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Comparing Shape Categorization to Circularity Measurement in the Evaluation of Median Nerve Compression Using Sonography

Buwen Yao, MBBS, **Kayla Gan**, **Annie Lee**, **Shawn C. Roll, PhD, OTR/L, RMSKS, FAOTA, FAIUM**
Chan Division of Occupational Science and Occupational Therapy, University of Southern California, Los Angeles, CA

Abstract

Purpose—This study aimed to develop a subjective categorization of nerve shape and to examine the relationship of shape categorizations to measurement of nerve circularity.

Methods—Wrists were evaluated with sonography in healthy participants. Images of the median nerve were obtained in the transverse plane at the level of pisiform with the fingers resting, gripping, and pinching. Nerves were categorized as ovoid, angular, or irregular, and the cross-sectional area and perimeter were measured to calculate nerve circularity.

Results—Across 167 participants, the median nerve shifted from being primarily ovoid at rest to angular shaped when the fingers were in a full fist or pinching. Approximately three-quarters of subjects exhibited a shape change during dynamic movement. Irregular nerves had the lowest circularity values; however, the majority of nerves had similar circularity measures despite having different shapes.

Conclusions—Subjective categorization of shape has the potential to be a valid technique for evaluation of the median nerve using sonography, and this evaluation may provide additional information regarding nerve compression that is not fully captured by a circularity measure. Further investigation is needed to determine how these two techniques may be best used individually or together to advance clinical diagnosis, prevention, and rehabilitative interventions.

Keywords

Sonography; carpal tunnel syndrome; median nerve; circularity

Carpal tunnel syndrome (CTS) is the most common nerve entrapment of the upper extremity caused by compression of the median nerve in the carpal tunnel.[1,2] Approximately 3.8% of the general population has CTS,[3] and the economic costs of CTS are a heavy burden to society.[4] Most cases of CTS are considered to be idiopathic;[5] however, several environmental risk factors are related to the condition, such as repetitive hand motions[6–8] and prolonged postures in extremes of wrist flexion or extension.[4] One underlying pathophysiologic theory behind these risk factors is that during hand motion the median nerve is deformed due to a combination of pressure and available space within the carpal

Corresponding Author: Shawn C. Roll, 1540 Alcazar Street, CHP 133, Los Angeles, CA 90089-9003, sroll@usc.edu.

tunnel.[9,10] For some hand motions or positions, the median nerve is more distorted and more vulnerable to pressures in the carpal tunnel.

Recently, sonography has been used to evaluate the median nerve in the carpal tunnel due to its ability to capture nerve anatomy and other advantages such as accessibility, low-cost, and noninvasiveness.[7,11] Most studies have used sonography to identify morphologic features and changes of the median nerve with quantitative measurements. Common nerve measures include cross-sectional area (CSA) and flattening ratio, that is, medial-lateral diameter divided by anterior-posterior diameter.[12–14] A less-common measure more recently appearing in literature is median nerve circularity.[15,16] Circularity is a measurement calculated using the CSA and perimeter of the median nerve (4π*CSA/perimeter^2), which indicates how close the median nerve's shape is to a circle.[15–17] Using circularity measurement, studies have shown that the median nerve is deformed during hand motions and during forced gripping, that is, when grip force increases, the median nerve becomes more flattened.[10,15,18–20] Identifying nerves that are more flat than round may serve as an indicator of increased compression, which is a risk factor for development of nerve pathology.

However, the quantitative measurement of circularity has several limitations. Calculating circularity is a challenging procedure that requires reliable and valid measurements of the CSA and perimeter of the median nerve. This process takes practice and time to develop the necessary skills and expertise. Calculating circularity also raises the potential for errors, because it is not an automatic value. Rather, the calculation requires additional steps beyond the measures directly reported on the machine or other imaging software. Additionally, current studies using circularity have conflicting results,[10,15,18–20] such that median nerves with a similar circularity can exhibit different shapes, which may correlate with different amounts of compression. The median nerve could be compressed by surrounding tendons and structures becoming flattened or irregular in shape during hand movement, or have a different circular or ovoid shape than when the hand is at rest due to varied compression by different surrounding tissues (e.g., slightly taller than longer vs. slightly longer than taller).

As such, it may be useful to further understand circularity by evaluating the amount of compression or variations in shape, thereby improving upon the use of circularity as a singular method for evaluating nerve pathology. Given the current limitations of circularity measurement and need for further refinement of our understanding of the applicability of the circularity measurement, we aimed to develop a subjective categorization of nerve shape and explore the usefulness of adding the proposed subjective categorization of nerve shape to existing protocols for measuring nerve circularity. This process can help to further a more nuanced understanding of nerve compression as it contributes to the identification of morphologic changes or individual morphologic patterns that are predictive of the onset of CTS in future research.

Methods

Participants

A total of 172 asymptomatic students were recruited from two universities between June 2015 to September 2018. Participants were excluded if they reported history of a carpal tunnel release surgery, median nerve pathology, or other polyneuropathy that involved the median nerve. Participants with bilateral bifid median nerves in the carpal tunnel were excluded. For participants with a unilateral bifid median nerve, the wrist with the bifid median nerve was excluded and the wrist with non-bifid median nerve was included in the final analysis. Demographic data including age, gender, ethnicity/race, and hand dominance were obtained via self-report. The study was approved by the institutional review board and written informed consent was signed by participants prior to participation in the study.

Ultrasound Technique

Participants were seated facing the sonographer with the shoulder adducted, elbow comfortably extended, the forearm fully supinated and resting on the table, and the hand in a relaxed position. Imaging was conducted using a Logiq-e portable sonography machine (GE Healthcare, Milwaukee, WI) with a 12-MHz linear array transducer, by two experienced musculoskeletal sonographers. The transducer was placed on top of the wrist with no additional force than the probe weight to the skin. Sonographic images were taken on both wrists by placing the transducer over the carpal tunnel at the level of pisiform in the transverse plane to obtain short-axis views of the median nerve.

Static images of carpal tunnel and median nerve were taken at three positions: resting, gripping, and pinching. For resting, the fingers were held in a naturally relaxed position, which resulted in slight composite flexion throughout all digits. During gripping, the participant started with the fingers fully extended, slowly flexed the fingers into a closed fist without any forceful gripping or squeezing with the fingers. After holding the closed fist for a brief moment, the participant opened the hand to a fully extended position. To capture the median nerve during pinching, participants held a pen in their hand using a tripod or modified tripod pinch, as if they were to write. While the pinch position was not standardized across participants, the technique was intended to capture the functional position most often used by each individual participant. Static images were obtained in both the resting and pinching positions, with image optimization focused on the median nerve. Dynamic cine clips were recorded while the participant completed the gripping motion, each lasting approximately 6 seconds. The sonographer ensured that the transducer was maintained in a stable position over the wrist throughout the motion, using pisiform as bony landmarks. Each image and cine clip were obtained at least twice to ensure that a high-quality, valid image was obtained for evaluation of the median nerve.

Image Analysis

Image Processing—Images and cine clips were archived and analyzed using ViewPoint 6 (GE Healthcare, Milwaukee, WI). Prior to analysis, all images within a participant file were screened to determine if a bifid nerve was present within the carpal tunnel. During this screening process, the resting and pinching images that most clearly depicted the median nerve were identified for analysis. Similarly, each of the cine clips were evaluated to select the clip that most clearly represented the median nerve throughout the movement of the fingers and was most stable as identified by no shifting of bony landmarks of pisiform within the frame. The rater then identified a frame at the start of the clip prior to initiation of movement and a frame in the middle of the cine clip where motion had paused, thus indicating the hand was in a full grip position. These frames were used along with the still images in the analysis of median nerve shape.

Nerve Shape—Through an iterative process of image review and discussion, the research team developed consensus on three categories of median nerve shape, which was followed by further iterations of image evaluation, review, and discussion to refine the evaluation criteria for categorizing nerve images. The research team consisted of a registered musculoskeletal sonographer and three students with limited previous sonography experience. As part of the criteria development process, three student raters analyzed nerve shapes in images obtained from the first 25 participants in the study across multiple rounds of 5–10 cases per round. In each round, we noted that a variety of shapes were represented within the images. Pairwise percent agreement between the three raters was calculated each time the raters completed analysis on a series of images, and the evaluation criteria were refined through discussions with the sonographer until the research team agreed upon definitions which resulted in acceptable inter-rater reliability (i.e., >80%). The final evaluation criteria used to categorize nerves into ovoid, angular, or irregular shapes are detailed in Table 1, and examples of nerve with each shape are shown in Figure 1. Using these criteria and the images or still frames selected in the screening process, the shape of the median nerve at the pisiform was subjective categorized for each wrist of every participant in the resting, gripping, and pinching position. All three trained raters evaluated images; only one rater categorized each image.

Shape Change—In addition to identifying the shape of the median nerve in specific static positions, the cine clips were subjectively evaluated to determine if the shape of the median nerve changed at any point during the gripping motion. Any indication that the nerve was compressed or impacted by the surrounding tendons or other structures during the gripping motion was recorded as a 'change.' This dynamic evaluation allowed for identification of nerve compression during functional movement, which may not be apparent if the shape of the median nerve were categorized as being same using static images at the beginning and end of the gripping movement. If the nerve shape remained the same and was not visually impacted by the surrounding structures during the entire gripping movement, shape change was recorded as 'no change.'

Nerve Circularity—Nerve circularity was calculated using the CSA and perimeter of the median nerve measured on the static images of resting, gripping, and pinching. A direct trace along the inner hyper-echoic border of the nerve was used to obtain CSA and perimeter.[21] CSA and perimeter of the nerve were measured three times and the average of the three measurements was used to calculate circularity as follows:[17]

$$\text{Circularity} = 4\pi * \text{CSA}/\text{perimeter}^2$$

Using this formula, a circularity of 1.0 indicates that the median nerve shape is a perfect circle; lower values are interpreted as the nerve being further away from a circle; however, the values do not indicate any distinct shape or type of compression on the nerve, merely that it is not circular.

Statistical Analysis

Descriptive statistics were calculated for all demographic data. A chi-squared test was performed to examine if median nerve shape and shape change was associated with hand dominance. A Shapiro-Wilk test for normality was performed for median nerve CSA, perimeter, and circularity data, confirming that these data were normally distributed; as such, these data were expressed and evaluated as parametric data using mean ± standard deviation (SD). A two-sample independent t-test was used to analyze the differences in the means of CSA, perimeter, and circularity between dominant and non-dominant sides. An analysis of variance was performed to examine differences in mean values of CSA, perimeter, and circularity between rest, grip, and pinch positions, and between three categorizations of nerve shapes. A post-hoc Bonferroni test was performed to identify the significant group differences. SPSS (IBM, version 24) was used for statistical analysis, and p-values of < 0.05 were considered statistically significant.

Results

A total of 172 asymptomatic participants were enrolled in the study. Five participants had bilateral bifid median nerves, resulting in data from 167 participants for the final analysis. These participants were predominately right-handed (92.2%) females (85.0%) who had a mean age of 24.6 ± 3.3 years (Table 2). Across the sample, 11 participants had a unilateral bifid median nerve in the carpal tunnel on their dominant hand, and 10 participants had a unilateral bifid median nerve in the carpal tunnel on their non-dominant hand. The analyses included data from 156 dominant wrists and 157 non-dominant wrists.

The frequency of the median nerve shapes across various finger positions in the static images and shape changes during dynamic gripping are reported in Table 3. When the hand is in the rest position, the largest number of the subjects exhibited an ovoid median nerve (48.7% and 38.2% for the dominant and non-dominant side, respectively), with the non-dominant hand having a higher proportion of irregularly shaped nerves with fewer ovoid nerves than the dominant hand ($p<.01$). In contrast, when gripping or pinching the majority of participants had an angular shape of the median nerve in both the dominant and non-dominant hands. Figure 2 depicts the distributions of median nerve shape across the three positions, highlighting a moderate shift in frequencies away from ovoid in resting to angular with grip and pinch. Despite moderate shifts in shapes between the start and end points of resting and gripping, approximately three-quarters of subjects exhibited a shape change at some point during the dynamic gripping movement (72.4% and 77.7% for the dominant and non-dominant side, respectively).

The mean and SD of median nerve CSA, perimeter, and circularity in resting, gripping, and pinching wrists for the dominant and non-dominate side are shown in Table 4. The mean CSA of the median nerve of the dominant wrist was significantly greater than the non-dominant wrist in gripping and pinching (p=0.001 and p=0.008, respectively), and the perimeter of the median nerve of the dominant wrist was significantly greater than the non-dominant wrist in pinching (p=0.013). There were no significant differences in average circularity measures of the nerve between the dominant and the non-dominant sides, nor between resting, gripping, and pinching positions.

Finally, the examination of differences in average CSA, perimeter, and circularity by nerve shape is presented in Figure 3. CSA measures were not found to be different among nerves of different shapes. In the dominant wrist, the average perimeter (14.14mm) was significantly larger and circularity (0.55) was significantly smaller for median nerves with irregular shapes as compared to the same measures in nerves with angular shape (12.85mm, $p<0.001$; 0.62, $p<0.001$ respectively) and ovoid shape (12.77mm, $p<0.001$; 0.65, $p<0.001$, respectively). These differences were also noted on the non-dominant side in similar magnitudes ($p<0.001$), with an additional significant difference in the circularity between ovoid (0.67) and angular (0.58) nerves (p=0.007). While the average circularity calculations across the three shape categories were significantly different, the range of values overlap across the categories. The ranges from 10% to 90% percentile for median nerve with the shape of ovoid, angular, and irregular were 0.54–0.79, 0.51–0.76, 0.45–0.69, respectively; 80.6% of all the median nerves had a circularity between 0.45 and 0.75 and were distributed across all three shape categories. Given these overlaps, these statistical differences in circularity may not be clinically meaningful. For example, as demonstrated in Figure 4, three median nerves each having a circularity of 0.63 may belong to three different shape categories due to differences in compression.

Discussion

The purpose of this study was to develop a subjective categorization of median nerve shape representative of the amount of compression on the nerve and explore the usefulness of adding the proposed subjective categorization of nerve shape to emerging measure of nerve circularity. We developed evaluation criteria for categorizing nerve shape into three categories, including ovoid, angular, and irregular. The median nerve was primarily found to be ovoid when the fingers were in a relaxed position, with the majority of nerves having an angular shape when the fingers were moved into a full fist or pinching to hold a pen for writing. While we explored the usefulness of these shape categorizations for concurrent measures of circularity, we found that subjective categorization provided additional information related to nerve compression. As sonography is being increasingly used to identify risk factors contributing to median nerve injury[15] and for diagnosis of carpal tunnel syndrome,[22,23] these findings may be useful for advancing both research and practice.

Circularity is a quantitative method to identify the roundness of an object in a 2-dimensional plane. Circularly was first suggested in 1927 by Cox, who measured the roundedness of sand grains using the formula noted in the methods section above.[17] This concept has been translated into healthcare as a means for detecting deformation of the median nerve, with multiple studies using this formula.[10,15,16,24] Others have used a reciprocal version of this formula were by the perimeter value is placed in the numerator and the area value is placed in the denominator.[18,19] In both methods a value of 1.0 suggests a perfect circle; however, in the original method lower values indicate the less a less circular object as opposed to higher values over 1.0 when using the reciprocal method. While both techniques provide an accurate measure of ciruculaty due to the fact that the same data inputs are used, the original formula may be easier to interpret and therefore should be used across the field to promote data comparision and eliminate confusion across studies.

Regardless of the method used, there is mixed evidence for the correlation between measures of median nerve circularity and finger positions. Cowley and colleagues noted a slight, non-significant decrease in median nerve circularity from 0.57 to 0.54 when the hand was in a neutral position versus a pinching.[15] Using the reciprocal formula, Yoshii and colleagues found a non-significant change in nerve circularity that increased from 1.69 to 1.75 when measured in full finger extension to full finger flexion.[19] This equates to a decrease in circularity from 0.59 to 0.57, when using normal circularity. Also using the reciprocal formula, Van Doesburg and colleagues reported a decrease in circularity that equates to 0.03 change (from 0.58 to 0.55) with finger movement.[18] In contrast, to these studies that may suggest that a nerve becomes less round with finger flexion, a fourth study noted that median nerve circularity improved when moving from finger extension to finger flexion (i.e., 0.52 to 0.55 using the original formula).

Results in our study showed slightly higher circularity but were similar to the first two studies noted above,[15,19] in that we did not find any significant difference in nerve circularity measures between resting, gripping, and pinching. However, irrespective of the position of the fingers, we were able to validate that circularity of the median nerve significantly decreased when the nerve was identified as ovoid shape versus angular or irregular. This was especially true for nerves with high circularity (>0.75) being primarily ovoid and angular and low circularity values (<0.45) being primarily irregular in shape. However, given that the majority of nerves had mid-range circularity values (0.45–0.75) that were distributed across all shape categories, circularity may be limited in providing clinically relevant information when values fall within this range. Instead the subjective categorization may be better at identifying nerve compression for these individuals than would be a circularity calculation alone.

As with providing additional information to circularity, subjective evaluation has other benefits in the examination of median nerve compression. Specifically, subjective assessment of dynamic cine clips identified that functional hand use such as gripping or pinching led to intermittent compression on the median nerve in approximately three-fourths of individuals. Moreover, the subject categorization identified a significant shift in the distribution of ovoid shaped nerves to angular or irregular shaped nerves when moving from resting to gripping or pinching. These finding are consistent with theories and literature that suggest the median nerve becomes compressed during finger movement.[15,25] Thus, subjective categorization has an advantage over circularity in that it can be evaluated dynamically rather than being limited to static images.

Both circularity and evaluation of shape or shape change may be useful in advancing research and practice for prevention and intervention for median nerve injury. It is important to further examine how each of these measures support the identification of nerve compression, to build upon the findings in our data. While a circularity calculation may be most useful when the values are higher or lower, a subjective examination of the nerve may be more important to identify either intermittent compression during dynamic activity or sustained compression due to finger positioning that results in change in shape. Employing these two techniques together further elucidate nuances of nerve compression that could be useful in research and practice. Future research should consider these measurement techniques individually and together to identify utility within clinical diagnosis and intervention, such that individualized care recommendations or splinting may be provided to assist a patient with CTS in minimizing movements that lead to compression. Alternatively, longitudinal studies could examine these measures to determine their ability to identify individuals at high-risk for development of median nerve pathologies, such as CTS, due to median nerve deformation during functional hand use.

Limitations

This article has several limitations as follows. Interpretation and use of our study findings is primarily limited by having only evaluated the measures in healthy participants. As such, we do not know how these measures would apply to individuals with median nerve pathologies who may have enlarged median nerves, edema, or other pathological considerations. Despite not being able to interpret our findings in clinical care, the results of our study showed potential usefulness of this subjective classification for median nerve shape. Translation of this work to determine the value of the classification system in differentiating high-risk populations from the normal population or as a support to diagnosis or treatment for individuals with CTS should be explored in future studies.

Conclusion

In our study, with a rather clear sonographic image, the shape of the median nerve in the carpal tunnel could be easily distinguished as ovoid, angular, or irregular by tracing inside the hypoechoic border of the median nerve. When compared to circularity, irregular shapes demonstrated the least amount of circularity as compared to ovoid shapes. Moreover, subjective evaluation of shape was more sensitive than circularity for identifying differences in nerve shape change during dynamic movement and in static images obtained in various finger positions. Shape change was highly prevalent in all individuals during movements and more angular and irregular shaped nerves were identified during functional positioning of the fingers than when at rest; differences circularity did not identify. These data suggest that a subjective evaluation may have additional value beyond what circularity may provide in the assessment of nerve compression for prevention, diagnosis, and intervention as a component of research and practice.

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References

1. Talbott NR. Prevalence of Carpal Tunnel Syndrome in a General Population. Physical Therapy. 1999;79(12):1226.
2. Papanicolaou GD, McCabe SJ, Firrell J. The prevalence and characteristics of nerve compression symptoms in the general population. Journal of Hand Surgery. 2001;26(3):460–466. [PubMed: 11418908]
3. Atroshi I, Gummesson C, Johnsson R, Ornstein E, Ranstam J, Rosen I. Prevalence of carpal tunnel syndrome in a general population. JAMA. 1999;282(2):153–158. [PubMed: 10411196]
4. Ibrahim I, Khan WS, Goddard N, Smitham P. Carpal tunnel syndrome: a review of the recent literature. Open Orthop J. 2012;6:69–76. [PubMed: 22470412]
5. Ashworth NL. Carpal tunnel syndrome. BMJ Clin Evid. 2014;2014:1114.
6. Toosi KK, Impink BG, Baker NA, Boninger ML. Effects of computer keyboarding on ultrasonographic measures of the median nerve. American Journal of Industrial Medicine. 2011;54(11):826–833. [PubMed: 21739468]
7. Jaeschke R, Thoirs K, Bain G, Massy-Westropp N. Systematic review: hand activity and ultrasound of the median nerve. Occupational Medicine. 2017;67(5):389–393. [PubMed: 28582584]
8. Ashworth NL. Carpal Tunnel Syndrome. Am Fam Physician. 2016;94(10):830–831. [PubMed: 27929273]
9. Ablove RH, Peimer CA, Diao E, Oliverio R, Kuhn JP, Buffalo N. Morphologic changes following endoscopic and two-portal subcutaneous carpal tunnel release. Journal of Hand Surgery. 1994;19(5): 821–826. [PubMed: 7806811]
10. Wang Y, Zhao C, Passe SM, et al. Transverse ultrasound assessment of median nerve deformation and displacement in the human carpal tunnel during wrist movements. Ultrasound Med Biol. 2014;40(1):53–61. [PubMed: 24210862]
11. Padua L, Coraci D, Erra C, et al. Carpal tunnel syndrome: clinical features, diagnosis, and management. The Lancet Neurology. 2016;15(12):1273–1284. [PubMed: 27751557]
12. Lu Y, Meng Z, Pan X, Qin L, Wang G. Value of high-frequency ultrasound in diagnosing carpal tunnel syndrome. Int J Clin Exp Med. 2015;8(12):22418–22424. [PubMed: 26885222]
13. Park D Ultrasonography of the Transverse Movement and Deformation of the Median Nerve and Its Relationships With Electrophysiological Severity in the Early Stages of Carpal Tunnel Syndrome. PM R. 2017;9(11):1085–1094. [PubMed: 28433831]
14. Chang Y-W, Hsieh T-C, Tzeng IS, Chiu V, Huang P-J, Horng Y-S. Ratio and difference of the cross-sectional area of median nerve to ulnar nerve in diagnosing carpal tunnel syndrome: a case control study. BMC Medical Imaging. 2019;19(1):52. [PubMed: 31272405]
15. Cowley JC, Leonardis J, Lipps DB, Gates DH. The influence of wrist posture, grip type, and grip force on median nerve shape and cross-sectional area. Clinical Anatomy. 2017;30(4):470–478. [PubMed: 28281294]
16. Bueno-Gracia E, Malo-Urriés M, Ruiz-de-Escudero-Zapico A, et al. Reliability of measurement of the carpal tunnel and median nerve in asymptomatic subjects with ultrasound. Musculoskeletal Science and Practice. 2017;32:17–22. [PubMed: 28800435]
17. Cox EP. A Method of Assigning Numerical and Percentage Values to the Degree of Roundness of Sand Grains. Journal of Paleontology. 1927;1(3):179–183.
18. Van Doesburg MHM, Henderson J, Yoshii Y, et al. Median nerve deformation in differential finger motions: Ultrasonographic comparison of carpal tunnel syndrome patients and healthy controls. Journal of Orthopaedic Research. 2012;30(4):643–648. [PubMed: 21953849]
19. Yoshii Y, Villarraga HR, Henderson J, Zhao C, An KN, Amadio PC. Ultrasound assessment of the displacement and deformation of the median nerve in the human carpal tunnel with active finger motion. J Bone Joint Surg Am. 2009;91(12):2922–2930. [PubMed: 19952256]

20. Marquardt TL, Gabra JN, Li Z-M. Morphological and positional changes of the carpal arch and median nerve during wrist compression. Clinical Biomechanics. 2015;30(3):248–253. [PubMed: 25661267]
21. Roll SC, Evans K. Feasibility of Using a Hand-Carried Sonographic Unit for Investigating Median Nerve Pathology. Journal of Diagnostic Medical Sonography. 2009;25(5):241–249.
22. Mhoon JT, Juel VC, Hobson-Webb LD. Median nerve ultrasound as a screening tool in carpal tunnel syndrome: Correlation of cross-sectional area measures with electrodiagnostic abnormality. Muscle & Nerve. 2012;46(6):861–870. [PubMed: 22996383]
23. Tai-Tzung K, Ming-Ru L, Yin-Yin L, Jiann-Perng C, Yen-Wei H, Chih-Kuang Y. Assessment of Median Nerve Mobility by Ultrasound Dynamic Imaging for Diagnosing Carpal Tunnel Syndrome. PLoS ONE. 2016;11(1):e0147051. [PubMed: 26764488]
24. Marquardt TL, Gabra JN, Li ZM. Morphological and positional changes of the carpal arch and median nerve during wrist compression. Clin Biomech (Bristol, Avon). 2015;30(3):248–253.
25. Van Doesburg MHM, Yoshii Y, Villarraga HR, et al. Median nerve deformation and displacement in the carpal tunnel during index finger and thumb motion. Journal of Orthopaedic Research. 2010;28(10):1387–1390. [PubMed: 20225286]

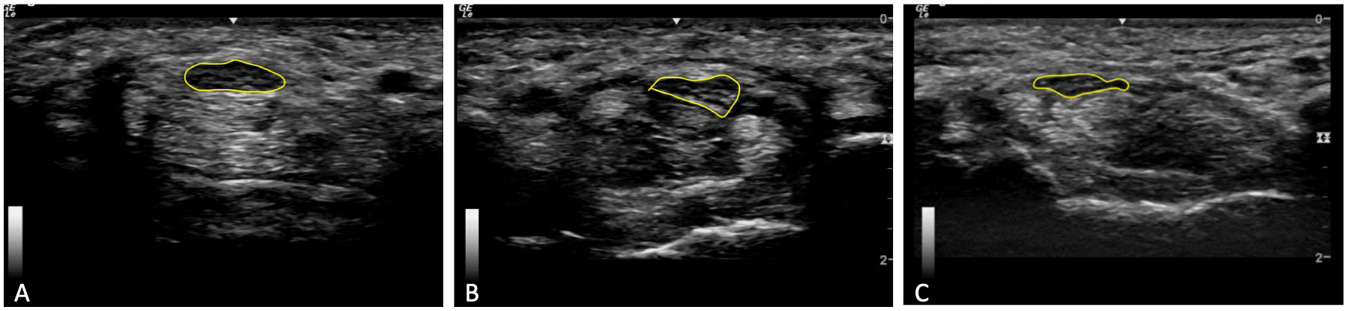

Figure 1.
Gray-scale transverse images taken of median nerve (yellow circle) at level of pisiform depicting three different categorizations of median nerve shape: (A) ovoid, (B) angular, and (C) irregular.

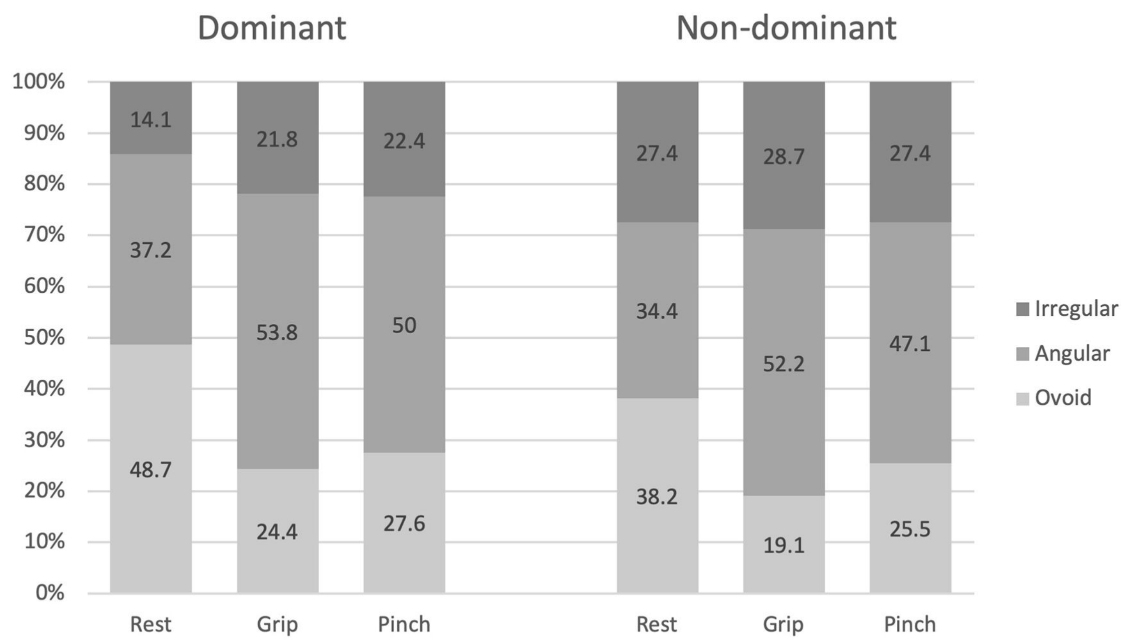

Figure 2.

The distribution of median nerve shape during hand rest, grip, and pinch for dominant (n=157) and non-dominant (n=156) wrists.

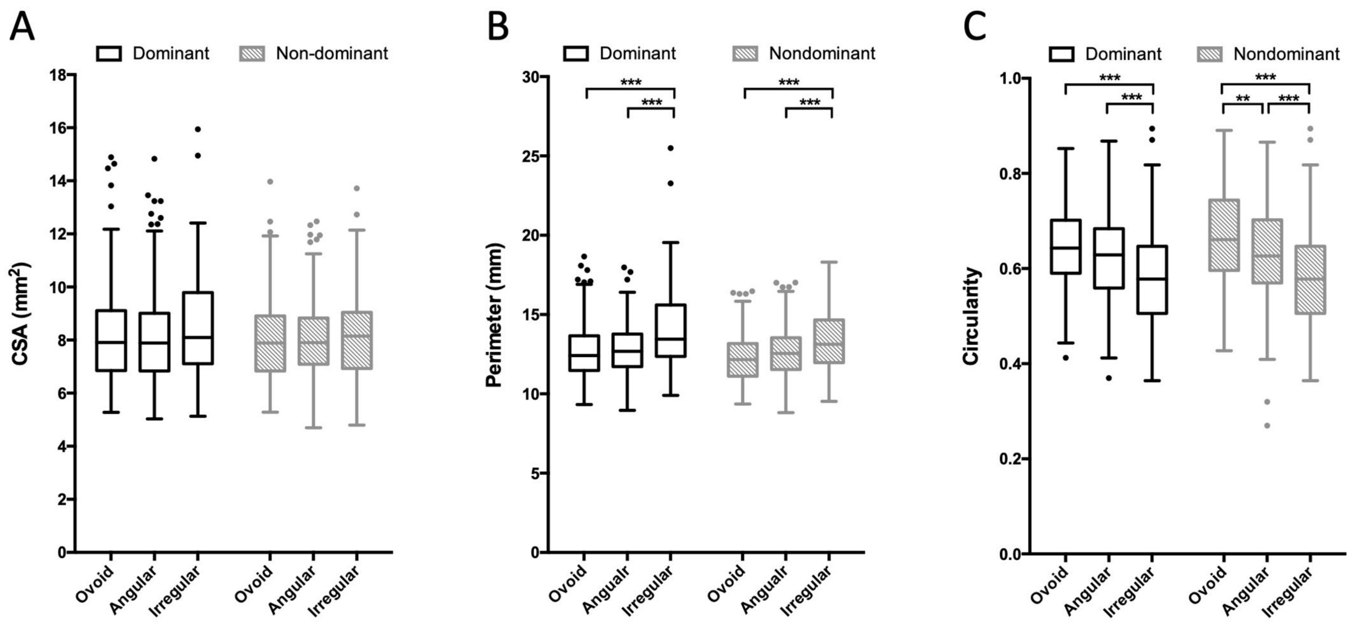

Figure 3.
Comparison of average cross-sectional area (CSA, A), perimeter (B), and circularity (C) among ovoid, angular, and irregular median nerves by hand dominance. Results of analysis of variance testing, with Bonferonni post-hoc testing for pairwise comparisons indicating significant differences: $^{**}P < 0.01$; $^{***}P < 0.001$.

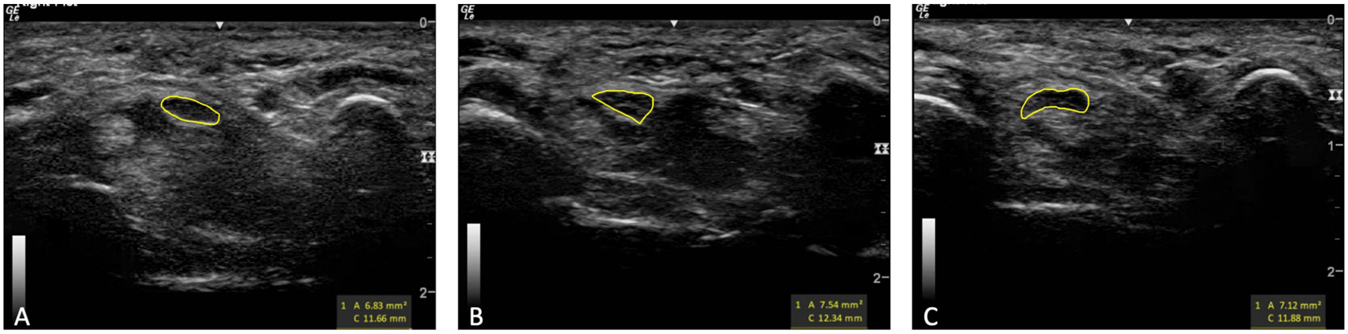

Figure 4.
Gray-scale transverse images taken at the level of pisiform within the carpal tunnel for measurement of the median nerve (yellow circle) shape and circularity, demonstrating three median nerves with similar circularity but different shapes due to varying amounts of compression by surrounding structures. (A) Ovoid median nerve with a circularity of 0.63. (B) Angular median nerve with a circularity of 0.62. (C) Irregular median nerve with a circularity of 0.63.

Table 1.

Evaluation criteria for categorizing median nerve shape within the carpal tunnel.

	Evaluation criteria
Ovoid	Ovoid was determined as a nerve with an "oval" shape with curved edges all around and no flat or angled sides. An ovoid median nerve was not impacted by any of the surrounding structures in a non-uniform manner, making it appear "free-floating."
Angular	Angular was defined as a nerve having at least one "flat" side causing an angle or sharp, distinctive change in direction when tracing the border of the nerve. Angular nerves could have two or three angles, to the extent of appearing like a triangle.
Irregular	Irregular was identified as a nerve compressed by multiple structures, causing a shape that could not be clearly characterized as ovoid or angular.

Table 2.

Descriptive statistics of participants enrolled in the study (n=167)

	Mean/Frequency (SD/%)*
Age, years	24.6 (3.3)
BMI, kg/m^2	23.3 (4.0)
Gender, male	25 (15.0%)
Handedness, right	154 (92.2%)
Race	
American Indian/Alaska Native	2 (1.2%)
Asian	64 (38.3%)
Native Hawaiian or other Pacific Islander	1 (0.6%)
Black	4 (2.4%)
White	74 (44.3%)
Other	22 (13.2%)
Ethnicity, Hispanic	41 (24.6%)

*Mean (SD) were calculated for continuous data and frequency (%) are reported for categorical data.

Table 3.

Distribution of median nerve shapes across finger positions in static images and shape change during dynamic gripping motion in the dominant and non-dominant sides.

	Dominant hand	Non-dominant hand	*p*-value*
Rest			
Ovoid	76 (48.7%)	60 (38.2%)	
Angular	58 (37.2%)	54 (34.4%)	0.01
Irregular	22 (14.1%)	43 (27.4%)	
Grip			
Ovoid	38 (24.4%)	30 (19.1%)	
Angular	84 (53.8%)	82 (52.2%)	0.29
Irregular	34 (21.8%)	45 (28.7%)	
Pinch			
Ovoid	43 (27.6%)	40 (25.5%)	
Angular	78 (50.0%)	74 (47.1%)	0.60
Irregular	35 (22.4%)	43 (27.4%)	
Shape change			
Yes	113 (72.4%)	122 (77.7%)	0.28
No	43 (27.6%)	35 (22.3%)	

*Chi-squared test

Table 4.

Comparison of mean ± SD of cross-sectional Area (CSA), perimeter, and circularity of the median nerve by finger position within the dominant (n=156) and non-dominant sides (n=157).

	Rest	Grip*	Pinch*	p-value**
CSA, mm²				
Dominant	8.09±1.57	8.53±1.97	8.33±2.05	0.12
Non-dominant	7.88±1.33	8.11±1.51	8.09±1.53	0.31
Perimeter, mm				
Dominant	12.75±1.43	13.42±2.19	13.06±2.13	0.01***
Non-dominant	12.62±1.51	12.92±1.77	12.77±1.65	0.27
Circularity				
Dominant	0.63±0.08	0.61±0.11	0.62±0.10	0.15
Non-dominant	0.63±0.09	0.62±0.11	0.63±0.11	0.66

* Two-sample independent t-test showed significant difference between dominant and non-dominant for grip CSA, pinch CSA, and pinch perimeter ($p < 0.05$).

** Analysis of variance was used to evaluate differences across the three finger positions within the dominant and non-dominant hands.

*** Bonferroni post hoc test showed a significant difference of mean perimeter between rest and grip in the dominant side.