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Accuracy of Ultrasonography Diagnostic Tests in Carpal Tunnel Syndrome (Electromyography-Nerve Conduction Velocity as Gold Standard)

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ABSTRACT

Introduction: Carpal Tunnel Syndrome is a collection of symptoms (pain in the median nerve distribution, numbness, tingling to motor weakness or muscle atrophy) due to ischemic compression of the median nerve. This causes a decrease in quality of life and disrupts work. EMG-NCV is a gold standard diagnostic tool with high sensitivity and specificity, but it is uncomfortable, high costs and an inadequate number of devices.

Methods: The authors consider the use of ultrasound with a specificity of 86.8% and a sensitivity of 77.6%, providing more convenience, lower cost, a greater number of devices available. Moreover, some literature explains that ultrasound can diagnose CTS earlier. Thus, the author conducted diagnostic test research with a cross-sectional design. The research sample underwent ultrasound and EMG-NCV examination, then receiver operating characteristic analysis was carried out to obtain cut-off point and analyze sensitivity, specificity and accuracy.

Results: The results of this study showed that mid-carpal CSA on ultrasound with a cut point of 12.5 mm^2 could be used to predict the diagnosis of CTS with a sensitivity of 78% and a specificity of 52.4% with a predictive power of 74.7%. In addition, each clinical grade is related to the ultrasound grade and EMG-NCV. Hence, ultrasound can confirm the diagnosis of CTS and can be applied in all healthcare facilities that have ultrasound so that the distribution of diagnosis of patients with CTS can be more even and make health services easier and faster.

Conclusion: It can be concluded that the ultrasound test (Mid-Carpal CSA) is sensitive, non-specific and accurate in diagnosing carpal tunnel syndrome. And, from this research, ultrasound can determine the severity of carpal tunnel syndrome. However, researchers recommend that this research be continued with a larger sample size to be more representative in determining the severity of carpal tunnel syndrome from an ultrasound examination.

Keywords: CTS, USG, CSA, EMG-NCV, diagnostic

INTRODUCTION

Carpal Tunnel Syndrome (CTS) is a collection of symptoms caused by ischemic compression of the median nerve in the wrist area. CTS occurs when the median nerve is pinched or compressed in the carpal

tunnel, leading to symptoms such as pain in the hand, especially in the distribution of the median nerve, numbness, tingling, and weakness. Motor weakness or muscle atrophy may occur in advanced stages of CTS. CTS is typically suspected if there are sensory disturbances such as tingling, a feeling of thickness, and pain in the distribution of the median nerve in the hand, accompanied by one or more positive provocative test results such as Tinel sign, Phalen test, and Durkan Test.1

As of now, EMG-NCV (electromyography-nerve conduction velocity) is the gold standard diagnostic tool for CTS, characterized by motor and sensory latency. EMG-NCV has high sensitivity and specificity in diagnosing CTS, with a sensitivity of 49-84% and specificity of 95-99%. EMG-NCV is also commonly used to evaluate nerve conduction changes after release, but it is often found that some nerve functions are still impaired on EMG-NCV even if there is symptomatic improvement. Therefore, the assessment of CTR outcomes is better done clinically and visually with ultrasound (USG). Additionally, EMG-NCV examinations can be uncomfortable due to the use of electrode needles, involve higher costs, and may face inadequate availability of EMG-NCV equipment in healthcare facilities.2

The use of ultrasound (USG) for diagnosing CTS has become very popular in the last two decades because it can visually clarify diagnostic criteria, is non-invasive, and has lower costs. This new diagnostic modality provides a specificity of 86.8% and sensitivity of 77.6%.3 Ultrasound has advantages in terms of comfort, lower cost, and greater availability of equipment in Indonesian hospitals. Moreover, literature suggests that ultrasound can diagnose CTS earlier than EMG-NCV. Considering these factors, the author aims to conduct research on the application of ultrasound as a diagnostic modality for CTS at Prof. DR. I.G.N.G Ngoerah General Hospital, with the hope that ultrasound can be used as an alternative diagnostic tool for CTS alongside EMG-NCV. This research will determine the sensitivity, specificity, and cutoff point for the use of ultrasound in diagnosing CTS, with the expectation of facilitating and expediting healthcare services, particularly in the diagnosis of CTS.

METHODS

Study Design

This study is a diagnostic test study classified as observational descriptive with a cross-sectional study design. It involves patients who visited the Orthopedic and Traumatology Clinic and Neurology Clinic at Prof. Dr. I.G.N.G. Ngoerah General Hospital in Denpasar, Bali, during the period from March 2023 to October 2023, exhibiting symptoms of carpal tunnel syndrome. The study has received approval from the Ethics Commission of the Faculty of Medicine, Udayana University, with the number 509/UN 14.2.2.VII.14/LT/2023. Inclusion criteria include adult male or female patients aged 20 to 60 years with clinically suggestive initial symptoms of carpal tunnel syndrome, having undergone EMG-NCV examination, Body Mass Index (BMI) between 18.5 and 25 kg/m2, no comorbidities such as malignancy, obesity, hormonal disorders, diabetes mellitus, autoimmune diseases, or infections, no history of trauma to the wrist (fracture, implantation), and agreement to participate in the study. Exclusion criteria include patients with a history of wrist trauma (fracture, implantation), comorbidities that may confound the study results such as malignancy, obesity, hormonal disorders, diabetes mellitus, autoimmune diseases, or infections, symptoms resembling carpal tunnel syndrome (tendinitis, ganglion, cubital tunnel syndrome, double crush CTS), previous wrist surgery with symptoms, congenital musculoskeletal abnormalities, clear clinical symptoms of CTS with thenar muscle atrophy, and refusal to participate in the study. Dropout criteria include patients who die before the end of the study period, experience

exclusion factors during the study, or refuse to continue the research.

Data Collection

Carpal Tunnel Syndrome is diagnosed clinically, with patients experiencing pain in the hand, especially in the distribution of the median nerve, numbness, and tingling, up to thenar muscle atrophy. The examination continues with a physical examination, including provocative tests such as Tinel sign or Phalen test. Each patient will be asked to sign consent forms for diagnostic procedures and participation in the study. Patient data will be kept confidential. The defined CTS is single crush or pure CTS symptoms due to peripheral nerve compression in the carpal tunnel without involvement of cervical radiculopathy. The electromyography machine used is the NATUS Ultra Pros S100 Series from 2014. Amplitude is measured from the baseline to the first negative deflection, indicating the number of stimulated axons. Data obtained are numerical with millivolt (mV) as the unit. Duration is measured from the first deflection to the point where the wave intersects the baseline. The unit used is milliseconds (ms). Latency is measured from the artifact stimulus to the first deflection from the baseline. The unit used is milliseconds (ms). Nerve Conduction Velocity amplitude is measured from the baseline to the first negative deflection, indicating the number of stimulated axons. Data obtained are numerical with millivolt (mV) as the unit. Duration is measured from the first deflection to the point where the wave intersects the baseline. The unit used is milliseconds (ms). Latency is measured from the artifact stimulus to the first deflection from the baseline. The unit used is milliseconds (ms). Ultrasonography will use the Mindray DnC3 brand and Linear Transducer Probe. The examination will be performed by a consultant musculoskeletal radiology specialist. The interpretation of the ultrasound examination on the carpal tunnel includes CSA at the carpal tunnel inlet, CSA at the carpal tunnel outlet, CSA at the midcarpal, and CSA inlet outlet ratio. CSA is a numerical data with the unit mm2. The Cross-Sectional Area (CSA) represents the cross-sectional area traced along the inner margin of the hyperechogenic perineural surrounding the hypoechogenic median nerve with electronic measurement. CSA at each location is measured three times, and the average of the three measurements is used as the CSA value. Data used are numerical with mm2 as the unit. Furthermore, the inlet-outlet CSA ratio is obtained by comparing numerical data of inlet and outlet CSA without a unit. CSA Inlet is the proximal margin of the flexor retinaculum between the scaphoid tubercle and pisiform bone, measured at the entrance to the carpal tunnel. The distal wrist fold serves as an external marker for scan initiation. CSA measurement is performed by tracing along the inner margin of the hyperechogenic perineural surrounding the hypoechogenic median nerve with electronic measurement. Data are numerical with mm2 as the unit. CSA Outlet is measured at the distal part of the carpal tunnel as the largest CSA of the median nerve before branching into digit nerves. Data are numerical with mm2 as the unit. CSA Midcarpal is measured from the smallest CSA inside the carpal tunnel. Data are numerical with mm2 as the unit.

STATISTICAL ANALYSIS

The results from Ultrasonography and EMG-NCV are then subjected to correlation analysis, mean difference between two groups, receiver operating characteristic (ROC) analysis to obtain the best cut-off point, and subsequent determination of sensitivity, specificity, and accuracy. The statistical analysis used includes the chi-square test for diagnostic testing, sensitivity, specificity, and accuracy analysis through ROC curve analysis comparing USG Inlet, Outlet, Mid-carpal, and IOR variables against CTS figures from EMG examination. The ROC curve analysis aims to determine the cut-off point on these variables for diagnosing CTS with USG.

The analysis is deepened using the chi-square test for proportion differences and risk analysis using odds ratio (OR) calculations to determine the relationship between the severity of CTS based on USG and EMG examinations. The significance level (α) of this study is set at a probability value (p) less than 0.05 in general. All statistical analyses are performed using the SPSS for Windows software (Version 25; IBM Corp, Armonk, NY, USA).

RESULTS

A. Research Subject Characteristics

Demographic characteristics of patients are listed in Table 1. The mean age of the study sample is 45.77 ± 12.73 years. The female-to-male gender ratio is 1.5:1, with a dominant female population (77.4%). The research subjects exhibit symptoms of carpal tunnel syndrome, such as numbness (86%), weakness (34%), thenar atrophy (8%), and tingling/numbness (10%). The clinical severity is categorized as mild (24.2%), moderate (22.6%), and severe (29%).

In the EMG examination, results of SNAP and CMAP are obtained based on their latency and amplitude. The average SNAP latency result is 3.458 ± 2.31, while the SNAP amplitude is 31.29 ± 22.28. The average CMAP latency result is 4.48 ± 1.60, while the CMAP amplitude is 5.47 ± 2.84.

Categorically, latencies are grouped into normal and prolonged. In the SNAP examination, 47 (54.7%) normal latencies and 15 (17.4%) prolonged latencies are found. In the CAMP examination, 29 (33.7%) normal latencies and 33 (38.4%) prolonged latencies are found. Amplitudes are grouped into normal and decreased. In the SNAP examination, 48 (55.8%) normal amplitudes and 14 (16.3%) decreased amplitudes are found. In the CAMP examination, 45 (52.3%) normal amplitudes and 17 (19.8%) decreased amplitudes are found.

In the wrist ultrasound examination, three measurement parameters are used to assess carpal tunnel syndrome: CSA Inlet, CSA Outlet, Mid-carpal CSA, and Inlet/Outlet CSA Ratio. The average CSA Inlet result is 10.44 ± 1.63, CSA Outlet is 13.61 ± 2.63, Mid-carpal CSA is 13.37 ± 2.69, and Inlet/Outlet CSA Ratio is 0.78 ± 0.12.

Table 1. Basic Sample Characteristics

Variable	n (%)	Mean ± SD
Age		45.77 ± 12.73
Gender		
- Male	7 (22.6)	
- Female	24 (77.4)	
Affected Side		
- Left	29 (46.8) 33 (53.2)	
- Right	43 (86.0) 17 (34.0) 4 (8.0) 5 (10.0)	
Clinical Symptoms		
- Numbness	15 (24.2) 14 (22.6) 18 (29.0)	
- Weakness	47 (54.7)	3.45 ± 2.31
- Thenar Atrophy	15 (17.4)	
- Tingling/Numbness	48 (55.8)	31.29 ± 22.28
Severity	14 (16.3)	
- Mild	29 (33.7)	4.48 ± 1.60
- Moderate	33 (38.4)	
- Severe	45 (52.3)	5.47 ± 2.84

SNAP: Latency	17 (19.8)	
- Normal		10.44 ± 1.63
- Prolonged		13.61 ± 2.63 13.37 ± 2.69
SNAP: Amplitude		0.78 ± 0.12

n: frequency, %: percentage, mean: mean, SD: standard deviation, CMAP: Compound Muscle Action Potential, SNAP: Sensory Nerve Action Potential

B. USG Diagnostic Test

In the diagnostic test in Table 2, Chi-Square analysis compares CTS interpretation results in wrist ultrasound with EMG examination. The analysis shows a significant relationship between wrist ultrasound examination and EMG ($p < 0.05$). Wrist ultrasound examination has a sensitivity of 90.24%, specificity of 57.14%, and accuracy of 79.03% in confirming the diagnosis of CTS.

Table 2. Chi-Square Test for USG and CTS

Variable		EMG		p-value
		CTS	Normal	
USG	CTS	37 (90,2%)	9 (42,9%)	0.00
	Normal	4 (9,8%)	12 (57,1%)	

EMG: Electromyography, USG: Ultrasonography, CSA: Cross Sectional Area, CTS: Carpal Tunnel Syndrome, OR: Odds Ratio, CI: Confidence Interval

C. ROC Curve Analysis for CSA Mid-Carpal

The cut-off point between the two groups, with a cut-off value of CSA Mid-carpal of 12.50 mm2 in patients who have undergone ultrasound examination ($p < 0.05$). The cut-off determination can be seen in Tables 3 and 4. The ROC curve is used to determine the cut-off point for CSA Mid-carpal in confirming the diagnosis of CTS. From the ROC curve, as shown in Figure 1, the intersection point of CSA Mid-carpal is 12.50 mm2 with a sensitivity of 90.2% (CI:95) and specificity of 57.1%, with an Area Under the Curve (AUC) value of 0.79, indicating a predictive strength of 79%.

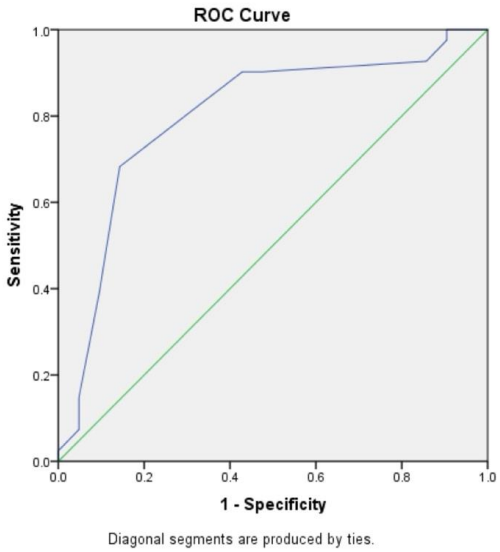

Figure 1. ROC Curve Analysis for CSA Mid-Carpal

Table 3. ROC of Mid-Carpal CSA

Cut off value	Area under curve (AUC)	p-value	Sensitivity	Specifity
12.5	0,799	0,00	0.902	0.571

Table 4. Coordinate Curve of Middle Carpal CSA

Degree	Sensitivity	1-Specifity
5.00	1.000	1.000
7.00	1.000	.905
9.00	.976	.905
10.50	.927	.857
11.50	.902	.476
12.50	**.902**	**.429**
13.50	.683	.143
14.50	.390	.095
15.50	.146	.048
16.50	.098	.048
17.50	.073	.048
20.50	.024	.000
24.00	.000	.000

D. ROC Curve Analysis for CSA Inlet

The cut-off point between the two groups, with a cut-off value of CSA Inlet of 9.50 mm2 in patients who have undergone ultrasound examination ($p > 0.05$). The cut-off determination can be seen in Tables 5 and 6. The ROC curve is used to determine the cut-off point for CSA Inlet in confirming the diagnosis of CTS. From the ROC curve, as shown in Figure 2, the intersection point of CSA Inlet is 9.50 mm2 with a sensitivity of 68.3% (CI:95) and specificity of 38.1%, with an AUC value of 0.598, indicating a predictive strength of 59.8%.

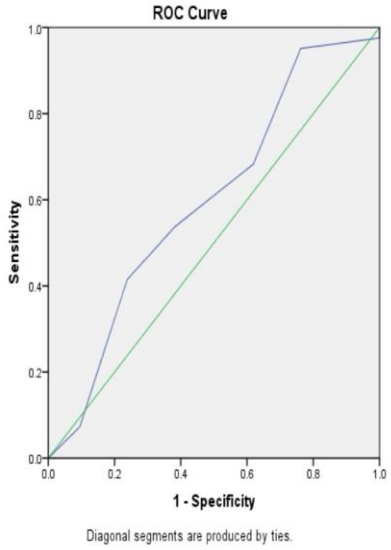

Figure 2. ROC Curve of CSA Inlet

Figure 2. ROC Curve Analysis for CSA Inlet

Table 5. ROC of CSA Inlet

Cut off value	Area under curve (AUC)	p-value	Sensitivity	Specifity
9.50	0,698	0.212	0.683	0.381

Table 6. Coordinate Curve of CSA Inlet

Degree	Sensitivity	1-Specifity
5.00	1.000	1.000
7.00	.976	1.000
8.50	.951	.762
9.50	**.683**	**.619**
10.50	.537	.381
11.50	.415	.238
12.50	.073	.095
14.00	.000	.000

E. ROC Curve Analysis for CSA Outlet

The cut-off point between the two groups, with a cut-off value of CSA Outlet of 12.50 mm2 in patients who have undergone ultrasound examination ($p < 0.05$). The cut-off determination can be seen in Tables 7 and 8. The ROC curve is used to determine the cut-off point for CSA Outlet in confirming the diagnosis of CTS. From the ROC curve, as shown in Figure 3, the intersection point of CSA Outlet is 12.50 mm2 with a sensitivity of 78.0% (CI:95) and specificity of 52.4%, with an AUC value of 0.747, indicating a predictive strength of 74.7%.

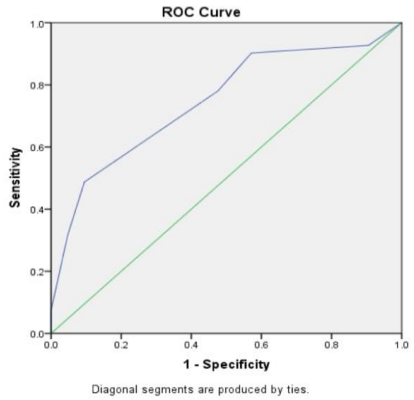

Figure 3. ROC Curve of CSA Outlet

Figure 3. ROC Curve Analysis for CSA Outlet

Table 7. ROC of CSA Outlet

Cut off value	Area under curve (AUC)	p-value	Sensitivity	Specifity
12.50	0,747	0.002	0.780	0.524

Table 8. Coordinate Curve of CSA Outlet

Degree	Sensitivity	1-Specifity
9.00	1.000	1.000
10.50	.927	.905
11.50	.902	.571
12.50	**.780**	**.476**
13.50	.561	.190
14.50	.488	.095
15.50	.317	.048
16.50	.073	.000
22.00	.024	.000
28.00	.000	.000

F. ROC Curve Analysis for CSA Inlet/Outlet Ratio

The cut-off point between the two groups, with a cut-off value of CSA Inlet/Outlet Ratio of 0.76 in patients who have undergone ultrasound examination ($p > 0.05$). The cut-off determination can be seen in Tables 9 and 10. The ROC curve is used to determine the cut-off point for CSA Inlet/Outlet Ratio in confirming the diagnosis of CTS. From the ROC curve, as shown in Figure 4, the intersection point of CSA Inlet/Outlet Ratio is 0.76 with a sensitivity of 61.9% (CI:95) and specificity of 58.5%, with an AUC value of 0.634, indicating a predictive strength of 63.4%.

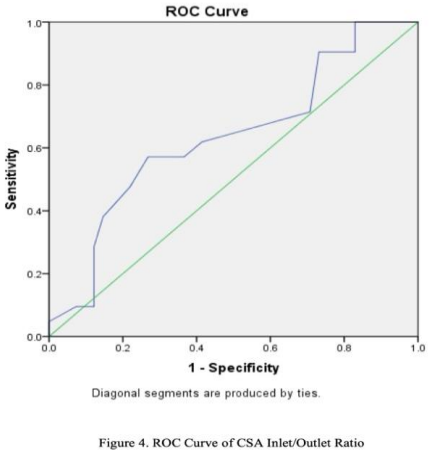

Figure 4. ROC Curve of CSA Inlet/Outlet Ratio

Figure 4. ROC Curve Analysis for CSA Inlet/Outlet Ratio

Table 9. ROC of CSA Inlet/Outlet Ratio

Cut Point Value	Strength Area under curve (AUC)	p-value	Sensitivity	Specifity
0.76	0,634	0.087	0.619	0.585

Table 10. Coordinate Curve of CSA Inlet/Outlet Ratio

Degree	Sensitivity	1-Specifity
-.63	1.000	1.000
.46	1.000	.976
.56	1.000	.951
.58	1.000	.927
.61	1.000	.829
.64	.905	.829
.66	.905	.780
.68	.905	.756
.71	.905	.732
.74	.714	.707
.76	**.619**	**.415**
.79	.571	.366
.81	.571	.317
.82	.571	.293
.84	.571	.268
.86	.476	.220
.88	.381	.146
.91	.286	.122
.92	.095	.122
.96	.095	.073
1.04	.048	.000
2.08	.000	.000

G. Boxplot Analysis

Further analysis is conducted using boxplot in Figure 5 to determine the upper and lower limits of the cut-off point determined based on the ROC curve. In this study, values between 11.50 - 14.00 mm2 are considered mild, while 14.50 to 15.00 mm2 is considered moderate, and above 15.00 mm2 is considered severe.

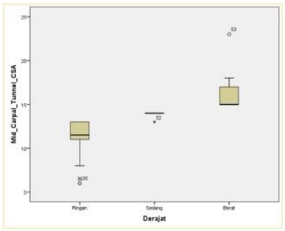

Figure 5. Boxplot Analysis

H. Analysis of the Relationship Between Severity of USG and EMG

Cross-tabulation analysis results show that 38 samples with positive EMG-NCV results (severity 1, 2, 3) also show positive CTS results on USG (severity 1, 2, 3), and 3 patients show normal USG results. In addition, 9 samples with normal EMG results show positive USG results with severity 1, 2, and 3; and 12 samples with normal USG results. Chi-square analysis shows that the severity of USG and EMG-NCV is significantly related (p = 0.00) (Table 11).

Cross-tabulation analysis results show that 12 samples with normal EMG results show normal USG results, 5 samples with severity 1 USG results, 2 samples with severity 2 USG results, and 2 samples with severity 3 USG results. Furthermore, there are 2 samples with severity 1 EMG results showing normal USG results, 7 samples with severity 1 USG results, and 1 sample with severity 2 USG results. There is also 1 sample with severity 2 EMG results showing normal USG results, 3 samples with severity 1 USG results, 10 samples with severity 2 USG results, and 3 samples with severity 3 USG results. Additionally, the analysis results also show that there are no samples with severity 3 EMG results showing severity 0 and 1 USG results, but there is 1 sample with severity 2 USG results and 13 samples with severity 3 USG results. Chi-square analysis in Table 12 shows that each USG severity and each EMG-NCV severity are significantly related (p = 0.000).

Cross-tabulation analysis results show that 37 samples with USG results indicating CTS show clinical CTS results, and 4 samples show normal clinical results. Furthermore, there are 9 samples with normal USG results showing clinical CTS results, and 12 samples show normal clinical results. Chi-square analysis in Table 13 shows that clinical interpretation results and USG interpretation results are significantly related (p = 0.000).

Cross-tabulation analysis results show that 12 samples with normal clinical results show normal USG results and none show severity 1, 2, and 3 USG results. There are 15 samples with severity 1 clinical results showing severity 1 USG results. There are 14 samples with severity 2 clinical results showing severity 2 USG results, and 18 samples with severity 3 clinical results showing severity 3 USG results. Chi-square analysis in Table 14 shows that each severity of USG (severity 1, 2, 3) and each severity of clinical interpretation (severity 1, 2, 3) are significantly related (p = 0.000).

Cross-tabulation analysis results show that 46 samples with EMG results indicating clinical CTS. In addition, there are 16 samples with normal EMG results showing normal clinical results. Chi-square analysis in Table 15 shows that clinical results and

EMG results are significantly related (p = 0.000).

Cross-tabulation analysis results show that 12 samples with normal EMG results show normal clinical results, 5 samples with severity 1 clinical results, 2 samples with severity 2 clinical results, and 2 samples with severity 3 clinical results. There are 2 samples with severity 1 EMG results showing normal clinical results, 7 samples with severity 1 clinical results, and 1 sample with severity 2 clinical results. There is also 1 sample with severity 2 EMG results showing normal clinical results, 3 samples with severity 1 clinical results, 10 samples with severity 2 clinical results, and 3 samples with severity 3 clinical results. Additionally, the analysis results also show that there are no samples with severity 3 EMG results showing normal clinical results and severity 1, but there is 1 sample with severity 2 clinical results and 13 samples with severity 3 clinical results. Chi-square analysis in Table 16 shows that each clinical severity and each EMG-NCV severity are significantly related (p = 0.000).

Cross-tabulation analysis results show that 37 samples with EMG results indicating CTS show clinical CTS results, and 4 samples show normal clinical results. Furthermore, there are 9 samples with normal EMG results showing clinical CTS results, and 12 samples show normal clinical results. Chi-square analysis in Table 17 shows that clinical results and USG results are significantly related (p = 0.000).

Table 11. Chi-Square Test for USG Degree and EMG-NCV Degree

Degree		EMG		p-value
		1, 2, 3	Normal	
USG	1, 2, 3	38 (92,7%)	9 (42.8%)	0.00
	Normal	3 (7,3%)	12 (57,2%)	

Table 12. Relationship Test for USG Degree with EMG-NCV Degree

Degree		EMG				p-value
		0	1	2	3	
USG	0	12 (57,2%)	2 (20%)	1(5,8%)	0 (0%)	0.00
	1	5 (23,8%)	7 (70%)	3 (17,7%)	0 (0%)	
	2	2 (9.5%)	1(10%)	10 (58,8%)	1 (7,1%)	
	3	2 (9,5%)	0 (0%)	3 (17,7%)	13 (92,9%)	

Table 13. Chi-Square Test for USG Interpretation with EMG-NCV Interpretation

Degree		USG		p-value
		CTS	Normal	
Clinical	CTS	37 (90,2%)	9 (42,9%)	0.00
	Normal	4 (9,8%)	12 (57,1%)	

Table 14. Chi-Square Test for USG Degree and Clinical Degree

Degree		Clinical				p-value
		0	1	2	3	
USG	0	15	0	0	0	0.00
	1	0	15	0	0	
	2	0	0	14	0	
	3	0	0	0	18	

Table 15. Chi-Square Test for EMG Interpretation with clinical Interpretation

Degree		EMG		p-value
		CTS	Normal	
Clinical	CTS	46	0	0.00
	Normal	0	16	

Table 16. Chi-Square Test for Clinical Degree and EMG Degree

Degree		EMG				p-value
		0	1	2	3	
Clinical	0	12	2	1	0	0.00
	1	5	7	3	0	
	2	2	1	10	1	
	3	2	0	3	13	

Table 17. Chi-Square Test for clinical Interpretation with EMG Interpretation

Degree		EMG		p-value
		CTS	Normal	
Clinical	CTS	37 (90,2%)	9 (42,9%)	0.00
	Normal	4 (9,8%)	12 (57,1%)	

DISCUSSION

A. General Characteristics of the Research Subjects

From 62 research samples (32 individuals), female patients (77.4%) more frequently experience Carpal Tunnel Syndrome (CTS) (22.6%) compared to males, with an average age of 45.77 years (± 12.35). This study is supported by the findings of Joshi et al., indicating that women have a smaller carpal tunnel space, leading to increased pressure on the median nerve and an elevated risk of CTS.[1]

The study by Farioli et al. indicates that hormones play a significant role in the risk of Carpal Tunnel Syndrome (CTS), especially during pregnancy or menopause. These hormonal changes can lead to tissue swelling around the carpal tunnel, increasing pressure on the median nerve.[4] This finding is supported by Tang et al.'s research, which states that estrogen has several anti-inflammatory properties and increases the levels of some inflammatory cytokines such as interleukin 1 (IL-1), interleukin 6 (IL-6), and tumor necrosis factor-alpha (TNF-α) after menopause. Therefore, a decrease in estrogen levels in menopausal women requiring hormone replacement therapy (HRT) may lead to an increase in cytokine levels, which can result in cell proliferation, angiogenesis, increased capillary permeability, edema changes, and ultimately fibrosis. When these changes occur, they indirectly contribute to the development of carpal tunnel syndrome (CTS).[5]

In patients with hypothyroidism, where the thyroid gland fails to produce sufficient thyroid hormones, hypothyroidism is often associated with carpal tunnel syndrome (CTS). Although the mechanisms are not fully understood, research findings from Aldaghri et al. suggest that the accumulation of glycosaminoglycans in the carpal tunnel can increase pressure on the median nerve.[6]

The research findings from Karne et al. indicate the presence of mucin/mucopolysaccharide deposition on the median nerve in patients with carpal tunnel syndrome (CTS) and hypothyroidism. Additionally, swelling of the synovial membrane was observed to be more pronounced in CTS patients with hypothyroidism compared to those without hypothyroidism.[7]

In their study involving 28 subjects, carpal tunnel syndrome (CTS) was more frequently found in the right wrist (71.4%) compared to the left wrist (28.6%). Although CTS can affect both sides of the hands, the right side is more commonly affected. This finding is supported by Saba et al.'s research, which explains that the right hand is more frequently used in daily activities. Consistent with this study, which

found that CTS is more often detected in the right wrist (53.2%) than the left wrist (46.8%). Fine motor skills can lead to increased fatigue in the wrist, placing extra pressure on the median nerve.[8] The excessive use of the wrist and hand can lead to tendon hypertrophy, which is a risk factor for carpal tunnel syndrome (CTS).

The study by Ramanandi indicates that repetitive motions at the wrist, such as typing or playing video games, can lead to swelling within the confined space formed by the bones and ligaments in the wrist. This swelling ultimately triggers carpal tunnel syndrome (CTS).[9] In this study, the most common complaints were tingling (86%), followed by weakness (34%), numbness (10%), and atrophy of the thenar muscles (8%).

These findings align with a study conducted by Paramita et al., which also found that tingling complaints were more prevalent in patients with carpal tunnel syndrome (CTS). This phenomenon is explained as a result of mechanical pressure originating from the subjects' work, which can lead to compression of the median nerve or work-related trauma that may result in ischemia (blood flow blockage) or damage to the nerve mucosa due to repetitive movements performed during work. This can cause complaints such as tingling, numbness, pain, and atrophy of the thenar muscles.[10] These findings are supported by a study conducted by Genova et al., which found that the pathophysiology of carpal tunnel syndrome (CTS) involves a combination of mechanical trauma, increased pressure, and ischemic damage to the median nerve within the carpal tunnel. When the median nerve experiences compression, it can lead to swelling and inflammation in the carpal tunnel, further compressing the nerve. Damage to the median nerve can result in abnormal sensations, such as tingling, in the fingers corresponding to the distribution of the median nerve.[11]

In the study conducted by the author, the average latency of the Sensory Nerve Action Potential (SNAP) examination was found to be 3.45 ± 2.31, while the amplitude of SNAP was 31.29 ± 22.28. The results align with a study by Lee et al., which found statistically significant differences in early and peak latencies in patients with carpal tunnel syndrome (CTS) compared to healthy individuals. Latency and amplitude of SNAP are crucial parameters in the diagnosis and evaluation of carpal tunnel syndrome (CTS), as evidenced by several journals. SNAP latency refers to the time it takes for the sensory nerve action potential to travel from the wrist to the fingers, while SNAP amplitude refers to the strength of the signal. In CTS, latency and amplitude of SNAP can be influenced by compression of the median nerve in the carpal tunnel.[12] According to the study by Hirani et al., which compared the amplitude and latency values of Sensory Nerve Action Potential (SNAP) with the severity, it indicates that SNAP latency and amplitude are crucial parameters in the diagnosis and evaluation of Carpal Tunnel Syndrome (CTS). These parameters can help identify abnormalities in nerve conduction and the severity of the condition. However, it is important to consider other factors that may affect SNAP latency and amplitude, such as concurrent medical conditions or technical factors during the procedure.[13]

In this study, the average latency of the Compound Muscle Action Potential (CMAP) examination was found to be 4.48 ± 1.60, while the amplitude of CMAP was 5.47 ± 2.84. CMAP latency and amplitude are also crucial parameters in the diagnosis and evaluation of Carpal Tunnel Syndrome

(CTS), as demonstrated by Lee et al.'s research. CMAP latency refers to the time it takes for the motor nerve action potential to travel from the wrist to the distal muscle, while CMAP amplitude refers to the strength of that signal. In CTS, CMAP latency and amplitude can be influenced by compression of the median nerve in the carpal tunnel. Examining the differences in early CMAP latency among the four fingers in the distribution of the median nerve can indicate the severity of CTS.12 Another study by Alanazy et al. discusses pitfalls that may arise during the clinical and electrophysiological evaluation of CTS. This study emphasizes the importance of using appropriate techniques and recognizing and correcting physiological and technical factors that can affect CMAP latency and amplitude. The study also mentions that a decrease in median nerve conduction velocity at the wrist is sometimes found in severe CTS.[14]

Furthermore, a study by Adebayo et al. found that the difference in median-ulnar F-wave latency appears to be a promising discriminative parameter between obese patients with mild CTS and those without CTS. Another study by Song evaluated the utility of Compound Muscle Action Potential (CMAP), early latency of sensory nerve action potential (SNAP), and amplitude in the diagnosis of CTS. This study found that these parameters can be useful in diagnosing CTS, especially in patients with mild to moderate symptoms.[15]

Finally, a study by Stefano found a significant increase in Compound Muscle Action Potential (CMAP) amplitude at the wrist compared to the elbow when stimulating the ulnar nerve and recording from the abductor digiti minimi muscle in patients with carpal tunnel syndrome (CTS).[16] Overall, this research indicates that Compound Muscle Action Potential (CMAP) latency and amplitude are crucial parameters in the diagnosis and evaluation of carpal tunnel syndrome (CTS). CMAP can help identify abnormalities in nerve conduction and assess the severity of the condition.

In this study, the average measurements of Cross-Sectional Area (CSA) were obtained from ultrasound as follows: CSA Inlet 10.44 ± 1.63 mm^2, CSA Outlet 13.61 ± 2.63 mm^2, CSA Mid-carpal 13.37 ± 2.69 mm^2, and CSA Inlet/Outlet ratio 0.78 ± 0.12 mm^2. According to a study by Pertea et al., the cross-sectional area of the median nerve (CSA) at the carpal tunnel entrance is a reliable parameter for diagnosing CTS. This research confirms the utility of ultrasonography in diagnosing CTS.[17]

Other findings from the study by Costoso et al. revealed that both Inlet and Outlet measurements on ultrasound (USG) showed sufficient accuracy for clinical use, although the overall accuracy was slightly higher for measurements at the inlet compared to measurements at the outlet. The addition of inlet and outlet measurements did not improve the accuracy of CTS diagnosis.[18]

The results of the study by Fu et al. also evaluated the diagnostic value of the Inlet:Outlet Ratio (IOR) in patients confirmed to have carpal tunnel syndrome (CTS). The research found that the IOR was significantly lower in patients with CTS compared to healthy individuals. This study suggests that the IOR can be a useful parameter for the diagnosis of CTS and may be used in combination with other ultrasound measurements to enhance diagnostic accuracy. Overall, these studies indicate that ultrasound is a beneficial diagnostic tool in diagnosing CTS, and the IOR is a reliable parameter for CTS diagnosis. [19]

The study conducted by Shim et al. in 2013 indicates that Mid-carpal Cross-Sectional Area (CSA) can also be used as a predictor for carpal tunnel syndrome (CTS).[20] The results of a prospective study by Cory and John suggest that Mid-carpal Cross-Sectional Area (CSA) can be used as a predictor for carpal tunnel syndrome (CTS) with a size limit for Mid Carpal CSA.[21] El-Bahnasawy et al.'s research found Mid Carpal CSA to be a predictor for CTS diagnosis (AUC=0.792, 95% CI 0.716–0.868).[22] A study by Griffith et al. in 2017 identified Mid Carpal CSA as a predictor for the diagnosis of Carpal Tunnel Syndrome (CTS) with a sensitivity of 88.6%, specificity of 87.5%, and predictive power of 88.2%. The considered significant threshold values varied from 9-15 mm², with sensitivity ranging from 62-97% and specificity from 57-100%. These variations are attributed to differences in patient and control selection criteria, as well as diagnostic methods. Nevertheless, in general, Mid-carpal CSA is recognized as one of the criteria with high sensitivity.[23]

B. The Usage of Wrist Ultrasonography in Determining the Diagnosis of Carpal Tunnel Syndrome

Ultrasonography has been proposed as an alternative method for diagnosing CTS. In CTS, nerve compression leads to local circulation disturbances accompanied by the collapse of the blood-nerve barrier, resulting in increased endoneurial fluid pressure and subsequent swelling of the nerve with disrupted local blood flow. Therefore, in CTS, nerve swelling in the carpal tunnel, as shown by ultrasonography, is acknowledged as a sign of compression within the tunnel. The quality of ultrasonographic images has significantly improved in the last decade due to the emergence of high-frequency ultrasonography transducers. Additionally, high-quality devices have become more affordable, making it feasible to acquire and use these devices in hand surgeon practices.[24] Studies by Wiesler et al. using ultrasonography imaging techniques have shown that nerve swelling is a crucial component of CTS. [25]

In the results of this study, the measurement of Mid-carpal Cross-Sectional Area (CSA) in ultrasound (USG) was found to be statistically significant with a P-value of 0.00 (P <0.05). Using a cutoff point of 12.5 mm² or more, the USG results can be utilized to predict the confirmation of Carpal Tunnel Syndrome (CTS) diagnosis with a sensitivity of 78% and specificity of 52.4%. The Area Under the Curve (AUC) value was 0.747, indicating a predictive strength of 74.7%. Additionally, the clinical degree, whether determined for each degree or set through USG and EMG-NCV, showed a significant correlation. These findings align with the study conducted by Shim et al. in 2013, which demonstrated that Mid-carpal CSA can serve as a predictor for CTS with a P-value of 0.036 (P <0.05). With a cutoff point for Mid-carpal CSA set at 13.5 mm², the prediction showed a sensitivity of 86.7% and specificity of 88.9%.[20]

While the results of the prospective study by Cory and John in 2022 indicate that Mid-carpal Cross-Sectional Area (CSA) can be used as a predictor for Carpal Tunnel Syndrome (CTS) with a cutoff point for Mid Carpal CSA set at 9.5 mm² in patients without diabetes mellitus (AUC=0.74) and a Mid-carpal CSA size greater than 10.5 mm² in patients with diabetes mellitus (AUC=0.85).21 The study by El-Bahnasawy et al. in 2020 obtained a result of 11.78 mm² as a predictor for CTS diagnosis (AUC=0.792, 95% CI 0.716–0.868). The

considered significant threshold values varied from 9-15 mm², with sensitivity ranging from 62-97% and specificity from 57-100%. These variations are due to differences in patient and control selection criteria, as well as methods used in diagnosing and measuring Mid-carpal CSA.[22] Another supporting study was conducted by Griffith et al. in 2017 found a result of 14 mm² as a predictor for Carpal Tunnel Syndrome (CTS) diagnosis with a sensitivity of 88.6%, specificity of 87.5%, and an Area Under the Curve (AUC) value of 0.882, indicating a predictive strength of 88.2%.[23]

In the results of this study, the measurement of Inlet Cross-Sectional Area (CSA) in ultrasound (USG) was also conducted. It was found that the measurement of Inlet CSA was not significant in predicting the confirmation of Carpal Tunnel Syndrome (CTS) diagnosis, with a P-value of 0.212 (P > 0.05). Using a cutoff point of 9.5 mm², the results showed a sensitivity of 68.3%, specificity of 38.1%, and an Area Under the Curve (AUC) value of 0.698, indicating a predictive strength of 69.8%. In another study by Razavi, the cutoff point for CSA in the inlet tunnel in patients with CTS ranged from 6.5 mm² to 15 mm², although the exact cutoff point was not determined.26 However, in the study conducted by Sarraf et al. in 2014, the optimal cutoff point for CSA in the inlet tunnel was found to be 10.5 mm² with a sensitivity and specificity of 80% and 76%, respectively, for the diagnosis of Carpal Tunnel Syndrome (CTS). This differs from the findings of Hacker et al., where the examination of Inlet CSA in ultrasound had specificity ranging from 75% to 85% with low sensitivity. An Inlet CSA examination >13 mm² could be used as a cutoff for diagnosing severe CTS (AUC 0.75, P >0.05).27 In Indonesia, according to the study by Prasetya, the examination of Cross-Sectional Area (CSA) in the inlet tunnel with a cutoff point of 10.6 mm² has achieved a sensitivity and specificity of 95%.28 The differences in research findings are influenced by several factors, one of which is the variation in sample populations or geographic variations that may impact study results.

In addition to measuring Inlet Cross-Sectional Area (CSA), this study also investigated Outlet CSA in ultrasound (USG) and found that the measurement of Outlet CSA was significant in predicting the confirmation of Carpal Tunnel Syndrome (CTS) diagnosis, with a P-value of 0.002 (P < 0.05). Using a cutoff point of 12.5 mm², the results showed a sensitivity of 78% and specificity of 52.4%, with an Area Under the Curve (AUC) value of 0.747, indicating a predictive strength of 74.7%. In the study by Nakamichi et al., which assessed Outlet CSA using an ultrasound probe with a speed of 5-10 MHz, it was found that Outlet CSA was significantly larger in CTS patients compared to normal subjects (P < 0.05).[23]

In the results of this study, the Inlet/Outlet Ratio was also measured in ultrasound (USG), and it was found that the measurement of Inlet/Outlet Ratio was not significant in predicting the confirmation of Carpal Tunnel Syndrome (CTS) diagnosis, with a P-value of 0.087 (P > 0.05). Using a cutoff point of 0.76, the results showed a sensitivity of 61.9% and specificity of 58.5%, with an Area Under the Curve (AUC) value of 0.634, indicating a predictive strength of 63.4%. According to previous research, the CSA Inlet parameter has proven to be effective and can be used to assist in diagnosing carpal tunnel syndrome, and similarly, the CSA Outlet parameter also shows positive correlation

but is not as widely used compared to CSA Inlet.

In the Chi-Square test results for EMG and USG in confirming the diagnosis of CTS (P = 0.525), it indicates that USG can be used as a diagnostic tool for CTS. A study by Azman et al. stated a positive correlation between ultrasound examination results and the diagnosis of carpal tunnel syndrome based on the Padua classification. Parameters with the highest correlation include: CSA Inlet 0.71 (P < 0.001), CSA Outlet 0.61 (P < 0.001), and CSA Mid-carpal 0.45 (P < 0.001). Meanwhile, according to the study by Ha et al., CSA Inlet has a correlation of 0.32 (P = 0.02), and CSA Outlet has a correlation of 0.23 (P = 0.09) with the diagnosis of carpal tunnel syndrome based on the Bland classification.20 According to the study by Lee et al., there was a consensus in establishing a relationship between the results of ultrasonography examinations and patients confirmed by EMG.[29]

In this study, further analysis was conducted using box plots to determine the upper and lower limits for each degree based on the previously defined cut-off points from the ROC curve. The study found that a Mid-carpal CSA value of 11.50 - 14.00 mm² is classified as mild, while 14.50 mm² to 15.00 mm² is classified as moderate, and values above 15.00 mm² are considered severe. Cross-tabulation analysis revealed that 38 samples with positive EMG-NCV results (degrees 1, 2, 3) also showed positive CTS results on USG (degrees 1, 2, 3), and 3 patients exhibited normal USG results. Additionally, 9 samples with normal EMG results showed positive USG results with degrees 1, 2, and 3, while 12 samples had normal results in both USG and EMG. Chi-square analysis indicated a significant association between USG degrees and EMG-NCV degrees (p = 0.00).

Several studies have identified similar USG cut-off points distinguishing various levels of CTS severity, including: 10.0–13.0 mm² for mild, 13.0–15.0 mm² for moderate, and >15.0 mm² for severe Mid-carpal CSA. In other research, severity ranges were almost similar: 12 ± 3 mm² for mild CTS, 15 ± 3 mm² for moderate CTS, and 19 ± 6 mm² for severe CTS. Moran et al. reported Inlet CSA values of 10.8 ± 1.9 mm², 11.4 ± 1.8 mm², and 12 ± 1.5 mm² for patients with mild, moderate, and severe CTS, respectively.

Differences in research results can also be influenced by several factors, such as variations in sample populations or geographic differences, which may impact research outcomes over time. Advanced measurement techniques or new discoveries in medical research can also affect study results. Clear visualization of the median nerve immediately distal to the carpal tunnel requires high-quality ultrasonography equipment and proficient ultrasound techniques to accurately define nerve boundaries. The slightly curved nature of the palm, thickness of the palm's skin, relatively deep location, and diagonal path of the nerve may slightly disrupt the clear visualization of this median nerve segment. This may explain the variations in cut-off point results observed in different studies.

Ancillary tests with wrist ultrasound can be utilized as a diagnostic method more widely available in hospitals compared to Electromyography-Nerve Conduction Velocity in supporting the confirmation of carpal tunnel syndrome diagnosis. Furthermore, from this study, wrist ultrasound can determine the severity level of carpal tunnel syndrome. However, the researchers recommend that further research with a larger sample size be conducted to

make the results more representative in determining the severity levels of carpal tunnel syndrome through ultrasound examinations.

CONCLUSION

Diagnostic testing with ultrasound (Mid-Carpal CSA) is sensitive and accurate in diagnosing carpal tunnel syndrome, but lacks specificity. There is a correlation between diagnostic ultrasound testing and the severity of carpal tunnel syndrome.

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