} Briefly, the benefits of needle EMG and NCS include confirmation of the clinical diagnosis of CTS and the probability of identifying concomitant or alternative neurological disorders as the cause of the patient’s symptoms. In a prospective study, Haig and colleagues\textsuperscript{45} reported that an EDX consultation, including EMG and NCS, changed the final clinical diagnosis 42% of the time.

This study has not undertaken a systematic evaluation of the economic costs and economic benefits of NCSs and needle EMG in the evaluation of patients suspected of CTS. The interested reader is referred to the outcome study by Boniface and colleagues.\textsuperscript{20}

**DISCLAIMER**

This report is provided as an educational service of the AAEM. It is based on an assessment of current scientific and clinical information. It is not intended to include all possible methods of care of a particular clinical problem or all legitimate criteria for choosing to use a specific procedure. Neither is it intended to exclude any reasonable alternative methodologies. The AAEM recognizes that specific patient care decisions are the prerogative of the patient and his/her physician and are based on all of the circumstances involved.

\textsuperscript{Approved by the Board of Directors of the American Association of Electrodiagnostic Medicine: May 2002.}

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All articles reviewed and classified by the Literature Inclusion Criteria are contained in the bibliography below. Articles that met 3 or less criteria are not cited in the text and are identified by an asterisk (*).

Abbreviations: abductor digiti minimi (ADM); abductor pollicis brevis (APB); compound motor action potential (CMAP); carpal tunnel (CT); carpal tunnel syndrome (CTS); distal motor latency (DML); distal sensory latency (DSL); electromyography (EMG); nerve conduction studies (NCSs); nerve conduction velocity (NCV); sensory nerve action potential (SNAP).

1. American Academy of Neurology Quality Standards Subcommittee. Practice parameter for carpal tunnel syndrome. Neurology 1993;43:2406-2409. Background Reference. Source: AAEM 2000 CTS Task Force member. Summary statement that notes that the likelihood of the diagnosis of CTS increases with the number of classic symptoms, provocative factors, mitigating factors, and abnormalities on the physical examination. The clinical investigator can construct a set of clinical criteria for the diagnosis of CTS from these symptoms and signs common to CTS.


8. Anastasopoulos D, Chroni E. Effect of carpal tunnel syndrome on median nerve proximal conduction estimated by F waves. J Clin Neurophysiol 1997;14:63-67. Background Reference. Source: Medline Search. Abstract: Slowing of median nerve proximal motor conduction in patients with carpal tunnel syndrome (CTS) could be considered as an indicator of an additional proximal lesion (double crush syndrome). The effect of CTS on proximal conduction was assessed by comparing motor velocities calculated by F-waves obtained from muscles with the same root and nerve supply but different median branches, one emerging before the carpal tunnel (pronator quadratus muscle) and one passing through the tunnel (abductor pollicis brevis). Data were obtained from 26 patients with CTS and 21 age-matched healthy subjects. In the control group, the proximal (spinal cord and elbow) F-wave maximal velocity calculated when recording from abductor pollicis brevis (FCVmax-APB) was not different from the F-wave maximal velocity calculated when recording from pronator quadratus (FCVmax-PQ), while it was significantly different in the group of CTS patients, especially in patients with terminal motor latency greater than 4.5 ms (approximately 9% less, p = 0.001, Wilcoxon signed rank test). The study showed that median nerve proximal conduction velocity slowing in patients with CTS is restricted to the fibers that distally pass through the carpal tunnel and does not necessarily imply an additional proximal lesion. We suggest that comparison of FCVmax-APB and FCVmax-PQ be useful when the question arises if a single (dural) or two (one distal, one proximal) lesions are responsible for a patient’s symptoms.

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13. Balsier JM, Cottrell AC, Cottrell WD. Is needle examination always necessary in evaluation of carpal tunnel syndrome? Arch Phys Med Rehabil 1998;79:S14-S16. Criteria Met (2/6: 2,3) Source: Medline Search. Abstract: Retrospective review of EMG/NCS reports to determine if needle EMG evaluation was abnormal if NCS were normal during the evaluation of patients suspected of CTS. In patients in whom only CTS was suspected, normal NCS predicted that EMG would be normal 89.8% of the time. These findings suggest that there may be a subpopulation of patients referred for electrophysiologic evaluation of CTS who may be adequately evaluated by nerve conduction studies alone.

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Abstract: With stimulation at the wrist, antidromic SNAPs were recorded from 50 hands in 25 healthy subjects and 36 hands of 21 CTS patients. DSL, amplitude, and duration of the SNAP were systemically evaluated, they were also compared to DMLs from previous studies. DSL was the most sensitive followed by DML and then duration of SNAP. They report 4 of 36 hands where the only abnormality was duration of SNAP (the statistics suggest that the criteria for abnormality was different for DSL and duration of SNAP).


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Criteria Met (normal population study 5/6: 1,3,4,5,6) Source: Bushbacher 1999 monograph. Abstract: Study performed to determine effect of body fat on NCS parameters. There was no correlation between Body Mass Index and conduction velocities but sensory/mixed nerve amplitudes were 20-40% lower in the obese compared to thin subjects.

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at the wrist, (b) antidiromic SNAPs were recorded over the ring finger using ring electrodes after stimulation of the median nerve and then the ulnar nerve at the wrist, (c) DSL difference by subtracting the ulnar DSL to the ring finger from the median DSL to the ring finger, and (d) median-ulnar DSL with stimulation at the wrist and recording over the APB. Three different groups were studied: (1) the control group with 100 hands in 60 healthy subjects; (2) 224 hands from 158 potential CTS patients; and (3) 30 hands from 30 patients with parasthesias into the middle and index fingers due to cervical spondylitic radiculopathy. They found the median-ulnar DSL difference to the ring finger the most sensitive technique followed in order by the median sensory NCV to ring finger, median sensory NCV to index finger and median DML. They report no differences between the cervical spondylitic radiculopathy group and the normal group and found no cases of abnormal median-ulnar DSL differences to the ring finger in this group (no false positives). They also report that amplitude was not a reliable parameter for the diagnosis of CTS.


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Practice Parameter: Carpal Tunnel Syndrome

Met (6/6: 1,2,3,4,5,6) Source: Medline Search. Abstract: Conventional median sensory and motor conduction studies of CTS do not determine whether low amplitude responses are due to axonal degeneration or demyelination in the carpal tunnel segment of the median nerve. In 98% control and 25% CTS hands we recorded amplitude and duration of the APB CMAP and of antidromic SNAP after wrist and palm stimulation to determine wrist to palm amplitude and duration ratios and segmental conduction velocities. In 16% of CTS hands there was an abnormal amplitude reduction without increased duration of CMAP or SNAP from wrist stimulation indicating partial conduction block in the carpal tunnel segment of the median nerve. In 148 hands distal motor latency to abductor pollicis brevis and/or sensory conduction to digit 2 were abnormal. In the remaining 146 hands wrist to palm motor conduction was less than 35 m/s in 22.6% and wrist to palm sensory conduction was less than 45 m/s in 13%. At least one segmental conduction was abnormal in 27% of hands. Segmental studies allow the discrimination between conduction block and axonal degeneration, increase diagnostic yield in CTS, and might be useful in addressing treatment and predicting outcome.


64. Eisen A, Schulzer M, Pant B, MacNeil M, Stewart H, Trueman S, Mak E. Receiver operating characteristic (ROC) curves were used to predict the risk of CTS. Patients were classified clinically as (1) normal exam and no symptoms (169 hands), (2) having motor and/or sensory deficit typical of CTS (156 hands); (3) having a history characteristic of CTS (115 hands); and (4) non-diagnostic symptomatology (122 hands). Differences between median and ulnar mixed palmar latency were calculated. Median DML combined with median-ulnar palmar latency differences discriminate over other measurements and correlated highly for all groups (r values = 0.71-0.73). These variables were used to construct ROC curves and prediction tables. The approach used allows one to assign a percentage risk of having CTS and can be used n outcome studies.


69. Felsenthal G. Median and ulnar distal motor and sensory latencies in the same normal subject. Arch Phys Med Rehabil 1977;58:297-302. Criteria Met (normal population study 4/6: 1,3,5,6) Source: Jackson, 1989. Abstract: The following techniques were studied in 50 normal subjects: (a) median DML after stimulation at the wrist and recording over APB, (b) ulnar DML after stimulation at the wrist and recording over abductor digiti minimi, (c) median DML with stimulation at the wrist and recording with ring electrodes over the index finger and (d) ulnar DML after stimulation at the wrist and recording with ring electrodes over the little finger. Additionally, side-to-side differences and median-ulnar latency differences are reported. No data on CTS patients is reported.

70. Felsenthal G. Median and ulnar muscle and sensory evoked potentials. Am J Phys Med 1978a;57:167-182. Criteria Met (normal population study 4/6: 1,3,5,6) Source: Jackson, 1989. Abstract: The following techniques were studied in 50 normal subjects: (a) CMAP potentials were recorded after stimulation at the wrist and recording over the APB, (b) CMAPs were recorded from the abductor digiti minimi after stimulation of the ulnar nerve at the wrist, (c) SNAPs were recorded from the ulnar nerve at the wrist and (d) SNAPs were recorded from ring electrodes from the little finger after ulnar nerve stimulation at the wrist. Amplitudes of the CMAP and SNAPs are reported and left-to-right comparisons and median-ulnar comparisons are reported. No CTS patients were studied.

71. Felsenthal G, Spindler H. Palmar conduction time of median and ulnar nerves of normal subjects and patients with carpal tunnel syndrome. Am J Phys Med 1979;58:131-138. Criteria Met (5/6: 1,2,3,5,6) Source: Redmond, 1988. Abstract: With stimulation at the wrist and palm, antidromic SNAP latencies were determined for the median and ulnar nerves from 60 hands in 33 normal patients and 33 patients with CTS. They found that both the absolute median-wrist-to-palm conduction time and the median ulnar wrist-to-digit comparison were more sensitive than the median wrist-to-digit latency. The latency ratio comparing median wrist-to-palm and wrist-to-digit latency was too variable to be useful in the diagnosis of CTS.

72. *Ferry S, Pritchard T, Keenan J, Croft P, Silman AJ. Estimating the prevalence of delayed median nerve conduction in the general population [see comments]. Br J Rheumatol 1998;37:630-635. Criteria Met (4/6: 1,2,4,6) Source: Medline Search. Abstract: The objective of this study was to determine the point prevalence of delayed median nerve conduction at the wrist in the general population by published criteria in a random sample of the general population. The details of the median NCS in the article were not sufficient to permit reproduction of the study. Non-response to the questionnaire and non-attendance for nerve conduction testing may have biased the prevalence estimates. After adjustment for such biases, a prevalence estimate for delayed median nerve conduction of between 7 and 16% was obtained, varying with different diagnostic criteria for delayed median nerve conduction. Those with hand symptoms consistent with CTS only explained 20% of all subjects with prolonged median nerve latency values. The authors concluded that delayed median nerve conduction across the wrist is not uncommon in the general population. A subsequent letter to the editor pointed out that the authors did not measure ulnar nerve conduction so that the clinical significance of the delayed median nerve conduction is not clear. In addition, this was a cross-sectional study so that the subsequent development of CTS symptoms in subjects with delayed median nerve latency values would not have been detected.

73. Fisher MA, Hoffen B. F-wave analysis in patients with carpal tunnel syndrome. Electromyogr Clin Neurophysiol 1997;37:27-31. Criteria Met (4/6: 1,3,5,6) Source: Medline Search. Abstract: The carpal tunnel syndrome (CTS) provides a model for analyzing the effects of focal nerve injury on F-waves. Twenty-four patients with clinical and electrophysiologic features for unilateral (5) or bilateral CTS (19) were studied. F-waves were evaluated following 20 supramaximal stimuli and recording from abductor pollicis brevis muscles. Minimal and mean latencies, persistences, chronodispersion (CD), mean F/M amplitude ratios, and repeater waves were evaluated. CD's in those limbs with the most prolonged distal motor latencies (DML) were significantly greater than in those with less prolonged DML's; 80% or greater repeater waves were found almost exclusively in those hands with decreased M-wave amplitudes; and mean F/M values were almost always larger in the hand with the more prolonged DML. The
data support differing effects of demyelinating and axonal injury on F-waves and suggest physiological compensation in those hands with the more pronounced neuropathic dysfunction.

74. Fitz WR, Mysiw WJ, Johnson EW. First lumbrical latency and amplitude. Comparison values and findings in carpal tunnel syndrome. Am J Phys Med Rehabil 1990;69:198-201. Criteria Met (5/6: 1,3,4,5,6) Source: Medline Search. Abstract: With stimulation at the wrist, CMAPs were recorded from the first lumbrical and APB from 44 healthy adults and 36 patients with CTS. Sensory latencies were also recorded, but not systematically reported. In CTS patients, 8% had an abnormal DML to the lumbral with a normal DML to the APB. They did not find any cases where the latency to the lumbral was abnormal and sensory studies were normal.

75. Foresti C, Quadri S, Rasella M, Tironi F, Viscardi M, Ubiali E. Carpal tunnel syndrome: which electrodiagnostic path should we follow? A prospective study of 100 consecutive patients. Electromyogr Clin Neurophysiol 1996;36:377-384. Criteria Met (4/6: 1,3,5,6) Source: Medline Search. Abstract: Based on written communications, it was learned that this was a prospective study of 6 different motor and sensory electrodiagnostic tests on both hands of 100 patients and on 25 healthy subjects. Reference values obtained from other sources if the reference values obtained from the health subjects in the study were “too far” from reference values previously adopted by the laboratory.


84. Gilliatt RW, Meer J. The refractory period of transmission in patients with carpal tunnel syndrome. Muscle Nerve 1990;13:445-450. Criteria Met (4/6: 1,3,4,5) Source: Medline Search. Abstract: With stimulation at the wrist and recording at the finger and elbow, the refractory period of transmission (RPT) was determined between 2 successive shocks by using averaging and signal subtraction techniques. Fourteen hands from 10 CTS patients and 15 control subjects were evaluated. The RPT was abnormal in 11 out of 14 CTS patients.


87. Gnatz SM, Conway RR. The role of needle electromyography in the evaluation of patients with carpal tunnel syndrome. Muscle Nerve 1999;22:282-286. Background Reference. Editorial. Source: Medline Search. Pros: (1) Identify other nerve pathology which may mimic CTS, e.g. (a) proximal median neuropathy with accompanying slowing of median nerve conduction across the CT and (b) cervical radiculopathy with normal median NCS and (2) identify coexisting cervical radiculopathy with CTS with abnormal median NCS. Cons: In the presence of clinical signs and radiographic evidence of nerve pathology proximal to CT, it is unclear how the needle EMG examination changes the course of management of a CTS patient.


91. Gunnarsson LG, Amilon A, Hellstrand P, Leissner P, Philipson L. The diagnosis of carpal tunnel syndrome. Sensitivity and specificity of some clinical and electromyographic tests. J Hand Surg [Br] 1997;22:34-37. Criteria Met (4/6: 1,3,4,6) Source: Medline Search. Abstract: Clinical, history, clinical exam, and handogram) and NCS studies were performed blinded from each other on 100 persons referred with suspected CTS. The diagnosis of CTS was based on the results of both clinical exam and NCS, and, in addition, relief of CTS symptoms after surgery was also required. The sensitivity and specificity for the combined results of the clinical examinations were 94% and 80% respectively, and for the electromyographic examinations, 85% and 87%. Of the neurophysiological methods used, the quantification of sensory nerve conduction velocity between palm to wrist and wrist to elbow was most sensitive and specific and the cut-off for this test was studied by means of an ROC-curve. Electrodiagnostic studies were (1) more specific than clinical findings and (2) are particularly useful to identify CTS suspects if there is a history of pain, atypical symptoms or previous fractures in the arm, wrist or hand.


95. Haig AJ, Tzeng HM, LeBreck DB. The value of electrodiagnostic consultation for patients with upper extremity nerve complaints: a prospective comparison with the history and physical examination. Arch Phys Med Rehabil 1999;80:1273-1281. Background Reference. Source: Medline Search. Abstract: Prospective study to determine whether electrodiagnostic testing changes diagnostic certainty compared with a detailed history and physical examination, and whether interactions between medical information, the extent of testing, and diagnostic certainty imply a need for advanced medical knowledge on the part of the examiner. Two hundred fifty-five consecutive referrals for upper extremity nerve complaints were subjects of the study. Diagnosis, diagnostic confidence, and severity of neurologic lesion were coded after standardized history and physical examination. Electrodiagnostic testing substantially altered 42% of diagnoses, confirmed 37%, and did not clarify 21%. The extent of testing correlated with the size of the differential diagnosis, the number of previous hospitalizations, and the number of other medical problems. Confidence in final diagnoses correlated positively with severity of the lesion, but negatively with the size of the differential diagnosis and the number of painful body areas. Hospitalizations and medical problems also tended towards negative correlations. This study, in which all electrodiagnostics, histories, and physical examinations were performed by a single physician, indicates that electrodiagnostic testing substantially alters clinical impressions in a large percentage of patients. The complex relationship between clinical information, the extent of testing, and final diagnostic certainty indicates that specialized medical knowledge is required for accurate
electrodiagnosis.

96. Hansson S. The association between nerve conduction velocity and the compound action potential amplitude during ischemic blocking. Electromyogr Clin Neurophysiol 1999;39:113-122. Criteria Met (3/6: 1) Source: Medline Search. Abstract: The agreement between the outcomes of various combinations of these procedures was assessed by determining the kappa coefficient. There was relatively poor overlap between the reported symptoms, the physical examination findings, and the electrodiagnostic results consistent with carpal tunnel syndrome. Overall, only 23 out of 449 subjects (5%) had at least 1 positive finding met all 3 criteria (symptoms, physical examination findings, and electromyographical results consistent with carpal tunnel syndrome) for the dominant hand. The screening procedures showed poor or no agreement with kappa values ranging between 0.00 and 0.18 for all the case definitions evaluated for carpal tunnel syndrome.

97. Hansson S, Nilsson BY. Median sensory nerve conduction block during wrist flexion in the carpal tunnel syndrome. Electromyogr Clin Neurophysiol 1995;35:99-105. Criteria Met 5/6: 1, 2, 3, 5, 6 Source: Medline Search. Abstract: Prospective study of the effect of prolonged passive wrist flexion on median and ulnar sensory amplitude and latency in 10 normal controls and 30 CTS patients with a clinical diagnosis of CTS of whom 10 had mild abnormalities of median sensory latency measurements: digit 4 CV >45 ms or median-ulnar latency difference from 4th digit to wrist >0.4 ms. During prolonged (up to 45 min) passive wrist flexion, the antidiromic median (wrist to 2nd finger) and ulnar (wrist to 5th finger) SNAP were recorded. The measurements were made every 2.5 min during sustained passive wrist flexion for up to 45 min and the time (T50) for the amplitude to fall to 50% of the initial amplitude determined. The median nerve SNAP conduction (but not the ulnar) became blocked in all CTS patients and also in 8 out of 10 controls. Median sensory nerve conduction returned to normal in all subjects 30 seconds after release of flexion. At 10 minutes of wrist flexion, no significant increase of the median SNAP peak latency in normal subjects (mean 0.01 ± 0.04 ms) and CTS patients (mean 0.24 ± 0.26 ms) was noted. The time (T50) necessary to reach a 50% reduction in median SNAP amplitude in 8 out of 10 probable CTS patients and in 14 out of 20 CTS patients was below the lowest recorded value in the control group (25 min). It was shown that ischemia caused the block (reduction in median SNAP amplitude) by demonstrating (1) that the reversal of a 70% block with release of wrist flexion was prevented by inflating a pneumatic cuff around the upper arm to above systolic pressure for 5 minutes before release of wrist flexion after which (2) the SNAP amplitude returned to normal 30 seconds after deflating the cuff. Determination of T50 of the median nerve SNAP during wrist flexion has the potential to add to the sensitivity and specificity of the electrophysiological diagnosis of CTS.

98. Harmon RL, Naylor AH. Sensory and mixed nerve action potential temporal dispersion in median neuropathy at the wrist. J Am Phys Med Rehabil 1989;78:213-215. Criteria Met (3/6: 1, 2, 3) Source: Medline Search. Abstract: Retrospective study to determine the usefulness of measuring SNAP and mixed nerve AP temporal dispersion to diagnose CTS demonstrated that increased median mixed nerve AP temporal dispersion may occur in association with peak latency prolongation in CTS. However, the small magnitude of the increase makes the clinical usefulness of this observation unclear.

99. Healy C, Watson JD, Longstaff MB, Campbell MJ. Magnetic resonance imaging of the carpal tunnel. J Hand Surg 1990;15:243-248. Criteria Met 3/6: 1, 2, 3 Source: Medline Search. Abstract: The poor overlap between the various screening procedures warns against the use of screening procedures with the symptom presentation being considered. The results of this study also point to a need for the further development and evaluation of methods for detecting carpal tunnel syndrome.

100. Hughes ACR. An evaluation of 2 electrodiagnostic procedures in patients with symptoms of a carpal tunnel syndrome. Electroencephalogr Clin Neurophysiol 1977;43:140. Criteria Met 5/6: (abstract only) Source: Medline Search. Abstract: Demonstrating (1) that the reversal of a 70% block with release of wrist flexion after which (2) the SNAP amplitude returned to normal 30 seconds after deflating the cuff. Determination of T50 of the median nerve SNAP during wrist flexion has the potential to add to the sensitivity and specificity of the electrophysiological diagnosis of CTS.


103. *Homan MM, Frenzlau A, Werner RA, Albers JW, Armstrong TJ, Bromberg MB. Agreement between symptom surveys, physical examination procedures and electrodagnostic findings for the carpal tunnel syndrome. Scand J Work Environ Health 1999;25:115-124. Background Reference. Source: Medline Search. Abstract: The goal of this study was to evaluate the concordance between various clinical screening procedures for carpal tunnel syndrome. The subject population consisted of 824 workers from 6 facilities. The procedures evaluated included bilateral median sensory and motor conduction, physical examinations, and symptom surveys, including hand diagrams. The agreement between the outcomes of various combinations of these procedures was assessed by determining the kappa coefficient. There was relatively poor overlap between the reported symptoms, the physical examination findings, and the electrodiagnostic results consistent with carpal tunnel syndrome. Overall, only 23 out of 449 subjects (5%) had at least 1 positive finding met all 3 criteria (symptoms, physical examination findings, and electromyographical results consistent with carpal tunnel syndrome) for the dominant hand. The screening procedures showed poor or no agreement with kappa values ranging between 0.00 and 0.18 for all the case definitions evaluated for carpal tunnel syndrome. The poor overlap between the various screening procedures warns against the use of screening procedures with the symptom presentation being considered. The results of this study also point to a need for the further development and evaluation of methods for detecting carpal tunnel syndrome.


amplitude ratio between median SNAP to index finger/ulnar SNAP to the little finger. One hundred thirty-one abnormal hands in 123 subjects and 38 normal hands in 38 people were evaluated with analysis focused on the 40 hands in the mild CTS group. Symptoms were sustained and were recorded and reported in each patient. The median-radial latency difference to the thumb and median-ulnar latency difference to ring finger was slightly more sensitive than the midpalms. Amplitude ratios were very insensitive.


112. Johnson EW, Kukla RD, Wongsam PE, Piedmont A. Sensory conduction studies of median and ulnar nerves. J Neurol Sci 1978;38:1-10. Criteria Met (3/6: 1,3,5) Source: Dunnan, 1991. Abstract: With stimulation of the wrist and recording over the ring finger, the median and ulnar nerve DSL were recorded across the wrist; 37 normal subjects and 18 cases of CTS were evaluated. The difference between median and ulnar DSL to the ring finger was abnormal in all 18 CTS patients.

113. Johnson EW, Melvin JL. Sensory conduction studies of median and ulnar nerves. Arch Phys Med Rehabil 1967;48:25-30. Criteria Met (4/6: 1,3,5,6) Source: Dunnan, 1991. Abstract: With stimulation of the middle or index finger and recording over the median nerve at the wrist, orthodromic SNAPs and DSLs were determined in 120 controls. Orthodromic ulnar SNAPs and DSLs were determined after stimulation of the ring finger or little finger and recording at the wrist and elbow. They report cases of abnormal DSL in patients with carpal tunnel syndrome, toxic neuropathy, early diabetic neuropathy, and other peripheral nerve involvement problems.


117. Joynt RL. Correlation studies of velocity, amplitude and duration in median nerves. Arch Phys Med Rehabil 1989;70:477-481. Criteria Met (4/6: 1,3,5,6) Source: Medline Search. Abstract: The following techniques were studied: (a) stimulation in the palm between the third and fourth metacarpals and median recording at the wrist and (b) stimulation at the wrist and CMAP recording over the ABP. Distal latencies, amplitudes, duration of response and residual latencies were evaluated; 390 patients were studied, all these were symptomatic and many of them had CTS. The results suggest that amplitude, duration and conduction velocity are relatively poorly correlated and independent variables. There is a very high correlation between residual latency and distal motor latency, thus suggesting limited usefulness for residual latency in the diagnosis of CTS.


119. Kabiraj MMU, Al Rajeh S, Al Tahan AR, Abduljabbar M, Al Bunyan M, Daif AK, Awada A. Carpal tunnel syndrome: a clinico-electrophysiological study. Medical Science Research 1998;26:631-633. Criteria Met (4/6: 2,3,4,5) Source: Medline Search. Retrospective review of 5 years record to identify 72 CTS patients 57% idiopathic, 19% associated with diabetes mellitus, 11% with rheumatoid arthritis, 7% with hypothyroidism, and 6% with renal or heart failure. The group of CTS patients showed abnormal median sensory and motor terminal latencies decreased median SNAP amplitude and velocity and median terminal latency index compared to a group of 65 normal subjects. There was a positive correlation between the median motor distal latency and the median terminal latency index. This study did not examine the percentage of CTS patients showing each type of NCS abnormality.


125. Kemble F. Electrodiagnosis of the carpal tunnel syndrome. J Neurol Neurosurg Psychiatry 1968;31:23-27. Criteria Met (4/6: 1,2,5,6) Source: Winn, 1989. Abstract: With stimulation over thumb, index, middle, and ring fingers and recording over the median nerve at the wrist and elbow, orthodromic SNAPs and CMAPs to the APB were determined in 120 hands in 66 female patients with CTS. They found that the DSL was more likely to be abnormal than the SNAP. It is concluded that ischemic compression may be sufficient to explain some of the intermittent symptoms and electrodiagnostic findings in patients with carpal tunnel syndrome, particularly when it is of mild or moderate severity.

126. Kemble F, Mogyoros I, Burke D. Conduction block in carpal tunnel syndrome. Brain 1999;122(Pt 5):933-941. Criteria Met (4/6: 1,4,5,6) Source: Medline Search. Abstract: Prolonged wrist extension was performed passively (written communication) in 6 healthy subjects and 7 CTS patients. Preliminary experiments demonstrated that in the CSAP (compound sensory action potential) developed sooner than in normal subjects. CMAPs in CSAP latencies were confined to the CSAP. During maintained wrist extension to 90 degrees, all subjects developed greater than 50% conduction block in cutaneous afferents in the wrist (but not distal to the wrist) and slight increases in distal latency (0.44 ± 0.07 ms for normal subjects and 0.51 ± 0.05 ms for CTS patients). The changes in normal subjects began after wrist extension for 21.8 ± 5.8 min and was maximal at 49.3 ± 10.7 min. The changes in CTS patients began after wrist extension for 12.8 ± 2.8 min and was maximal at 28.1 ± 3.3 min. The reduction in the amplitude of the SNAP potential in normal subjects and CTS patients was associated with changes in axonal excitability at the wrist with a decrease in supernormality and an increase in refractoriness compatible with axonal depolarization. All subjects (normals and patients) reported mild paresthesiae during prolonged wrist extension and more intense paresthesiae were reported following the release of wrist extension. It is concluded that wrist extension produces a depolarization block in both normal subjects and CTS patients, much as occurs with ischemic compression, but that this block cannot be altered merely by compensating for the axonal depolarization. It is argued that conduction block and conduction slowing need not always be attributed to disturbed myelination, and that ischemic compression may be sufficient to explain some of the intermittent symptoms and electrodiagnostic findings in patients with carpal tunnel syndrome, particularly when it is of mild or moderate severity.

127. Kim LYS. Palmar digital nerve stimulation to diagnose carpal tunnel syndrome. Orthop Rev 1983;59-63. Criteria Met (4/6: 1,3,5,6) Source: Joynt, 1989. Abstract: With stimulation in the midpalp and recording at the wrist, median and ulnar distal latencies and median-ulnar distal latency differences were determined in 66 hands in 33 normal control subjects and 50 hands in 39 mild CTS patients. Mild CTS was defined as patients who had symptoms who were highly suggestive of CTS, but had normal DSL between the finger and wrist. Sixty percent of these mild CTS patients were abnormal by the median-ulnar difference criteria (greater than or equal to 0.4 ms). Criteria Met (5/6: 1,2,3,5,6) Source: Paillyath, 1990. Abstract: With stimulation at the wrist and midpalp and recording SNAPs over the index finger and CMAPs from the APB, NCVs were determined across the carpal tunnel for both motor and sensory nerves; 50 hands.
from 25 control subjects and 20 hands from 13 patients with mild CTS were evaluated. The motor and sensory NCV across the carpal tunnel were more likely to be abnormal than conventional DLS and DMLs determined from the wrist.

129. Kimura J. Localization of conduction abnormalities within the distal segment of the median nerve. Brain 1979;102:619-635. Criteri Met (6/6: 1,2,3,4,5,6) Source: Shurr, 1986. Abstract: With stimulation at the elbow and wrist, orthodromic SNAPs were recorded over the index finger and median CMAP from the wrist to APB were recorded from 122 hands from 61 normal subjects and 172 hands from 105 CTS patients. Sixty-one percent of the median CMAPs were abnormal, 63% of the wrist-to-finger latencies were abnormal and 81% of the wrist to palm latencies were abnormal. They also reported cases where 1 cm inhibiting stimulation across the carpal tunnel was abnormal in patients with otherwise normal studies.

131. Kimura I, Ayyar DR. The carpal tunnel syndrome: Electrophysiological aspects of 639 symptomatic extremities. Electromyogr Clin Neurophysiol 1985;25:151-164. Criteri Met (4/6: 1,2,3,5) Source: Mortier, 1988. Abstract: The following techniques were studied: (a) with stimulation at the elbow, wrist and mid-palm, orthodromic DSL were determined to the index finger and median CMAP from the wrist to APB were recorded from 122 hands from 61 normal subjects and 172 hands from 105 CTS patients. Sixty-one percent of the median CMAPs were abnormal, 63% of the wrist-to-finger latencies were abnormal and 81% of the wrist to palm latencies were abnormal. They also reported cases where 1 cm inhibiting stimulation across the carpal tunnel was abnormal in patients with otherwise normal studies.


136. Kothari MJ, Rutherford SB, Careess JB, Hinchee J, Logigian EL, Preston DC. Comparison of digital sensory studies in patients with carpal tunnel syndrome. Muscle Nerve 1995;18:1272-1276. Criteri Met (5/6: 1,3,4,5,6) Source: Medline Search. Abstract: Prospective study to evaluate the relative sensitivity of antidromic sensory studies of the four digital segments during vibration. In CTS patients, abnormalities were determined to the basis of a combination of clinical and median NCS abnormalities. The conduction distance was 10 cm for D1 and 13 cm for D2-D4. The reference population of 30 was composed of healthy volunteers or patients with lower extremity radiculopathies. In the 26 CTS patients with a normal DML to APB, digit 1 was abnormal in 81%, digit 2 in 42%, digit 3 in 54%, and digit 4 in 38%. In the 33 CTS patients with a prolonged DML, digit 1 was abnormal in 94%, digit 2 in 88%, digit 3 in 91%, and digit 4 in 88%. We conclude that in CTS patients with a normal DML to the APB, digit 1 is the most sensitive in identifying focal slowing of sensory conduction across the wrist. However, in CTS patients with a prolonged DML, the sensitivity of sensory conduction is not significantly different among the four digits.

137. *Koyoumdjian JA, Morita Mda P. Comparison of nerve conduction techniques in 95 mild carpal tunnel syndrome hands. Arch Neuropsiqiatri 1999:57-195-197.Criteri Met (3/6: 1,3,4). Source: Medline Search. Abstract: Prospective study of 5 NCS techniques in patients suspected of CTS and selected for the study at least one of the 5 studies was abnormal: (1) wrist-index finger onset latency (WIF), abnormal ≥ 2.5 ms, 14 cm; (2) palm-wrist onset latency (PW), abnormal ≥ 1.8 ms, 8 cm; (3) comparison median/ulnar palm-wrist onset latency (MPW), abnormal ≥ 0.4 ms, 14 cm; (4) comparison median/palmar onset latency, wrist-ring finger (CMU), abnormal ≥ 0.5 ms, 14 cm; (5) comparison of median/radial onset latency, wrist-thumb (CMR), abnormal ≥ 0.4 ms, 10 cm. All 95 CTS hands selected have the WIF ≤ 3.5 ms to identify “mild CTS.” We found the CMR (97.8%) technique the most sensitive for mild CTS electrodiagnosis and the only comparable method with all potentials recordable when compared to CPW (88.4%), PW (84.2%), CMU (72.6%) and WIF (68.4%).

138. Kremer GH, Halvorson GA. Median nerve residual latency: Normal value and use in diagnosis of carpal tunnel syndrome. Arch Phys Med Rehabil 1983;64:221-226. Criteri Met (4/6: 1,3,5,6) Source: Bleecker, 1987. Abstract: With stimulation at the elbow and wrist and recording over the APB, DMLs and forearm NCVs were determined in 100 normal subjects and 3 CTS patients. The residual latency (DML-distance between stimulation and recording electrodes in mm forearm NCV in ms). They present 3 cases where the residual latency was the only abnormality found.


140. Kuntzer T. Carpal tunnel syndrome in 100 patients: sensitivity, specificity of multi-neuropathological procedures and estimation of axonal loss of motor, sensory and sympathetic median nerve fibers. J Neurol Sci 1994;127:221-229. Criteri Met (6/6: 1,2,3,4,5,6) Source: Medline Search. Abstract: Study of 70 control subjects and of the more symptomatic hands of 100 CTS patients diagnosed independently by clinical history and examination. Study specifically designed to meet all six AAEM criteria for evaluation of usefulness of NCS to diagnose CTS including continuous monitoring of hand temperature during the NCS. Reports the criteria for abnormalities, sensitivities and specificities of 19 sensory, motor and autonomic parameters. 9/19 parameters reached a specificity of 97%. At least 1/9 of the parameters was abnormal in 87% of the CTS patients. Normal median CMAP and SNAP amplitudes and abnormal median F-wave parameters were diagnostic for CTS. They conclude that SNAPs are the most sensitive signs (69 and 66%, respectively), and are recommended as part of the examination of CTS. Median nerve hyperesthesia and the Phalen sign both have fair sensitivity (51%) but good specificity (85 and 76%, respectively). The median nerve compression sign and the Hoffmann-Tinel sign both have poor sensitivity (28 and 23%, respectively), and thus are less helpful in evaluating subjects with suspected CTS.


142. Laroy V, Spaans F, Reulen J. Nerve conduction studies show no evidence of mononeural innervation of D4 by median and ulnar nerves in 260 patients referred for electrodiagnostic evaluation of brachialgia (not defined in paper). No case of mononeural innervation of D4 by the median or ulnar nerve was encountered. In all cases in which D4 SNAPs were obtained with both median and ulnar stimulation, it could be demonstrated that the SNAPs were not due to co-stimulation by simultaneous recording of SNAPs from another median or ulnar innervated finger. The authors discuss the reasons why some previous clinical and experimental studies may have mistakenly concluded that mononeural innervation of D4 occurred as a result of ulnar innervation. Finally, comparison of SNAP parameters in 183 hands with increased median nerve distal latencies showed conduction to be more impaired in the fibers innervating D4 than in those supplying D3.

143. Lauritsen M, Ligouri R, Trojaborg W. Orthodromic sensory
conduction along the ring finger in normal subjects and in patients with a carpal tunnel syndrome. Electroencephalogr Clin Neurophysiol 1991;81(1):18-23. Criteria Met (5/6: 1,3,4,5,6) Source: Medline Search. Abstract: With stimulation of the ring finger using ring electrodes and needle electrode recording intratunnel, over the median and ulnar nerves, DSLs and median-ulnar differences were recorded in 23 normal volunteers and 38 CTS patients. Their findings suggest that the median-ulnar orthodromic DLSL difference from the ring finger was a useful screening technique in the diagnosis of CTS, but did not identify every patient when compared to stimulation of thumb and/or middle finger.

144. Lesser EA, Vrenoush S, Preston DR, Logigian EL. Stimulation distal to the lesion in patients with carpal tunnel syndrome. Muscle Nerve 1995;18:503-507. Criteria Met (5/6: 1,3,4,5,6) Source: Medline Search. Abstract: In CTS patients, a low amplitude median CMAP or SNAP with stimulation at the wrist crease (proximal to the carpal tunnel) is due to either demyelination or axonal degeneration or both. With axonal degeneration, the amplitude of the CMAP and SNAP is the same with stimulation above and below the site of the pathology. With focal demyelination, the amplitude of the CMAP and SNAP is greater with stimulation below compared to stimulation above the site of the pathology. Of 59 consecutive CTS patient hands, 36 (61%) showed significant reduction in CMAP and/or antidromic SNAP amplitudes with stimulation at the wrist compared to stimulation at the palm which indicated the presence of focal demyelination resulting in conduction block and/or pathologic dispersion with phase cancellation. The authors conclude that in patients with CTS, as in other entrapment neuropathies, stimulation both proximal and distal to the carpal tunnel provides important information about the median nerve pathology in the carpal tunnel.

145. Lew HL, Wang L, Robinson LR. Test-retest reliability of combined sensory index: implications for diagnosing carpal tunnel syndrome. Muscle Nerve 2000;23: 1261-1264. Criteria Met (5/6: 1,2,3,5,6) Source: Medline Search. Abstract: Robinson and colleagues (1998) previously showed that, compared to a single NCS, the combined sensory index (CSI) has superior sensitivity and specificity for the diagnosis of CTS. This prospective study evaluated the test-retest reliability of a single NCS versus the CSI by the same examiner in one hand of 32 subjects: 26 normal subjects and 6 CTS patients. In a subgroup of 18 subjects, the study evaluated the effect of temperature on the absolute latencies and latency differences derived from the NCS. CSI had the highest test-re test reliability and the CSI score (the sum of 3 latency differences) was less affected by temperature changes than absolute latency values of individual NCSs.

146. Logigian EL, Bussis NA, Berger AR, Bruynincky F, Khalil N, Shahani BT, Young RR. Lumbarling stimulation in carpal tunnel syndrome: anatomic, physiologic, and diagnostic implications. Neurology 1984;34:1499-1505. Criteria Met (5/6: 1,2,3,5,6) Source: Medline Search. Abstract: With stimulation at the wrist, simultaneous recording of CMAP to the second lumbrical and APB were recorded in 16 normal subjects. They found that the lumbrical distal latency was relatively spared when compared to the distal latency to the APB and that this may be a sensitive test that could be used in addition to other tests for the diagnosis of CTS. They also found that it was not specific for CTS since it occasionally was abnormal in more proximal lesions of the median nerve.


148. Loong SC, Seach CS. Comparison of median and ulnar sensory nerve action potentials in the diagnosis of the carpal tunnel syndrome. J Neurol Neurosurg Psychiatry 1971;34:750-754. Criteria Met (5/6: 1,2,3,5,6) Source: Macleod, 1987. Abstract: With stimulation at the index and little fingers and recording at the wrist over the median and ulnar nerves, DSL and SNAP amplitudes were recorded in 30 healthy female subjects and 22 hands in 15 CTS patients. They found that the median-to-ulnar SNAP amplitude ratio of less than 1 was a sensitive test to the diagnosis of CTS and particularly useful in patients who showed a normal DML and DSL.


151. *Luchetti R, Schoenhuber R, Nathan P. Correlation of segmental carpal tunnel pressures with changes in hand and wrist positions in patients with carpal tunnel syndrome and controls. J Hand Surg [Br ] 1998;23:598-602. Criteria Met (3/6: 1,2,5) Source: Medline Search. Abstract: The authors investigated pressure with an endoscopic pressure monitor at 1 cm intervals along the carpal tunnel in 39 patients with CTS and 12 controls. Pressures were measured for relaxed and gripping hand positions in combination with neutral, extended, and flexed wrist positions. The study confirmed previous reports that CT pressures are generally higher in CTS patients than controls, and that intratunnel pressures are generally increased with pinched and with increased pressure in the carpal tunnel. Maximum intratunnel pressures were generally found in the central part of the tunnel and minimum pressures in the distal tunnel. Gripping hand pressures in the tunnel were lowest with the wrist flexed. In both controls and CTS patients, only in the neutral wrist and relaxed hand positions were pressures highest at the point where nerve conduction studies have indicated the nerve is most likely to be compromised (in the midpalmar just distal to the distal margin of the carpal tunnel).


157. Macleod WN: Repeater F-waves: a comparison of sensitivity with sensory antidromic wrist-to-palm latency and distal motor latency in the diagnosis of carpal tunnel syndrome. Muscle Nerve 1981;4:777-783. Criteria Met (4/6: 1,3,5,6) Source: Medline Search. Abstract: With stimulation at the wrist and recording of F waves over the APB, the frequency of repeater F waves (identical recurring F waves in latency, configuration, and amplitude) was determined by measuring 100 supramaximal shocks; 209 healthy hands and 147 entrapped median nerves were evaluated. The repeater F waves was compared to the sensory 1 cm DSL inching latency across the wrist. A high percent repeater F-wave value was considered indicative of CTS and the sensitivity approaches that of the sensory antidromic inching technique across the carpal tunnel.

158. Marin EL, Vennick S, Friedmann LW. Carpal tunnel syndrome: Median nerve stress test. Arch Phys Med Rehabil 1983;64:206-208. Criteria Met (5/6: 1,2,3,5,6) Source: Borgh, 1986. Abstract: With median stimulation at the wrist and recording over the APB and ring electrodes to the index finger, DML and DSL were obtained from the median nerve in the neutral position, then in extreme tolerable extension at 5 minutes and 10 minutes followed by the testing in the extreme tolerable flexion position after 5 and 10 minutes. An orthosis was devised to enable the wrist to be held in extreme tolerable extension which ranged from 45E-85E and extreme tolerant flexion which ranged from 45E-90E. Fourteen hands in 14 patients with CTS and 12 hands from 12 volunteers were evaluated. Of the 14 patients, 5 of these had normal DSL and DML latencies in the neutral position. Three of these 5 showed an increase in DSL from the upper range of normal to above normal following extension or flexion.
159. Marinacci AA. Comparative value of measurement of conduction velocity and electromyography in the diagnosis of carpal tunnel syndrome. Arch Phys Med Rehabil 1964;45:548-554. Criteria Met (4/6: 1,2,3,5) Source: Nathan, 1988. Abstract: With stimulation at the wrist and recording over the APB, motor NCVs and DMLs were determined in 204 patients having CTS and 64 control subjects. Needle EMG was also performed in this group; 70% of CTS cases had abnormal wrist DML and the needle EMG was abnormal in 96% of the cases (fibrillations, polyphasic units, and large amplitude motor units). Sensory latencies were also recorded in 23 CTS patients.


161. Mavor H, Shiozawa R. Antidromic digital and palmar nerve action potentials. Electroencephalogr Clin Neurophysiol 1971;30:210-221. Criteria Met (4/6: 1,3,5,6) Source: Buchthal, 1974. Abstract: With stimulation at the elbow and wrist and recording over the middle finger, SNAPs and DSLs were recorded in 21 normal subjects. With stimulation over the ulnar nerve at the elbow and wrist, antidromic SNAPs and DSLs were recorded in 13 normal subjects. No CTS patients were studied.

162. Mayer RF. Nerve conduction studies in man. Neurology 1962;12:733-744. Criteria Met (4/6: 1,3,5,6) Source: Kraft, 1983. Abstract: The following techniques were studied in 64 normal subjects and 31 diabetics without peripheral neuropathy: (a) stimulation in axilla, above elbow and wrist with recording of the CMAP over the APB, surface and concentric needle electrodes were used, (b) with stimulation in the axilla, above the elbow and wrist, SNAPs were recorded from digital nerves using surface and needle electrodes, (c) ulnar, (d) peroneal, (e) tibial, and (f) H reflex. They found a slight decrease in NCV in patients older than 50, and in patients with diabetes mellitus without clinical signs of peripheral neuropathy. No CTS patients were studied.


164. McLellan DL, Swash M. Longitudinal sliding of the median nerve during movements of the upper limb. J Neurol Neurosurg Psychiatry 1976;39:566-570. Background Reference. Source: AAEM CTS Task Force 2000 member. Normal subjects. An incidental finding during recording of median NAP with monopolar needle electrode in the median nerve from below elbow and wrist with recording of the CMAP over the APB. Quantitative sensory threshold (QST) testing was done using vibration thresholds and thermal sensitivity thresholds comparing the palm to wrist over the index to little finger in 23 age matched control subjects. Abnormal QST was found in only 3 of the 28 symptomatic hands (11%) and was found to be much less sensitive than NCSs.

165. Mills KR. Orthodromic sensory action potentials from palmar stimulation in the diagnosis of carpal tunnel syndrome. J Neurol Neurosurg Psychiatry 1985;48:250-255. Criteria Met (4/6: 1,3,5,6) Source: Golding, 1986. Abstract: While recording at the wrist over the median and ulnar nerves, SNAPs were elicited by stimulation over the index and little fingers and from stimulation in the palm (mixed nerve), 72 hands with CTS, 53 healthy hands and 20 hands of patients with unrelated neurological conditions were evaluated. They found that the palm-to-wrist conduction velocity and the palm-to-wrist median-ulnar comparison was more likely to be abnormal than the DML or DSL. They also found no significant difference between the normal control group and the 20 hands with unrelated neurologic conditions.


167. Monga TN, Laidlow DM. Carpal tunnel syndrome measurement of sensory potentials using ring and index fingers. J Phys Med Rehabil 1982;61:123-129. Criteria Met (4/6: 1,2,3,5) Source: Redmond, 1988. Abstract: With stimulation of the fourth digit (D4), orthodromic SNAPs were simultaneously recorded at the wrist over the median and ulnar nerves, SNAPs were elicited by stimulation over the index and little fingers and from stimulation in the palm (mixed nerve); 72 hands with CTS, 53 healthy hands and 20 hands of patients with unrelated neurological conditions were evaluated. They found that the palm-to-wrist conduction velocity and the palm-to-wrist median-ulnar comparison was more likely to be abnormal than the DML or DSL. They also found no significant difference between the normal control group and the 20 hands with unrelated neurologic conditions.

168. Monga TN, Shanks GL, Poole BJ. Sensory palmar stimulation in diagnosis of carpal tunnel syndrome. Arch Phys Med Rehabil 1985;66:598-600. Criteria Met (5/6: 1,2,3,5,6) Source: Jackson, 1989. Abstract: The following techniques were studied: (a) ring stimulation over the index and little fingers and recording at the wrist over the median and ulnar nerve, (b) median palm stimulation and recording at the wrist over the APB, (c) wrist stimulation over median and ulnar nerves and recording over the APB and ADM were evaluated in 36 hands in 22 CTS patients and 22 normal patients. They found the palm-to-wrist stimulation to be abnormal in 88%, the median index finger DSL (in 86%), median- ulnar finger DSL comparison (in 81%), and median DML (in 81%).


172. Melvin JL, Schuchmann JA, Lanese RR. Diagnostic specificity of motor and sensory nerve conduction variables in the carpal tunnel syndrome. Arch Phys Med Rehabil 1973;54:69-74. Criteria Met (5/6: 1,2,3,5,6) Source: Redmond, 1988. Abstract: With stimulation at the wrist and recording CTS patients and 22 normal patients. They found that the DSL followed by the DML were the best tests and that sensory duration, sensory amplitude, motor amplitude, and motor duration were not sensitive.

173. Monga TN, Laidlow DM. Carpal tunnel syndrome measurement of sensory potentials using ring and index fingers. J Phys Med Rehabil 1982;61:123-129. Criteria Met (4/6: 1,2,3,5) Source: Redmond, 1988. Abstract: With stimulation of the fourth digit (D4), orthodromic SNAPs were simultaneously recorded at the wrist over the median and ulnar nerves, SNAPs were elicited by stimulation over the index and little fingers and from stimulation in the palm (mixed nerve); 72 hands with CTS, 53 healthy hands and 20 hands of patients with unrelated neurological conditions were evaluated. They found that the palm-to-wrist conduction velocity and the palm-to-wrist median-ulnar comparison was more likely to be abnormal than the DML or DSL. They also found no significant difference between the normal control group and the 20 hands with unrelated neurologic conditions.

174. Monga TN, Shanks GL, Poole BJ. Sensory palmar stimulation in diagnosis of carpal tunnel syndrome. Arch Phys Med Rehabil 1985;66:598-600. Criteria Met (5/6: 1,2,3,5,6) Source: Jackson, 1989. Abstract: The following techniques were studied: (a) ring stimulation over the index and little fingers and recording at the wrist over the median and ulnar nerve, (b) median palm stimulation and recording at the wrist over the APB, (c) wrist stimulation over median and ulnar nerves and recording over the APB and ADM were evaluated in 36 hands in 22 CTS patients and 22 normal patients. They found the palm-to-wrist stimulation to be abnormal in 88%, the median index finger DSL (in 86%), median- ulnar finger DSL comparison (in 81%), and median DML (in 81%).


176. Murga L, Moreno JM, Menendez C, Castilla JM. The carpal tunnel syndrome. Relationship between median distal motor latency and

177. Nakamichi K, Tachibana S. Restricted motion of the median nerve in carpal tunnel syndrome. J Hand Surg 1995;20B:460-464. Background Reference. Source: AAEM 2000 CTS Task Force member. Ultrasound imaging of the mid carpal tunnel permits measurement of the magnitude of median nerve sliding with finger flexion. The studies demonstrated control subjects median nerves slid 1.75 ± 0.49 mm with finger flexion whereas CTS patients median nerves slid 0.37 ± 0.49 mm. The findings were compatible with limited longitudinal sliding on the median nerve in the CT of CTS patients.


179. *Nathan PA, Keniston RC, Meadows KD, Lockwood RS. Predictive value of nerve conduction measurements at the carpal tunnel. Muscle Nerve 1993;16:1377-1382. Criteria Met (3/6: 3,5,6) Source: Medline Search. Abstract: We compared the predictive values of three measurements of sensory conduction of the median nerve at the carpal tunnel (maximum latency difference [MLD], 8 cm latency [S8], and 14 cm latency [S14]) in 2334 hands of industrial workers, workers’ compensation patients, and students. The MLD for the median sensory nerve across the wrist was determined by the centimetric technique (inching study). The threshold, sensitivity, and specificity of abnormalities were as follows: MLD 0.40 ms, 86%, 82%, S8 ± 2.3 ms, 67%, 90% and S14 ± 3.6 ms, 56%, 94%.


181. Nathan PA, Meadows KD, Doyle LS. Nerve sensory and motor nerve conduction in the median nerve for a fascicle area of normal individuals. Arch Phys Med Rehabil 1988;69:499-501. Criteria Met (6/6: 1,2,3,4,5,6) Source: Medline Search. Abstract: With stimulation at 1 cm intervals at the wrist and across the carpal tunnel and recording over the middle finger, 70 normal hands and 54 CTS hands were evaluated for relative sensitivity and specificity at 2 levels of abnormality. At 0.5 ms abnormality, the specificity was 97% and sensitivity was 54%. At 0.4 ms or greater, the sensitivity improved to 81% and specificity dropped to 81%. Positive predictive values were 0.95% at 0.5 ms and decreased to 0.77% at the 0.4 ms abnormality.

182. Nathan PA, Srinivasan H, Doyle LS, Meadows KD. Location of impaired sensory conduction of the median nerve in carpal tunnel syndrome. J Hand Surg Br 1990;15:89-92. Criteria Met (6/6: 1,2,3,4,5,6) Source: Medline Search. Abstract: Stimulation in 1 cm segments across the carpal tunnel was performed from 2 cm proximal to the distal wrist crease (DWC) to 6 cm distal and SNAPs were recorded. The median were recorded over the middle finger in 70 normal and 217 CTS hands. The focal areas of slowing were reported with the most common area of slowing 3 to 4 cm distal to the DWC with slowing proximal to the DWC being unusual.


184. Nesathurai S, Gwardian A, Kamath AN. Median-to-ulnar sensory nerve action potential amplitude ratio as an electrodiagnostic adjunct for carpal tunnel syndrome. Arch Phys Med Rehabil 1999;80:756-759. Criteria Met (normal population study 3/6: 3,4,6). Source: Medline Search. Abstract: Retrospective review of previously obtained NCS data in 46 normal controls to obtain normative data for the median-to-ulnar sensory nerve action potential (SNAP) amplitude ratio (MUSAR) and to discuss the potential use of MUSAR in diagnosis of CTS. Antidromic median and ulnar SNAPs were recorded and the respective MUSAR ratios were calculated. Descriptive statistical analysis was completed with the assumption that SNAP values are not Gaussian in distribution. The normal MUSAR ranged from .74 (5th percentile) to 2.5 (95th percentile). The MUSAR value on the interpersonal nerve action potential SNAP amplitudes positives and false negatives that would otherwise arise when using absolute values of SNAP amplitudes. Further studies are needed to determine the clinical and application of the MUSAR value to the diagnosis of CTS.

185. Nielsen VK. Sensory and motor nerve conduction in the median nerve in normal subjects. Acta Med Scand 1973;194:435-443. Criteria Met (normal population study 5/6: 1,3,4,5,6) Source: Buchthal, 1974. Abstract: Orthodromic SNAPs were recorded over the median nerve using needle electrodes at the wrist and elbow after stimulation of the thumb and middle fingers. CMAPs were recorded with concentric needle electrodes placed in the endplate zone of the APB after stimulation at the wrist and elbow. NCVs were determined for 28 male and 20 female normal subjects aged 16 to 62 years. There was no significant difference in NCV between male and female subjects. There was a decrease in NCV with increasing age. No CTS patients were used in this study.


188. Padua L, Lo Monaco M, Valente EM, Tonali PA. A useful electrophysiologic parameter for diagnosis of carpal tunnel syndrome. Muscle Nerve 1996;19:48-53. Criteria Met (6/6: 1,2,3,4,5,6). Source: Medline Search. Abstract: In 43 patients (50 hands) with clinical manifestations of mild-moderate CTS and 36 healthy volunteers (40 hands), orthodromic sensory nerve conduction velocity (SNCV) was measured with surface electrodes in the median nerve between the third digit and palm and between the palm and wrist. These values were used to calculate the ratio of distal to proximal conduction (distoproximal ratio). All 90 hands were also subjected to other nerve conduction studies used for diagnosis of CTS. All control hands presented distoproximal ratios less than 1.0 reflecting higher conduction rates in the proximal segment. In contrast, 49 of 50 CTS hands (98%) presented reversed ratios (>1.0) indicating compromised proximal conduction. The specificity of this test was significantly greater than that of other methods evaluated, including comparative studies and segmental study of the palm-wrist portion of the median nerve. Segmental study of median SNCV with calculation of the distoproximal ratio is a sensitive technique for diagnosis of CTS in patients with normal findings in standard nerve conduction studies. Note: The author indicated by correspondence that the mean ± SD for the Control DML in Table 1 should read 3.2 ± 0.4 and not 3.2 ± 0.8 as posted.

189. Padua L, LoMonaco M, Gregori B, Valente EM, Padua R, Tonali P. Neurophysiologic classification and sensitivity in 500 carpal tunnel syndrome hands. Acta Neurol Scand 1997;96:211-217. Criteria Met (6/6: 1,2,3,4,5,6) Source: Medline Search. Abstract: Prospective study of 500 hands (379 patients) with clinical diagnosis of CTS symptoms. Normal values from the same laboratory previously published (Padua, 1996). In the 500 CTS patients, DML was prolonged (55%) and orthodromic sensory latency was prolonged (D2, 74%; D3, 67%). Of the remaining 117 patients with normal DML and median orthodromic sensory studies over 14 cm, the median sensory palm-wrist NCV over 8 cm was abnormal in 21% and the distoproximal ratio of the median palm and digit segments was abnormal in 87%.

190. Pailiyuth SK, Holden L. Refractory studies in early detection of carpal tunnel syndrome. Electromyogr Clin Neurophysiol 1990;30:307-309. Criteria Met (5/6: 1,3,4,5,6) Source: Medline Search. Abstract: Using paired stimuli and varying the inter-stimulus interval, the absolute refractory period (ARP) and relative refractory period (RRP), were determined in 10 patients with mild electrophysiologic changes suggestive of CTS. They found that the sensory RRP was sensitive in diagnosing early CTS.


192. Pease WS, Cannell CD, Johnson EW. Median to radial latency difference test in mild carpal tunnel syndrome. Muscle Nerve 1989;12:905-909. Criteria Met (4/6: 1,3,5,6) Source: Medline Search. Abstract: Sensory and motor latency differences were recorded for the median-to-ulnar DML, median radial differences to the thumb, (b) antidromic DSL, median ulnar DML latency difference between the ulnar

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PHALEN GS, Gardner WJ, LaLonde AA. Neuropathy of the median nerve due to compression beneath the transverse carpal ligament. J Bone Joint Surg 1988;67:117-119. Criteria Met (5/6: 1,3,4,5,6) Source: Medline Search. Abstract: With needle stimulation at the wrist and midpalp, CMAPs were recorded over the APB in 25 CTS patients and 23 healthy asymptomatic persons. They found a significant difference in the amplitude of the CMAP in the CTS group when compared to the control group. They propose that this is evidence for conduction block (neuapraxia) in CTS.

PEASE WS, Lee HH, Johnson EW. Forearm median nerve conduction velocity in carpal tunnel syndrome. Electromyogr Clin Neurophysiol 1990;30:299-302. Criteria Met (4/6: 1,3,4,5) Source: Medline Search. Abstract: The NCV of the median nerve in the forearm was determined by 2 methods: (a) stimulation in the forearm and recording the nerve action potential at the wrist, and (b) stimulation at the wrist and elbow with recording over the APB, in 21 CT patients and 16 control subjects. They found that the forearm NCV was slowed in the CTS group using either technique. The authors have proposed that this suggests that proximal nerve dysfunction as a result of median nerve compression in the carpal tunnel.


Plaja J. Comparative value of different electrophysiological methods in carpal tunnel syndrome. Scan J Rehabil Med 1971;3;101-108. Criteria Met (4/6: 1,3,5,6) Source: Joynt, 1989. Abstract: The following techniques were studied: (a) CMAP potentials were recorded after stimulation at the wrist and recording with coaxial needle electrodes, (b) orthodromic SNAPs with stimulation at the wrist and recording with surface electrodes at the wrist, (c) needle EMG using a coaxial needle, (d) strength/duration curves and chronaxie. Fifty-six cases of CTS and 20 normal subjects were evaluated. Sensory latencies were more likely to be abnormal than the other techniques measured.

PRESTON DC, Loggian EL. Lumbral and interossei recording in carpal tunnel syndrome [see comments]. Muscle Nerve 1992; 15:1253-1257. Criteria Met (5/6: 1,3,4,5,6) Source: Medline Search. Abstract: Median motor studies are commonly “normal” in mild carpal tunnel syndrome (CTS). This reflects either the sparing of motor compared to sensory fibers, or the inability of conventional studies to detect an abnormality. A novel approach to demonstrate early motor fiber involvement in CTS is the placement of the same active electrode lateral to the third metacarpal, allowing recording from the second lumbral or the deeper interossei, when stimulating the median or ulnar nerves at the wrist, respectively. We compared the difference between these latencies in 51 normal control hands to 107 consecutive patient hands referred with symptoms and signs suggestive of CTS, who were subsequently proven to have electrophysiologic CTS by standard nerve conduction criteria. A paired t-test revealed no significant difference between the second lumbral or the deeper interossei latency measured with the second lumbral or the deeper interossei electrode. A significant difference between the two lumbrals was found to be a sensitive indicator of CTS in all patient groups. It was also helpful in patients with coexistent polynuropathy, where localization of median nerve pathology at the wrist was otherwise difficult.

*PRESTON DC, Ross MH, Kothari MJ, Plotkin GM, Venkatesh S, Loggian EL. The median-ulnar latency difference studies are comparable in mild carpal tunnel syndrome. Muscle Nerve 1994; 17:1469-1471. Criteria Met (2/6: 1,3). Source: Medline Search. Abstract: Comparisons between studies of orthodromic motor and median-ulnar peak latency difference with normal <0.4 ms, antidromic wrist-D4 sensory median-ulnar onset latency difference with normal <0.5 ms, and the second lumbral-interossei motor with normal <0.5 ms. See discussion of benefits of techniques and diagrams of electrode placements and line drawings of electrode and stimulator placement.

Pitts JG. The effect of stimulus intensity in motor latency in carpal tunnel syndrome. J Neurol Neurosurg Psychiatry 1963;26:398-401. Criteria Met (4/6: 1,3,5,6) Source: Loong, 1971. Abstract: With stimulation at the wrist and coaxial needle electrode recording from the APB, DMLs were recorded at super-maximal stimulation and threshold stimulation in 29 CTS hands from 25 patients and 25 control subjects. Over 80% of the patients were identified with an abnormality either with super-maximal stimulation or threshold stimulation. Threshold stimulation was more sensitive than super-maximal stimulation.


REDMOND MD, Rivner MH. False positive electrodiagnostic tests in carpal tunnel syndrome. Muscle Nerve 1988;11:511-518. Criteria Met (4/6: 1,3,5,6) Source: Medline Search. Abstract: Several techniques were evaluated in a normal population using literature norms to assess for specificity in 100 hands of 50 normal subjects. Fifteen percent of the hands (30% of people) exhibited an abnormal median-to-ulnar sensory amplitude ratio, 8% of hands (14% of people) had abnormal residual latencies, and 4% of hands (8% of people) had prolonged median-ulnar palm to wrist latency (8 cm) differences. They suggested a more conservative abnormality of >0.5 ms between median and ulnar nerve for midpoint stimulation to avoid false positive tests for CTS. No CTS patients were studied.

Rempel D, Evanoff B, Amadio PC, de Krom M, Franklin G, Frankblau A, Gray R, Gerr F, Hagberg M, Hales T, Katz JN, Pransky G. Consensus criteria for the classification of carpal tunnel syndrome in epidemiologic studies. Am J Public Health 1998;88:1447-1451. Source: Medline Search. Background Reference. Source: Criteria for the classification of carpal tunnel syndrome for use in epidemiologic studies were developed by means of a consensus process. Twelve medical researchers with experience in conducting epidemiologic studies were asked to review the existing data and to arrive at a consensus process. The group reached agreement on several conceptual issues. First, while there is no perfect gold standard for carpal tunnel syndrome, the combination of electrodiagnostic study findings and symptom characteristics will provide the most accurate information for diagnosis of carpal tunnel syndrome. Second, use of only electrodiagnostic study findings to diagnose CTS is not recommended. Finally, specific combinations of symptom characteristics and physical examination findings may be useful to diagnose CTS but are likely to result in greater misclassification of patients than the combination of finding on the clinical history and the results of electrodiagnostic studies.


RESEND LA, Adamo AS, Bononi APO, Castro HA, Kmaid PA, Fortinguerres CH, Schelp AO. Test of a new technique for the diagnosis of carpal tunnel syndrome. J Electromyogr Kinesiol 2000;10:127-133. Criteria Met (4/6: 1,3,5,6) Source: Medline Search. Abstract: Study of 55 CTS hands (32 patients) compared to 40 normal hands (20 normal subjects) of the difference between the median motor distal latency to the second lumbral muscle and the ulnar motor distal latency to the interossei muscle. The test was more sensitive to identify CTS than measurement of the median motor distal latency to the APB.


210. Robinson LR, Micklesen PJ, Wang L. Optimizing the number of tests for carpal tunnel syndrome. Muscle Nerve 2000;23:1880-1882. Criteria Met (3/6: 3,5,6). Source: Medline Search. Abstract: The combined sensory index (CSI), the sum of three latency differences, median-ulnar across the palm (palmdiff), median-ulnar to the ring finger (ringdiff), and median-radial to the thumb (thumbdiff), has higher sensitivity and reliability for CTS than individual tests. The objective of this study was to develop an approach that maximizes testing but maximizes accuracy. A retrospective study of 300 hands determined that there were endpoints for individual tests that confidently predicted the results of the CSI; for ranges between these endpoints, further testing was required. These ranges were: palmdiff 0-0.3 ms; ringdiff 0.1-0.4 ms; and thumbdiff 0.2-0.7 ms. Therefore, if the results of one of these three tests exceeded these values, it was not necessary to perform all the NCS necessary to calculate a CSI without losing sensitivity and reliability.

211. Robinson LR, Micklesen PJ, Wang L. Strategies for analyzing nerve conduction data: superiority of a summary index over single tests. Muscle Nerve 1998;21:1166-1171. Criteria Met (5/6: 1,2,3,5,6) Source: Medline Search. Abstract: Comparison of three strategies for diagnosing CTS with NCSs: use of a single NCS result; requirement that one, two, or three of three NCSs results be abnormal; and one of a single summary variable incorporating data from three different NCSs. Sixty-five hands of subjects without clinical CTS were compared with 66 hands with clinical CTS. Three latency differences were measured: median-ulnar (8 cm) midpalmar orthodromic (palmdiff); median-ulnar ring finger (14 cm) antidromic (ringdiff); and median-radial thumb (10 cm) antidromic (thumbdiff). The combined sensory index (CSI) was the sum of these three differences. Sensitivity for the tests was palmdiff 69.7%, ringdiff 74.2%, thumbdiff 75.8%, and CSI 83.1%. Specificity was 95.4-96.9%. Requiring one, two, or three of three tests to be abnormal yielded sensitivities of 84.8%, 74.2%, or 56.1%, respectively, but specificities of 92.3%, 98.5%, and 100%, respectively. We conclude that a combined index improves diagnostic classification over use of single test results.


213. Rosecrance JC, Cook TM, Bingham RC. Sensory nerve recovery following median nerve provocation in carpal tunnel syndrome. Electromyogr Clin Neurophysiol 1997;37:219-229. Criteria Met (6/6: 1,2,3,4,5,6) Source: Medline Search. Abstract: The latency and amplitude of orthodromic median SNAP from palm to wrist were measured 5 minutes before and at intervals up to 10 minutes until recovery after sustained maximal wrist flexion combined with the fingers simultaneously performing finger flexion against resistance. 35 hands with a clinical diagnosis of CTS were subdivided into 24 with a prolonged baseline latency (>NCS) and 11 with normal latencies (-NCS), and 25 asymptomatic control hands were studied. Four measures were analyzed: difference in latency and amplitude before flexion and at 2 minutes afterward, time for the SNAP amplitude to recover to 95% initial value, and time for latency to return to initial latency. The latency increased only 1-2% in CTS hands compared to controls, but the amplitude decreased to a greater extent (17%) compared to control hands. The recovery time was longer. For groups, mean recovery times were 0.6 minutes controls, 2.25 minutes CTS (-NCS) group, and, paradoxically, 4.74 minutes for CTS (+NCS) group. Amplitude recovery time greater than 1.62 minutes (asymptomatic mean + 2SD) was considered abnormal for individual hands. With this criterion, abnormalities were present in 71% of clinically symptomatic hands, including 8 of 11 without other NCS abnormalities. SNAP recovery time may be complimentary to other NCS to diagnosis CTS but does not replace median orthodromic SNAP latency. SNAP testing could be used to determine the severity of the CTS in 14 hands of 20 CTS patients compared to 20 normal subjects.

214. Rosen I. Neuropsychological diagnosis of the carpal tunnel syndrome: evaluation of neurographic techniques. Scand J Plast Reconstr Surg Hand Surg 1993;27:95-101. Criteria Met (4/6: 3,4,5,6) Source: Medline Search. Abstract: Retrospective study of 28 patients diagnosed with CTS on basis of combination of clinical, NCS and EMG data. The median motor DML, orthodromic median SNCV for D1 and D3, palmar median NCV and D3 NCV versus the quotient of SNCV across CT to forearm were calculated in 86 normal controls and the results compared to the same studies in the 28 CTS patients. The palmar mixed median NCV was superior to the quotient of SNCV across CT to forearm and the other tests for the diagnosis of CTS.

215. Rosenberg JN. Anterior interosseous/median nerve latency ratio. Arch Phys Med Rehabil 1994;75:330-334. Criteria Met (4/6: 3,4,5,6) Source: Medline Search. Abstract: With stimulation at the antebrachial fossa and simultaneous recording over the APB and pronator quadratus (needle electrode) DMLs were determined from 100 anterior interosseous nerves in 61 normal volunteers, 5 patients with anterior interosseous syndrome, and 35 patients with CTS. The results show abnormal ratios for both CTS and anterior interosseous syndrome.

216. Rossi S, Giannini F, Passero S, Paradiso C, Battistini N, Cioni R. Sensory neural conduction of median nerve from digits and palm stimulation in carpal tunnel syndrome. Electroencephalogr Clin Neurophysiol 1994;93:330-334. Criteria Met (4/6: 3,4,5,6) Source: Medline Search. Abstract: A variation of palmar stimulation with more distal stimulation over the metacarpophalangeal interphalangeal spaces so that the conduction distances was 1-1.5 cm longer than the usual 8 cm orthodromic palmar conduction study. The more distal stimulation was performed to evaluate the median nerve palmar branches to the adjacent surfaces of the index and middle finger (P2), the middle finger and ring finger (P3), and the ulnar palmar branches to the adjacent surfaces of the ring and little finger (P4). The authors noted that the sensitivity of the modified orthodromic palmar study paralleled the sensitivity of the orthodromic sensory digit stimulation studies to diagnose CTS. The modified palmar stimulation technique had the advantages (1) of frequently demonstrating a measurable response in CTS patients with stimulation at P3 whereas the response was absent with stimulation of D4 and (2) of demonstrating an abnormality when the response with stimulation at P2 was normal. Since the authors used NCS criteria to select patients for the study, the clinical sensitivity and specificity of the modified palmar studies could not be calculated although they could compare the sensitivity of one study to another.


218. Salerno DF, Franzblau A, Werner RA, Bromberg MB, Armstrong TJ, Albers JW. Median and ulnar nerve conduction studies among workers: normative values. Muscle Nerve 1998;21:999-1005. Criteria Met: (normal population study 4/6: 1,2,5,6) Source: Medline Search. Abstract: To determine normative values for NCS among active workers, a prospective cross-sectional study was performed of active workers in contrast to the typical reference populations. The authors selected a subset of 326 workers from 955 subjects who participated in medical surveys in the workplace. Bilateral median (D2) and ulnar (D5) antidromic sensory conduction studies over a 14 cm conduction distance to the wrist were performed after checking midpalm temperature greater than 32.0 degrees centigrade or greater with or without warming the limb; limb temperatures were not monitoring during the study (personal communication). Median and ulnar SNAP amplitude and latency (onset and peak) were measured. Workers with upper extremity symptoms, ages 17-64 years, and no evidence of peripheral nerve function, low hand temperature, or highly repetitive jobs were excluded from the “normal” cohort. Linear regression models explained variance in nerve function with covariate of age, sex, hand temperature, and anthropometric factors and provide...
evidence that electrophysiologic testing should control for those relevant covariates to improve diagnostic accuracy. The median-ulnar peak latency difference was the best measure to use if corrections are not made to account for relevant covariates. However, the authors noted the 95th percentile at 0.8 ms in contrast to current standards of 0.4 to 0.5 ms so that current standards for diagnosing CTS among workers appear too sensitive.

Salerno DF, Werner RA, Albers JW, Becker MP, Armstrong TJ. Reliability of nerve conduction studies among active workers. Muscle Nerve 1999;22:1372-1379. Criteria Met (worker population study 4/6: 1,3,5,6). Source: Medline Search. Abstract: Prospective study of the inter-examiner variability for the measurement of antidromic median (D2) and ulnar (D5) sensory conduction from wrist with conduction distance of 14 cm and without averaging of responses. The first round of testing evaluated inter-examiner reliability in 158 workers by comparison of the results of NCS performed by two different examiners on the same day. The second round of testing was performed 3 weeks later and analyzed data from 58 subjects retested by examiner 1 and 76 subjects retested by examiner 2. Midpalmar temperature was recorded at the beginning of testing and subjects with cool hands were warmed to 32 degrees centigrade when possible; temperature was not monitored continuously during the testing. The data was analyzed with and without correction of latency measurements by 0.3 ms for each degree below 35 degrees centigrade. Inter-examiner reliability analysis noted (1) median sensory nerve measurements of amplitude, onset latency, and peak latency were more reliable than onsets latency measurements, (2) amplitude and peak latency measurements were more reliable than median-ulnar peak latency difference had consistently high reliability, (4) ulnar onset latency had the poorest reliability. Inter-examiner reliability analysis showed a high congruence between examiners and the same pattern of inter-examiner results between median and ulnar measurements as noted in the intra-examiner variability analysis described above. Temperature correction made a small change in reliability of ulnar latency measurements. Based on these results, the authors recommended that the same examiner perform the repeated NCS in longitudinal studies to minimize inter-examiner variability and use of median-ulnar peak latency differences (in addition to short segment orthodromic median nerve studies) to evaluate patients for CTS.

Sander HW, Quinto C, Saadeh PB, Chokroverty S. Sensitive median-ulnar motor comparative techniques in carpal tunnel syndrome. Muscle Nerve 1999;22:88-95. Criteria Met (5/6: 1,3,4,5,6) Source: Medline Search. Abstract: CTS was diagnosed in 50 patients (79) hands based on a combination of clinical and electrophysiologic criteria (median-palm-wrist mixed NAP onset latency greater than 1.7 ms or onset latency exceed the ipsilateral ulnar palm-wrist latency by more than 0.2 ms) as described by Jasson and Clifford in 1992. Three motor conduction studies were evaluated: the median-to-ulnar latency difference (TTLD), the median- to ulnar-hypothalern latency difference (TLHD), and the ulnar-to-median F-wave latency difference (FWLD). The abnormal cutoffs based upon 34 normal controls are: TTLD, 0.8 ms; THLD, 1.2 ms; FWLD, 0.6 ms. The diagnostic sensitivities were: 95.98%, 85.88%, and 75.78% respectively, in this CTS patient group with abnormal median sensory nerve conduction studies as described above.

Scheu SN, Herskovitz S, Bieri P, Berger AR. Median mixed and sensory nerve conduction studies in carpal tunnel syndrome. Electroencephalogr Clin Neurophysiol 1998;109:268-273. Criteria Met (6/6: 1,2,3,4,5,6) Source: Medline Search. Abstract: To assess the sensitivities and specificities of velocity differences between median mixed nerve conduction across the wrist (Medmxpw) and (I) median mixed nerve conduction in the forearm (Medmx) and (II) palm to D2 sensory conduction (MedpD2), we prospectively studied 67 limbs of patients with clinically definite carpal tunnel syndrome (CTS). Medmx and Medmxpw were performed by stimulating the median nerve at the elbow and palm respectively and recording at the proximal wrist crease. We also compared conventional median sensation (D2-wand and mixed (palmar-sensory) tests in all patients, the presence of asymptomatic subjects served as normal controls and 21 limbs of subjects with other neuropathies served as diseased controls; control data was collected prospectively. The sensitivity of the MedpD2-Medmxpw difference (0.87) was significantly greater than that of the Medmx-Medmxpw difference (0.61, P <0.001). Both tests were similar and highly specific (0.98 and 0.96, respectively). The MedpD2-Medmxpw study is among the most sensitive and specific electrophysiologic tests for CTS.

Seror P. Comparative diagnostic sensitivities of orthodromic or antidromic sensory conduction in mild carpal tunnel syndrome. Arch Phys Med Rehabil 2000; 81:442-446. Criteria Met (4/6: 1,3,5,6) Source: Medline Search. Abstract: Prospective study comparing the orthodromic inching test (OIT) to the antidromic inching test (AIT) in the dominant hand of 20 CTS patients with control data from 20 normal subjects. The diagnosis of the 20 CTS patients was based on clinical criteria and confirmed by NCS. To select cases of definite but mild CTS, the criteria for NCS results was as follows: normal median motor distal latency (0.0 ms) or normal sensory conduction velocity (palmar-wrist:<45 m/s) and abnormal median-ulnar latency difference of the fourth digit (<0.4ms). Temperature was measured at the start of the study, but not monitored continuously during the study. The IT (100% positive) was superior to the AIT (20% positive) in the 20 CTS patients.


Seror P. Orthodromic inching test in mild carpal tunnel syndrome. Muscle Nerve 1998a;21:1206-1208. Criteria Met (4/6: 2,3,5,6) Source: Medline Search. Abstract: Orthodromic inching test (OIT) of the median nerve at wrist was performed on the dominant wrist of 80 controls and 100 patients with CTS. The OIT was based on four features and chosen for study because standard electrodiagnostic tests for CTS were normal (median motor distal latency less than 4 ms and palm-to-wrist orthodromic sensory conduction velocity greater than 45 m/s). In controls the mean conduction delay per centimeter (CD/cm) was 0.184 ms and was slightly higher inside than outside the carpal tunnel, the maximal CD/cm (across the carpal tunnel) was never greater than 0.34 ms (mean 0.247). The CD/cm was 0.36 ms or more in 96 CTS patients. This abnormality was located within the carpal tunnel in 92% of cases. Outside the entrapment site CD/cm values remained normal and similar to those found in the controls. On the whole, this results in an overall specificity of 100% and sensitivity of 96% for the OIT.

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study of 150 hands in 96 patients suspected of CTS. Patients were included in the study because at least one EDX test for CTS was abnormal; patients suspected of CTS with normal EDX tests were excluded from the analysis. The data was used to compare the relative sensitivity of multiple different EDX tests to diagnose CTS. The m-TLI was calculated as median to ulnar peak latency difference (m-TLI) to diagnose CTS. The m-TLI is a diagnostic test for CTS potentially as useful as the median palmar conduction study (see 1999b reference).

239. Simovic D, Weinberg DH. The median nerve terminal latency index in carpal tunnel syndrome: a clinical case selection study. Muscle Nerve 1999b:22:573-577. Criteria Met: (6/6: 1,2,3,4,5,6) Source: Medline Search. Abstract: The median terminal latency index (TLI) is a calculated value derived from the conventional median motor NCS data. The TLI is a ratio that adjusts the median motor distal latency (DL) for the terminal conduction distance (CD) and the proximal nerve conduction velocity (CV): TLI = terminal CD (mm) [proximal CV (m/s) × DL (ms)]. The ratio decreases as the conduction time increases across the carpal tunnel. In this prospective study of 66 patients to assess the sensitivity of the median nerve TLI for the diagnosis of CTS, the median nerve TLI was abnormal in all patients with abnormal median palmar peak latency differences (likely to have CTS) while group 2 contains patients with normal median palmar peak latency differences (less likely to have CTS). The m-TLI was less than 0.34 in all patients in Group 1 and equal or greater than 0.34 in all patients in Group 2. The authors concluded that the m-TLI is a diagnostic test for CTS potentially as useful as the median palmar conduction study (see 1999b reference).


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244. Stevens JC, Smith BE, Weaver AL, Bosch EP, Deen HG Jr, Wilkens JA. Symptoms of 100 patients with electromyographically verified carpal tunnel syndrome. Muscle Nerve 1999;22:1448-1456. Background Reference. Source: Medline Search. Abstract: To determine the symptoms of carpal tunnel syndrome (CTS), screening evaluations were performed in 244 consecutive patients with sensory symptoms in the hand and unequivocal slowing of median nerve conduction at the wrist. This yielded 100 patients thought to have no explanation other than CTS for their upper limb complaints. These patients completed a hand symptom diagram (HSD) and questionnaire (HSQ) about their symptoms. CTS symptoms were most commonly reported in median and ulnar digits, followed by median digits only and a glove distribution. Unusual sensory patterns were reported by some patients. Based on the HSQ, paresthesias or pain proximal to the wrist occurred in 36.5% of hands. The usefulness of the HSD and HSQ for diagnosis was determined by asking three physicians, blinded to the diagnosis, to rate the likelihood of CTS in the patients with CTS and in 50 patients with other causes of upper extremity paresthesia. The sensitivities of the independent instruments ranged from 54.1% to 85.5%. Based on the combined instrument ratings, the sensitivities in the test group were shown to vary from 79.3% to 93.2%.


248. Tackmann W, Kaeser HE, Magun HG. Comparison of orthodromic and antidromic sensory nerve conduction velocity measurement in the carpal tunnel syndrome. J Neurol 1981;224:257-266. Criteria Met (6/6: 1,2,3,4,5,6) Source: Uncini, 1989. Abstract: Using ring electrodes on the middle finger and subdural electrodes at the midpoint and wrist, orthodromic and antidromic SNAP latencies were recorded from 56 hands from 50 CTS patients and 32 hands from 32 healthy subjects. They report no significant differences in latencies of orthodromic and antidromic recordings and that palmar latencies are more likely to be abnormal in CTS than digit latencies.


250. Trojaborg W, Grewal RP, Weimer LH, Sheriff J. Value of latency measurements to the small palm muscles compared to other conduction parameters in the diagnosis of mild carpal tunnel syndrome. Muscle Nerve 1996;19:243-245. Criteria Met (5/6: 1,2,3,5,6). Source: Medline Search. Abstract: Study of 170 hands of 105 patients with clinical diagnosis of CTS. There was an abnormal lumbro-interosseus latency difference in 83% of hands whereas there was an abnormal median sensory conduction velocity from the thumb to the wrist in 93% of hands. The authors concluded that the lumbro-interosseus latency difference was especially useful in confirming CTS in patients with absence of the median SNAP or APB motor response or both.

251. Trojaborg W, Grewal RP, Weimer LH, Sheriff J. Sensitivity and specificity of three median-to-ulnar comparative tests in diagnosis of mild carpal tunnel syndrome [see comments]. Muscle Nerve 1993;16:1366-1373. Criteria Met (6/6: 1,2,3,4,5,6). Source: Medline Search. Abstract: Study of 193 hands of 113 patients with clinical diagnosis of CTS compared to reference population of 72 hands of 47 volunteers. Ninety-five (49%) hands had normal median DML (=4.2 ms) and normal or borderline median SNVC from digit 2 stimulation (≥45 ms/s). In this subpopulation of 95 hands, the authors performed three median to ulnar comparative tests: (1) difference between median and ulnar distal motor latencies recorded from the second lumbro-interosseus muscles (2L-INT); (2) difference between median and ulnar sensory latencies from digit 4 stimulation (D4M-D4U); and (3) difference between median and ulnar sensory latencies from palmar stimulation (PM-PU). The 2L-INT difference was greater than or equal to 0.6 ms in 10 (10%) of the subpopulation of 95 hands. PM-PU and D4M-D4U were greater than or equal to 0.5 ms in 53 (56%) and 73 (77%) of the subpopulation of 95 hands, respectively. If each of these three studies were abnormal in the 98 hands with abnormal median DML, the median sensitivity for the three tests would be (10 + 98 = 108)/193 = 56%, (53 + 98 = 151)/193 = 78%, and (73 + 98 = 171)/193 = 89%. The comparison of median and ulnar sensory conduction across the CT was more sensitive than comparison of median and ulnar motor conduction across the CT. The sensitivity of D4M-D4U might be explained by the funicular topography and consequent greater susceptibility to compression of the cutaneous fibers from the third interspace which, at the distal carpal tunnel, are clamped superficially in the volar-ulnar portion of the median nerve just beneath the transverse ligament.

252. Uncini A, Lange DJ, Solomon M, Soliven B, Meer J, Lovelace RE. Ring finger testing in carpal tunnel syndrome: A comparative study of diagnostic utility (comments in Muscle Nerve 1990;13:560). Muscle Nerve 1989;12:735-741. Criteria Met (4/6: 1,2,3,5) Source: Medline Search. Abstract: With stimulation at the ring finger, the median and ulnar DSL latency differences were recorded in 43 hands of 33 normals and 42 hands in 32 patients with mild CTS as defined by electrodiagnostic criteria. Standard DML from wrist to APB, and median DSL from wrist to index finger were also determined. They found that the median ulnar difference to the ring finger was more likely to be abnormal than the DML and DSL.

253. Valls-Sole J, Alvarez R, Nunez M. Limited longitudinal sliding of the median nerve in patients with carpal tunnel syndrome. Muscle Nerve 1995; 18: 761-767. Criteria Met (4/6: 1,3,5,6) Source: Medline Search. Abstract: During normal movements or changes in position of the limbs, nerve structures must accommodate the resulting changes in length of the nerve path. In patients with CTS, we monitored electrophysiologically the longitudinal adjustment of the median nerve to positions of extreme flexion and extreme extension of the wrist and elbow, by measuring the differences induced in the latency of the SNAP recorded in the forearm and upper arm. In patients, the latency difference was significantly shorter than in normal subjects (0.13 ± 0.04 ms vs. 0.12 ± 0.02 ms). These results indicate that the displacement of the source of the median nerve SNAP with movements of flexion and extension is limited in patients with carpal tunnel syndrome. Since the latency changes in CTS...
patients were less than but within the range of latency changes in normal controls, the procedure cannot be used to distinguish CTS patients from controls. However, the abnormality noted may be a manifestation of the pathophysiology of entrapment syndromes: limited longitudinal sliding of nerves in nerve channels, including median sensory peak latency and amplitude, and median motor distal latency and amplitude. Logistic regression analysis identified gender, median motor distal latency, and median motor amplitude (all p ≤0.08) as contributing to the prediction of denervation. Needle EMG of the cases with a median CMAP amplitude <7 mV detected 95.3% (141/148) of all cases with denervation. However, the model is not applicable for predicting the presence of denervation in the individual patient.

259. Verghese J, Galanopoulou AS, Herskovitz S. Autonomic dysfunction in idiopathic carpal tunnel syndrome. Muscle Nerve 2000;23:1209-1213. Criteria Met (5/6, 1,3,4,5,6) Source: AAEM CTS Task Force 2000 member. Abstract: A prospective study of autonomic disturbances in 139 limbs of 76 CTS patients diagnosed on the basis of clinical and sensory and motor NCS abnormalities. Autonomic disturbance indices were identified as follows (39%), dry palms (33%), Raynaud’s phenomenon (32%) and blanching of the hand (32%), finger tip ulcers (0%) and nail changes (0%). Cold sensation of the fingertips (too non-specific) and excessive sweating (not reported in a preliminary survey) were not included. Sym pathetic Skin Response (SSR) abnormalities (latency >1.72 ms or absent response) were noted in 24% (33 of 139) symptomatic hands (34%; 26 of 76 hands). Compared to control patients, the SSR had a specificity of 89%.

260. Wang AK, Raynor EM, Blum AS, Rutkove SB. Heat sensitivity of sensory fibers in carpal tunnel syndrome [see comments]. Muscle Nerve 1999;22:37-42. Criteria Met (5/6, 1,3,4,5,6) Source: Medline Search. Abstract: CTS used as a model to study the effect of heat on normal nerves with focal demyelination secondary to CTS. Median SNAP amplitude and area decreased more in 12 CTS patients than in 12 normal controls at 42 degrees C compared to baseline measurements at 32 degrees centigrade. It is hypothesized that these reductions in response amplitude are secondary to the occurrence of heat-induced conduction block in demyelinated sensory nerves.

261. Werner RA, Albers JW. Relation between needle electromyography and nerve conduction studies in patients with carpal tunnel syndrome. Arch Phys Med Rehabil 1995;76:246-249. Criteria Met (2/6, 3,6) Source: Medline Search. Abstract: Retrospective study of 480 cases of electrophysiologically confirmed CTS reviewed to determine if the findings on NCS could predict the presence or absence of fibrillation potentials or motor unit changes on the needle EMG of the APB. Two hundred thirty-one CTS patients had an abnormal needle EMG exam defined by presence of fibrillation activity (105 patients) and/or abnormal MUAP configuration. Motor and sensory evoked potential latencies were the most important predictors of an abnormal needle EMG examination.

262. Werner RA, Bir C, Armstrong TJ. Reverse Phalen’s maneuver as an aid in diagnosing carpal tunnel syndrome. Arch Phys Med Rehabil 1994;75:783-786. Criteria Met (6/6, 1,2,3,4,5,6) Source: Medline Search. Abstract: Direct intracarpal canal pressure measurements in 5 subjects demonstrated that a reverse Phalen’s maneuver (wrist and finger extension) results in a significantly higher intracarpal canal hydrostatic pressure compared to a traditional Phalen’s maneuver (wrist flexion and finger extension) or a modified Phalen’s maneuver (wrist flexion while pinching a flat object between the thumb and third digit). 31 individuals with a clinical diagnosis of carpal tunnel syndrome and 20 normal controls were evaluated to determine whether the reverse Phalen’s maneuver would have an antidromic median sensory latency and amplitude measured with the wrist and hand in the neutral position. Both groups demonstrated slight (1-4%) prolongation of the peak latency and reduction in the amplitude of the median SNAP after 1 minute of this maneuver. The control group had a mean peak latency prolongation of 0.05 ms (1.6% of the mean) and a mean amplitude reduction of 1.5 microvolts (2.6% of the mean) compared to 0.13 ms (3% of the mean) and 0.9 microvolts (4% of the mean) in the carpal tunnel syndrome group. Only the median SNAP measurements between the two groups was significant at a p = 0.05 level. Additional studies with longer periods of maintained wrist extension were recommended to evaluate this technique to diagnose CTS.

263. Werner RA, Franzblau A, Albers JW, Armstrong TJ. Median mononeuropathy among active workers: are there differences between symptomatic and asymptomatic hands? Am J Ind Med 1998;33:374-378. Criteria Met: (worker population study 3/6, 1,3,6). Source: Medline Search. Abstract: A prospective cross-sectional study of 700 active workers identified 184 with median neuropathies as a prolongation of the median SNAP peak latency compared to the ulnar SNAP peak latency by at least 0.5 ms, antidromic studies, conduction distances 14 cm each to D2 and D5. Cool hands were warmed before testing. Focal changes in peak latency were noted before testing. A more prolonged median sensory distal latency. As noted by the authors, the study is limited because it is cross-sectional and cannot answer many of the questions raised: a longitudinal study would be necessary to determine the incidence and natural history of median mononeuropathy among active workers.

264. White JC, Hansen SR, Johnson RA. A comparison of EMG procedures in the carpal tunnel syndrome with clinical-EMG correlations. Muscle Nerve 1988;11:1177-1182. Criteria Met (3/6, 1,2,3) Source: Medline Search. Abstract: Two hundred one hands in 122 patients were evaluated with several techniques for CTS. The asymptomatic hands of 43 of these patients served as controls. The following techniques were evaluated: (a) DML from wrist to APB, (b) DML from wrist to index finger, (c) motor inching studies across the wrist to APB, (d) sensory inching studies across the wrist to index finger, (e) inching studies to the lumbral, (f) palmar-to-wrist median latency, (g) comparison of median and radial DSLs, and (h) terminal latency index. Motor inching studies were most likely to be abnormal in both the CTS group and asymptomatic group. Motor inching studies were abnormal in 92% of mild CTS and 72% of the asymptomatic hands. All of the studies had high rates of abnormality in asymptomatic hands varying from 9% to 72%.

265. Wiederholt WC. Median nerve conduction velocity in sensory fibers through carpal tunnel. Arch Phys Med Rehabil 1970;51:328-330. Criteria Met (normal population study 5/6, 1,3,4,5,6) Source: Macleod, 1987. Abstract: With stimulation over the middle finger and recording distal and proximal to the carpal tunnel, sensory NCVs were determined across the carpal tunnel and proximal to the carpal tunnel in 30 normal adults. Sensory NCV was faster proximal to the carpal tunnel than across the carpal tunnel. No CTS patients were studied.


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Direct measurement of the forearm segment of the median nerve were made to distinguish between these two possibilities. Median motor conduction studies and mixed nerve action potential (MNAP) recordings were performed on the forearm segment of the median nerve in patients (n = 32 limbs, aged 24 to 76) and controls (n = 15 limbs, aged 33 to 76). The results strongly support the hypothesis that the slowing seen in the forearm is caused by conduction block of the fastest conducting fibers within the carpal tunnel and is not caused by retrograde demyelination.


271. Wongsam PE, Johnson EW, Weinerman JD. Carpal tunnel syndrome: use of palmar stimulation of sensory fibers. Arch Phys Med Rehabil 1983;64:16-19. Criteria Met (3/6: 3,5,6) Source: Pease, 1989. Abstract: With stimulation at the wrist and midpalms and recording with ring electrodes over the middle finger, DSLs were obtained from the median nerve and 100 hands from 50 normal subjects, 15 patients with early CTS, and 6 with diabetes mellitus and superimposed median nerve entrapment. Amplitudes and durations of the SNAP were also reported. This technique is reported as useful in the diagnosis of CTS and underlying mild peripheral neuropathy.

272. You H, Simmons Z, Freivalds A, Kothari MJ, Naidu SH. Relationships between clinical symptom severity scales and nerve conduction measures in carpal tunnel syndrome. Muscle Nerve 1999;22:497-501. Criteria Met (5/6: 1,3,4,5,6). Source: Medline Search. Background Reference. Abstract: This study examined the severity of symptoms in carpal tunnel syndrome (CTS) in relation to nerve conduction measures of the median nerve. Significant relationships identified among the clinical scales resulted in a dichotomous symptom classification scheme into primary symptoms more specific for nerve injury (numbness, tingling, nocturnal symptoms) and secondary symptoms (pain, weakness, clumsiness). There were significant relationships between symptom severity and nerve conduction abnormality, and the primary symptom scale correlated more strongly with the electrodiagnostic measures of nerve injury than did the secondary symptom scale.
