Biomechanics of median nerve during stretching assessing by ultrasonography

Journal:	*Journal of Applied Biomechanics*
Manuscript ID:	JAB.2015-0026.R1
Manuscript Type:	Original Research
Keywords:	biomechanics, physical therapy, ultrasound, neurophysiology

June 8, 2015

JAB_2015_0026. R1

Biomechanics of median nerve during stretching assessing by ultrasonography.

Jacinto Javier Martínez-Payá[1], José Ríos-Díaz[1], María Elena del Baño-Aledo[1], David García-Martínez[2], Ana de Groot-Ferrando[2], Javier Meroño-Gallut[1].

[1]Group of research ECOFISTEM, Health Sciences Deparment, Facultad de Ciencias de la Salud, Universidad Católica San Antonio de Murcia, Spain; [2]Private Practice. Alicante. Comunidad Valenciana, Spain.

Correspondence Address: *Dr. María Elena del Baño Aledo. Health Sciences Deparment, Facultad de Ciencias de la Salud. UCAM. Campus de los Jerónimos s/n 30107 Guadalupe (Murcia). Tel. (+34) 968 278758. Fax. (+34) 968 278820. E-mail: mbano@ucam.edu, jmartinez@ucam.edu, jrios@ucam.edu.*

Running title: Biomechanics of median nerve during stretching

Abstract

The objective of this observational cross-sectional study was to investigate the normal motion of the median nerve when stretched during a neurodynamic exercise. In recent years, ultrasonography has been increasingly accepted as an imaging technique for examining peripheral nerves in vivo, offering a reliable and non-invasive method for a precise evaluation of nerve movement. Transverse motion of the median nerve in the arm during a neurodynamic test was measured. A volunteer sample of 22 healthy subjects (11 women) participated in the study. Nerve displacement and deformation were assessed by dynamic ultrasonography. Excellent interobserver agreement was obtained with kappa coefficient of 0.7 to 0.8. Ultrasonography showed no lateral motion during wrist extension in 68% of nerves while 73% moved dorsally, with statistically significant differences between sexes (OR_{lat}=6.3; 95%CI=1.4 to 27.7 and OR_{dor}=8.3; 95%CI=1.6 to 44.6). The cross sectional area was significantly greater in men (3.6 mm^2). Quantitative analysis revealed no other statistically significant differences. Our results provide evidence of substantial individual differences in median nerve transverse displacement in response to a neurodynamic exercise.

Keywords: biomechanics, ultrasound, neurophysiology, physical therapy.

Word count: 2649

Introduction

Neurodynamics has become increasingly popular as part of the assessment and treatment of nervous system and musculoskeletal disorders.[1] Neural tissue provocation tests apply mechanical loads to the nervous system by using multijoint movements to alter the length and dimensions of the nerve bed surrounding corresponding to neural structures[2] and they are used to reproduce the patient's symptoms and thereby confirm the diagnosis.[3, 4]

Neural mobilization has been associated with decreased ratings of pain and disability when it is applied for the treatment of several neurogenic and musculoskeletal disorders. [5, 6]

Clinical research has focused on evaluation of neurodynamic tests using range of motion (ROM) and sensory response[3,4,7] or investigating its validity and reliability on both, symptomatic and asymptomatic subjects.[8-11] Several biomechanical and anatomical studies using cadavers have contributed to the validation and knowledge of these tests, measuring longitudinal excursion and strain of median nerve during gliding and tensioning techniques[5,12,13] or with different sequences of movements.[6]

A classical neural mobilization technique is the Upper Limb Neurodynamic Test 1 (ULNT 1), which is thought to add tensile stress to the median nerve.[7] Although standardized sequence for ULNT has been recommended (while preventing elevation of the shoulder girdle, the shoulder is abducted and the wrist extended, supination of the forearm is followed by lateral rotation of the shoulder and elbow extension);[14] in research most frequently contralateral flexion of the cervical spine is applied in order to add more tension to the nerve bed and some changes in the order of movement are allowed.[3,15,16]

In last years, ultrasonography has become in a good imaging technique for examining peripheral nerves in vivo, offering a reliable and non-invasive method for a precisely evaluation of nerve movement.[17] In addition, there are several previous studies in which the longitudinal motion behavior of the median nerve has been examined by ultrasonography.[18-21]

But the median nerve can also slide transversely; which has been deeply study in the carpal tunnel, because it is the most commonly entrapment site. In fact, ultrasound studies on patient with nerve entrapment have previously demonstrated reduced transverse median nerve sliding at the wrist during wrist and finger movements.[22-24] However, there is little research available providing information about normal transverse motion pattern of median nerve when it is stretched during a neurodynamic technique.

The present study is a preliminary examination of transverse median nerve motion during a neurodynamic technique in healthy subjects. Using method previously described[25,26] median nerve was examined with ultrasonography imaging in the arm, just before passing though the pronator teres muscle. This point was selected for study because it is an uncommon site of entrapment, the nerve has no branches in that level and it passes superficial to the muscle bellies, so the nerve can slide freely. When establishing normal values, sex and/or arm dominance could influence results. However, limited research has investigated this point.[27,28]

In summary, the aim of this study was to investigate the normal transverse motion of median nerve when it is stretched during a neurodynamic technique using ultrasonography. The reliability of the image analysis process was established prior to the beginning of the investigation, and differences in median nerve motion depending on arm dominance and sex were also examined.

Methods

We performed an observational cross-sectional study with 22 volunteers measuring transverse motion of median nerve in the arm before passing though the pronator teres muscle during a neurodynamic tests with ultrasonography. The Catholic University Ethics Committee approved the study, and all participants provided written consent to participate in this research.

The sample was recruited from Catholic University of San Antonio. Inclusion criteria were asymptomatic and sedentary people, older than 18 years. The exclusion criteria included the following: (1) presence of prosthetic material or osteosynthesis in the wrist or elbow, (2) history of recent cervicobrachial pathology or (3) previous median nerve neuropathy.

Each subject underwent bilateral dynamic ultrasonography (a total of 44 records) of median nerve. Transverse images of median nerve were obtained using a LogiqE ultrasound machine (Enraf-General Electric, Germany, 2012), with a 12L-RS linear array transducer with a 5-13 MHz acquisition frequency. The transducer was manually placed transversely at the level of proximal insertion of pronator teres in the medial epicondyle (figure 1). Ultrasonography examinations were performed by one researcher (JJMP) with 12 years of experience in musculoskeletal imaging. The starting and ending frames of each sequence were stored in uncompressed digital format (* bmp) with a size of 640 x 480 pixels (8 bit).

The participants were in supine position with cervical spine in contralateral flexion. The neural tissue loading was performed by an experienced physiotherapist (DGM) as described by Shacklock[1] (2005). The starting position of neural mobilization was 90º abduction and external rotation of the shoulder; elbow completely extended, forearm supination and wrist in maximum flexion. One hand of the investigator was placed on the shoulder girdle to prevent elevation, the other hand slowly moved participant´s hand to maximum extension of wrist and fingers maintaining forearm supination. The examiner performed two consecutive repetitions of the movement.

Before the start of the study, the investigators examined together the starting and ending frames of 10 nerves and reached a consensus on the image analysis protocol to try the best standardization of the observation. The observed variables for the qualitative analysis were lateral nerve displacement, posterior nerve motion and nerve deformation. Lateral motion was considered positive when a displacement of the median nerve in the radial direction was observed, posterior nerve motion was considered positive when a displacement of the median nerve in the dorsal direction was observed and nerve deformation was positive when changes in the area of the nerve was observed. Before that, all images were evaluated by the sonographer and an independent researcher (JJMP, MEDBA). The inter-observer reliability was calculated for all these variables.

For the quantitative analysis, the initial and final frames of the motion cycle were analyzed using ImageJ 1.46a software (Rasband W, National Institute of Health, USA, 2013) (figure 2). The CSA was measured on maximum flexion of wrist and fingers and maximum extension by manually tracing the outer hyperechogenic rim that defines the epineural margin.[29]

The centroid of the nerve was determinated and its X-Y coordinates were saved in both images. Movements were defined as differences on the X axis (radial-ulnar) and the Y-axis (anterior-posterior) between the wrist and fingers flexion and extension positions. A deformation measurement of the nerve was calculated according to the following formula:

Deformation = [(CSA in wrist extension / CSA in wrist flexion) x 100] – 100

A positive result indicates that the nerve is not deformed in extension movement, whereas a negative one indicates that the nerve suffers a deformation.

All data were recorded in an electronic database. The following data analyses were performed: Firstly, kappa (*k*) coefficient and agreement frequencies were used for reliability of categorical variables. Following Fleiss et al (2003), we used the next criteria to judge the magnitude reliability index: poor reliability *k* less than 0.40, moderate reliability *k* between 0.40 and 0.75; and high reliability *k* at least 0.70.[30]

Secondly, frequencies were used to summarize categorical variables. Chi-square was calculated to evaluate differences between men and women on all the outcomes measurements. Odds ratios (OR) were obtained.

Thirdly, non-parametric statistical hypothesis tests were chosen for the quantitative study because the sample could not be assumed to be normally distributed. We calculated Wilcoxon signed-rank test for assessing differences in median nerve movements between right and left side and the Mann–Whitney U test to analyze possible differences between men and women. Comparison between mean values of CSA in flexion and extension of the wrist in the whole sample was carried out using paired t tests.

All statistical calculations were carried out using the Statistical Package for Social Sciences (version 15.0: SPSS, Chicago, Illinois, 2006), and the level of significance was set at $p < 0.05$.

Results

A total of 22 volunteers (11 men and 11 women) participated in the study, with a mean age of 22 years (SD: 5.0 years). The results showed a high inter-observer reliability for *lateral nerve motion* (k=.83; C.I. 95%= .69 to .97; p≤.01) and *posterior nerve motion* (k = .94; C.I. 95%= .83 to 1.00; p≤.01). A moderate inter-observer reliability was found for determining *nerve deformation* (k=.66; C.I. 95%=.36 to .97; p≤.01), but the proportion of agreement was 90.9% (95% C.I.= 78.8% to 96.4%).

The results from this study showed a wide range of normal median nerve motion during wrist movements through the transverse plane when the nerve is stretched. Table 1 contains data from the evaluation of the sonographer, who is the most experienced researcher of the investigation team.

Ultrasonography records showed ulnar *lateral motion* in 32% of nerves and no motion was perceived in 68% of nerves. There was a statistically significant difference between men and women for *lateral nerve motion* (OR=6.3; 95% C.I.=1.4 to 27.7; p=.01), women were the reference group.

Most of median nerves moved towards dorsal side during wrist extension (32 of 44, 73%) with a statistically significant difference between sex groups. *Posterior nerve motion* was observed in 55% of women and in 91% of men (OR=8.3; 95% C.I.=1.6 to 44.6; p=.007), men were the reference group. In addition, *absence of deformation* was observed in most of the median nerves (86%), although there was no statistical difference between sex groups because the same percentages were obtained (table 1).

Although significant differences between men and women were found for observed mean nerve motion, the quantitative study of displacement distance (mm) and deformation measurement revealed no statistically significant difference between sexes or between right and left side (table 2).

The mean CSA of men was 12.4 mm^2 in flexion and 13.69 mm^2 in extension. These are significantly higher ($p < .001$) than the CSA of women in both positions (8.82 mm^2 in flexion and 10.06mm^2 in extension). On average, the CSA of median nerve with wrist extension was 1.30 mm^2 higher than with wrist flexion (95% C.I= .70 to 1.84 mm^2; $p<.001$) with a moderate-large effect size. Statistically significant difference between right and left side was not found.

Discussion

In this study, we observed a highly variable transverse-plane motion pattern of median nerve when it is stretched. The quantitative study shows that observed differences of movement between men and women were not statistically significant. As expected, CSA was significantly lower in women than in men, which is consistent with Peiteado et al (2008) where higher values of CSA were found in men too;[31] whereas there were no significant differences between the values of CSA and range of motion for the right and left arms.

A clear pattern of transverse movement in response to stretch could not be established for median nerve due to high variation. Our study show that median nerve tends to stay in the same position when it is stretched and in a third of the cases (32%) moves towards ulnar direction in a range of 1.01-9.81 mm (mean: 3.72 mm). No previous study has reported nerve transverse motion measurements at the same location. However, there have been several studies in which ultrasonography was used to evaluate nerve displacement in the wrist. Nakamichi and Tachibana (1992) studied transverse sliding of the median nerve in asymptomatic wrists of human cadavers, with ultrasonography.[22] They found a mean transverse sliding of 2.1 mm. Ugbolue (2005) found in another study of cadaver hands values ranging 1.4-5.1 mm transverse displacement.[32] The range of their results is slightly lower than our, probably due to they measured nerve displacement in cadavers. These authors did not determine in which direction the median nerve moves specifically.

Yoshii et al (2009) showed that median nerve moved in the ulnar and palmar direction at wrist level when it is flexioned.[33] Nakamichi and Tachibana (2000) also observed that median nerve slides in the ulnar direction during wrist flexion.[34] This probably relates to the fact that they measured nerve motion at the wrist crease level, where the flexor tendons push the median nerve towards ulnar deviation. However, in our test, the nerve is directly surrounded by brachialis and pronator teres that do not contract in the wrist motion. As a result, rather than moving to the side, the stretched nerve is supposed to slide longitudinally towards the moving joint and also it goes deep to reduce the distance between the two fixed points, which explains the high frequencies of observed posterior motion of the nerve.

Presence of this movement is significantly more frequent in men than women. This may be due to the differences in passive and dynamic resistance of the surrounding structures like muscle and connective tissue. As this resistance is greater in men than women;[35] the nerve moves more frequently in men to avoid additional tension. Despite this, we did not identify significant differences between these two groups in displacement measurements, so this data should be taken with caution and show the need for further research in this area to be able to explain qualitative differences.

Several investigators have reported the median nerve motion and deformation in the carpal tunnel during wrist motion.[5,7,11,12] They have suggested that median nerve deforms between the tendons and the flexor retinaculum during wrist flexion.[4] In our study, deformation also occurred with wrist flexion but not when it is stretched during wrist extension. This finding suggests that when the nerve is stretched it does a displacement that helps to dissipate the tension; consistently with Shacklock hypotheses (2005).[1] This result also appears to support the hypothesis that deformation is an adaptive process that takes place during longitudinal nerve displacement. For better understanding of changes in shape of the median nerve, future research should include the analysis of more variables as short- and long-axis diameters and circularity.

There are several limitations to our study. First, ultrasound measurements are known to be operator-dependent, specifically with regard to image interpretation. However, in this study, the observation protocol was standardized minimizing researcher dependency, and the inter-observer reliability was assessed. Furthermore, ultrasonography has some advantages over electrodiagnostic studies of peripheral nerves: it can identify structural or anatomical abnormalities that electrodiagnosis studies cannot, it is inexpensive and painless. In this regard, ultrasound could complement the information obtained through electrodiagnostic studies.

Second, we did not test subjects with pathology of median nerve. We chose to limit the study to normal subjects so that we could investigate in detail the normal mechanics of the nerve with ultrasonography before trying to investigate the abnormal condition.

Third, we not take additional background information about the subjects as body mass index (BMI) or arm size. This can be particularly important when nerve CSA is compared between individuals. However, our measures are consistent with previous studies,[31] so we think that standardization of the area probably does not modify the results.

Fourth, longitudinal direction motion analysis was not performed in this study. Since it seems that the changes in CSA were caused by the longitudinal motion of the median nerve, for future studies it would be interesting to know if there is any correlation between longitudinal and transverse median nerve motion.

In conclusion, our results provide more evidence for large individual differences in median nerve transverse displacement in response to a neurodynamic technique, which highlight the need to relate the nerve biomechanical behavior with sensory response and range of joint motion. The relationship between median nerve motion and clinical measurements like pain and limitation of movement could be useful to improve the neurodynamic mobilization techniques from a mixed biomechanics and clinical perspective.

Sex and arm dominance did not influence the quantitative displacement of median nerve in transverse motion. This finding could indicates that valid bilateral normative values can be obtained from mixed sexes samples, but this affirmation must be taken with caution due to the small number of volunteers in each group. Indeed, the present study found a difference in CSA between men and women, which needs to be taken into consideration by researchers when they compare individuals.

References

1. Shacklock M. *Clinical Neurodynamics: a New System of Neuromusculoskeletal Treatment*. Oxford: Elsevier; 2005.

2. Nee B, Butler D. Management of peripheral neuropathic pain: integrating neurobiology, neurodynamic and clinical evidence. *Phys Ther Sport.* 2006;7(1):36-49.

3. Lohkamp M, Small K. Normal response to Upper Limb Neurodynamic Test 1 and 2A. *Manual Ther.* 2011;16(2):125-30.

4. Van der Heide B, Allison GT, Zusman M. Pain and muscular responses to a neural tissue provocation test in the upper limb. *Man Ther*. 2001;6(3):154-62.

5. Coppieters MW, Butler DS. Do "sliders" slide and "tensioners" tension? An analysis of neurodynamic techniques and considerations regarding their application. *Man Ther*. 2008;13(3):213-21.

6. Nee RJ, Yang Ch, Liang Ch, Tseng GF, Coppieters MW. Impact of order of movement on nerve strain and longitudinal excursion: A biomechanical study with implications for neurodynamic test sequencing. *Man Ther*. 2010;15(4):376-81.

7. Butler D, Gifford L. The concept of adverse mechanical tension in the nervous system. *Physiotherapy.* 1989;75(11):622-9.

8. Vanti C, Conteddu L, Guccione A, Morsillo F, Parazza S, Viti C. The upper limb neurodynamic test I: intra and intertester reliability and the effect of several repetitions on pain and resistance. *J Manipulative Physiol Ther*. 2010;33(4):292-9.

9. Vanti C, Bonfiglioli R, Calabrese M, Marinelli F, Guccione A, Violante FS, et al. Upper limb neurodynamic test 1 and symptoms reproduction in carpal tunnel syndrome. A validity study. *Man Ther*. 2011;16(3):258-63.

10. Vanti C, Bonfiglioli R, Calabrese M, Marinelli F, Violante FS, Pillastrini P. Relationship between interpretation and accuracy of the upper limb neurodynamic test I in carpal tunnel syndrome. *J Manipulative Physiol Ther*. 2012;35(1):54-63.

11. Apelby-Albrecht M, Andersson L, Kleiva IW, Kvale K, Skillgate E, Josephson A. Concordance of upper limb neurodynamic tests with medical examination and magnetic resonance imaging in patients with cervical radiculopathy: a diagnostic cohort study. *J Manipulative Physiol Ther*. 2013;36(9):626-632.

12. Byl C, Puttlitz C, Byl N, Lotz J, Topp K. Strain in the median and ulnar nerves during upper-extremity positioning. *J Hand Surg*. 2002;27(6):1032-40.

13. Kleinrensink GJ, Stoeckart R, Mulder PG, Hoek G, Broek Th, Vleeming A et al. Upper limb tension tests as tool in the diagnosis of nerve and plexus lesions. Anatomical and biomechanical aspects. *Clin Biomech*. 2000;15(1):9-14..

14. Butler D. *Mobilisation of the Nervous System*. Stockholm: Churchill Livingstone Inc.; 1991.

15. Coppieters MW, Stappaerts KH, Everaert DG, Staes FF. Addition of test components during neurodynamic testing: effect on range of motion and sensory responses. *J Orthop Sports Phys Ther*. 2001;31(5):226-37.

16. Coppieters MW, Stappaerts KH, Janssens K, Jull G. Reliabilty of detecting "onset of pain" and "submaximal pain" during neural provocation testing of the upper quadrant. *Physiother Res Int*. 2002;7(3):146-56.

17. Martinoli C, Bianchi S, Derchi LE. Ultrasonography of peripheral nerves. Seminars in Ultrasound. *Semin Ultrasound CT MR*. 2000;21(3):205-13.

18. Hough AD, Moore AP, Jones MP. Measuring longitudinal nerve motion using ultrasonography. *Man Ther*. 2000;5(3):173-80.

19. Dilley A, Lynn B, Greening J, De Leon N. Quantitative in vivo studies of median nerve sliding in response to wrist, elbow, shoulder and neck movements. *Clin Biomech.* 2003;18(10):899-907.

20. Dilley A, Odeyinde S, Greening J, Lynn B. Longitudinal sliding of median nerve in patients with non-specific arm pain. *Man Ther*. 2008;13(6):536-43.

21. Coppieters MW, Hough AD, Dilley A. Different nerve-gliding exercises induce different magnitudes of median nerve longitudinal excursion: an in vivo study using dynamic ultrasound imaging. *J Orthop Sports Phys Ther.* 2009;39(3):164-71.

22. Nakamichi K, Tachibana S. Transverse sliding of the median nerve beneath the flexor retinaculum. *J Hand Surg Am*. 1992;17(2):213-6.

23. van Doesburg MH, Yoshii Y, Villarraga HR, Henderson J, Cha SS, et al. Median nerve deformation and displacement in the carpal tunnel during index finger and thumb motion. *J Orthop Res*. 2010;28(10):1387–90.

24. vanDoesburg MHM, Henderson J, Mink van der Molen AB, An K-N, Amadio PC. Transverse Plane Tendon and Median Nerve Motion in the Carpal Tunnel: Ultrasound Comparison of Carpal Tunnel Syndrome Patients and Healthy Volunteers. *PLoS ONE*. 2012;7(5):e37081.

25. Cartwhight MS, Shin HW, Passmore LV, Walker FO. Ultrasonographic reference values for assessing the normal median nerve in adults. *J Neuroimaging*. 2009;19(1):47-51.

26. Cartwhight MS, Walker FO, Griffin LP, Caress JB. Peripheral nerve and muscle ultrasound in amyotrophic lateral sclerosis. *Muscle Nerve*. 2011;44(3):346-51.

27. Owen TJ, Brew J, Parlas P. A single blind investigation into the potential differences in passive range of movement at the elbow, between dominant and non-dominant arm when using the upper limb tension test 1. *Physiotherapy*. 2000;86(1):40.

28. Reisch R, Williams K, Nee RJ, Rutt RA. ULNT2 – median nerve bias: examiner reliability and sensory responses in asymptomatic subjects. *J Man Manip Ther*. 2005;13(1):44-55.

29. Mondelli M, Filippou G, Gallo A, Frediani B. Diagnostic utility of ultrasonography versus nerve conduction studies in mild carpal tunnel syndrome. *Arthritis Rheum*. 2008;59(3):357–66.

30. Fleiss JL, Levin B, Park HC. *Statistical Methods for Rates and Proportions*. 3rd ed. New Jersey: John Wiley & Sons; 2003.

31. Peiteado D, Bohórquez C, de Miguel E, Santiago S, Ugalde A, Martín E. Validity and usefulness of echography in the Carpal Tunnel Syndrome. *Reumatol Clin*. 2008;4(3):100-6.

32. Ugbolue UC, Hsu WH, Goitz RJ, Li ZM. Tendon and nerve displacement at the wrist during finger movements. *Clin Biomech*. 2005;20(1):50–6.

33. Yoshii Y, Villarraga HR, Henderson J, Zhao Ch, An KN, Amadio P. 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):2922–30.

34. Nakamichi KI, Tachibana S. Enlarged median nerve in idiopathic carpal tunnel syndrome. *Muscle Nerve*. 2000;23(11):1713-8.

35. Blackburn JT, Bell DR, Norcross MF, Hudson JC, Kimsey MH. Sex comparison of hamstring structural and material properties. *Clin Biomech*. 2009;24:65-70.

Tables

Table 1 2 x 2 contingency tables for observed median nerve behavior and sex group.

VARIABLES		SEX Men	Women	Total
Lateral nerve motion	Ulnar	3 (14%)	11 (50%)	14 (32%)
	No	19 (86%)	11 (50%)	30 (68%)
Posterior nerve motion	Yes	20 (91%)	12 (55%)	32 (73%)
	No	2 (9%)	10 (45%)	12 (27%)
Nerve deformation	No	19 (86%)	19 (86%)	38 (86%)
	Yes	3 (14%)	3 (14%)	6 (14%)

Data are presented as number of cases (percentage). Data from sonographer evaluation.

Table 2. Amount of median nerve movement, CSA and deformation value of median nerve.

		DISPLACEMENT (mm)		CSA (mm^2)		DEFORMATION
		Posterior	*Ulnar*	*Flexion*	*Extension*	*%*
Men	Max	3.60	7.59	16.49	20.59	44.5
	Min	.69	3.49	8.22	8.67	-11.5
	Mean	1.40	5.54	12.40	13.69	10.6
	SD.	.73	2.90	2.40	3.13	13.3
	N	20	3	22	22	22
Women	Max	3.09	9.81	11.62	15.02	78.0
	Min	1.01	1.01	4.19	7.23	-27.7
	Mean	1.85	3.32	8.82	10.06	17.3
	SD	.57	2.84	1.85	2.19	26.2
	N	12	11	22	22	22
Total	Max	3.60	9.81	16.49	20.59	78.0
	Min	.69	1.01	4.19	7.23	-27.7
	Mean	1.58	3.72	10.61	11.88	13.9
	SD	.70	2.84	2.79	3.24	20.8
	N	32	14	44	44	44

CSA: Cross-sectional area. SD: standard deviation. In deformation variable positive values indicate that the nerve is not deformed in extension and negative values indicate deformation. Cases of non-movement were excluded from the statistical analysis.

Figure Captions

Figure 1 -- Position of subject and transducer location. In the initial position, the subject was in supine position with the neck flexed contralaterally, 90º abduction and shoulder rotated externally; elbow completely extended, forearm supine and wrist in maximum flexion. The final position was with the wrist and fingers in maximum extension. The transducer was placed transversely at the level of proximal insertion of the pronator teres in the medial epicondyle.

Figure 2 -- Example of measurement of median nerve motion direction. The centroids of the median nerve (white dot) were taken in flexion (left picture) and extension (right picture) to calculate motion direction. Images show the motion in the radial-palmar direction. PronT: superficial fascicle of muscle pronator teres. Tr: Trochlea. Brach: muscle brachialis. BA: brachialis artery.

Figure 1 -- Position of subject and transducer location. In the initial position, the subject was in supine position with the neck flexed contralaterally, 90º abduction and shoulder rotated externally; elbow completely extended, forearm supine and wrist in maximum flexion. The final position was with the wrist and fingers in maximum extension. The transducer was placed transversely at the level of proximal insertion of the pronator teres in the medial epicondyle.
130x244mm (150 x 150 DPI)

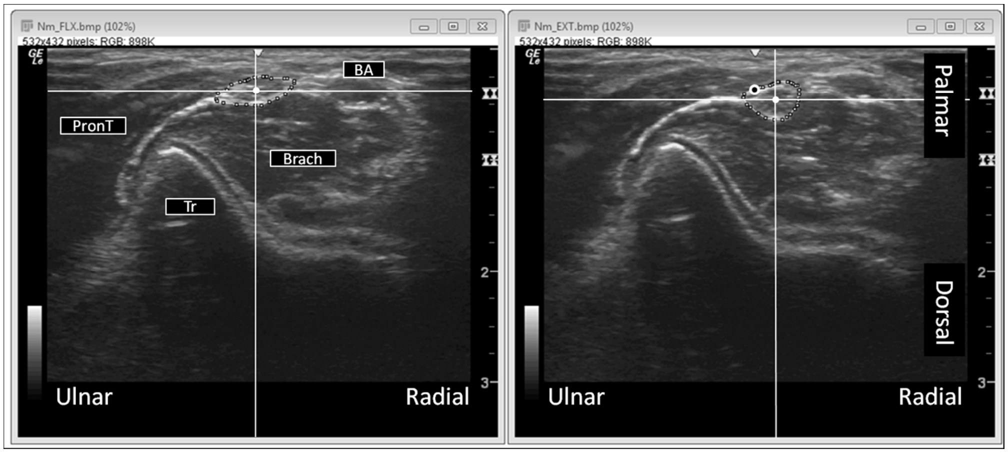

Figure 2 -- Example of measurement of median nerve motion direction. The centroids of the median nerve (white dot) were taken in flexion (left picture) and extension (right picture) to calculate motion direction. Images show the motion in the radial-palmar direction. PronT: superficial fascicle of muscle pronator teres. Tr: Trochlea. Brach: muscle brachialis. BA: brachialis artery.
247x110mm (150 x 150 DPI)