

Clinical and Electrodiagnostic Testing of Carpal Tunnel Syndrome: A Narrative Review

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Carpal Tunnel Syndrome (CTS) is a pressure-induced neuropathy that causes sensorimotor disturbances of the median nerve, which impair functional ability. A clear history that elicits relevant personal and work exposures and the nature of symptoms can lead to a high probability of a correct diagnosis. Hand diagrams and diagnostic questionnaires are available to provide structure to this process. A variety of provocative tests have been described and have variable accuracy. The Phalen's wrist flexion and the carpal compression tests have the highest overall accuracy, while Tinel's nerve percussion test is more specific to axonal damage that may occur as a result of moderate to severe CTS. Sensory evaluation of light touch, vibration, or current perception thresholds can detect early sensory changes, whereas 2-point discrimination changes and thenar atrophy indicate loss of nerve fibers occurring with more severe disease. Electrodiagnosis can encompass a variety of tests and is commonly used to assess the presence/severity of neuropathic changes and to preclude alternative diagnoses that overlap with CTS in presentation. The pathophysiologic changes occurring with different stages of nerve compression must be considered when interpreting diagnostic test results and predicting response to physical therapy management. *J Orthop Sports Phys Ther* 2004;34:565-588.

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Carpal tunnel syndrome (CTS) has the highest prevalence of all forms of compression neuropathy and, as such, has attracted substantial controversy.¹²⁸ By definition, a syndrome is defined by its characteristic clinical symptoms, suggesting that clinical diagnosis has a predominant role. Unfortunately, the related literature has wide discrepancies on the value of specific symptoms and clinical tests. Systematic reviews of studies evaluating these tests have been conducted in an attempt to address these deficiencies, but have had difficulty in making clear conclusions, due to fundamental methodological problems in evaluating the validity of clinical tests.^{82,87} Despite these limitations, judicious use of clinical tests in conjunction with a well-constructed history are sufficient to produce a confident diagnosis in most cases.

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A PATHOPHYSIOLOGIC BASIS FOR CLINICAL EXAMINATION

The median nerve is susceptible to pressure as it passes, with the flexor tendons, through the carpal tunnel in a space defined by the concave arch of the carpus and enclosed by the transverse carpal ligament (TCL).¹¹⁸ The narrowest region is located about 2.0 to 2.5 cm distal to the origin of the canal and corresponds to the region where constriction or "hourglass" deformity of the median nerve is reported during surgery. The superficialis and profundus tendons of the index finger lie immediately dorsal to the median nerve, providing a rationale for stretching these tendons when performing the tethered median nerve test. The palmar wrist crease corresponds to the proximal border of the TCL and is often used as a landmark for carpal compression tests. The TCL attaches medially to the pisiform and hamate, and laterally to the scaphoid tuberosity and trapezium.

The median nerve normally enters the carpal tunnel in the midline or slightly radial to it. The thenar branch most commonly separates from the median nerve distal to the TCL, but can branch off within the carpal tunnel. Sensory branches supply the 3 radial digits and the radial half of the

fourth digit. However, the cutaneous skin of the palm is supplied by the palmar sensory cutaneous branch of the median nerve which arises, on average, 6 cm proximal to the TCL and, therefore, should not be affected in CTS. Anatomical variations in the median nerve itself, as well as anomalous muscles, tendons, or tissue interconnections, have been described as a basis for atypical presentations.^{14,51,77,118,129}

Nerve fibers have layers of connective tissue. The extensibility of these layers is critical to nerve gliding. It has been demonstrated that the median nerve will move up to 9.6 mm with wrist flexion and slightly less with extension.⁸⁸ Chronic compression is thought to cause fibrosis, which will inhibit nerve gliding. Injury/scarring of the mesoneurium will cause the nerve to adhere to surrounding tissue. This may result in traction of the nerve during movement as the nerve attempts to glide from this fixed position. This forms the rationale for the tethered median nerve test as an indicator of chronic CTS.

The median nerve receives blood supply from the radial and ulnar arteries just proximal to the flexor retinaculum. These vessels send descending nutrient branches that accompany the median nerve through the carpal tunnel. The blood-nerve barrier is made up of the inner cells of the perineurium and the endothelial cells of the endoneurial microvessels. A breakdown in this blood-nerve barrier within this vasculature will occur with elevated pressure, resulting in an accumulation of proteins and inflammatory cells. The vascular contribution to inflammation and delayed axonal transport will vary between patients, but may be particularly relevant in patients with other vascular problems or prolonged exposure to static loading. In some patients, it may be observed as focal swelling seen at the level of the proximal wrist crease.

The pathophysiology of nerve compression and how it relates to evaluation and treatment has been well described by MacKinnon.⁸³ The pathophysiology of grade 1 nerve injury (neuropraxia) involves conduction block (CB) and may be associated with some segmental areas of demyelination. The axon is not injured and does not undergo regeneration. Provocative tests that heighten the effects of pressure are likely to result in increased paresthesia at this stage, whereas those that depend on regenerating fibers (Tinel's) should be negative. Sensory changes should be evident in the largest nerve fibers and thus reflected in altered touch or vibration thresholds.

A grade 2 nerve injury (axonotmesis) involves injury to the axon itself. The nerve will have lost some fibers and be in a process of nerve repair. One might expect fibrillations on EMG, a positive Tinel's test, and changes in 2-point discrimination to accompany this level of nerve injury. As sensory loss becomes more profound, the patient may no longer experience increased paresthesia with provocative tests because of numbness. Loss of strength may now

be measurable. Despite these changes, this injury also has potential to recover completely.²³

A grade 3 injury has both loss of axons and some degree of scar tissue in the endoneurium. These patients will have constant numbness and observable thenar atrophy. These patients have severe CTS and complete recovery may not be achievable. Grades 4 and 5 involve complete scarring or transection of the nerve and do not apply to CTS.

This spectrum of pathophysiology underlies the interpretation of sensory, motor, and provocative test results. Patient complaints follow a continuum, beginning with intermittent paresthesia, where tingling is the predominant feature, to a more constant sensory deficit, which is more often characterized as numbness. Early sensory changes are intermittent and thought to result, in part, from the intermittent compromise of neural blood flow to large myelinated fibers affected by localized segmental demyelination. These early sensory changes are found in vibration and pressure thresholds. Early motor complaints may be difficult to detect and limited to aching or mild weakness, whereas advanced motor changes may be reflected in measurable decreases in muscle strength (ie, Oxford rating scale score of less than grade 4). With prolonged compression, Wallerian degeneration produces changes in 2-point discrimination and muscle atrophy. While many clinical studies^{11,97,101} confirm the association between clinical presentation and pathophysiology, this interpretation is not uniform.⁹⁰ The implication of this clinical spectrum is that certain tests are more relevant in certain grades of compressive injury. Thus the clinical examination must be planned and interpreted on the basis of this spectrum. Provocative, sensory, or motor tests should be selected following the history on the basis of a hypothesis on the probability of CTS and its severity. Additional clinical tests are added as the therapist uses the results of selected tests to modify or confirm this hypothesis.

ISSUES IN EVALUATING DIAGNOSTIC TESTS FOR CTS

One of the primary problems in evaluating whether any individual test is accurate in diagnosis of CTS is the lack of an accepted "gold standard."^{12,84} Potential gold-standard diagnoses would include expert clinical diagnosis, positive response to carpal tunnel release/injection, and electrodiagnosis. Using an expert clinical diagnosis is problematic in any situation because of the difficulty in standardization. However, when evaluating clinical tests, one must insure that the tests under evaluation are not a component of the expert's decision-making process. Surgery/injection is not an appropriate gold standard because complications^{13,61,124} and placebo effects can complicate the response and, therefore, result in

TABLE 1. History/symptoms used in diagnosis of CTS. Sensitivity and specificity are reported from a systematic review of diagnostic test studies where there were appropriate data.⁸¹

Subjective/History				
Element	Description of Positive Result	Accuracy		Comments
		Sensitivity	Specificity	
Symptom diagram ^{10,67,114}	Patient completes a diagram of where symptoms are located (see Figure 1 for descriptors)	75%	72%	Highly suited to industrial/population screening where examination is not possible
Flick sign ⁷⁰	Patients report waking at night and flicking (shaking) their hands to relieve symptoms	47%	62%	
Subjective swelling ²⁰	Patient reports feeling of swelling			Specificity questionable; authors report that patients with subjective swelling are less likely to respond to splinting, suggesting that it may have value as a prognostic test
Symptom severity scale ⁷⁵	Designed to measure severity of CTS			Designed as an outcome measure, but shown to differentiate between patients with hand injuries and patients with CTS, ³ particularly if sensory questions selected There are no data to evaluate diagnostic properties in prospective use
Nocturnal paresthesia ¹²	Patient reports waking at night with numbness and tingling			This symptom was most strongly related to positive nerve conduction when comparing a variety of symptoms ¹¹
Diagnostic questionnaire ⁵⁸	Elements of history that are characteristic for CTS are used to establish likelihood (see Figure 2)			Agreed with NCV ⁵⁸ but requires independent evaluation

Abbreviations: CTS, carpal tunnel syndrome; NCV, nerve conduction velocity.

misclassification. Not all patients with CTS, particularly mild CTS, will have surgery and, therefore, the spectrum sampled would be biased in such studies. Electrodiagnosis is the most common gold standard, despite the fact that false positives and negatives are known to exist.¹²⁹ Electrodiagnosis may not detect transient or mild CTS, as the more permanent physiological changes that cause median nerve slowing may not yet be present. Both clinical and systematic reviews⁵⁷ have questioned the role for electrodiagnosis, particularly where the presentation fits classic criteria. Variation in electrophysiological methods or interpretation between examiners will also contribute to difference between studies. Inaccuracies in the gold standard will result in misclassification of the “true diagnoses,” lowering both the sensitivity and specificity of evaluated tests. Despite this, electrodiagnostic tests are the most common comparators in studies evaluating clinical tests.

A number of important design issues for diagnostic studies have been well described elsewhere.^{119,120,121} Critical design flaws occur commonly in CTS diagnostic test studies.⁸² One of these is the inclusion of “normals” as the control group. Diagnostic studies should mimic clinical practice in that tests need to distinguish patients with or without the target disorder.

There is no diagnostic challenge to distinguishing patients with symptoms from people who have no complaints. Our systematic review demonstrated that studies using asymptomatic controls report overly high specificity.⁸² Another common flaw is that the diagnosis is not obtained in a blinded manner. For example, a number of studies that report that clinical tests are not useful describe a procedure where the examiner performs the electrodiagnosis and conducts the clinical tests on the same occasion. This calls into question the objectivity of the comparison, particularly if the examiner is biased towards a particular test either because of training or experience. Unfortunately, the experience/training of evaluators is typically not stated.⁸² This limits generalizability, as the familiarity of the person with proper test procedures and their skill in interpretation can have a major impact on the validity of test results.

STANDARDIZATION OF CLINICAL TESTS

Standardization is an important concept in clinical evaluation. This implies that documented methods have been described, are known to be reliable and valid, and are used by different clinicians across different clinical studies. In fact, for the most part, this is not true. Variation in how CTS clinical tests are

performed is common, and some of these variations are listed in Table 1. There is a need to have clear descriptions of clinical test methods and their associated reliability, so that different examiners will use similar and reliable techniques. While many studies have addressed the validity of CTS diagnostic tests, few have addressed the interrater or test-retest reliability of diagnostic tests. Our data suggest that interrater reliability varies between tests: almost perfect (Phalen's, Tinel's), substantial (Pinch, wrist extension, vibration with a tuning fork), moderate (tethered median nerve), or fair (Semmes-Weinstein monofilaments).^{79,80}

THE CLINICAL EXAMINATION

History

The most important element of diagnosis in CTS is the obtaining of a relevant history.^{12,66,101,102} This includes description of the symptoms, their intensity, the frequency, aggravating factors (particularly posture and activity), and relieving factors. The interview should identify any medical or environmental risk factors that might be contributing and determine how the symptoms have evolved over time.

Medical risk factors include: (1) extrinsic factors that increase the volume within the tunnel (outside or inside the nerve); (2) intrinsic factors within the nerve that increase the volume within the tunnel; (3) extrinsic factors that alter the contour of the tunnel;

and (4) neuropathic factors. Extrinsic factors that can increase the volume within the tunnel include conditions that alter fluid balance (pregnancy, menopause, obesity, renal failure, hypothyroidism, the use of oral contraceptives, congestive heart failure, and others). Inflammatory conditions, such as arthritis, infection, or nonspecific tenosynovitis, are also potential underlying causes. Masses such as ganglia, myeloma, lipoma, or fibroma can also increase volume within the tunnel; as can, hemorrhagic disorders such as hemophilia, leukemia, or anticoagulation. Finally, a variety of anatomical abnormalities, such as vascular malformations and anomalous muscles, have been described.^{144,149}

Intrinsic factors within the nerve that increase volume inside the tunnel include tumors and tumor-like lesions. Extrinsic factors can alter the contour of the tunnel following fractures of the distal radius or carpus, directly or via posttraumatic arthritis. A number of neuropathic factors can elicit CTS symptoms by affecting the nerve without increasing interstitial pressure. These include diabetes, alcoholism, vitamin toxicity or deficiency, and exposure to toxins.

Environmental risk factors are a primary consideration. Prolonged postures in extremes of wrist flexion or extension, repetitive use of the flexor muscles, and exposure to vibration are the primary exposures to be considered.^{22,86,93,107} The pathophysiology of repetitive-motion injury is well described in this issue of the *Journal*.

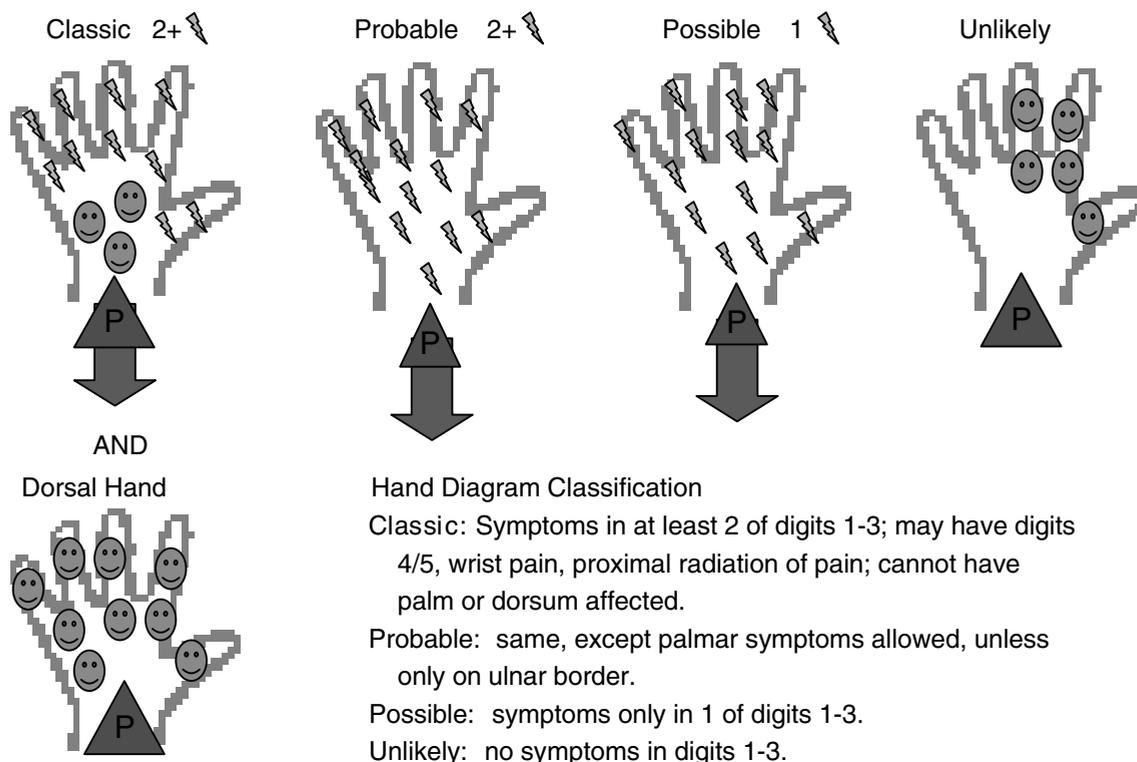


FIGURE 1. Hand diagram classification adapted from Katz et al.⁶⁷ The hand diagram allows one to determine the likelihood of CTS on the basis of the distribution of self-reported symptoms.

The characteristic symptoms of CTS are numbness and tingling in the median nerve distribution. This classic distribution will typically include the palmar aspect of the thumb, index, middle, and half of the ring finger. The remaining half of the ring finger and small finger should be excluded, as they are usually innervated by the ulnar nerve. The palm should be excluded, as it is typically innervated by the palmar cutaneous branch of the median nerve arising proximal to the carpal tunnel.¹¹⁷ This fits the classic description of symptoms described by Katz and Stirrat⁶⁷ in their hand diagram interpretation as described in Figure 1. The reliability of these hand diagrams has been confirmed. Physicians agreed with each other exactly 83% of the time, and in the remaining cases, differed by 1 category when interpreting hand diagrams.⁶⁷ Some studies suggest that hand diagrams have a high accuracy in classification of CTS.^{67,134} It is known that these case definitions are less sensitive in community screening (survey) than in a clinical situation.³⁴

During an interview, it is not uncommon for patients to report that symptoms include their fifth finger. The reason for this is debatable. Some authors suggest this indicates ulnar neuropathy.⁸⁴ Others appear comfortable with these complaints being consistent with CTS.⁴⁶ It may be that some patients fail to attend to the specific nature of their symptoms and thus report the entire hand as being involved, when, in fact, the small finger is not affected. Clinical examination often reveals sparing of sensory changes in the small finger. Where definitive changes in the fifth finger are evident on clinical examination, the possibility of concomitant ulnar neuropathy or nerve root compression should at least be considered.

Occasionally we see older patients with marked electrodiagnostic changes and thenar atrophy, in which the subjective complaints of pain and/or tingling are minimal, although functional deficits may be profound. These patients have severe disease, with sensory impairment of sufficient severity that paresthesia is no longer apparent. A large multicenter study has confirmed that patients with mild to moderate CTS are more likely to report substantial symptoms and mild functional limitations, whereas patients with more severe disease may report less severe symptoms, but have more severe functional limitations of the hand.¹⁰² This apparent contradiction relates to the fact that severe compromise of the median nerve may impair sensory functioning to the extent that the profound numbness minimizes the experience of tingling and pain. However, this level of numbness and motor impairment does have profound functional implications.

At the other end of the spectrum are the patients who only have symptoms with rigorous activity, usually work-related, and who present with minimal symptoms or objective findings when examined in the

clinic. Some authors have used the term *dynamic CTS* for these patients.¹⁶ These patients are likely to benefit from conservative management, including alteration of work duties. Therefore, the importance of a well-defined history is particularly important in these cases.

Other characteristic subjective findings of CTS are waking at night with numbness and tingling and the so-called "flick sign,"⁷⁰ where patients report that shaking or flicking their wrists relieves symptoms. It is also common for patients with CTS to report subjective feelings of swelling in their hands or wrists.²⁰ These subjective elements have been described as diagnostic by some authors. In a study of over 8000 patients with suspected CTS, it was found that symptoms on the radial part of the hand and nocturnal exacerbation of symptoms were most strongly predictive of positive nerve conduction tests.¹² In patients with abnormal nerve conduction studies, who were asked about things that made their hands worse, 80% checked "at night," 72% "in the morning," and 77% "while working with their hands." Fifty-six percent of patients reported that symptoms could be relieved by shaking the hand or hanging it out of bed.¹²

Kamath and Stothard CTS Diagnostic Scale

1. Has pain in the wrist woken you up at night? (yes = 1, no = 0)
2. Has tingling and numbness in your hand woken you during the night? (yes = 1, no = 0)
3. Has tingling and numbness in your hand been more pronounced first thing in the morning? (yes = 1, no = 0)
4. Do you have any tricks or movements to make the tingling or numbness go from your hands? (yes = 1, no = 0)
5. Do you have tingling and numbness in your little finger any time? (yes = 1, no = 3)
6. Has tingling and numbness presented when you were reading a newspaper, steering a car or knitting? (yes = 1, no = 0)
7. Do you have any neck pain? (yes = -1, no = 0)
8. If applicable, has the tingling and numbness in your hand been severe during pregnancy? (yes = 1, no = -1, N/A = 0)
9. Has it helped the tingling and numbness on wearing a splint on your wrist? (yes = 2, no = 0)

Sum (total of responses) =

FIGURE 2. Diagnostic CTS Scale.⁵⁸ The Diagnostic scale uses patient self-report of characteristic features of CTS to determine the likelihood of CTS.

A recent questionnaire developed for diagnosis of CTS was reported to have 85% sensitivity and 90% positive predictive value, which was considered sufficient to replace nerve conduction studies. Patients were asked a series of 9 questions and were provided a likelihood score on the basis of these responses.⁵⁸ While a score of 3 was compared to the results of nerve conduction studies in the validation paper, the authors recommended a score of 5 or more be used as a cutoff for a screening tool in place of nerve conduction studies (Figure 2).

The Symptom Severity Scale (SSS) and Functional Scale (FS)⁷⁵ were designed to measure the severity of CTS, but have potential to be used as diagnostic tools as well. In a study comparing scores obtained from patients with a high probability of CTS, as defined by a hand diagram (classic/probable) (Figure 1), versus patients whose hand diagrams were not consistent with CTS (possible/unlikely),³ it was found that the SSS scores were higher in patients with hand diagrams consistent with CTS, particularly if the sensory questions were selected. However, the definitive studies required to determine the appropriate questions/cutoff scores have not been conducted.

A well-constructed interview supplemented with 1 of the structured diagnostic instruments described above can form a substantial component of a CTS diagnosis.

Observation

When examining a patient for CTS, one must check for thenar eminence atrophy. The abductor pollicis brevis is innervated by the median nerve and located superficially on the radial aspect of the thenar mass. This can best be appreciated by comparing the profiles of both thenar eminences.¹⁰⁵ One might find atrophy of this muscle in moderate to severe CTS.¹⁴³ Averaging over reported studies and 107 patients, we found that only 12% of patients exhibited this finding; however, specificity was very high (94%).⁸² Thus, a finding of thenar atrophy with symptoms of CTS is sufficient to confirm the presence of moderate to severe CTS, while its absence does not exclude the presence of CTS.

Provocative Testing

Using a provocative maneuver to elicit the symptoms of CTS is a routine component of a physical therapy clinical examination. One form of provocation is positional. Patients with CTS are thought to have a mismatch between the space required and the space availability. Positions which further compromise this mismatch are sufficient to reproduce symptoms. Phalen's wrist flexion test,^{108,110,111} the wrist extension test,¹²⁶ and the lumbrical test⁵⁹ are founded on this theoretical construct (Table 2). The sensitivity

and specificity of positional tests varies greatly between studies, and the lack of complete documentation on study methods makes it difficult to ascertain which studies used acceptable clinical methods and research designs.⁸²

One of the most consistently studied and supported tests is Phalen's wrist flexion test.^{19,35,38,47,92,97,148} As originally described by Phalen,^{110,111} the wrists were dropped by gravity assistance into flexion and CTS was indicated by symptoms that were reproduced. A number of variations on this test can be seen in the clinic (Table 2), and an overall estimate of sensitivity (68%) and specificity (73%) was obtained across 4855 studied patients in our systematic review.⁸² Wrist extension appears to be less sensitive than wrist flexion in detection of CTS (57% in 640 patients).⁸² Variations of either test that require the patient's shoulder to be elevated or the elbow flexed should be avoided, because compression at these sites could potentially confound the test results.

An increase in pressure applied directly to the median nerve is the premise for the carpal compression test, sometimes credited to Durkan, who described it in 1991.³¹ Some authors have reported this to be one of the most valuable provocative tests,^{87,134,136} and our systematic review supports its use (64% sensitivity and 83% specificity in 3077 patients).⁸² This test is not dependent on wrist motion and thus it is particularly useful in patients with limited wrist motion. Dr Robert McMurtry described the technique for performing this test, based on his 10-year experience using it (with a resident coauthor) in 1985.¹⁰⁴ Durkan's contribution was to describe standardization of pressure when performing the test.³²

Another provocation test is the providing of a mechanical deformation stimulus to the nerve, producing the "shock" described by Tinel, which is thought to occur from regenerating nerve fibers.²⁷ While a number of authors have questioned the validity of this test, most studies, including our systematic review, suggest that it is more specific than sensitive (70% versus 50%)—that is, false negatives are more common than false positives.^{2,19,28,39,47,91,123} It has been demonstrated that Tinel's test is more commonly positive with moderate to severe CTS, which is consistent with its mechanism.^{2,97,127} It has also been suggested that use of a Queen's square reflex hammer and wrist extension increases the sensitivity of the test; but the effect of this practice on specificity was not studied.⁹¹

A single study has reported using therapeutic ultrasound along the course of the nerve to elicit symptoms.⁸⁹ In this case, sound waves may provide a form of mechanical deformation. While interesting, this application has not been replicated by other authors, so its relative value remains unclear.

TABLE 2. Provocative tests used in diagnosis of carpal tunnel syndrome (CTS). Sensitivity and specificity are reported from a systematic review of diagnostic test studies.⁸² Where only a single study was available, tests were not included in the systematic review, but some results of such studies are reported under the comments.

Test Name	Rationale	Method	Positive Result	Variations	Accuracy		Comments
					Sensitivity	Specificity	
Wrist flexion Phalen's test ^{108,109,110,111}	Flexion increases pressure in the carpal tunnel; the median nerve is compromised by high pressures in the carpal tunnel, which are exacerbated by extreme wrist flexion	Patient places elbows on table, forearm vertical, the wrist falls into gravity-assisted flexion for up to 1 minute; the fingers are left in an extended position	Paresthesia develops or increases in median nerve distribution	Examiner passively flexes the wrist in full flexion (elbow extended); the patient places the dorsum of both wrists together, forcing them into flexion (shoulder flexion) should not be elevated) The time for symptoms to emerge can be recorded; add-ons include making a fist or carpal compression	68	73	Data based on 29 studies, including clinic based and population based, false negatives may result in patients with limited wrist flexion or when profound numbness exists, as altered sensation due to positional effects may not be perceived
Wrist extension test Reverse Phalen's	Wrist extension increases pressure in the carpal tunnel as above	Patient actively extends wrist and fingers for up to 2 minutes	Paresthesia develops or increases in median nerve distribution	Patient places palms together, forcing both wrists into extension; 1-minute time limit	57	78	Data based on 3 studies, false negatives may result in patients with limited wrist extension or when profound numbness exists, as positional effects may not be perceived
Carpal compression test ¹⁰⁴ Durkan's test McMurtry's test	Direct pressure increases compromise to impaired median nerve	Examiner compresses median nerve by pressing over proximal edge of carpal ligament (proximal wrist crease) with his/her thumbs (wrist neutral)	Paresthesia develops or increases in median nerve distribution	Pressure cuff or algometer used to apply pressure; location of pressure at exit of canal also reported	64	83	Data based on 9 studies
Carpal compression plus wrist flexion	Pressure plus positional compromise will increase sensitivity of test	Examiner compresses median nerve by pressing over proximal edge of carpal ligament (proximal wrist crease) with his/her thumbs (wrist flexed)	Paresthesia develops or increases in median nerve distribution		80	92	Data based on 3 studies

TABLE 2. (continued)

Test Name	Rationale	Method	Positive Result	Variations	Accuracy		Comments
					Sensitivity	Specificity	
Tinel's test ²	Regenerating nerve fibers are susceptible to mechanical deformation	Examiner taps along the median nerve at the carpal tunnel	Tingling or electric shocks felt along the median nerve	Use of a Queen's square reflex hammer is reported to increase sensitivity ⁹¹ ; tapping may be just at proximal edge of ligament, or transverse median nerve from distal to proximal edge of carpal tunnel	50	77	Data based on 7 studies; a Tinel's test is thought to test regenerating nerve fibers, therefore, may not be present in mild disease ^{1,26,128}
Tourniquet test ^{1,33} Gilliat Test	Increase in vascular pressure in compromised nerve will cause symptoms	Examiner uses a blood pressure cuff on the patient's arm, above the elbow, to the level of their systolic blood pressure	Paresthesia develops or increases in median nerve distribution within 60 seconds		59	61	Data based on 5 studies; effect of cardiovascular disease on test results is unknown
Ultrasound ⁸⁹	Regenerating nerve fibers are susceptible to mechanical deformation or altered membrane permeability	Examiner slowly moves the ultrasound head along the median nerve at the carpal tunnel at 1, 1.5, and 2 W/cm ²	Paresthesia, pain develops or increases in median nerve distribution				Supported by a single study ⁹² but may provide a novel test that could be useful when evaluating sincerity of response.
Relief Maneuver ⁸⁵	Theorized that it modifies the shape and dimensions of the carpal tunnel, and the spatial relationship between the median nerve and the surrounding structures	With the palm up, the examiner gently squeezes the distal heads of the metacarpal together, inducing adduction of the fingers	Paresthesia, pain is relieved or decreased in the median nerve distribution	When this is not sufficient to relieve symptoms, the examiner stretches digits 3 and 4			Studied and supported by a single study ⁸⁷
Tethered median nerve stress test ^{2,7,74}	This test produces maximum excursion of the median nerve and thus accelerates localized neuroischemia in chronic CTS; due to adherence of the median nerve to the flexor tendons	Examiner hyperextends the index finger (and wrist) by pressing on the distal end (forearm supinated)	Produces proximal forearm radiation of pain in patients with chronic CTS		48	76	Data based on 4 studies; high accuracy reported by developers, ^{72,74} but lower by independent evaluators ^{69,79,108,114}

TABLE 2. (continued)

Test Name	Rationale	Method	Positive Result	Variations	Accuracy	
					Sensitivity	Specificity
Lumbrical provocation test ⁵⁹	Lumbricals can move into the carpal tunnel during finger flexion; thought that this might increase compression	Patient is asked to make a fist for 1 minute	Reproduce or worsen symptoms			Compared with the findings obtained with electrodiagnosis, the sensitivity of the LPT was 37%; specificity 71%. ⁵⁹ in a single study
Dynamic CTS is a condition where symptoms are only brought on by activity and activity can be used to provoke the temporary nerve blocks accounting for symptoms	Patient performs upper extremity activity for 7 minutes; the type of activity was not standardized	Swelling and changes in sensory thresholds				Reported in a single study; stated that patients diagnosed this way responded to surgical management ¹⁶
Pinch test ³⁰	Lumbricals are moved proximally into carpal tunnel, the index flexor tendons are beneath the median nerve and thus adhesions may traction nerve	The patient actively pinches a piece of paper between the tips of the thumb, index and long fingers (MCPs flexed, IPs extended)	Symptoms of paresthesia are reproduced			70%-72% sensitive and 78%-88% specific, as reported in a single study ⁸¹
Hand elevation test ¹	Not clearly specified, but further vascular compromise might be produced	Both arms are elevated by the patients with the elbows and shoulders in a relaxed position; position is held for up to 2 minutes	Symptoms of paresthesia are reproduced			Reported in a single study; while originating authors suggest that it is accurate (76% sensitivity, 98% specificity in normal controls), the potential for confounding with a number of other upper extremity conditions undermines the validity of the test from a theoretical view and thus warrants independent examination

The tethered median nerve test appeared promising when first reported,^{72,73} but has not been supported by independent authors.^{68,79,112} As the tethered median nerve test assumes adhesions have developed between the nerve connective tissue and surrounding structures, a positive result should not be anticipated in all cases. Therefore, it should be viewed more as an etiological test than a routine diagnostic test. This was supported by the low sensitivity (48%) and higher specificity (76%) reported in our systematic analysis of 346 patients.⁸²

Less commonly used and less supported are a number of other provocative tests described in Table 2. A number of tests have limited formal analysis and their utility could not be evaluated at this time. These include the Wisconsin Functional Sensory and Psychomotor Battery,^{54,55} the 7-minute stress test,¹⁶ combined wrist and finger flexion test, and the relief maneuver.⁸⁵

In most provocative tests, a positive test result is reproduction of symptoms. However, in an attempt to develop more sensitive tests, some authors have used change in sensibility with provocation to indicate neuropathic changes. Some authors have reported that combining wrist flexion with sensory evaluation, such as vibration threshold or touch,¹³⁴ provides a more sensitive test. It is important that patient-based controls be studied in these cases to define whether sensitivity is improved by sacrificing specificity.

Sensory Evaluation

As sensory symptoms predominate in CTS, objective sensory tests should be valuable both in diagnosis and evaluating response to intervention. Studies of artificially induced median nerve compression have demonstrated that vibration and light touch threshold are affected early in nerve compression, whereas altered 2-point discrimination is a late finding.^{37,38} Clinical studies^{97,134} have also supported these findings.

Changes in light touch can be assessed using cotton balls or light examiner touch. Patients are asked to identify if touch within the median nerve distribution feels the same or different from a comparative site. The index or middle fingertips are most commonly assessed. The comparative site can be the opposite hand, but with the common occurrence of bilateral CTS, comparative sites are often chosen as being ulnar based (ie, tip of the small [fifth] finger). A quantitative version of this process has been described as useful in diagnosis of CTS. During the 10 test, the patient is instructed that the reference site is normal (10 on a range of 0 to 10, with a 0 being no feeling and 10 normal feeling) in terms of feeling, and the examiner then asks the patient to report the feeling in the median nerve innervated site.^{130,131} This approach might be useful in both diagnosis¹⁰⁶

and monitoring response to interventions, although further investigation of this test is warranted.

Touch threshold can be measured using Semmes-Weinstein monofilaments (SWMF) or West Enhanced Sensory Test filaments (WEST). These filaments are designed to bend with a known force. The bending of the filament dampens variations in force application due to the examiner, eliminating one of the sources of variation that plague 2-point discrimination tests. The physiologic properties of the filaments have been well described by Bell-Krotoski.^{5,8} Although study results vary widely on SWMF, our systematic review suggested that SWMF testing is useful (sensitivity 72% and specificity 62% in 1378 subjects).⁸² Most studies agree that sensitivity is greater than specificity for the SWMF^{82,87,134}—that is, false positives are more common than false negatives. This can be affected by the threshold at which abnormality is defined,^{5,7,134} contact time,¹⁴¹ or other aspects of technique. Clear descriptions of application techniques and decision rules should assist with defining reliability and validity and how it varies in different conditions. One of the few studies to address both reliability and validity showed low to moderate agreement between therapists, high sensitivity, and low to moderate specificity.⁸⁰

Thresholds greater than normal, defined as 2.83 (3.61 in the 5-piece SWMF kit or 3.22 in the 20-piece kit), may indicate sensory deficits attributable to CTS. A number of published studies have used decision rules based on a threshold of 2.83 as normal.^{79,81,103} However, the threshold for defining abnormality varies between examiners, and contact time,¹⁴¹ and also varies based on the type of test filaments,⁶ which limits standardization. Differences in decision rules about whether the small finger is used as a comparison have been shown to increase specificity, but decrease sensitivity.⁸¹

Skill is involved in both administration and interpretation of SWMF tests. Multiple factors should be considered when determining that a given result is abnormal. Elevated thresholds can result from sensory loss due to other pathologies, aging, or increased skin resistance (such as occur with calluses). These would be a source of false positives if simple decision rules are used in defining a test result as positive or negative for CTS. Experienced examiners may be able to select appropriate comparisons for specific patients more effectively, apply filaments more consistently, or use clinical reasoning to sort out sources of potentially misleading findings. However, studies have not specifically addressed this practice. In general, studies with hand therapist examiners^{80,82} have reported more favorable results than studies in which examiners were not identified as such,¹⁰³ suggesting that the experience of the examiner may be important.

TABLE 3. Sensory/motor tests used in diagnosis of carpal tunnel syndrome (CTS). Sensitivity and specificity are reported from a systematic review of diagnostic test studies.⁸²

Test	Method	Positive Result	Variations	Accuracy		Comments
				Sensitivity	Specificity	
Touch threshold measured by SWMF/WEST ^{5,6,7,9}	A 5-piece SWMF/WEST set is used; filaments are applied (to just bend) on digit pulps; 2.83 is usually applied 3 times	Decisions rules can vary; a threshold greater than 2.83 is abnormal in digits 1-3; usually digit 2 or 3 is assessed; comparison with digit 5 may improve specificity by eliminating thresholds greater than 2.83 because of calloused skin or age-related decline	Variation in application techniques (rate, number, contact time), and decision rules ⁸² ; variations in test protocols are common	72	62	Data averaged over 6 studies; bilaterality and ulnar neuropathy can complicate comparative site; skin callouses, aging can be expected to increase threshold; 5 piece kit may be preferable for diagnosis, 20-piece kit may be preferable for outcome evaluation; a number of studies have found high sensitivity, ^{7,9,81} most agree that specificity is lower ⁸⁷
Touch threshold measured by the PSSD ⁵⁶	PSSD is applied to pulp digits 1-3 and patient signals threshold by pushing a trigger; 5 measures are taken with largest and smallest values dropped and the remaining 3 thresholds averaged; if 2 points are used, the points on the device are separated according to a standard 2-point discrimination test	Thresholds greater than normals; normal is taken as 1 g/mm ² for adults <45 years of age and 2.2 g/mm ² for those >45 years of age	Variation in application techniques (rate, number, duration) and decisions rules			Expensive, sensitivity reported to be greater than NCV when history plus physical examination used as a gold standard but, specificity was lower ¹³⁶
Touch measured by Strauch's 10 test ¹³²	The pulp of the patient's normal finger (preferably little finger same hand) is stroked lightly with the pulp of the examiners finger and is assigned a score of 10; patient reports the perceived sensation on the affected finger on a scale of 1-10; this is repeated with both areas being stroked at the same time	Threshold lower than comparative site	Where sensory abnormality exists within or between hands, a reference site on the face may be used			2% of patients reported to not be able to understand the 10 concept

CLINICAL COMMENTARY

TABLE 3. (continued)

Test	Method	Positive Result	Variations	Accuracy		Comments
				Sensitivity	Specificity	
Vibration threshold measured with tuning forks ^{2,6}	Tuning fork (256 cps) is hit and the prong applied tangentially to the fingertip pulp of digits 1 to 3 of affected side and comparative site	Patient signals as to whether feeling is different to compared normal site (digit 5) or alternate side (can be increased or decreased)	Variation in application techniques (rate, number, duration, end of tuning fork used) and decisions rules	55	81	Data averaged over 6 studies; studies by surgeons/therapists had higher sensitivity; substantial reliability between hand therapist examiners ⁷⁹
Vibration threshold measures with vibrometers	Vibration stimulus is contacted to digital pulp through a device that modulates and records variations in intensity and/or frequency of stimulus	Thresholds greater than norms	Models vary with respect to the frequencies of vibration they can apply and contact area ⁷⁸		73	Averaged over 7 studies; high variability between studies; expensive
Current perception threshold ^{64,85}	Patient is touched by equipment that stimulates sensory nerves by delivering current at different frequencies	Patient signals when stimulus is perceived; thresholds and frequency ratios are compared to established norms; computer software performs these analyses				Katims reported high accuracy (compared to NCV) in patients undergoing hemodialysis, detected more abnormalities when screening workers. ⁶⁴ Expensive
Static 2-point discrimination	Patient has to distinguish between touch of prongs (either 1 or 2); prongs should be applied until skin just blanches	>5 mm on pulps is considered abnormal	Disk-Criminator is well suited; other devices are on the market	24	95	Data averaged over 6 studies; requires a flat, even stimulus-sharp devices, paperclips, or uneven prongs should not be used
Moving 2-point discrimination ^{2,8}	Patient has to distinguish between touch of prongs (either 1 or 2); prongs are moved along the finger proximal to distal perpendicular to papillary ridges	>4-5 mm on pulp is considered abnormal				Paperclips are used by some, but are unable to provide the flat even stimulus required; standardization of force applied is difficult; with 4 mm as abnormal sensitivity in stage 1, CTS was 23%, in stage 2 it was 33%, and in stage 3 it was 67% ¹⁰

TABLE 3. (continued)

Test	Method	Positive Result	Variations	Accuracy		Comments
				Sensitivity	Specificity	
Thenar weakness	The thenar muscles are innervated by the median nerve; compromise of the motor fibers results in impairment of these muscles	Oxford grading of abductor pollicis brevis ⁴⁸ indicates less than grade 5	Devices which could measure actual force are more sensitive but not widely available; customized test units developed by some	29	80	Data averaged over 2 studies; quantitative test methods deficient; reported in around 25% of patients who were evaluated ^{1,5,53}
Thenar atrophy	The thenar muscles are innervated by the median nerve; compromise of these fibers leads to atrophy	Visual inspection of abductor pollicis brevis reveals loss of muscle bulk		12	94	Data averaged over 2 studies; reported in only 0% to 20% of patients, ^{5,53} except in Phalen's original work, where high rate (41%) likely was due to acquiring more severe cases when disease first recognized; indicates severe CTS

A continuous scale of measurement (0.5 to 100 g) on touch threshold is a potential advantage of the PSSD test device.^{29,56,135} Touch threshold is measured using this device by requiring patients to fire a hand-held trigger device when they feel the application of a prong that is connected to a computer-based pressure-sensing device. The NK Hand Assessment System software (NK Biotechnical Engineering Co, Minneapolis, MN) records and averages thresholds. The recommended protocol suggests that application by the examiner should occur 5 times, with the middle 3 trials averaged. Sensitivity has been reported to be favorable, although specificity has been questioned.¹³⁵ Concepts regarding the role of skill are similar to those discussed for SWMF. Much of available evidence originates from the developer and more independent testing is required. As a hand-held device, it remains susceptible to the effects of the examiner varying the rate of force application, although recent software attempts to mitigate this problem by signaling when the device is applied incorrectly.

The patient's ability to perceive a vibratory stimulus can be a useful diagnostic tool. This concept has been supported both by data from experimentally induced nerve compression studies^{36,37,38} and clinical data reported by Dellon.²⁶ In its simplest format, the stimulus is provided using a tuning fork and the patient is asked to identify whether the stimulus feels the same as a comparative site. Despite obvious difficulties in standardizing the stimulus provided, reliability and validity have been established using this simple technique.⁸⁰ A more quantitative assessment of vibration threshold is possible with custom or commercial vibrometers, which provide a standardized stimulus in which the intensity and frequency can be controlled.^{40,146,147} These have been reported to be accurate by a number of authors,^{50,133} although potential advantages of quantitative devices have not yet been adequately supported by formal studies.^{83,145}

Current perception threshold (CPT) testing^{64,65} is another form of sensory threshold testing. In this case, the stimulus is electrical and may affect nerve fibers directly. It is thought that different frequencies can target specific fiber types (A-beta, A-delta, and c).^{62,63,64,65,115} Theoretically, this provides a more comprehensive assessment capability than traditional sensory tests or nerve conduction tests, which focus on larger beta fibers. It is also proposed that CPT has the unique ability to measure hyperesthesia associated with the early stage of nerve compression—an advantage for community or industrial screening.⁶⁴ However, the role for this testing has not yet been fully established.

Sensory modalities that are less affected in CTS include static or moving 2-point discrimination or thermal sensations. While 2-point discrimination remains popular with some clinicians,¹⁴² it has more

value as a test of severity than presence of CTS. Experimental and clinical evidence support the fact that changes in this modality occur only with more severe CTS.^{37,97,134} Only patients with sensory abnormalities in light touch and vibration will manifest abnormalities in 2-point discrimination.^{105,133} In the 381 subjects reported in the literature, abnormal 2-point discrimination occurred 24% of the time.⁸²

Motor Evaluation Muscle testing of the abductor pollicis brevis is conducted by evaluating the patient's ability to abduct the thumb away from the palm. Typically this is conducted using a graded manual muscle test (0, nothing; 1, trace; 2, full-range gravity-eliminated movement; 3, full-range against-gravity movement; 4, some resistance; 5, normal) (Table 3).⁴⁸ This method is useful for detecting gross loss in strength, but insensitive to mild weakness.³³ Quantitative testing of abductor pollicis brevis has been described, although the device is not commercially available.⁴ For physiological and methodological reasons, motor deficits are indicative of severe CTS, and changes in abductor strength are reported in only 29% of 107 subjects with CTS.⁸²

Making Decisions With Multiple Tests

Clearly no single test insures a correct diagnosis, and to conduct all the described tests would be foolhardy. In our systematic review, we were able to identify a number of tests with a preponderance of evidence suggesting that they have some utility. However, all were subject to error.⁸² A few studies have focused on strategies for combining test results^{35,98} (Table 4). Selecting an examination strategy and interpreting the findings requires knowledge of the test properties and consideration to the realities of the clinical situation. It is advisable to adopt a standardized method of conducting a few routine tests. Others may be selected based on the findings of interview or clinical examination. Phalen's and carpal compression tests are complementary in terms of source of provocation and interpretation.³⁵ Both are sensitive in milder disease and have commonly been shown to be useful.⁸² Thus, they fit the requirements for routine application. Tinel's test indicates more severe CTS and might be used for confirmation of appropriate cases.

A rigorous sensory evaluation should be included, with consideration to the factors that might cause altered sensory thresholds other than compression within the carpal tunnel. Preferably, this would be conducted using quantitative devices like current perception threshold, SWMF (full kit), or vibrometry, although practical considerations may dictate otherwise. SWMF/WEST (5-filament sets) are an alternative of more moderate cost and the 10 test introduces rigor to the sensory evaluation process without any cost.

TABLE 4. Studies on test combinations in diagnosis of carpal tunnel syndrome (CTS).

Combined Tests		
Test	Analysis	Results
Diagnostic algorithm using a hand diagram, Phalen, and Tinel's ⁹⁸	Bayes theorem used to assign probabilities for combinations of these 3 test (+/-)	Accuracy similar to electrodiagnoses ⁹⁸
Hand diagram, SWMF, Durkan's and night pain ¹³⁴	Looked at impact of different test result combinations on probability of having CTS	If all 4 positive CTS probability 86%, if all negative 0.6%; other test combinations provided; electrodiagnosis did not add to diagnostic power
Wrist flexion or extension combined with median nerve pressure ¹³⁶ ; wrist and finger flexion	Combinations of positional and pressure provocation	Most sensitive was wrist flexion with pressure; highest specificity for combined wrist/finger flexion
CTS-7 ⁴⁵	A delphi consensus process used to develop a set of core symptoms and physical findings and their associated weights (see Figure 3)	Not available

TABLE 5. Steps towards a conclusive clinical diagnosis: the influence of different test outcomes on likelihood of carpal tunnel syndrome (CTS).

Strong Increase	Increase	No impact	Decrease	Strong Decrease
1. Define the nature of the symptoms				
<ul style="list-style-type: none"> • Paresthesia, numbness and pain • Focal swelling just proximal to wrist crease • Waking at night with paresthesia 	<ul style="list-style-type: none"> • Hand swelling • Relieved by flicking of wrists • Paresthesia with activity or position 	<ul style="list-style-type: none"> • Pain aggravated by movement or position 	<ul style="list-style-type: none"> • Pain only 	
2. Define location of sensory complaints				
<ul style="list-style-type: none"> • Digits 1-3 included • Ring-splitting • Exclusion of digit 5 • Exclusion of palm 	<ul style="list-style-type: none"> • Symptoms in 1 or more radial digits 	<ul style="list-style-type: none"> • Diffuse including hand 	<ul style="list-style-type: none"> • Digit 5 involved • Include palm (forearm ++) • Radiate proximal to wrist 	<ul style="list-style-type: none"> • Symptoms follow dermatome (neck ++) • Extend into forearm (forearm ++) • Digit 5 only (ulnar ++)
3. Sensory examination				
<ul style="list-style-type: none"> • Abnormal threshold (vibration, SWMF, current perception) in digits 1-3 with normal digit 5 • Abnormal 2-point in digits 1-3 	<ul style="list-style-type: none"> • Abnormal threshold in at least 1 of digits 1-3 	<ul style="list-style-type: none"> • Normal 2-point in digits 	<ul style="list-style-type: none"> • Abnormal threshold digit 5 (ulnar nerve +) 	<ul style="list-style-type: none"> • Normal threshold in digits 1-3
4. Motor examination				
<ul style="list-style-type: none"> • Weak abduction of thumb • Atrophy of thenar bulk 		<ul style="list-style-type: none"> • Decreased grip strength, grip endurance • Normal thenar bulk 	<ul style="list-style-type: none"> • Proximal or hypothenar weakness, (+ forearm, neck or disuse atrophy) 	<ul style="list-style-type: none"> • Proximal atrophy (neck/brachial plexus); abnormal reflexes (+ neck)
5. Special tests				
<ul style="list-style-type: none"> • Wrist flexion + • Carpal Compression + • Nerve percussion + 		<ul style="list-style-type: none"> • Percussion – 	<ul style="list-style-type: none"> • Wrist flexion or carpal compression – 	<ul style="list-style-type: none"> • Carpal compression and wrist flexion –
6. Response to night splints				
<ul style="list-style-type: none"> • Reduced symptoms 				<ul style="list-style-type: none"> • No reduction in symptoms

It should not be expected that the entire battery of tests would always agree with each other, particularly during screening, where pretest probabilities are low. The experienced clinician will select and interpret relevant tests with consideration to the apparent severity of nerve compression, potential confounding conditions, and physical/psychosocial factors. The relative importance of test findings on diagnostic probabilities is illustrated in Table 5. By weighting the influence of the test result to these considerations, the clinician can synthesize the key findings from the history and clinical examination into a confident diagnosis on the presence and severity of CTS. One approach to synthesizing examination findings, the CTS-7, was developed by Graham⁴⁵ through a Delphi consensus process incorporating a variety of physician specialties. Regression analyses were used to define the validity of a specific diagnostic algorithm illustrated in Figure 3. This algorithm, as in Table 5, emphasizes that some findings affect the probability of diagnosis to a greater extent than others. Table 6 provides a summary of patient presentation for different levels of severity of CTS.

ELECTRODIAGNOSIS

Electrodiagnostic (EDX) assessment, or electromyography (EMG), is often used to confirm the presence and severity of CTS when a clinical diagnosis is suspected. While it has been suggested that EDX studies are the diagnostic gold standard for CTS, in reality, CTS is a clinical condition suspected when a typical constellation of signs and symptoms are present; EDX studies are used to confirm the presence or absence of a median neuropathy at the wrist as the underlying cause. In addition, EDX studies do the following: (1) provide information with regard to severity of the median neuropathy; (2) provide baseline values to evaluate the degree of progression or responsiveness to treatment, including surgical release of the flexor retinaculum; and (3) examine the possibility of alternate or associated diagnoses, including ulnar neuropathy, cervical radiculopathy, brachial plexus lesion, or generalized polyneuropathy. Thus, EDX studies are best considered as an extension of the clinical examination of CTS to provide helpful confir-

CTS-7

- 1. The symptoms and history**
 - a. The numbness is primarily or exclusively in median nerve territory (3.5 points)**
 - Sensory symptoms are mostly in the thumb, index, middle and/or ring fingers
 - b. Nocturnal numbness (4 points)**
 - Symptoms are predominant when patient sleeps; numbness wakes patient from sleep
 - c. Condition ameliorated by appropriate therapy (3 points)**
 - Steroid injection, wrist splinting, modification of activity
- 2. Physical examination**
 - a. Thenar atrophy and/or weakness (5 points)**
 - The bulk of the thenar area is reduced or manual muscle testing shows strength of grade 4 or less
 - b. Positive Phalen's test (5 points)**
 - Flexion of the wrist reproduces or worsens symptoms of numbness in the median nerve territory
 - c. Loss of 2-point discrimination (4.5 points)**
 - A failure to discriminate 2-points held 5 mm or less apart from one another, in the median nerve innervated digits
 - d. Positive Tinel's sign (4 points)**
 - Light tapping over the median nerve at the level of the carpal tunnel causing radiating paraesthesia into the median nerve innervated digits (not proximally)

Interpretation:
Score ≥ 12 : Probability of CTS is at least 80%. Proceed with nonoperative treatment or referral to a surgeon. Electrodiagnostic tests are probably not indicated.
Score ≤ 4 : Probability of CTS is less than 25%. Search for an alternative diagnosis. Electrodiagnostic tests are probably not indicated.
Score 5-11: Probability of CTS is between 25%-80%. Begin nonoperative treatment. Further investigation with electrodiagnostic tests is indicated.

FIGURE 3. CTS-7.⁴⁴ This algorithm weights key features of the presented symptoms and clinical examination to determine the likelihood of carpal tunnel syndrome (CTS).

TABLE 6. Summary of patient presentation in carpal tunnel syndrome (CTS) for different levels of severity.

Patient Presentation Considering Severity of CTS				
	“Dynamic” or Preclinical	Mild	Moderate	Severe
Symptoms	<ul style="list-style-type: none"> • Tingling/numbness/swelling with activity • Symptoms only associated with prolonged position or activity and resolve after activity terminated 	<ul style="list-style-type: none"> • Tingling and numbness which are intermittent and moderate • Waking at night with numbness and tingling (usually) • Positional and activity effects are clearly associated with symptoms and may only be present with aggravating factors 	<ul style="list-style-type: none"> • Numbness and tingling more persistent and severe • Waking at night with tingling/numbness and pain • Symptoms exist beyond aggravation 	<ul style="list-style-type: none"> • Numbness predominates and may mask other sensory symptoms • Symptoms are constant/exist beyond aggravating activity
Hand function	<ul style="list-style-type: none"> • Restricted activity capacity due to symptom provocation 	<ul style="list-style-type: none"> • Restricted activity capacity due to symptom provocation • Mild reduction fine motor dexterity at rest, but increased difficulty with moderate activity 	<ul style="list-style-type: none"> • Persistent/moderate functional difficulties • Difficulty manipulating coins • Difficulty with fine motor, dexterity and strength tasks 	<ul style="list-style-type: none"> • Persistent severe functional problems which include difficulty with manipulation of objects, holding objects and grip/pinching, which affect a broad spectrum of activities using the hand
Phalen’s	<ul style="list-style-type: none"> • Expect – 	<ul style="list-style-type: none"> • High probability of + 	<ul style="list-style-type: none"> • High probability of + 	<ul style="list-style-type: none"> • Moderate probability of +
Tinel’s	<ul style="list-style-type: none"> • Expect – 	<ul style="list-style-type: none"> • Low probability of + 	<ul style="list-style-type: none"> • Moderate probability of + 	<ul style="list-style-type: none"> • High probability of +
Touch threshold	<ul style="list-style-type: none"> • Normal at rest • May Increase with sustained wrist flexion or activity 	<ul style="list-style-type: none"> • Increased with wrist flexion • >2.83 at rest and may increase to >3.22 with provocation 	<ul style="list-style-type: none"> • Threshold >3.22 at rest, >3.61 with provocation 	<ul style="list-style-type: none"> • >3.61 at rest
2-point discrimination	<ul style="list-style-type: none"> • Normal 	<ul style="list-style-type: none"> • Normal 	<ul style="list-style-type: none"> • 5-7 mm 	<ul style="list-style-type: none"> • >7 mm
Strength	<ul style="list-style-type: none"> • Static normal • Dynamic endurance may be decreased 	<ul style="list-style-type: none"> • Grip strength may be normal; • Oxford grading of APB may be normal • May detect mild weakness of APB with dynamometer/gauge (if comparative side normal) 	<ul style="list-style-type: none"> • Oxford grading of APB = 4 • May be able to detect moderate weakness of APB with dynamometer/gauge 	<ul style="list-style-type: none"> • Grip strength decreased • Oxford grading of APB ≤ 4 • Profound measurable weakness APB
Prognosis for conservative management	<ul style="list-style-type: none"> • Activity modification indicated to minimize progression 	<ul style="list-style-type: none"> • Good-excellent; better if treatment includes Rx + risk factor management 	<ul style="list-style-type: none"> • High probability that some relief will be obtained but low probability that relief will be complete unless major changes in activity are associated 	<ul style="list-style-type: none"> • Minimal role; immediate surgery indicated

matory information and, in some cases, raise the possibility of alternate or additional diagnoses.

The underlying pathology and pathophysiology of compressive or entrapment neuropathy relate to changes expected on EDX (see Brown and Watson¹⁸ for review). Pathologic changes to myelin are the earliest indication of injury related to nerve compression. Low levels of force or compression lead to paranodal demyelination, which, in turn, leads to

conduction abnormalities seemingly out of proportion to the extent of myelin loss with injury. Greater and more prolonged compressive forces cause myelin loss over a greater length of nerve, which is referred to as segmental demyelination. Depending on the extent of the segmental demyelination, conduction velocity (CV) may be slowed, or conduction may fail entirely, leading to CB. If CB involves all of the nerve fibers it is termed complete. However, more com-

monly, CB is partial, with some fibers displaying block and others displaying conduction slowing without block.

The pathologic features of acute and chronic compression neuropathy differ, with the latter being more relevant to CTS in most cases.¹⁸ The most characteristic feature of acute experimental compression is distortion of internodes and intussusception of one internode into the adjacent internode at the edge of the compression. In chronic experimental compression neuropathy, myelin is displaced from the center of the internode toward the ends, with changes in the myelin through the length of a given internode. With more severe compression, axonal damage or injury occurs. Wallerian degeneration refers to the axonal degeneration distal to the site of a focal axonal lesion. It is this degeneration that leads to denervation of muscle and subsequent atrophy.^{41,42,95}

After nerve compression is relieved, nerve repair occurs. With lesions involving only the myelin sheath, repair can occur rapidly over days to weeks. However, the new internodes replacing the damaged myelin are abnormally short and the myelin is thinner than normal. Therefore, CV remains slower than normal. In this setting, if no CB exists, function should be relatively unimpaired. Therefore, despite resolution of symptoms, conduction slowing may persist. With axonal damage and Wallerian degeneration, recovery is much slower paced, with the regenerating axons extending 1 to 3 mm per day from the site of the injury to the target muscle. Therefore, even a distal lesion of the median nerve at the wrist may require upwards of 3 or 4 months before reinnervation of intrinsic hand muscles occurs.^{18,41,42} Given the above typical pathologic features of compressive neuropathy, the goal of EDX testing in a focal compressive or entrapment neuropathy such as CTS is to determine the presence and extent of conduction slowing, CB, and axonal injury. Moreover, in the case of CTS, it is necessary to demonstrate the presence of these findings focally at the wrist in median nerve sensory and motor fibers.

Basics of EDX Assessment

EDX assessment typically consists of motor and sensory nerve conduction studies and needle EMG. When performing motor nerve conduction studies, electrical stimuli are delivered to the nerve percutaneously, while typically recording from a more distal muscle (eg, thenar eminence for the median nerve) (Figure 4). The electrical stimulus is increased, such that the resulting compound muscle action potential is maximized in amplitude. At this point, all of the axons, including the most rapidly conducting, are considered to have been excited and all of the muscle fibers are considered to have been

activated. Therefore, the onset latency of the response reflects the conduction time of the most rapidly conducting motor axons and the amplitude represents the muscle mass or volume of excitable tissue in the nerve's distal innervation territory, which, and at least in chronic stable conditions, is correlated with the number of motor axons innervating the muscle group. Sensory nerve conduction studies are completed by delivering supramaximal stimuli to the nerve (eg, the median nerve at the wrist), while recording from the digital sensory branches (eg, the second digit) for antidromic studies, or vice versa for orthodromic studies (Figure 4). Needle EMG involves inserting a concentric or monopolar needle electrode into the muscle under examination (typically the abductor pollicis brevis for the median nerve) and determining whether denervation, as indicated by fibrillation potentials or positive sharp waves, has occurred. If so, this provides an indication of Wallerian degeneration. In addition, the sizes, shapes, and recruitment patterns of voluntarily activated motor unit action potentials are examined, which provides an indication of the extent of motor unit remodeling following axonal injury and repair, or motor axon loss in the case of decreased motor unit interference patterns. The interested reader is referred to standard texts of electrodiagnostic medicine for further details.

From a historical perspective, Dawson and Scott²⁵ described the recording of electrically evoked nerve action potentials with surface electrodes in the upper extremities of healthy subjects. In 1956, Simpson¹²⁵ reported conduction slowing for the median nerve across the wrist in those with CTS; this was later confirmed independently by Thomas¹³⁷ in 1960 and Lambert⁷⁴ in 1962. Dawson²⁵ described a technique for measuring median sensory nerve CV across the carpal tunnel. Gilliatt and Sears⁴³ capitalized on this technique and demonstrated median nerve sensory CV slowing across the wrist in those with CTS. Brown and coworkers,¹⁷ using intraoperative nerve conduction studies, confirmed that the abnormalities in those with CTS were localized to the section of the median nerve under the TCL. Numerous other studies have verified these reports and median sensory and motor studies have become the mainstay for the laboratory evaluation of CTS.

EDX Studies

EDX assessment is directed toward establishing a focal lesion of the median nerve at the wrist and ruling out other peripheral neurologic conditions that can present with similar symptoms, including C6 or C7 radiculopathy, brachial plexus lesions, generalized polyneuropathy, or more proximal lesions of the median nerve. This is generally accomplished by performing standard motor and sensory nerve conduction studies and demonstrating characteristic find-

ings for CTS, including: (1) slowing of conduction in the median motor and sensory fibers across the wrist; (2) CB in median nerve fibers across the wrist; (3) decreased amplitude of the motor and sensory compound responses; and (4) normal ulnar and radial nerve studies (except in the case of an associated polyneuropathy or coexisting entrapment neuropathy of these nerves). In severe cases, needle EMG reveals signs of active (fibrillation potentials and positive sharp waves) or chronic (increased amplitude and duration potentials, recruitment deficits) denervation in median-innervated hand muscles (eg, abductor pollicis brevis).

In most cases, those with typical clinical features of CTS demonstrate distal slowing with standard median motor and sensory testing across the wrist (Figures 4 and 5). In more severe cases with associated CB or axonal loss, median motor and sensory amplitudes are reduced. These routine studies involve stimulation of the median nerve at the wrist with recording from the thenar eminence (motor), and typically antidromic sensory studies, which involve stimulation of the median nerve at the wrist while recording from the second or third median innervated digit (sensory) (Figure 4).

Overall, as outlined in Table 7, sensitivity for median sensory conduction studies ranged from 44% to 80%, while motor nerve conduction studies had sensitivities of 43% to 80%. Specificities for both motor and sensory studies have been higher in most reports, ranging from 95% to 100%. Thus, based on these values, EDX testing is better able to rule in those with suspected CTS. However, all of these

studies compared a group of normal controls with a group of subjects with clinically suspected CTS, and not with a large cohort of those referred for EDX testing for suspected CTS.⁵²

When considering the broad spectrum of patients with symptoms suggestive of CTS, standard median motor and sensory studies are often diagnostic. In a significant number of patients (10%-25%),⁵² however, these standard studies remain normal, which in the case of a high-probability clinical presentation, constitutes a false negative test. Investigators have developed other techniques in an attempt to improve upon the sensitivity while maintaining specificity for CTS. These tests primarily involve comparing the latencies of the median nerves with those of the ipsilateral ulnar and radial nerves, or short-segment studies designed to eliminate the effects of the distal segment of normal nerve that can, in effect, negate subtle slowing in a short segment of nerve across the carpal tunnel.⁵²

Many electromyographers prefer testing an adjacent nerve in the same hand, because these studies use standard sensory nerve conduction techniques and provide a direct internal comparison. The comparison studies most frequently used include the median versus ulnar sensory latency from wrist to digit 4, the median versus radial sensory latency from wrist to thumb, and the median (second lumbrical) versus ulnar interosseous motor latency comparison. When using such comparative studies, temperature effects, age, and in some cases the effects of superimposed disease are controlled for. These studies are most useful for those with mild disease or underlying

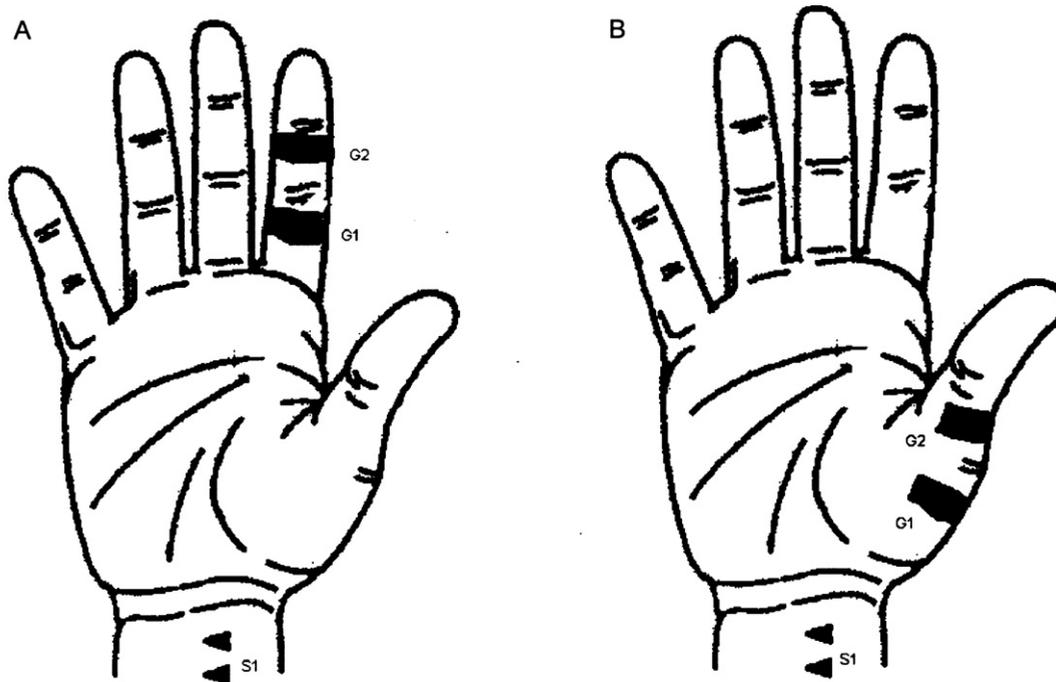


FIGURE 4. (A) Illustrates the usual sites for stimulation of the median nerve at the wrist (S1) and recording electrode placement (G1, G2) for an antidromic median sensory study. Figure B illustrates the stimulation site (S1) and recording electrode placement (G1, G2) for a median motor study to the thenar eminence.

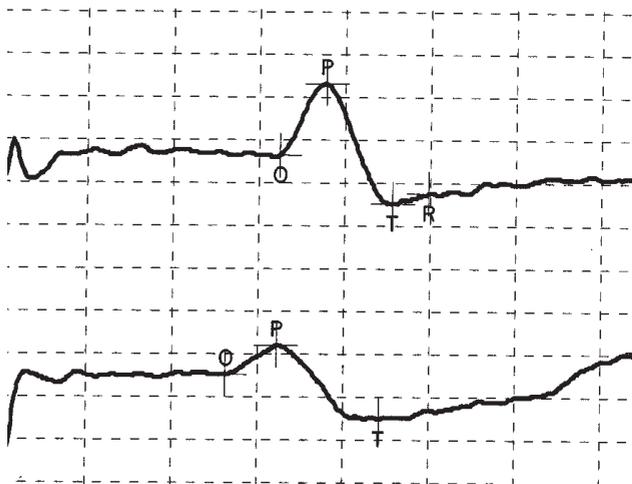


FIGURE 5. This figure illustrates the results of a median-ulnar mixed nerve comparison. This is a short-segment study which involves stimulation of the nerves in the midpalm, while recording the mixed nerve response at the wrist. The upper trace from the median nerve is clearly delayed in comparison to the lower trace from the ulnar nerve over the same 8-cm distance.

polyneuropathy. The sensitivity values of these studies are somewhat higher than those reported for standard conduction studies. For example, 82%⁵³ and 77%^{138,139} for median versus ulnar wrist-to-digit 4 comparison, and 69%⁵³ and 74%¹⁰⁰ for the radial versus median wrist-to-digit 1 comparison.

Short-segment studies are designed to focus the examination over the area of the flexor retinaculum. In doing so, the majority of the conduction time is computed over the area of pathology, while the length of the normal nerve that may dilute slowing is minimized. For example, median versus ulnar palm-to-wrist mixed nerve latencies typically are done over a short distance of 8 cm. The sensitivity of this method has been reported as 61%.⁷¹ Studies involving short-segment stimulation at multiple sites proximal and distal to the wrist crease have yielded sensitivity values as high as 81%.⁹⁴

The use of multiple potentially more sensitive tests deserves a note of caution. The use of such tests will decrease the number of false negatives, but also potentially increase the number of false positives.¹¹³ For example, in one longitudinal study, controls who tested positive for CTS were found to be true false positive cases on follow-up, not subclinical cases.¹¹³ Thus, some have suggested that when performing multiple sensitive tests, diagnostic validity may be increased by requiring that 2 or more tests be abnormal.¹⁴⁰ For example, Robinson et al¹¹⁶ have advocated the use of a combined sensory index, defined as the sum of 3 latency differences: (1) median to ulnar midpalmar orthodromic study; (2) median to ulnar antidromic sensory study; and (3) median to radial thumb antidromic sensory study. They reported that the combined sensory index was more sensitive and reliable than individual tests for

diagnosing mild CTS. Lew et al,⁷⁶ from this same group, later reported that when any 1 of these 3 studies was markedly abnormal, it was unnecessary to perform all 3 to maintain high sensitivity and specificity.

All of the above noted studies have used rigid cutoffs separating normal from abnormal. These cutoffs are typically based on the mean plus 2 standard deviations over control values. Alternatively, Nodera et al⁹⁶ derived receiver-operating curves and interval likelihood ratios for commonly performed conduction studies used to diagnose CTS. Based on their data, it is recommended that more conservative cutoffs are required for subjects with low pretest probability. For example, to maintain a set specificity of 97% conservative cutoff values of 0.5-millisecond difference for median versus ulnar wrist to digit 4 comparison values were required when the pretest probability was ≤ 0.50 ; whereas less conservative values (cut-off of 0.4 milliseconds) sufficed when the pretest probability was ≤ 0.75 . This type of analysis has been applied in a very limited fashion in studies of EDX methodology; however, in reality, it reflects the way most experienced electromyographers practice. That is, less stringent cutoffs are often used when the clinical scenario is highly probable, and similarly, additional tests with increased sensitivity are used when the pretest probability is high. In doing so, the chances of false negatives are reduced.

CONCLUSION

Carpal tunnel syndrome is a clinical entity characterized by sensory disturbances in the median nerve distribution of the hand. No single clinical or electrophysiological test is sufficient to identify this disorder. A clear history and definition of the type/distribution of symptoms is the primary component

TABLE 7. Sensitivity and specificity of electrodiagnostic testing for carpal tunnel syndrome.

	Sensitivity	Specificity
Median motor nerve conduction studies		
Jackson and Clifford, 1989 ⁵³	74%	95%
Kimura, 1979 ⁶⁹	61%	98%
Padua et al, 1996 ¹⁰⁰	44%	98%
Padua et al, 1997 ⁹⁹	55%	98%
Kuntzer et al, 1994 ⁷¹	47%	99%
Cioni et al, 1989 ²⁴	80%	98%
Median sensory nerve conduction studies		
Kimura, 1979 ⁶⁹	63%	98%
Carroll, 1987 ²¹	49%	100%
Jackson and Clifford, 1989 ⁵³	66%	98%
Cioni et al, 1989 ²⁴	80%	98%
Kuntzer, 1994 ⁷¹	49%	100%
Padua et al, 1996 ¹⁰⁰	49%	98%
Padua et al, 1997 ⁹⁹	67%	98%
Scelsa et al, 1998 ¹²²	40%	98%

of diagnosis. Certain clinical tests are useful in making the diagnosis, while others are of little or uncertain value. The value of tests reported in the literature varies, although routine use of Phalen's and/or carpal compression test, in combination with sensory evaluation, is a viable routine practice. Additional tests can be added to clarify etiology, severity, and provide a greater probability of accuracy if clinicians are competent in dealing with multiple and potentially conflicting test results. This ability is expected for more experienced examiners.⁶⁰ Despite controversy, electrophysiological tests are commonly performed in suspected cases and can be useful, even when the diagnosis appears clear, to determine the severity of nerve damage, evaluate concomitant nerve disorders, or to provide an objective measure of nerve status in case the success of treatment is questioned. Consideration of the severity of CTS is important when interpreting the results of clinical tests, selecting treatment interventions, and predicting response to conservative management.

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