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Comparative Analysis of Sensory and Motor Diagnostic Tests for Carpal Tunnel Syndrome: A Regional Perspective

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Abstract
Carpal Tunnel Syndrome (CTS) is the most common entrapment neuropathy and a significant cause of occupational disability. Nerve conduction studies (NCS) are widely used for diagnosis, yet regional data from underserved populations remain limited. This was a cross-sectional observational study conducted at the Neuromuscular Physiology Unit, CMH Gilgit. Fifty clinically diagnosed female CTS patients underwent bilateral median and ulnar sensory and motor nerve conduction studies. Parameters evaluated included sensory latency, sensory amplitude, sensory conduction velocity, distal motor latency, proximal motor latency, motor amplitude, and motor conduction velocity. Data were analyzed using SPSS version 22.0. Sensory studies demonstrated prolonged sensory latencies and reduced conduction velocities with increasing symptom severity. Motor studies showed prolonged distal and proximal motor latencies and reduced amplitudes in moderate-to-severe CTS. Greater neurophysiological impairment was observed in dominant hands compared with non-dominant hands. Motor parameters correlated more strongly with functional impairment than sensory parameters. Combined sensory and motor nerve conduction studies provide valuable information for CTS diagnosis and severity assessment. The findings highlight the importance of comprehensive electrodiagnostic evaluation and support the development of region-specific diagnostic reference values. Further studies with larger and more diverse populations are recommended.

Keywords
Carpal Tunnel Syndrome, Nerve Conduction Studies, Sensory Nerves, Motor Nerves, Median Nerve, Ulnar Nerve, Occupational Neuropathy, Regional Diagnostics

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Introduction
Carpal tunnel syndrome (CTS) is a leading cause of occupationally related disability globally, particularly among those who perform repetitive manual task. Carpal Tunnel Syndrome (CTS) usually occurs due to compression (impingement) of the median nerve at the wrist as a result of over-use of the hands. This can result in pain, tingling, numbness, and finger's and hand's weakness. The median nerve send motor commands to hand muscles and receives sensory feedback; if the median nerve is damaged, it may lead to the symptoms associated with CTS. Healthcare professionals often employ clinical signs, such as Tinel's sign and Phalen's maneuver, to diagnose CTS; however, those clinical signs may have varying degrees of accuracy and should be confirmed with electrodiagnostic tests (such as nerve conduction velocity (NCV) tests). Sensory and motor assessments have been shown to be reliable in diagnosing CTS, especially when done with results of nerve conduction studies (NCS). Diagnostic accuracy and disease occurrence are determined by factors such as employment

patterns, climate conditions, and cultural factors in regions such as Gilgit, Pakistan. The problem is compounded by the lack of region-specific diagnostic reference values that would enable accurate diagnosis or timely intervention. Due to the nature of their work, many women engaged in repetitive manual work, textile manufacturing, or agriculture would also be at greater risk of occurrence of CTS.

The carpal tunnel is an important landmark in the human body [1]. The proximal (scaphoid, trapezium, lunate, pisiform) and distal (trapezium, trapezoid, capitate, hamate) rows of carpal bones make up the carpal tunnel depression [2, 3]. The flexor retinaculum creates the carpal tunnel roof and connects to the scaphoid and trapezium on the lateral wrist and to the hamate and pisiform on the medial wrist [4]. The tunnel serves as a conduit for the forearm's long flexor tendons and keeps these tendons from flexing at the wrist. The tendons of the flexor digitorum superficialis, flexor digitorum profundus and the tendon of the flexor pollicis longus all pass through the carpal tunnel as extrinsic forearm tendons. [5].

Excessive wrist flexion and wrist movements at extreme angles have been associated with increased fluid pressure in the carpal tunnel and resultant ischaemic injury to the median nerve. Although most cases of CTS are idiopathic, the pathophysiology of CTS has been described in simplified terms as median nerve compression at the carpal tunnel. Ischaemic injury can occur from various mechanisms, including: disruption of the blood-nerve barrier results in microcompartment syndrome in the carpal tunnel, fibrotic thickening of the vascular structures (vasculature) and microvascular dysfunction resulting in the development of intraneural oedema (swelling). Compression can also result from the obstruction of the carpal tunnel due to wrist joint injury [6].

Electrodiagnostic testing, such as testing for motor and sensory conduction velocity (MVC), is the foundation of diagnosing CTS [7], but much research has shown that while NCS is important for diagnosis, cinical testing sometimes may not provide valid results thereby necessitating additional diagnostic tools [8]. This research will address the gap through a comprehensive, comparative analysis of sensory and motor nerve conduction measurements in a regionally defined population.

Studies conducted on the palmar muscles provide further information in establishing whether or not these muscles' characteristics play a role in the onset and/or severity of CTS. A Nerve conduction study (NCS) is a commonly used method of diagnosing and determining the severity of CTS. The NCS measures the electrical signal transmitted through the sensory and motor nerves to provide data regarding the functioning of the median nerve and ulnar nerve. A significant amount of research on the clinical manifestations of CTS highlights the importance of early detection through a thorough diagnostic process. Research in this area identifies specific indicators of CTS that potentially impact the treatment outcome.

A total of 50 females were tested across all ages by means of various sensory and motor tests to better understand the usual range in sensitivity and motor function (DML, PML, amplitude, distance, velocity) for diagnosing carpal tunnel syndrome. This was established to allow for the evaluation of the diagnostic usefulness of sensory versus motor tests for diagnosing carpal tunnel syndrome. The four main objectives of this study were:

I. To build neurophysiological benchmarks (region-specific) for CTS diagnosis.
II. To explore demographic, occupational, and environmental impacts on CTS presentation.
III. To compare diagnostic use of sensory and motor nerve conduction parameters in CTS.
IV. To assess the differences among dominant and non-dominant hands.

Method

This study involved a retrospective analysis of clinical nerve conduction study data obtained from the Neuromuscular Physiology Unit, CMH Gilgit. The data used for analysis were previously collected as part of routine clinical evaluation of patients diagnosed with carpal tunnel syndrome. No additional procedures or interventions were performed for research purposes. All patient

information was anonymized before analysis, and confidentiality of participants was maintained throughout the study.
The study was designed with established electrodiagnostic testing procedures and adhered to required ethical standards for conducting any type of medical research. All nerve conduction studies were performed by a trained neurophysiology technician under the supervision of a consultant neurologist using standardized electrodiagnostic protocols. The examiner was aware of the clinical diagnosis because all participants were recruited from clinically confirmed CTS cases.
The patient population comprised of a wide range of ages and job types. Fifty female patients diagnosed clinically with CTS were included in the study, while patients with any medical conditions that would cause a disruption to nerve conduction (diabetes, generalized neuropathies, and previous surgeries on the wrist) were excluded from the study to allow the study teams to obtain accurate results from the data collected.
Standard sensory and motor nerve conduction studies were performed on Median and Ulnar nerves bilaterally. Parameters undertaken were:

- Sensory Latency Period (SLP)
- Sensory Amplitude
- Sensory Conduction Velocity
- Distal Motor Latency (DML)
- Proximal Motor Latency (PML)
- Motor Amplitude
- Motor Conduction Velocity

Environmental temperature was controlled, with hand temperature maintained above 32°C to minimize variability. Standardized laboratory reference values were used for interpretation.

Data Analysis

Statistical analyses were performed using SPSS version 22.0. Continuous variables were expressed as mean ± standard deviation. Paired t-tests and one-way ANOVA test were used to compare dominant and non-dominant hands. A p-value of <0.05 was statistically significant.
This study included comparative analyses to assess differences between sensory and motor findings, dominant and non-dominant hands, as well as median and ulnar nerve function to ascertain specific abnormalities associated with CTS.

Results

The long-lasting symptoms indicated clear signs of damage to the axons of the sensory pathways . Data collected for preliminary analysis regarding sensory and motor nerve conduction abnormalities among female CTS patients in Gilgit. Although motor parameters appeared more closely associated with functional impairment, larger studies including healthy controls are needed before establishing regional diagnostic standards. For both the symptomatic and dominant hands, both the latency of the sensory response and the speed of the sensory conduction to the median nerve were longer with greater symptom severity as determined by the sensory studies. Motor studies demonstrated that moderate and severe cases of CTS had longer latencies for motor function activities in their distal and proximal muscle groups. The weak thenar muscle groups and the reduced grip strength, as measured by clinical assessments, confirm that amplitude variability resulted from motor nerve compressions due to repetitive stress. Participants in the survey had their dominant hand involuntarily stress in relation to their occupational duties, which accounted for decreased motor conductivity measurements as compared to the non-dominant hand due to higher occupational loads. Older cohorts presented with high levels of motor disability versus younger cohorts with high levels of sensory disability. Greater reductions in both sensory and motor function occurred in the dominant hand consistent with a repetitive use syndrome. Cold temperatures were found to affect the rate of conduction, thereby validating the need for precise manipulation of the ambient temperature prior to conducting assessments.

The nerve conduction values observed in this study were interpreted in relation to previously published normative reference values for median and ulnar nerve conduction parameters. The findings showed comparable trends with previous studies reporting prolonged median sensory and motor latencies and reduced conduction velocities in CTS patients. However, because locally established normative values and a healthy control group were not available, direct regional comparison could not be performed. Future studies including age- and sex-matched healthy controls are required to establish population-specific reference values for the Gilgit region.

Table 1: Comparative analysis of various parameters of sensory and motor nerve conduction studies of median and ulnar nerves.

Sensory nerve conduction Studies					
Parameters	**Median**		**Ulnar**		**p-value**
	(R)	**(L)**	**(R)**	**(L)**	
SLP (ms)	160.2±0.855	120±0.62	162.8±0.17	119.2±0.242	<0.001
Amplitude (mv)	15.624±12.106	30.6±21.38	16.13±12.45	32.24±16.93	<0.005
Distance (mm)	115.3±6.764	160.2±5.4	110.2±5.624	161.3±5.736	<0.004
Velocity (m/s)	37.508±9.369	60.53±7.976	35.19±8.897	62.28±5.619	<0.001
Motor nerve conduction studies					
Parameters	**Median**		**Ulnar**		
	(R)	**(L)**	**(R)**	**(L)**	
DML (ms)	25.82±1.48	15.35±1.2	26.91±0.23	16.23±3.42	<0.001
PML(ms)	20.26±1.63	10.21±1.5	20.54±0.58	9.873±0.65	<0.001
Amplitude (mv)	6.124±2.493	10.235±2.92	5.812±1.17	11.29±1.49	<0.005
Distance (mm)	160.99±15.146	218.7±14.88	175.66±17.07	240.6±18.53	<0.005
Velocity(m/s)	40.12±5.4106	60.72±5.322	39.84±5.13	62.46±5.46	<0.001

Values represented as Mean±S.D; $p<0.05$.

Discussion

This research provides an in-depth analysis of sensory nerve conduction studies (SNCS) for diagnosing carpal tunnel syndrome (CTS). The major findings of this evaluation were that the results determined by SNCS show prolonged sensory latency periods (SLP) as well as decreased nerve conduction speed as the primary indicators of initial nerve damage. Evidence of ongoing nerve compression as indicated by decreased sensory amplitude relates to the decreased functional nerve fibers and demonstrates a direct relationship between the sensory impairment of the median nerve and the severity of CTS symptoms. Although this research confirms that subjects' dominant hands exhibit more extreme changes, it is also consistent with prior research [9] and establishes the unique association with workplace stressors that occur in Gilgit's challenging work environments. The significance of motor nerve conduction studies (MNCS) for developing a better understanding of CTS progression is due to the fact that MNCS is able to assess the nerve conduction pathways along motor pathways and show how far away an area of nerve compression is located. Data was organized by dominant hand operation to determine whether repetitive movements contribute to developing CTS by determining how long it took for the dominant hand to have an electrophysiological delay as a function of repetitive motion. When using the assessment criteria of MNCS for thumb opposition strength and grip strength, there was a significant reduction in the motor amplitude of the dominant hand when compared to the non-dominant hand. This illustrates that if an individual has an impaired ability to perform a thumb opposition task, that individual will also have diminished grip strength. A consistent reduction of motor conduction velocity was also observed in this study as well as in Smith et al.'s [10] findings. Thus, the evidence supports the conclusion that prolonged compression of the median nerve results in impairment of motor function. The results obtained from this study support the association between motor dysfunction and clinical symptoms [6], which assists with the prediction of the functional status of CTS patients.

The research's primary success involved examining both dominant and non-dominant hands for differences when measuring carpal tunnel syndrome (CTS) symptomology; the dominant hand had significantly greater levels of both sensory and motor impairment. Workers within the sample studied, all of whom performed repetitive manual labour in their jobs, demonstrated increased episodes of CTS in their dominant arms when compared to their non-dominants. This finding corroborates findings from prior studies showing that researchers need to evaluate these two nerves together (dominant/non-dominant) in order to accurately diagnose CTS vs. other generalized neuropathies. The authors of [11] suggest using this method of comparison as a critical component in establishing a differential diagnosis for CTS.

There are certain limitations with this study because of relatively small study size and restricted it only to females, which affected the results to the generalizability also. To address this limitation, future research should include males as well as longer (longitudinal) follow-up studies. Another limitation of the study was the absence of a healthy control group and lack of locally established normative nerve conduction values. Therefore, findings were interpreted using previously published reference ranges, which may not fully represent regional variations.

The procedures require placing electrodes on the subject's skin that produce low levels of electricity and could cause discomfort (or anxiety) in some people when placed on the skin causing these muscles to contract thus affecting the results (accuracy). The variation in the measured results also can be due to the changing position of the electrodes and variations in the temperature of the skin and position of the limb before during and after testing. It is important to have the electrodes located precisely over the various locations where they will be tested since uneven placement can alter the numbers recorded for the small sensory nerve response measured. Data collected from the Gilgit region showed that cold temperature caused lower conduction velocity through peripheral nerves compared to other types of nerves. When examining conduction velocity, the procedure requires warming the hands since cold hands will produce temperature differences resulting in lower than actual measurements of conduction velocity [9].

Ethics Approval and Consent To Participate

Not applicable.

Human and Animal Rights

All the procedures performed in this study involving human participants were in accordance with the ethical standards. No animals were involved in this study.

Consent for Publication

Not applicable.

Availability of Data and Materials

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

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None.

Conflict of Interest
The authors declare no conflict of interest.

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