A thorough understanding of the anatomy of the distal forearm, wrist, and hand is critical to maximize success and minimize complications during carpal tunnel release. This is particularly important in light of the currently used endoscopic and open techniques that emphasize a minimally invasive approach. While there are many reports on anatomical variations around the carpal tunnel, there is little mention of the median nerve (MN) in the distal forearm as it approaches the wrist. Most figures depict the MN as taking a linear course that parallels the long axis of the forearm (LAF). We have noted both in our clinical practice and in the anatomy laboratory that in many individuals the MN takes an angular approach to the carpal tunnel in the distal forearm. This places it at risk for injury during release of the proximal transverse carpal ligament (TCL) and distal forearm fascia (antebrachial fascia) or when instruments are passed parallel to the long axis of the arm across the wrist crease. In this report we attempt to quantify this angle and discuss its clinical significance.

**Methods**

**Measurements**

The right and left wrists of 38 formalin-fixed cadavers—20 female and 18 male, with a mean age of 81.6 years

**Abbreviations**

FCR = flexor carpi radialis; FDS = flexor digitorum superficialis; LAF = long axis of forearm; MN = median nerve; PL = palmaris longus; WR = wrist ratio.

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(range 57–104 years) at the time of death—were dissected to identify the MN, flexor carpi radialis (FCR) tendon, and palmaris longus (PL) tendon. (Fig. 1). Prior to dissection, each wrist was carefully inspected to identify previous surgical scars or obvious deformities. One wrist was excluded from analysis due to a severe arthritic deformity leaving 75 wrists for evaluation. Three measurements were recorded to the nearest half centimeter using calipers: 1) the width of the wrist at the distal volar wrist crease, 2) the distance from the center of the MN to the radial side of the wrist at the distal volar wrist crease, and 3) the distance between the distal volar wrist crease and the MN where it first becomes visible between the FCR tendon and the flexor digitorum superficialis (FDS) (Fig. 1). Next, a high-resolution digital photograph was taken of each wrist in its anatomical position. Two angles were then measured using ImageJ and recorded to 2 decimal places. The first measured angle was between the MN in the forearm and the LAF (Fig. 1). The second was the between the MN and the FCR tendon in the forearm (Fig. 1). Finally, the presence or absence of the PL was recorded. All measurements were completed by 2 independent observers.

Statistical Analysis

After excellent correlation was demonstrated between the 2 observers using linear regression to calculate an $R^2$ value, the 2 values obtained for each measurement were averaged and recorded. Descriptive statistics for the data sets, including the mean and median values, standard deviation, and 95% confidence intervals, were calculated and reported to 1 decimal place. A Student t-test was used to compare mean values for males versus females and for right versus left hands. The level of statistical significance was set at $p < 0.05$. A ratio of the distance from the MN to the radial side of the wrist and the total wrist width was calculated for each wrist and reported to 2 decimal places. This was then used to identify whether the MN was radial or ulnar to the center of the wrist and the wrist crease. A value less than 0.5 places the MN radial to midline while a value greater than 0.5 places the MN ulnar to midline (Fig. 1). A Student t-test was used to evaluate whether there was a statistically significant difference between the right and left hands or between females and males.

Results

Angle of the MN to the LAF

The mean angle of the MN to the LAF measured on 75 wrists was found to be 9.0° on the right wrist and 8.6° on the left wrist. Overall the mean angle was 8.8° (95% CI 7.3°–10.2°). Linear regression showed excellent correlation between the 2 independent observers, with a $R^2$ value of 0.99 (Table 1). There were 8 wrists (10.7%) in which the MN took a course perfectly parallel to the LAF with a LAF-MN angle of 0.00°. In 1 wrist (1.3%), the MN took a radial trajectory at 7.4°. In the remaining 66 (88%), the MN took an ulnar trajectory (Fig. 1).

Angle of the MN to the FCR Tendon

The mean FCR tendon–MN angle (measured on 75 wrists) was 13.7° on the right hand and 14.6° on the left hand. Overall, the mean FCR tendon–MN angle was 14.1° (SD 5.1°, 95% CI 13.0°–15.3°). Linear regression showed a $R^2$ value of 0.88 (Fig. 2).
Relative Position of the MN at the Wrist

The mean wrist width at the distal volar wrist crease (measured on 75 wrists) was 58.9 mm on the right and 57.6 mm on the left. Overall, the average wrist width was 58.2 mm (SD 6.4, 95% CI 56.8–59.7 mm). Linear regression revealed a $R^2$ value of 0.98.

The mean distance from the MN to the radial side of the wrist at the distal volar wrist crease (measured on 76 wrists) was 28.9 mm on the right and 28.4 mm on the left. Overall, the mean distance was 28.1 mm (SD 4.7, 95% CI 27.1–29.2 mm). Linear regression revealed a $R^2$ value of 0.96.

The mean ratios of the distance from the MN to the radial side of the wrist divided by the total wrist width (wrist ratio [WR]) were calculated to be 0.49 on the right and 0.48 on the left. Overall, the mean WR value was 0.48 (SD 0.06, 95% CI 0.47–0.50). The values ranged from 0.31 to 0.62. The MN was found to be radial to midline (WR < 0.50) in 46 wrists (60.0%) and ulnar to midline (WR > 0.50) in 24 wrists (32%) (Table 1).

Median Nerve to Wrist Crease

The mean distance between the wrist crease and the MN measured on 75 wrists was 34.4 mm on the right and 34.8 mm on the left. Overall, the mean distance between the wrist crease and the MN was 34.6 mm (SD 6.3 mm, 95% CI 33.2–36.0 mm) (Table 2).

Absence of PL Tendon

The absence of the PL was recorded on each wrist. The muscle was not present in a total of 14 (18.4%) of 76 wrists of 8 (21%) of 38 cadavers. In 6/76 the absence was bilateral. In 3 cadavers, the absence was bilateral. There was no association between presence or absence of the PL and the angles measured.

There were a few statistically significant differences between males and females. Not surprisingly, males were found to have a larger wrist width value ($p < 0.0001$) and a larger distance from the radial side of the wrist to the MN ($p < 0.0005$). There was no statistically significant difference between males and females when comparing the studied angles or the presence or absence of the PL. There were no statistically significant differences when comparing the right hand to the left.

Discussion

Because current endoscopic and open techniques of carpal tunnel release emphasize a minimally invasive approach, a thorough understanding of the anatomy and variants around the distal forearm, wrist, and hand is critical. There have been numerous reports and reviews regarding anatomy related to carpal tunnel surgery. Most reports detail the branching variations of the recurrent motor and palmar cutaneous sensory nerves as well

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**TABLE 1. Wrist ratio**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Right</th>
<th>Left</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SD</td>
<td>0.49 ± 0.06</td>
<td>0.48 ± 0.06</td>
<td>0.48 ± 0.06</td>
</tr>
<tr>
<td>95% CI</td>
<td>0.47–0.51</td>
<td>0.46–0.49</td>
<td>0.47–0.50</td>
</tr>
<tr>
<td>Min/max</td>
<td>0.33/0.61</td>
<td>0.31/0.62</td>
<td>0.31/0.62</td>
</tr>
<tr>
<td>No. (%) of specimens w/ MN radial to midline, WR &lt;0.50</td>
<td>21 (55.3%)</td>
<td>24 (63.2%)</td>
<td>46 (60.0%)</td>
</tr>
<tr>
<td>No. (%) of specimens w/ MN midline, WR = 0.50</td>
<td>3 (7.9%)</td>
<td>2 (5.3%)</td>
<td>5 (6.7%)</td>
</tr>
<tr>
<td>No. (%) of specimens w/ MN ulnar to midline, WR &gt;0.50</td>
<td>13 (34.2%)</td>
<td>12 (31.6%)</td>
<td>24 (33.3%)</td>
</tr>
</tbody>
</table>

MN = median nerve; WR = wrist ratio (ratio of the distance from the MN to the radial side of the wrist divided by the total wrist width).

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**FIG. 2.** The longitudinal axis of the forearm to median nerve angle (LAF-MN angle) and flexor carpi radialis tendon to median nerve angle (FCR tendon–MN) measurements from independent observers were averaged to provide a single value for each wrist (75 total). They were then rounded to the nearest whole number and plotted in a frequency distribution. The x-axis values indicate angle measurements in degrees.
as anatomical anomalies such as a bifid median nerve, a persistent median artery, and the presence of anomalous muscles and tendons.

Based on our clinical and anatomical experience noting a variable angle of approach of the MN to the carpal tunnel, we chose to evaluate the course of the MN in the distal forearm.

Quantification of the relative position of the MN across the wrist was done in our study. As expected based on the anatomical corridor of the carpal tunnel, the nerve position fell approximately within the middle third of the width of the wrist in all specimens and was on average just radial to midposition across the wrist (0.49 and 0.48 for the right and left, respectively). This is consistent with the report of Demircay et al., who described the MN at the carpal tunnel to be in midposition in 35% of cases, radial in 55%, and ulnar to midposition in 10%. To avoid injury to the MN, some recommend placing an incision/injection just ulnar to the PL tendon at the wrist. We found that the PL tendon was absent in 18.4% of limbs studied. This is within the broad range noted in prior reports.

Knowledge of the relative location of the MN at the wrist may be helpful in cases where the PL tendon is absent.

### Median Nerve Angle of Approach

While the position of the MN at the wrist is important, we argue that the angle the MN takes to reach the wrist while traveling in the forearm is equally important as it may make the nerve more susceptible to injury when instruments are passed across the wrist. The angle of the MN within the carpal tunnel has been described. Rotman and Donovan noted that it travels from superficial to deep at a 24° angle, and Demircay et al. noted the potential for a variable angle of the nerve in a radial/ulnar plane. No note, however, has been made of the angle of approach of the MN to the carpal tunnel in the distal forearm.

Many anatomy texts indicate a linear course of the MN parallel to the LAF. This is in keeping with the way that the nerve is illustrated, with rare exception, in most anatomical and surgical texts and reports. Table 2 demonstrates how the MN can become trapped and immobile between the tendons of the forearm when the wrist is placed in extension.

### Clinical Relevance

While carpal tunnel release is generally a safe procedure, nerve lacerations and transections are known to occur. When the MN takes an angular approach to the carpal tunnel, it is situated between the flexor tendons deep to the nerve and the distal forearm or antebrachial fascia and PL superficial to the nerve. An angularly coursing MN is at risk for injury when instruments are passed longitudinally across the wrist, particularly when the wrist is extended and the nerve is relatively tethered between FDS and the PL.

Knowledge of the relative location of the MN at the wrist may be helpful in cases where the PL tendon is absent.

<table>
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<td>34.6 ± 6.3</td>
</tr>
<tr>
<td>95% CI</td>
<td>32.2–36.5</td>
<td>32.9–36.7</td>
<td>33.2–36.0</td>
</tr>
<tr>
<td>Min/max</td>
<td>22.5/50.5</td>
<td>20.3/50.5</td>
<td>20.3/50.5</td>
</tr>
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</table>

*All measurements are in millimeters.*
Angular course of the median nerve in the distal forearm

intermittent acute shock-like pain some carpal tunnel syndrome patients note with wrist motion.

The variable MN angle should also be kept in mind in cases requiring reoperation, as the nerve can be difficult to localize within scar. An expectation on the part of the surgeon, that the nerve course should be parallel to the long axis of the arm, may lead to confusion and/or misidentification of a tendon for the median nerve. The knowledge that the MN is located on the ulnar side of the FCR tendon 3–5 cm proximal to the wrist crease may be helpful in cases of trauma or reoperation. Although not measured in this study, the palmar cutaneous branch of the median nerve has been demonstrated to arise from the anterolateral side of the median nerve approximately 5 to 6 cm from the transverse carpal ligament under the radial margin of FDS.12,26,41 This should also be considered during median nerve exploration above the wrist.

Study Limitations and Future Directions

A limitation of this paper is the fact that our measurements were done in a static setting in formalin fixed cadavers. Future studies will use ultrasound to assess changes in the angle in normal subjects with active and passive finger flexion and varying wrist position. This information will be important since nerve mobility is one of the variables assessed when utilizing ultrasound for the determination of carpal tunnel syndrome.5,7 This modality will also allow us to investigate changes in the course of the MN after carpal tunnel surgery. Additionally, some have suggested that an ulnar location of the median nerve is associated with more significant carpal tunnel syndrome.55 Determining whether the angle of approach of the median nerve is associated with a relative ulnar location of the nerve and/or severity of symptoms in a clinical population is another subject for future studies.

Conclusions

Despite its typical depiction, the median nerve ap-

References

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FIG. 3. Left: Coronal T1-weighted MR image of a right wrist with an enlarged and fibrotic MN as it takes an oblique course (white arrow) proximal to the wrist crease and then normal nerve traveling under the flexors in the forearm (hollow arrow). In this case, the incision was made in the palm proximal to the wrist crease (hollow arrowhead).

Pouched the carpal tunnel in the distal forearm at a mean angle of approximately 8.8° and was parallel to LAF in only 10% of limbs. This angle should be considered when performing carpal tunnel release in particular when the wrist is extended as this may cause the nerve to be relatively tethered between the PL tendon superficially and the FDS tendons deep, putting it at risk for injury.


37. Pierre-Jerome C, Smitson RD Jr, Shah RK, Sieg, Rizk, Harbaugh. Critical revising the article: Payne, Harbaugh. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Payne, Administrative/technical/material support: Glantz. Study supervision: Harbaugh.


Disclosures
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions
Conception and design: Payne, Harbaugh. Acquisition of data: Payne, Nasralah, Sieg, Rizk, Harbaugh. Analysis and interpretation of data: Payne, Harbaugh. Drafting the article: Payne, Nasralah, Sieg, Rizk, Harbaugh. Critically revising the article: Payne, Glantz, Harbaugh. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Payne, Administrative/technical/material support: Glantz. Study supervision: Harbaugh.

Supplemental Information
Videos

Previous Presentations
Portions of this work were presented in poster form at the 83rd AANS annual scientific meeting on May 6, 2015, in Washington, DC.

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