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COMPARISON OF MEDIAN NERVE CROSS-SECTIONAL AREA AT THE PISIFORM AND HOOK OF HAMATE LEVELS USING ULTRASONOGRAPHY IN CARPAL TUNNEL SYNDROME

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Abstract

Introduction: *Carpal tunnel syndrome (CTS) is the most common entrapment neuropathy and results from compression of the median nerve at the wrist. High-resolution ultrasonography is a non-invasive, low-cost tool for assessing nerve swelling, yet the best measurement level and cutoff values remain debated.*

Objective: *To compare median nerve cross-sectional area (CSA) at the pisiform and hook of hamate levels, with a pronator quadratus forearm reference, in patients with CTS.*

Methodology: *This cross-sectional analytical study was conducted at Gulberg Medical Center, Islamabad, over nine months. A total of 118 participants were recruited by non-probability purposive sampling. Median nerve CSA was measured with a Toshiba Xario-Prime system using a 7–14 MHz linear transducer at the pisiform, hook of hamate and pronator quadratus levels. Intraneural vascularity was assessed with power Doppler. Paired t-tests, repeated-measures ANOVA, chi-square tests and receiver operating characteristic (ROC) analysis were applied.*

Results: *Mean age was 53.6 ± 9.0 years and 76.3% were female. Mean CSA was 16.82 ± 3.32 mm² at the pisiform, 12.60 ± 2.32 mm² at the hook of hamate and 7.11 ± 0.89 mm² at the pronator quadratus ($p < 0.001$). Hypervascularity was present in 68.6%, and surgery was recommended in 80.5%. A pisiform CSA of at least 13.0 mm² identified surgical candidates with 97.9% sensitivity, 100% specificity and an area under the curve of 0.998.*

Conclusion: *Median nerve CSA is greatest at the pisiform level and falls progressively distally. Pisiform CSA combined with power Doppler is a practical basis for sonographic assessment and surgical triage in CTS,*

although validation against electrodiagnostic testing and healthy controls is still needed.

INTRODUCTION

Carpal tunnel syndrome (CTS) is the most common compression neuropathy and results from entrapment of the median nerve at the wrist [1,2]. Early diagnosis and adequate treatment, whether conservative or surgical, are therefore essential for optimal patient management. In United States working populations reported a prevalence of 7.8% and an incidence of 2.3 per 100 person-years, with higher rates among women and among people older than 50 years [3].The carpal tunnel can be divided into a proximal part at the level of the pisiform bone and a distal part at the level of the hook of the hamate. These bony structures serve as landmarks for quantitative analysis of the median nerve [4]. The ventral border of the tunnel is formed by the flexor retinaculum, which is thickest distally, and the median nerve lies just beneath it in close relation to the tendons of flexor pollicis longus and flexor digitorum superficialis [4]. The median nerve is the only nerve that passes through the tunnel [5]. The pisiform is a small sesamoid bone of the proximal carpal row. It forms part of the ulnar border of the tunnel and gives attachment to the flexor retinaculum, flexor carpi ulnaris and abductor digiti minimi [6,7]. The hook of the hamate projects from the palmar surface of the hamate, forms the ulnar border of the tunnel and receives the transverse carpal ligament [6].Diagnosis is mainly clinical, based on history and examination with Tinel's sign, Phalen's test and the direct compression test, and it is supported by ultrasound [8]. Treatment depends on severity, duration of symptoms and patient preference. Splinting, physical therapy and corticosteroid injection are tried first, and surgical release of the transverse carpal ligament is considered when they fail, although operative release slows recovery and carries a risk of morbidity [8]. A reliable imaging marker that separates patients who need surgery from those who can be managed conservatively would therefore be clinically useful.High-resolution ultrasonography has become an established tool for upper-limb entrapment neuropathies [9]. It is simple, rapid, relatively inexpensive and non-invasive, and it can show altered nerve echogenicity, increased CSA and bowing of the flexor retinaculum [10]. Median nerve swelling is the most predictive sonographic parameter, yet there is no consensus on cutoff values, and indices that compare the swollen nerve with a reference level in the same patient have been proposed so that each patient acts as his or her own control [11]. Power Doppler is more sensitive than colour Doppler to slow flow and can reveal the hypervascular neural pattern that accompanies entrapment [12].Published work supports these tools but varies in design and measurement level. In 62 patients scheduled for surgery, Kapuścińska and Urbanik found nerve compression in every case, a mean CSA of 17.45 mm^2 proximal to the pisiform, hypoechogenicity in all patients and increased vascularity in 80.65% [13]. Gamil et al. reported a mean wrist CSA of 17 mm^2 in patients versus 8 mm^2 in controls; wrist CSA gave 95% sensitivity and 88% specificity at its cutoff, and power Doppler was the most specific parameter (100%) but the least sensitive (76%) [14]. Lu et al. found significantly larger pisiform-plane CSA in patients, and a 10 mm^2 threshold gave 92% sensitivity and 86% specificity [15]. Mohammadi et al. showed that hypervascularity, retinacular bowing and CSA increased with severity confirmed by nerve conduction study [16], and Kasius et al. found that CSA was enlarged in most patients with severe CTS, so atrophy does not explain negative scans [17]. Roll et al. reported moderate to strong correlations between electrodiagnostic results and CSA at the pisiform, whereas the flattening ratio showed none [18]. In 117 participants, a wrist-to-forearm CSA difference and hypervascularity gave high sensitivity but low specificity [19], and in 200

hospital workers CTS was diagnosed sonographically in 34% [20].Because the measurement level and cutoff still differ between studies [18,21], a direct comparison of CSA at the pisiform and hook of hamate levels, referenced to the forearm within one cohort, remains worthwhile. The aim of this study was to compare the median nerve CSA measured at the level of the hook of hamate and the pisiform bone, using the pronator quadratus level as a baseline, in patients with CTS on ultrasonography.

METHODOLOGY

Study design, setting and duration

This was a cross-sectional analytical study conducted at Gulberg Medical Center, Islamabad, over nine months after approval of the synopsis. The protocol was approved by the institutional ethical review committee of the University of Lahore.

Participants and sampling

Participants were recruited by non-probability purposive sampling. Symptomatic patients with wrist or hand pain, nocturnal paranesthesia, or positive Tinel's or Phalen's signs radiating towards the fingers were eligible, together with asymptomatic age-matched individuals from the same area. Pregnant women and patients with previous median nerve surgery were excluded. Patients with prior surgical release of the flexor retinaculum, wrist trauma or fracture, or systemic polyneuropathy were also excluded. The sample size was calculated with $n = z^2pq/d^2$, where $q = 1 - p$, using a 90% confidence level ($z = 1.645$), a 6% margin of error and an expected proportion of 80.64% for patients selected for surgery after high-resolution ultrasonography [13]. This gave 117.4, which was rounded up to 118 participants.

Ultrasound technique

Examinations were performed with a Toshiba Xario-Prime system using a 7–14 MHz linear array transducer, which is the preferred probe for CTS studies [22]. Patients sat with the forearm supine on a firm, flat support and the wrist in a neutral position. Transverse images were obtained at three levels: the pisiform bone at the distal wrist crease, the hook of the hamate, and the pronator quadratus muscle in the distal forearm, which served as the baseline reference [23]. Minimal probe pressure was used to avoid artificial flattening of the nerve. Patients also moved from finger extension to a clenched fist and back, so that sliding of the median nerve against the flexor tendons could be observed on dynamic imaging.

Variables and measurements

For each patient the following data were recorded on a standard proforma: age, sex, pain, edema, grayscale findings, median nerve CSA in mm^2 at each level, fluid collection, vascularity, blood flow pattern, site of compression and the surgical recommendation. Grayscale sonography was used to assess median nerve edema and bowing of the flexor retinaculum. Intraneural hypervascularity and blood flow were assessed with power Doppler. The compression site was recorded as the hook of the hamate, the pisiform bone or the pronator quadratus level. Surgical release was recommended on the basis of clinical severity and sonographic features, namely nerve swelling, hypervascularity and retinacular bowing. All cases were idiopathic CTS diagnosed clinically from history, including nocturnal discomfort and sensory impairment in the median nerve distribution.

Statistical analysis

Data were entered in Microsoft Excel and analysed with statistical software (SPSS version 24 was specified in the protocol). Continuous variables are presented as mean ± standard deviation, with median and interquartile range where relevant, and categorical variables as frequencies and percentages. Paired t-tests compared CSA between levels, and repeated-measures ANOVA compared the three levels together. An independent t-test compared CSA between the surgical and conservative groups, and chi-square tests assessed associations between categorical variables. ROC analysis evaluated pisiform CSA, and sensitivity, specificity,

predictive values and accuracy were calculated at the optimal cutoff with 95% confidence intervals. A p-value below 0.05 was considered significant.

RESULTS

Baseline characteristics

A total of 118 patients were analysed. The mean age was 53.6 ± 9.0 years (range 29–76 years), and 90 patients (76.3%) were female. Pain was reported by 112 patients (94.9%), perineural edema was present in 71 (60.2%), and intraneural hypervascularity was present in 81 (68.6%). Surgery was recommended for 95 patients (80.5%), which closely matched the 80.64% assumed in the sample size calculation (Table 1).

Table 1. Baseline demographic and clinical characteristics (n = 118)

Variable	Value (n = 118)	Percentage
Age	53.6 ± 9.0	-
Gender	90 / 28	76.3% / 23.7%
Wrist pain	112 / 6	94.9%
Perineural edema	71 / 47	60.2%
Intraneural hypervascularity	81 / 118	68.6%
Surgical recommendation	95 / 118	80.5%

Median nerve CSA across the three landmarks

Median nerve CSA was largest at the pisiform level and fell progressively towards the hook of the hamate and the pronator quadratus (Table 2, Figure 1). The mean CSA was 16.82 ± 3.32 mm² at the pisiform, 12.60 ± 2.32 mm² at the hook of hamate and 7.11 ± 0.89 mm² at the pronator quadratus. In every one of the 118 patients the pisiform CSA exceeded the hook of hamate CSA. A paired t-test showed a mean difference of 4.22 mm² between the pisiform and hook of hamate levels ($t = 15.43$; $p < 0.001$), and the difference between the pisiform and pronator quadratus was also significant ($t = 31.39$; $p < 0.001$). Repeated-measures ANOVA confirmed a highly significant gradient across the three planes ($F = 488.72$; $p < 0.001$).

Table 2. Median nerve cross-sectional area at the three anatomical landmarks

Landmark	Mean CSA (mm²)	SD (mm²)	Median (IQR)	Test statistic	p-value
Pisiform bone	16.82	3.32	17.14 (4.50)	Reference	—
Hook of hamate	12.60	2.32	12.41 (3.58)	t = 15.43	< 0.001
Pronator quadratus	7.11	0.89	7.19 (1.03)	t = 31.39	< 0.001

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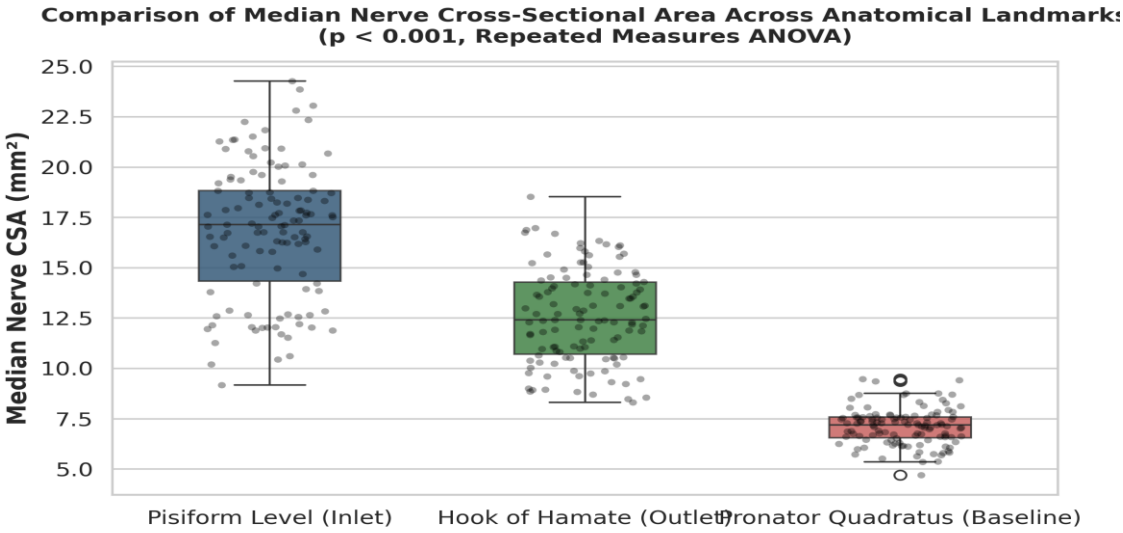


Figure 1. Comparison of median nerve CSA across the pisiform, hook of hamate and pronator quadratus landmarks ($p < 0.001$, repeated-measures ANOVA).

Patients recommended for surgery had significantly larger pisiform CSA than those managed conservatively (18.04 ± 2.41 mm^2 versus 11.80 ± 0.91 mm^2; $t = 12.19$; $p < 0.001$). The same pattern was present at the hook of hamate level (13.28 ± 2.02 mm^2 versus 9.78 ± 0.90 mm^2). The pisiform and hook of hamate measurements were moderately correlated ($r = 0.49$), and the mean pisiform-to-hook of hamate ratio was 1.36 (range 1.07–2.42). Age was not correlated with pisiform CSA ($r = -0.09$; $p = 0.35$).

Compression site and surgical recommendation

The pisiform level was the dominant compression site, accounting for 94 patients (79.7%), followed by the pronator quadratus level in 22 (18.6%) and the hook of the hamate in 2 (1.7%). Surgery was recommended for 91 of 94 patients (96.8%) with pisiform-level compression and for both patients with hamate-level compression. In contrast, only 2 of 22 patients (9.1%) with pronator quadratus-level compression were recommended for surgery (Table 3, Figure 2).

Table 3. Primary site of compression and surgical recommendation

Anatomical site	Total, n (%)	Surgery recommended	Conservative management
Pisiform bone	94 (79.7%)	91 (96.8%)	3 (3.2%)
Hook of hamate bone	2 (1.7%)	2 (100.0%)	0 (0.0%)
Pronator quadratus muscle	22 (18.6%)	2 (9.1%)	20 (90.9%)

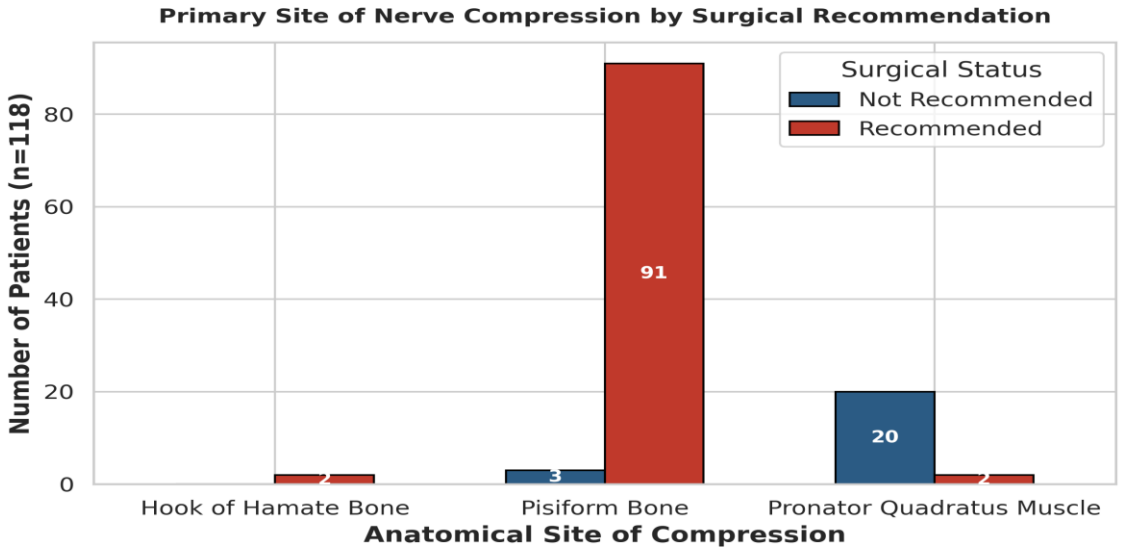


Figure 2. Primary site of nerve compression stratified by surgical recommendation (n = 118).

Power Doppler vascularity and blood flow

Power Doppler detected intraneural hypervascularity in 81 patients (68.6%). Increased blood flow was seen in 80 of these, one had a normal flow pattern, and all 37 patients without hypervascularity (31.4%) had normal flow (Figure 3). Hypervascularity was strongly associated with surgical recommendation ($\chi^2 = 44.30$; $p < 0.001$). Surgery was recommended for 79 of 81 hypervascular patients (97.5%) but also for 16 of 37 patients without hypervascularity (43.2%) (Table 4).

Table 4. Intraneural hypervascularity and surgical recommendation

Hypervascularity	Total, n (%)	Surgery recommended	Conservative management
Present	81 (68.6%)	79 (97.5%)	2 (2.5%)
Absent	37 (31.4%)	16 (43.2%)	21 (56.8%)

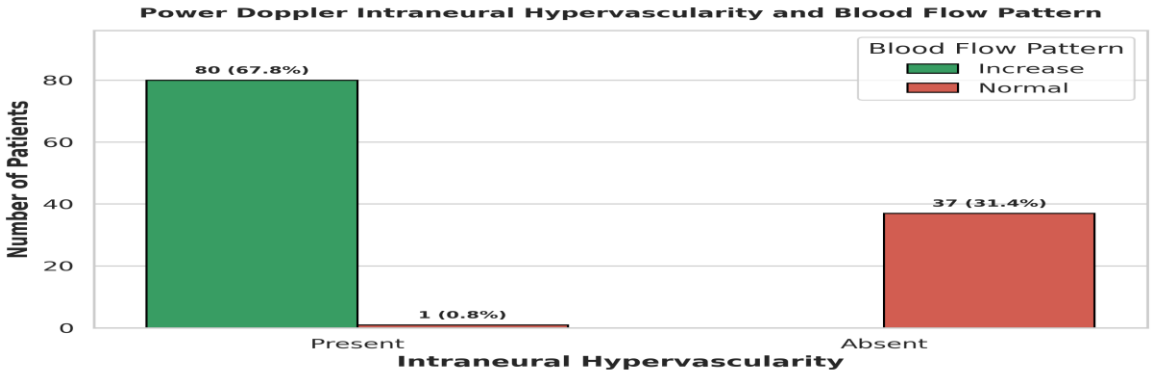


Figure 3. Intraneural hypervascularity and blood flow pattern assessed by power Doppler sonography.

Diagnostic performance of pisiform CSA

ROC analysis of the pisiform CSA gave an area under the curve (AUC) of 0.998 (95% CI 0.992–1.000; Figure 4). At the optimal cutoff of 13.0 mm² or more, the test classified 93 patients as positive, all of whom were recommended for surgery, and 25 as negative, of whom 23 were managed conservatively and 2 were recommended for surgery. This corresponded to a sensitivity of 97.9%, a specificity of 100.0% and an overall accuracy of 98.3% (Table 5). The reference standard for these estimates was the surgical recommendation.

Table 5. Diagnostic performance of pisiform CSA at a cutoff of 13.0 mm² or more

Diagnostic metric	Estimate (%)	95% confidence interval
Sensitivity	97.9	93.2–99.5
Specificity	100.0	85.2–100.0
Positive predictive value	100.0	96.1–100.0
Negative predictive value	92.0	85.0–98.2
Overall accuracy	98.3	94.2–99.8

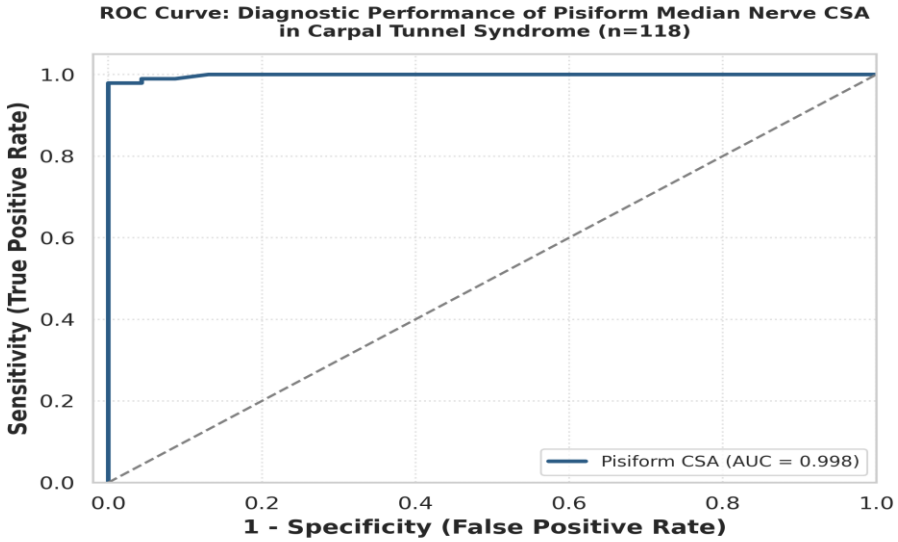


Figure 4. ROC curve for pisiform median nerve CSA (AUC = 0.998).

DISCUSSION

This study compared median nerve CSA at three standardised levels in 118 patients. The main finding is a consistent proximal-to-distal gradient: CSA was highest at the pisiform, lower at the hook of hamate, and close to a forearm baseline at the pronator quadratus. The pisiform value exceeded the hook of hamate value in every patient, and the repeated-measures analysis confirmed the gradient. Nerve swelling was therefore greatest at the tunnel inlet, which fits the view that the nerve enlarges just proximal to the point where it meets the rigid flexor retinaculum, which is thickest distally [4,12]. A similar inlet-versus-outlet comparison underlies the ratio proposed by Zhang et al., who related it to CTS severity [11].The mean pisiform CSA of 16.82 mm² is close to values reported elsewhere. Kapuścińska and Urbanik found 17.45 mm² in patients scheduled for surgery [13], and Gamil et al. found 17 mm² in patients with suspected CTS [14]. Our surgical subgroup, at 18.04 mm², was slightly higher than the former, which is plausible because both groups were selected for operative

treatment. The forearm baseline of 7.11 mm² is similar to the 8 mm² that Gamil et al. reported for healthy controls [14], supporting the use of the pronator quadratus level as a reference for the unaffected nerve. Roll et al. likewise found that CSA at the pisiform was among the measurements that correlated best with electrodiagnostic findings [18], and Lu et al. showed larger pisiform-plane CSA in patients than in controls [15].Hypervascularity was present in 68.6% of our patients, somewhat less often than the 80.65% reported by Kapuścińska and Urbanik [13]. Its association with surgical recommendation was strong, in line with the correlation between Doppler findings and severity described by Mohammadi et al. [16]. Almost every hypervascular patient was offered surgery (97.5%), yet 43.2% of patients without hypervascularity were also offered surgery. Power Doppler therefore appears highly specific but not sufficiently sensitive to be used alone, which mirrors the specificity of 100% and sensitivity of 76% reported by Gamil et al. [14]. Combining grayscale CSA with Doppler findings is a sensible approach. A caveat is that hypervascularity was one of the features used to reach the surgical decision, so part of this association is built in.The demographic profile was typical. Women made up 76.3% of the cohort and the mean age was 53.6 years, consistent with the higher rates reported in women and in people older than 50 years [3]. Pain was almost universal and edema was common. Age did not correlate with CSA, so the gradient is unlikely to be explained by age alone.The diagnostic figures need careful interpretation. An AUC of 0.998 is much higher than values published for CSA against electrodiagnostic reference standards, such as 0.759–0.899 in the study by Roll et al. [18] and 0.58–0.59 in the study by Gonzalez-Suarez et al. [19]. Three features of our design probably explain the difference. The reference standard was the surgical recommendation rather than nerve conduction study, and that recommendation drew partly on the same sonographic findings. The cohort contained almost no healthy controls, so specificity reflects separation of surgical from conservative patients rather than patients from non-patients. The cutoff was also derived and tested in the same sample. The 13.0 mm² threshold should thus be read as a marker of surgical-grade swelling in symptomatic patients, not as a validated diagnostic cutoff for CTS. It sits above the 10 mm² threshold of Lu et al. [15], which was set against controls.Two further observations are clinically relevant. First, two patients with a pisiform CSA below 13.0 mm² were still recommended for surgery, which supports the view that CSA alone cannot capture every case. Kasius et al. also cautioned that nerve size and test results do not always track severity in a simple way [17]. Second, the 22 patients assigned to the pronator quadratus level had a lower mean pisiform CSA (11.75 mm²) and were mostly managed conservatively. This suggests that the pronator quadratus group represents milder or less localised disease. Because that level lies in the forearm rather than within the tunnel, this category should be interpreted cautiously.

RECOMMENDATIONS

Future studies should include a matched group of healthy controls and electrodiagnostic confirmation so that cutoffs can be validated against an independent reference standard. Multicenter recruitment and a separate validation cohort would reduce the risk of overfitting. Inter-observer and intra-observer reliability should be reported, and measurement landmarks should be standardised across centers. In routine practice, sonographic assessment of suspected CTS can start with median nerve CSA at the pisiform level, with the hook of hamate and forearm levels used for comparison. Power Doppler should be added to grayscale measurements to document intraneural hypervascularity. Surgical decisions should continue to combine clinical severity with imaging, and postoperative follow-up should be linked to the baseline findings.

CONCLUSION

Median nerve CSA is greatest at the pisiform level, lower at the hook of hamate and near

baseline at the pronator quadratus, with a highly significant gradient across the three landmarks. Intraneural hypervascularity on power Doppler was strongly associated with surgical recommendation. A pisiform CSA of 13.0 mm^2 or more separated surgical from conservative patients almost perfectly in this cohort. These findings support pisiform-level CSA measurement with power Doppler as a practical sonographic approach in CTS, but validation against nerve conduction studies and healthy controls is needed before the cutoff is used diagnostically.

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