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Original Article

"Mild", "Moderate", or "Severe" Carpal Tunnel Syndrome? Depends on Who You Ask: Analysis of Existing Classification Systems in 665 Hands

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Abstract

Objectives: Carpal tunnel syndrome (CTS) is the most common entrapment neuropathy in the body and impacts approximately 5% of the U.S. population costing nearly $5 billion/year. Electrodiagnostic (EDX) testing is considered the gold standard for CTS diagnosis. Classification systems exist that categorize CTS severity based on EDX findings. This investigation evaluated EDX findings across consecutive CTS severity categories within existing classification systems and *consolidated* classifications. **Methods**: This retrospective study analyzed 665 hands from 468 patients undergoing EDX testing for suspected CTS. Complete classification systems and *consolidated* classifications were evaluated for discrimination capability across consecutive CTS severity categories based on EDX findings. Additional analysis evaluated the relationship of sex and age factors and CTS severity. **Results**: *Consolidated* classifications demonstrated superior discrimination capability between consecutive CTS severity categories regardless of classification system used. Demographic factors significantly influenced EDX findings and categorization of CTS severity. **Conclusions**: This study underscores the value of *consolidated* classifications for enhancing discrimination between consecutive CTS severity categories based on EDX findings. Demographic factors should be considered when interpreting EDX findings for the purpose of categorizing CTS severity. Future research should refine existing classification systems and explore additional factors influencing CTS severity used to inform medical management.

Keywords: Carpal Tunnel Syndrome, Classification, Electrodiagnostic, Electromyography, Nerve Conduction

Introduction

Median neuropathy at the wrist, commonly referred to as carpal tunnel syndrome (CTS), is the most common entrapment neuropathy in the body with an incidence of approximately 5% in the United States[1] and associated costs estimated around $5 billion/year[2]. Electrodiagnostic (EDX) testing, comprised of peripheral sensory and motor nerve conduction testing and needle electromyography (EMG), has long been considered the gold standard test for diagnosing neuropathic changes in the peripheral nervous system[3-9]. In patients presenting with symptoms suggesting CTS, EDX testing is routinely performed to confirm the presence of median neuropathy at the wrist while ruling out competing diagnoses and helping inform selection of interventions based on severity of the nerve lesion[10-14].

Systems classifying the relative severity of CTS based on EDX findings have been proposed by Padua et al[12], Bland[14], and Greathouse et al (GEHS)[15]. The specific EDX criteria used by each of these classification systems to categorize CTS severity are summarized in Figure 1. All of these classification systems assume a linear relationship between the progression of median neuropathy and severity of EDX findings, namely early sensory-only conduction abnormalities followed by motor conduction abnormalities and eventually progressing to sensory and motor nerve

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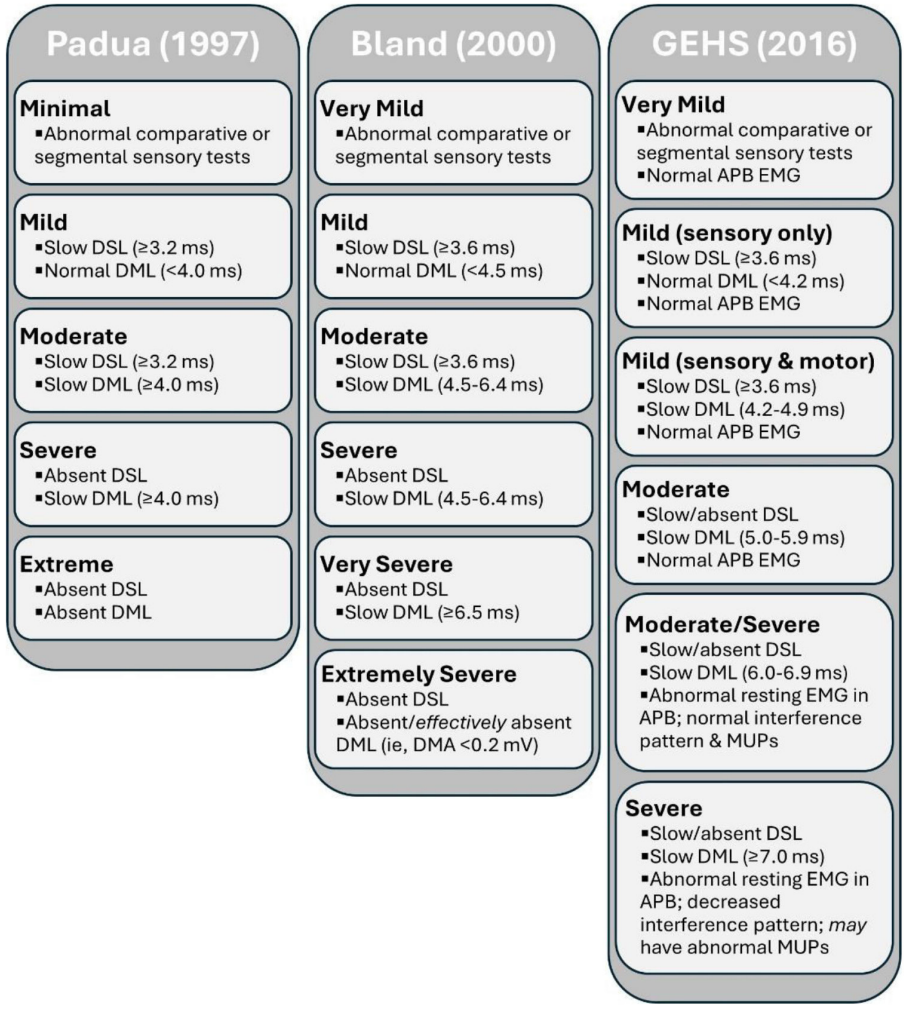

Figure 1. Summary of CTS severity classification systems. *DSL: distal sensory latency; DML: distal motor latency; DMA: distal motor amplitude; APB: abductor pollicis brevis; EMG: electromyography; MUP: motor unit potential; ms: milliseconds; mV: millivolts.*

axonopathy[10,12,14,15]. The criteria used by each of these classification systems to categorize CTS severity includes median distal sensory latency/conduction velocity, including more sensitive comparison studies (eg, superficial radial vs median at the thumb or trans-carpal conduction)[16,17], and median distal motor latency. These classification systems largely ignore median sensory and motor amplitude, with the lone exception being Bland's consideration of distal motor amplitude in their "Extremely Severe" category. Notably, the GEHS classification system is unique in consideration of EMG findings in the abductor pollicis brevis (APB) muscle[11,15,18].

Previous studies have investigated the relationship between clinical symptoms and severity of CTS;[9,10,12-14] however, no studies were found investigating the ability of existing classification systems to discriminate between consecutive categories of CTS severity based on EDX findings. In other words, it is unknown if EDX findings are significantly different across consecutive CTS severity categories within existing classification systems. Additionally, a direct comparison of existing classification systems has not been conducted, including analysis of the proportion of hands that can be correctly categorized based on proposed criteria. Sasaki et al[19] recently compared the Padua and Bland classification systems in 1120 hands and found that "boundary values" likely prevented accurate categorization of CTS severity, which occurred in 15% of hands in their study under the Padua classification. When EDX findings do not meet the specified criteria of a particular CTS severity category within a classification system, the clinician is left to determine severity based on the data before them, which can introduce subjectivity and variability across clinicians. Similarly, Sucher[10] argued that classification systems with

multiple categories of CTS severity are likely problematic because of the inherent variability of sensory and motor conduction findings (ie, non-linear neuropathic changes) and that more complex classification systems are likely to be met with resistance by clinicians resulting in limited use and ultimately limited value as a diagnostic aid. Alternatively, Sucher argued that using 3 primary categories of severity (ie, "Mild", "Moderate", or "Severe") is more likely to be adopted by clinicians and less likely to have borderline values preventing accurate categorization.

The primary purpose of this investigation was to evaluate EDX findings across consecutive CTS severity categories within existing classification systems. We hypothesized that EDX findings would poorly discriminate between consecutive CTS severity categories within existing classification systems and that consolidating multiple categories into 3 primary categories would improve discrimination capability of all existing classification systems. Additionally, we hypothesized that *consolidated* classifications would significantly differ from one another and that categorization of "Mild", "Moderate", or "Severe" CTS would be highly dependent on the classification system used.

Materials and Methods

In this retrospective study of cross-sectional patient data, the primary outcome was categorization of CTS severity. Study participants were patients undergoing EDX testing and ultrasound imaging for suspected CTS in the Department of Physical Therapy, Therapy West Physical Therapy & Sports Medicine Centers located in Richfield and Gunnison, Utah. Participating patients provided written informed consent prior to testing and every effort was made to ensure their rights were protected, including handling of personal and health-related information.

Examiners & EDX Testing

EDX testing was performed by two examiners (NJS and JSM), but the final EDX impression was determined by the principal investigator (NJS) who is Board Certified in Clinical Electrophysiology by the American Board of Physical Therapist Specialties with over 17 years of experience performing and teaching EDX testing. Ultrasound imaging was performed by a single examiner (NJS) who is Registered in Musculoskeletal® sonography by the Alliance for Physician Certification & Advancement with over 7 years of experience performing and teaching neuromusculoskeletal ultrasound imaging. Sierra Wave and Sierra Summit devices (Cadwell; Kennewick, WA) were used for all EDX testing. Upper extremity nerve conduction studies were performed with patients seated and skin temperature maintained ≥32°C. Sensory and motor nerve conduction studies followed the standardized setup and performance described by Buschbacher[16], including analysis of distal latencies, conduction velocities, and amplitudes based on normative values considering patient sex and age. Needle EMG was performed with patients in supine using monopolar needle electrodes evaluating insertional and resting activity followed by volitional muscle activation to analyze morphology and recruitment pattern of observed motor unit potentials (MUP).

Antidromic superficial radial and median distal sensory latencies (DSL1) were obtained by wrist stimulation and thumb recording over 10 cm. Antidromic median and ulnar distal sensory latencies were obtained by wrist and palm stimulation and middle (DSL3) and little finger recordings over 14 cm and 7 cm, respectively. Orthodromic median and ulnar distal motor latencies (DML) were obtained by wrist stimulation and abductor pollicis brevis (APB) and abductor digiti minimi muscle recording over 8 cm, respectively. Needle EMG of muscles in the upper extremity representing C5-T1 nerve roots and all primary peripheral motor nerves were used to evaluate for axonal loss at rest and/or neuropathic MUP during volitional activation. Needle EMG of the APB muscle was routinely included in hands with median motor conduction abnormalities, but rarely included in hands with median sensory-only findings.

A final EDX impression was determined for all hands and used the following categorization of median neuropathy at the wrist: "Normal", "Mild", "Moderate", or "Severe". In general, "Mild" involved sensory-only findings, "Moderate" involved sensory and motor findings, including volitional EMG abnormalities when present, and "Severe" involved absent sensory responses, prolonged/absent motor responses, and EMG evidence of axonopathy in the APB muscle at rest.

Classification Systems

Hands were categorized according to CTS severity based on criteria defined in the Padua[12], Bland[14], and GEHS[15] classification systems. Notably, each classification system utilizes different cut-off values for determining abnormalities in median DSL and DML, which also differ from the normative values described by Buschbacher that are organized by sex and age categories[16]. For the purposes of analysis, and consistent with clinical practice, hands not meeting a specified criteria for a particular CTS severity category within a classification system were placed in the category that best fit the available EDX findings. Additionally, because Padua describes 5 categories and Bland and GEHS describe 6 categories of CTS severity, each classification system was consolidated into 3 primary categories ("Mild", "Moderate", or "Severe") for statistical comparison.

Statistical Analysis

IBM© SPSS© Statistics, version 28.0.1.0. (Armonk, NY, USA) was used for all data analysis. Descriptive statistics summarized characteristics of participating patients and hands tested. Multiple analysis of variance (MANOVA) was used to compare EDX findings across CTS severity categories within each classification system and within each *consolidated* classification[20]. Chi Square analysis was used to compare *consolidated* classifications. Additional analyses

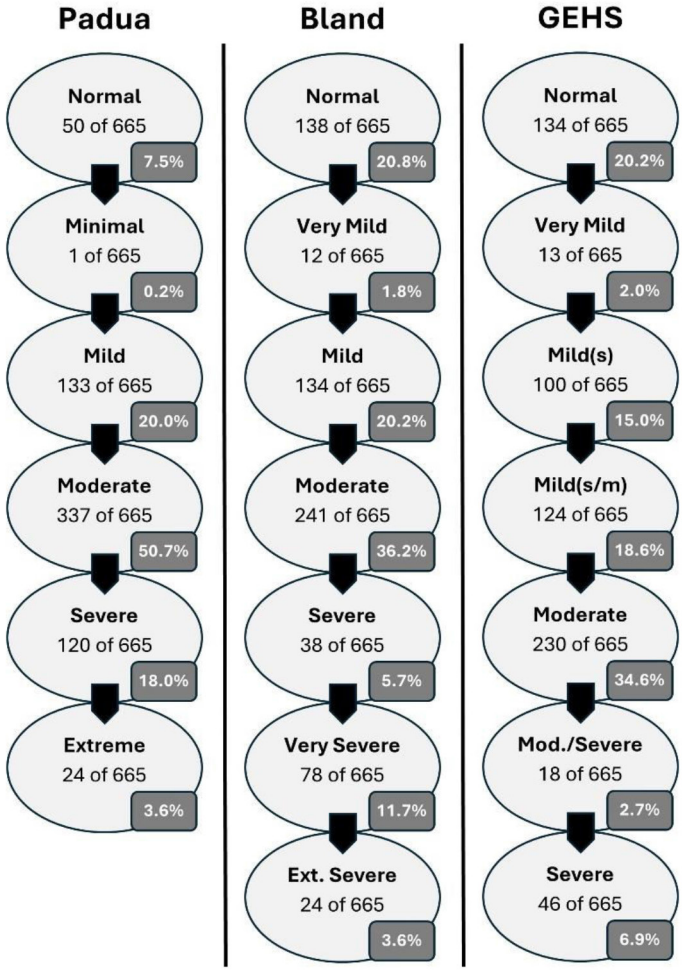

Figure 2. Distribution of hands in CTS severity categories within classification systems. *Ext.: Extreme; s: sensory only; s/m: sensory & motor; Mod.: Moderate.*

were performed using MANOVA and Chi Square to investigate the relationship between EDX findings, sex, age category, and CTS severity categories within complete and *consolidated* classification.

Results

Participants

Data was collected from December 2019 through July 2023 on 468 patients (54.6±16.8 years; 67.0±3.9 inches; 59% female) referred for EDX testing for suspected CTS (50% PA/NP; 49% MD/DO; 1% Other) that contributed 665 hands (51% right). EDX testing was completed by two examiners (78% NJS; 22% JSM), but the final EDX impression for all hands was determined by the principal investigator (NJS). After consideration of median sensory and motor latencies, amplitudes, and EMG of the APB muscle (when included in the examination), the final EDX impression resulted in the following categorizations: 171 hands "Normal" (26%), 91 hands "Mild" (14%), 316 hands "Moderate" (48%), and 87 hands "Severe" (13%) for median neuropathy at the wrist.

Classification Systems

Based on a strict application of criteria used for each CTS severity category, the Padua classification system categorized 658 of 665 hands (99%), the Bland system categorized 625 of 665 hands (94%), and the GEHS system categorized 318 of 665 hands (48%). Because the GEHS system is unique in considering EMG findings, the percentage strictly categorized rises to 69% when analyzing only the 464 hands that included needle EMG of the APB muscle. For the purposes of analysis, and consistent with clinical practice, hands not meeting the criteria for a particular CTS severity category were placed in the category best fitting the EDX findings (Figure 2).

Table 1. MANOVA of nerve conduction parameters across categories of CTS severity in the Padua classification system (A) and *consolidated* Padua classification (B).

(A) Padua

CTS Severity	N	Category Comparison	DSL1 (ms)	Mean Δ	p value	DSL3 (ms)	Mean Δ	p value
Normal	50		2.39 ± 0.14			2.97 ± 0.11		
*Minimal	1	NA	NA	NA	NA	NA	NA	NA
Mild	133	Mild v Norm	2.79 ± 0.27	0.41	.256	3.49 ± 0.41	*0.52*	*<.001*
Moderate	337	Mod v Mild	3.42 ± 1.12	0.62	*<.001*	4.61 ± 0.82	*1.12*	*<.001*
Severe	120	Sev v Mod	0.90 ± 1.77	-2.51	*<.001*	0.00 ± 0.00	*-4.61*	*<.001*
Extreme	24	Ext v Sev	0.17 ± 0.84	-0.73	.034	0.85 ± 1.95	*-0.85*	*<.001*
CTS Severity	**N**	**Category Comparison**	**DML (ms)**	**Mean Δ**	**p value**	**DMA (mV)**	**Mean Δ**	**p value**
Normal	50		3.23 ± 0.29			9.54 ± 3.03		
*Minimal	1	NA	NA	NA	NA	NA	NA	NA
Mild	133	Mild v Norm	3.59 ± 0.26	0.36	.604	8.68 ± 2.94	-0.86	.591
Moderate	337	Mod v Mild	5.09 ± 0.92	1.50	*<.001*	6.76 ± 2.66	*-1.92*	*<.001*
Severe	120	Sev v Mod	7.45 ± 2.24	2.35	*<.001*	4.66 ± 2.53	*-2.09*	*<.001*
Extreme	24	Ext v Sev	0.00 ± 0.00	-7.45	*<.001*	0.00 ± 0.00	*-4.66*	*<.001*

*p<0.0125 for post hoc comparisons. *Combined with "Mild" to conduct MANOVA*

(B) *Consolidated* Padua

CTS Severity	N	Category Comparison	DSL1 (ms)	Mean Δ	p value	DSL3 (ms)	Mean Δ	p value
Negative	50		2.39 ± 0.14			2.97 ± 0.11		
Mild	134	Mild v Neg	2.79 ± 0.27	0.41	.159	3.49 ± 0.41	*0.52*	*<.001*
Moderate	337	Mod v Mild	3.42 ± 1.12	0.62	*<.001*	4.61 ± 0.82	*1.12*	*<.001*
Severe	144	Sev v Mod	0.78 ± 1.67	-2.64	*<.001*	0.14 ± 0.84	*-4.47*	*<.001*
CTS Severity	**N**	**Category Comparison**	**DML (ms)**	**Mean Δ**	**p value**	**DMA (mV)**	**Mean Δ**	**p value**
Negative	50		3.23 ± 0.29			9.54 ± 3.03		
Mild	134	Mild v Neg	3.59 ± 0.26	0.36	1.00	8.68 ± 2.94	-0.86	.376
Moderate	337	Mod v Mild	5.09 ± 0.92	*1.50*	*<.001*	6.76 ± 2.66	*-1.92*	*<.001*
Severe	144	Sev v Mod	6.21 ± 3.45	*-1.11*	*<.001*	3.89 ± 2.89	*-2.88*	*<.001*

p<0.0167 for post hoc comparisons. DSL1: distal sensory latency to thumb; DSL3: distal sensory latency to middle finger; DML: distal motor latency; DMA: distal motor amplitude; Norm: Normal; Mod: Moderate; Sev: Severe; Ext: Extreme; ms: milliseconds; mV: millivolts; NA: not applicable

Nerve Conduction Parameters

A significant moderate correlation was found between DSL1 and DSL3 (r=0.65, *p<.001*) with all other parameters having small or insignificant correlations. Because the "Minimal" CTS severity category in the Padua classification system contained only 1 hand it was combined with the "Mild" CTS severity category to allow for statistical analysis. In the Padua classification system, significant differences were found across CTS severity categories for DSL1 (F=144.5, df=4, *p<.001*), DSL3 (F=997.2, df=4, *p<.001*), DML (F=320.8, df=4, *p<.001*), and DMA (F=87.2, df=4, *p<.001*). Effect sizes were large ranging from η^2=.35 for DMA to η^2 =.86 for DSL3 (Table 1A). In the consolidated Padua classification, significant differences were found across CTS severity categories for DSL1 (F=187.6, df=3, *p<.001*), DSL3 (F=1267.8, df=3, *p<.001*), DML (F=68.9, df=3, *p<.001*), and DMA (F=88.2, df=3, *p<.001*). Effect sizes were large ranging from η^2=.24 for DML to η^2 =.85 for DSL3. DSL3 provided the best discrimination between consecutive CTS severity categories in the complete classification system and consolidated classification at 100% (4 of 4 and 3 of 3 comparisons, respectively). Overall, the complete classification system and *consolidated* classification performed equally, discriminating 75% (12 of 16 and 9 of 12 comparisons, respectively) of CTS severity categories (Table 1B).

In the Bland classification system, significant differences were found across CTS severity categories for DSL1 (F=100.8, df=6, *p<.001*), DSL3 (F=665.4, df=6, *p<.001*),

Table 2. MANOVA of nerve conduction parameters across categories of CTS severity in the Bland classification system (A) and *consolidated* Bland classification (B).

(A) Bland

CTS Severity	N	Category Comparison	DSL1 (ms)	Mean Δ	p value	DSL3 (ms)	Mean Δ	p value
Normal	138		2.57 ± 0.23			3.20 ± 0.22		
V Mild	12	V Mild v Norm	3.06 ± 0.19	0.49	1.00	3.40 ± 0.15	0.19	1.00
Mild	134	Mild v V Mild	3.09 ± 0.49	0.04	1.00	3.82 ± 0.81	0.42	1.00
Moderate	241	Mod v Mild	3.51 ± 1.29	0.42	.011	4.87 ± 0.80	*1.05*	*<.001*
Severe	38	Sev v Mod	1.45 ± 2.05	-2.06	*<.001*	0.00 ± 0.00	*-4.87*	*<.001*
V Severe	78	V Sev v Sev	0.61 ± 1.57	-0.84	*.003*	0.00 ± 0.00	0.00	1.00
E Severe	24	E Sev v V Sev	0.17 ± 0.84	-0.43	1.00	0.85 ± 1.95	*0.85*	*<.001*
CTS Severity	**N**	**Category Comparison**	**DML (ms)**	**Mean Δ**	**p value**	**DMA (mV)**	**Mean Δ**	**p value**
Normal	138		3.49 ± 0.37			8.94 ± 3.08		
V Mild	12	V Mild v Norm	3.75 ± 0.22	0.26	1.00	8.58 ± 2.73	-0.36	1.00
Mild	134	Mild v V Mild	4.00 ± 0.34	0.26	1.00	8.05 ± 2.75	-0.53	1.00
Moderate	241	Mod v Mild	5.45 ± 0.85	*1.44*	*<.001*	6.34 ± 2.52	*-1.71*	*<.001*
Severe	38	Sev v Mod	5.44 ± 0.51	*-0.02*	*<.001*	5.59 ± 2.83	-0.74	1.00
V Severe	78	V Sev v Sev	8.58 ± 1.96	3.15	1.00	4.12 ± 2.22	-1.47	.104
E Severe	24	E Sev v V Sev	0.00 ± 0.00	*-8.58*	*<.001*	0.00 ± 0.00	-4.12	*<.001*

p<0.0083 for post hoc comparisons.

(B) *Consolidated* Bland

CTS Category	N	Category Comparison	DSL1 (ms)	Mean Δ	p value	DSL3 (ms)	Mean Δ	p value
Normal	138		2.57 ± 0.23			3.20 ± 0.22		
Mild	146	Mild v Norm	3.09 ± 0.47	*0.53*	*.001*	3.79 ± 0.79	*0.59*	*<.001*
Moderate	241	Mod v Mild	3.51 ± 1.29	*0.42*	*.002*	4.87 ± 0.80	*1.08*	*<.001*
Severe	140	Sev v Mod	0.76 ± 1.67	*-2.75*	*<.001*	0.15 ± 0.86	*-4.72*	*<.001*
CTS Category	**N**	**Category Comparison**	**DML (ms)**	**Mean Δ**	**p value**	**DMA (mV)**	**Mean Δ**	**p value**
Normal	138		3.49 ± 0.37			8.94 ± 3.08		
Mild	146	Mild v Norm	3.99 ± 0.34	0.49	.082	8.09 ± 2.74	-0.84	.063
Moderate	241	Mod v Mild	5.45 ± 0.85	*1.47*	*<.001*	6.34 ± 2.52	*-1.76*	*<.001*
Severe	140	Sev v Mod	6.26 ± 3.49	*0.81*	*<.001*	3.82 ± 2.88	*-2.52*	*<.001*

p<0.0167 for post hoc comparisons. DSL1: distal sensory latency to thumb; DSL3: distal sensory latency to middle finger; DML: distal motor latency; DMA: distal motor amplitude; V: Very; E: Extremely; Norm: Normal; Mod: Moderate; Sev: Severe; Ext: Extreme; ms: milliseconds; mV: millivolts.

DML (F=453.1, df=6, *p<.001*), and DMA (F=63.4, df=6, *p<.001*). Effect sizes were large ranging from η^2=.37 for DMA to η^2 =.86 for DSL3. DSL3 and DML provided the best discrimination between consecutive CTS severity categories in the complete classification system at 50% (3 of 6 comparisons, respectively) (Table 2A). In the *consolidated* Bland classification, significant differences were found across CTS severity categories for DSL1 (F=188.1, df=3, *p<.001*), DSL3 (F=1264.7, df=3, *p<.001*), DML (F=84.4, df=3, *p<.001*), and DMA (F=94.4, df=3, *p<.001*). Effect sizes were large ranging from η^2=.28 for DML to η^2 =.85 for DSL3. DSL1 and DSL3 provided the best discrimination between consecutive CTS severity categories in the *consolidated* classification at 100% (3 of 3 comparisons, respectively). Overall, the *consolidated* classification outperformed the complete classification system, discriminating 83% (10 of 12 comparisons) compared to 42% (10 of 24 comparisons) of CTS severity categories, respectively (Table 2B).

In the GEHS classification system, significant differences were found across CTS severity categories for DSL1 (F=20.1, df=6, *p<.001*), DSL3 (F=21.1, df=6, *p<.001*), DML (F=59.4, df=6, *p<.001*), and DMA (F=57.2, df=6, *p<.001*). Effect sizes were large ranging from η^2=.16 for DSL1 to η^2=.35 for DML. DSL3, DML, and DMA provided the best discrimination

Table 3. MANOVA of nerve conduction parameters across categories of CTS severity in the GEHS classification system (A) and *consolidated* GEHS classification (B).

(A) GEHS

CTS Severity	N	Category Comparison	DSL1 (ms)	Mean Δ	p value	DSL3 (ms)	Mean Δ	p value
Normal	134		2.56 ± 0.23			3.20 ± 0.22		
V Mild	13	V Mild v Normal	3.05 ± 0.19	0.49	1.00	3.45 ± 0.22	0.25	1.00
Mild(s)	100	Mild(s) v V Mild	3.05 ± 0.42	-0.05	1.00	3.85 ± 0.62	0.41	1.00
Mild(s/m)	124	Mild(s/m) v Mild(s)	3.33 ± 0.73	0.28	1.00	4.13 ± 0.91	0.27	1.00
Moderate	230	Mod v Mild(s/m)	2.53 ± 2.04	*-0.80*	*<.001*	3.08 ± 2.58	*-1.04*	*<.001*
Mod/Sev	18	Mod/Sev v Mod	2.03 ± 2.23	-0.50	1.00	3.64 ± 2.67	0.56	1.00
Severe	46	Sev v Mod/Sev	0.84 ± 1.97	-1.19	.500	0.95 ± 2.12	*-2.69*	*<.001*
CTS Severity	**N**	**Category Comparison**	**DML (ms)**	**Mean Δ**	**p value**	**DMA (mV)**	**Mean Δ**	**p value**
Normal	134		3.46 ± 0.34			9.05 ± 3.05		
V Mild	13	V Mild v Normal	3.75 ± 0.21	0.29	1.00	8.16 ± 3.03	-0.89	1.00
Mild(s)	100	Mild(s) v V Mild	3.89 ± 0.30	0.13	1.00	8.19 ± 2.81	0.03	1.00
Mild(s/m)	124	Mild(s/m) v Mild(s)	4.61 ± 0.19	0.72	.019	7.13 ± 2.49	-1.06	.073
Moderate	230	Mod v Mild(s/m)	6.33 ± 1.43	*1.72*	*<.001*	5.57 ± 2.57	*-1.56*	*<.001*
Mod/Sev	18	Mod/Sev v Mod	6.42 ± 0.25	0.09	1.00	5.37 ± 2.59	-0.20	1.00
Severe	46	Sev v Mod/Sev	4.57 ± 5.18	*-1.86*	*<.001*	1.72 ± 2.33	*-3.65*	*<.001*

p<0.0083 for post hoc comparisons.

(B) *Consolidated* GEHS

CTS Severity	N	Category Comparison	DSL1 (ms)	Mean Δ	p value	DSL3 (ms)	Mean Δ	p value
Normal	134		2.56 ± 0.23			3.20 ± 0.22		
Mild	113	Mild v Norm	3.19 ± 0.61	*0.64*	*<.001*	3.97 ± 0.79	*0.77*	*<.001*
Moderate	354	Mod v Mild	2.53 ± 2.04	*-0.67*	*<.001*	3.08 ± 2.58	*-0.89*	*<.001*
Severe	64	Sev v Mod	1.17 ± 2.09	*-1.36*	*<.001*	1.71 ± 2.57	*-1.37*	*<.001*
CTS Severity	**N**	**Category Comparison**	**DML (ms)**	**Mean Δ**	**p value**	**DMA (mV)**	**Mean Δ**	**p value**
Normal	138		3.46 ± 0.34			9.05 ± 3.05		
Mild	146	Mild vs Norm	4.26 ± 0.44	*0.79*	*<.001*	7.63 ± 2.70	*-1.42*	*<.001*
Moderate	279	Mod vs Mild	6.33 ± 1.43	*2.07*	*<.001*	5.57 ± 2.57	*-2.07*	*<.001*
Severe	102	Sev vs Mod	5.09 ± 4.46	*-1.24*	*<.001*	2.74 ± 2.90	*-2.82*	*<.001*

p<0.0167 for post hoc comparisons. DSL1: distal sensory latency to thumb; DSL3: distal sensory latency to middle finger; DML: distal motor latency; DMA: distal motor amplitude; V: Very; s: sensory only; s/m: sensory & motor; Norm: Normal; Mod: Moderate; Sev: Severe; ms: milliseconds; mV: millivolts.

between consecutive CTS severity categories in the complete classification system at 33% (2 of 6 comparisons, respectively) (Table 3A). In the *consolidated* GEHS classification, significant differences were found across CTS severity categories for DSL1 (F=35.8, df=3, *p<.001*), DSL3 (F=29.6, df=3, *p<.001*), DML (F=104.6, df=3, *p<.001*), and DMA (F=98.9, df=3, *p<.001*). Effect sizes were moderate to large ranging from η^2=.12 for DSL3 to η^2=.32 for DML. All nerve conduction parameters provided 100% discrimination (3 of 3 comparisons, respectively) between consecutive CTS severity categories in the *consolidated* classification. Overall, the *consolidated* classification outperformed the complete classification system, discriminating 100% (12 of 12 comparisons) compared to 29% (7 of 24 comparisons) of CTS severity categories, respectively (Table 3B).

Comparing nerve conduction parameters across the Padua and Bland classification systems, a single significant difference was found in DMA (F=7.6, df=2, *p<.001*) with a small effect size (η^2=.02). Comparing nerve conduction parameters across the Padua and GEHS classification systems, significant differences were found in DSL3 (F=3.4, df=6, *p=.003*) and DML (F=3.2, df=6, *p=.005*) with small effect sizes of η^2=.03, respectively. Comparing nerve conduction parameters across the Bland and GEHS classification systems, significant

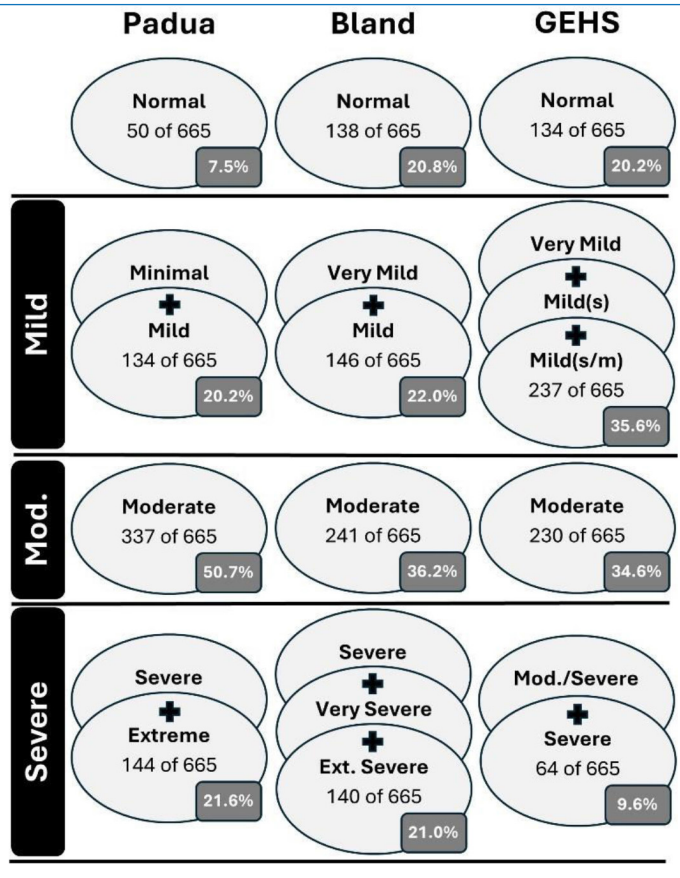

Figure 3. Distribution of hands in consolidated classifications of CTS severity. *Ext.: Extreme; s: sensory only; s/m: sensory & motor; Mod.: Moderate.*

differences were found in DSL1 (F=4.2, df=5, *p<.001*), DSL3 (F=21.1, df=5, *p<.001*), and DML (F=6.9, df=5, *p<.001*) with small to large effect sizes ranging from η^2=.03 for DSL1 to η^2=.14 for DSL3.

Needle EMG

A total of 454 hands (68%) underwent needle EMG of the APB muscle in this study. Among those hands, 42% were "Negative", 44% had volitional MUP abnormalities, and 14% had abnormalities at rest with or without volitional MUP abnormalities. Significant differences were found between EMG findings and all nerve conduction parameters including DSL1 (F=21.6, df=3, *p<.001*), DSL3 (F=18.3, df=3, *p<.001*), DML (F=36.4, df=3, *p<.001*), and DMA (F=67.3, df=3, *p<.001*) with medium to large effect sizes ranging from η^2=.08 for DSL3 to η^2=.23 for DMA. On average, sensory and motor latencies were slower/absent and motor amplitudes were lower/absent in the presence of EMG abnormalities at rest.

Planned comparisons revealed that only DML and DMA discriminated between all consecutive EMG categories finding significant differences between "Volitional abnormalities" and "Normal" (1.38 ms, *p<.001* and -1.8 mV, *p<.001*, respectively) and "Resting abnormalities" and "Volitional abnormalities" (-0.8 ms, *p=.016* and -2.4 mV, *p<.001*). Significant differences were also found between "Resting abnormalities" and "Volitional abnormalities" in DSL1 (-1.2 ms, *p<.001*) and DSL3 (-1.6 ms, *p<.001*). Linear regression analysis revealed that age (β=-0.3, *p=.022*), DML (β=-4.4, *p<.001*), and DMA (β=3.2, *p<.001*) were significantly correlated with EMG findings, with the overall model explaining about 16% of the variance. Chi Square analysis revealed significant differences between EMG findings and CTS severity in the final EDX impression and all *consolidated* classifications (EDX Impression, χ^2=430.3, p<.001; Padua, χ^2=234.8, p<.001; Bland, χ^2=258.7, p<.001; GEHS, χ^2=564.9, p<.001). On average, volitional EMG abnormalities were more prevalent in "Mild" and "Moderate" CTS categories and EMG abnormalities at rest were more prevalent in the "Severe" CTS category regardless of classification used.

Consolidated Classifications

For the final EDX impression, significant differences were found across categories of median neuropathy at the wrist for DSL1 (F=91.7, df=3, *p<.001*), DSL3 (F=104.8, df=3, *p<.001*), DML (F=74.8, df=3, *p<.001*), and DMA (F=99.2, df=3, *p<.001*). Effect sizes were large ranging from η^2=.25 for DML to η^2=.32 for DSL3. DSL1, DML, and DMA provided the best discrimination between consecutive categories of median neuropathy at the wrist at 67% (2 of 3 comparisons, respectively). Overall, the final EDX impression discriminated 58% (7 of 12 comparisons) of consecutive categories of median neuropathy at the wrist.

The *consolidated* Padua classification resulted in the following categorizations: 50 hands "Normal" (8%), 134 hands "Mild" (20%), 337 hands "Moderate" (51%), and 144 hands "Severe" (22%) for CTS. The *consolidated* Bland classification resulted in the following categorizations: 138 hands "Normal" (21%), 146 hands "Mild" (22%), 241 hands "Moderate" (36%), and 140 hands "Severe" (21%) for CTS. The consolidated GEHS classification resulted in the following categorizations: 134 hands "Normal" (20%), 237 hands "Mild" (36%), 230 hands "Moderate" (35%), and 64 hands "Severe" (10%) for CTS (Figure 3). Chi Square analysis revealed significant differences between all consolidated classifications (Padua vs Bland, χ^2=1114.7, *p<.001*; Padua vs GEHS, χ^2=621.4, *p<.001*; Bland vs GEHS, χ^2=1043.4, *p<.001*).

Comparison of nerve conduction parameters across consolidated Padua and Bland classifications found a single significant difference in DMA (F=11.9, df=1, *p<.001*) with a small effect size (η^2=.02). Comparison of nerve conduction parameters across consolidated Padua and GEHS classifications found significant differences in DSL3 (F=5.5, df=3, *p<.001*), DML (F=16.9, df=3, *p<.001*), and DMA (F=4.7, df=3, *p<.001*) with small to medium effect sizes ranging from η^2=.01 for DSL3 to η^2=.09 for DML. Comparison of nerve conduction parameters across consolidated Bland and GEHS classifications found significant differences in DSL3 (F=31.9, df=3, *p<.001*) and DML (F=17.7, df=3, *p<.001*) with medium effect sizes ranging from η^2=.08 for DML to η^2=.13 for DSL3.

Additional Analyses

A significant moderate correlation was found between age and DMA (r=-0.49, *p<.001*) with all other variables having small or insignificant correlations. Sex-specific analysis revealed significant differences between men and women in all nerve conduction parameters including DSL1 (F=5.2, df=1, *p=.023*), DSL3 (F=8.7, df=1, *p=.003*), DML (F=13.4, df=1, *p<.001*), and DMA (F=22.4, df=1, *p<.001*) with small to medium effect sizes ranging from η^2=.01 for DSL1 to η^2=.03 for DMA. On average, women had slower DSL1/DSL3, faster DML, and larger DMA. In the Padua classification system, significant differences were found between men and women in DSL3 (F=4.1, df=4, *p=.003*) and DML (F=2.8, df=4, *p=.026*) with small effect sizes of η^2=.02, respectively. On average, women had slower DSL3, faster DML, and more normality with less overall severity. In the Bland classification system, a single significant difference was found between men and women in DSL3 (F=2.9, df=6, *p=.009*) with a small effect size (η^2=.03). On average, women had slower DSL3 but more normality with less overall severity. In the GEHS classification system, no significant differences were found between men and women in any nerve conduction parameter. In the Padua and Bland *consolidated* classifications, significant differences were found between men and women only in DMA (F=3.6, df=3, *p=.013* and F=3.6, df=3, *p=.014*, respectively) with small effect sizes of η^2=.02, respectively. On average, women had larger DMA and more normality with less overall severity. In the GEHS consolidated classification, no significant differences were found between men and women in any nerve conduction parameter. Chi Square analysis revealed significant differences between men and women in CTS severity comparing consolidated classifications (Padua, χ^2=44.4, *p<.001*; Bland, χ^2=37.1, *p<.001*; GEHS, χ^2=37.7, *p<.001*). On average, women had a higher proportion of normality with a lower proportion of overall severity.

Age categories used in this study were based on those commonly used in normative data sets and included <50 years and ≥50 years for DSL1, DSL3, and DML and <40 years, 40-59 years, and ≥60 years for DMA. Age category-specific analysis revealed significant differences between age categories in all nerve conduction parameters including DSL1 (F=7.4, df=1, *p=.007*), DSL3 (F=8.9, df=1, *p=.003*), DML (F=16.8, df=1, *p<.001*), and DMA (F=79.2, df=1, *p<.001*). Effect sizes were small to large ranging from η^2=.01 for DSL1 to η^2=.19 for DMA. On average, patients ≥50 years had faster DSL1/DSL3 (likely associated with a higher proportion of absent responses reflected in larger standard deviations), slower DML, and smaller DMA. Because DMA includes 3 age categories, a significant difference was found comparing patients ≥60 years with those 40-59 years (-2.72 mV, *p<.001*) but not found comparing patients 40-59 years with those <40 years (-0.49 mV, *p=.346*). Only the Bland classification system found a significant difference based on age category, and that was only in DSL3 (F=2.2, df=6, *p=.043*) with a small effect size (η^2=.02). On average, patients ≥50 years had slower DSL3 and less normality with more overall severity. Only the *consolidated* Bland and GEHS classifications found significant differences based on age category, both in DSL3 (F=3.6, df=3, *p=.013* and F=3.6, df=3, *p=.014*, respectively) with small effect sizes of η^2=.01, respectively. On average, patients ≥50 years had slower DSL3 and less normality with more overall severity. Chi Square analyses revealed significant differences between age category and consolidated classifications, whether analyzed using 2 or 3 age categories (Padua, χ^2=80.4 to 87.3, *p<.001*; Bland, χ^2=67.1 to 74.3, *p<.001*; GEHS, χ^2=37.7, *p<.001*). On average, patients ≥50 years had a lower proportion of normality and a higher proportion of overall severity.

Discussion

This study evaluated the value of common EDX findings to discriminate across consecutive CTS severity categories within existing classification systems. The results support the use of *consolidated* classifications to improve discrimination capability between consecutive CTS severity categories regardless of classification system used. In addition, significant differences were found in EDX findings and categorization of CTS severity when comparing complete classification systems and *consolidated* classifications, which is clinically significant considering the implications of CTS severity diagnosis on the subsequent medical management and selection of interventions[10,11]. While the Padua classification showed the highest discrimination capability between consecutive CTS severity categories at 75%, it should be remembered that because only a single hand was categorized as "Minimal" it had to be combined with the "Mild" category for statistical analysis, resulting in a true discrimination capability to 60%. Similarly, while the *consolidated* GEHS classification showed the higher discrimination capability between consecutive CTS severity categories at 100%, it should be remembered that only 48% of hands could be strictly classified, which improved to just 69% when analyzed only in hands including needle EMG of the APB muscle. Having to determine the CTS severity category best fitting the EDX findings in nearly 1 out of 3 hands may limit the clinical utility of the GEHS systems and potentially introducing large variability across clinicians.

Because the final EDX impression used by the examiners in this investigation discriminated just 58% of CTS severity categories, the value of EMG findings and/or the evaluation of median sensory and motor amplitudes to inform categorization of CTS severity should be considered[18,21]. Although only one of the classification systems in this study considers EMG findings in the APB muscle[11,15], inclusion of needle EMG in patients with suspected CTS appears (when appropriate) appears warranted based on the results of this investigation. Among the 68% of hands undergoing needle EMG of the APB muscle in this study, the most common finding was volitional MUP abnormalities, a finding that was most prevalent in hands categorized as "Mild" or "Moderate" CTS regardless of the classification system used. An abnormal EMG finding in the presence of otherwise "Normal" or "Mild" sensory-only findings presents a diagnostic challenge for a clinician who is seeking to accurately categorize CTS severity. Alternatively, the findings of this investigation were consistent with prior studies demonstrating the relationship between EMG abnormalities at rest are more severe CTS[11,18,21]. Additionally, DML and DMA provided the best discrimination between categories of EMG findings and were most predictive of the presence of EMG abnormities in general.

While none of the existing classification systems evaluated in this study use sex or age-specific criteria, sex and age category-specific analysis revealed significant differences related to CTS severity. Significant differences were found in all nerve conduction parameters, with women generally exhibiting slower sensory latencies, faster motor latencies, and larger motor amplitudes. Significant differences were found between men and women in the distribution of CTS severity categories regardless of classification system used, with women exhibiting a higher proportion of normality and lower proportion of overall severity. Age category-specific analysis demonstrated significant differences in all nerve conduction parameters, with patients ≥50 years generally exhibiting slower sensory and motor latencies and smaller motor amplitudes. Significant differences were found between age categories in the distribution of CTS severity categories regardless of classification system used, with patients ≥50 years exhibiting a lower proportion of normality and higher proportion of overall severity. Additionally, age was among the predictive factors of EMG findings generally. These findings suggest that sex and age may be important factors to consider when interpreting EDX findings for the purpose of categorizing CTS severity.

This original study contributes significant insights into the evaluation of existing classification systems describing categories of CTS severity through a comprehensive analysis of EDX findings. This investigation found that *consolidated* classifications provide superior discrimination capability between consecutive CTS severity categories within existing classification systems based on EDX findings. These results also highlight the importance of considering demographic factors when interpreting EDX findings for the purposes of categorizing CTS severity. Future research is needed to further refine existing classification systems and explore additional factors that may influence the categorization of CTS severity for the purposes of enhancing diagnosis and improving selection of interventions.

Ethics approval

All study-related procedures were approved by the Institutional Review Board at Winston-Salem State University (IRB-FY2023-37).

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Supplementary file. STROBE Statement—Checklist of items that should be included in reports of cross-sectional studies.

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	216
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	216
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	216-218
Objectives	3	State specific objectives, including any prespecified hypotheses	218
Methods			
Study design	4	Present key elements of study design early in the paper	218
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	218-219
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	218
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	218-219
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	218-219
Bias	9	Describe any efforts to address potential sources of bias	NA
Study size	10	Explain how the study size was arrived at	218
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	218-219
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	218-219
		(*b*) Describe any methods used to examine subgroups and interactions	NA
		(*c*) Explain how missing data were addressed	NA
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	NA
		(*e*) Describe any sensitivity analyses	NA
Results			
Participants	13*	(*a*) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	219
		(*b*) Give reasons for non-participation at each stage	NA
		(*c*) Consider use of a flow diagram	NA
Descriptive data	14*	(*a*) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	219
		(*b*) Indicate number of participants with missing data for each variable of interest	219-222
Outcome data	15*	Report numbers of outcome events or summary measures	219-222
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	219-224
		(*b*) Report category boundaries when continuous variables were categorized	219-224
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	NA
Discussion			
Key results	18	Summarise key results with reference to study objectives	225
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	NA
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	225
Generalisability	21	Discuss the generalisability (external validity) of the study results	225
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	NA

**Give information separately for exposed and unexposed groups.*