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Shear wave elastography of the ulnar nerve at the forearm

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Abstract

The study included 38 ulnar nerves in 20 healthy subjects. High-resolution ultrasound and Shear wave elastography were used to evaluate the ulnar nerve at the mid forearm. The mean cross-sectional area of the ulnar nerve was 7.1 mm^2. The mean shear elastic modulus of the nerve in the short axis was 27.4 kPa. The mean shear elastic modulus of the nerve in long axis was 24.7 kPa. No statistical relation could be noted between elasticity measurements in long and short axes. The ulnar nerve elastic modulus also showed no correlation with CSA neither in the long axis nor short axis. Age, height, weight, and body mass index showed no correlation with the ulnar elastic modulus in short or long axes. The elastic modulus of the ulnar nerve has been determined in healthy subjects and can serve as a reference for future assessment of compressive neuropathies of the ulnar nerve.

Abbreviations: BMI = body mass index, CSA = cross sectional area, LA = long axis, SA = short axis, SWE = shear wave elastography.

Keywords: elastography, nerve, neuropathy, shear wave, ulnar, ultrasound

1. Introduction

The origin of the ulnar nerve comes from the ventral rami of C8 and T1, arising from the medial cord of the brachial plexus as one of 5 terminal branches. The ulnar nerve contributed to the sensory and motor innervation of the upper limb. The nerve passes along the medial aspect of the arm and forearm, then it passes to the hand and wrist.[1] There are 2 common sites of entrapment of the ulnar nerve. The first one is at the cubital tunnel, named ulnar neuropathy at the elbow, and is considered the second most common entrapment neuropathy after carpal tunnel syndrome.[2] It occurs due to chronic compression or repetitive trauma of the ulnar nerve at the elbow between the medial epicondyle and the olecranon process of the elbow. The other common site fir ulnar nerve entrapment is at the wrist due to compression of the ulnar nerve at the Guyon's canal.[3–5] The diagnosis is of ulnar neuropathy/entrapment is primarily based on physical examination, clinical history, and electrodiagnostic tests. Ultrasound (US) was introduced as an imaging resource for evaluation of peripheral nerve entrapments. US could assess the nerve size by measuring the cross-sectional area (CSA). Ultrasound could also assess nerve echogenicity and fascicular pattern; however, US cannot assess the biomechanical properties of nerves.[5] Sonoelastography is an emerging technique that involves quantification of tissue elasticity in response to applied force with evaluation of the mechanical properties of tissues. Shear wave elastography (SWE) is one of the 2 main types of sonoelastography and is widely used for assessment of the musculoskeletal system.[5] In SWE, a pulse is induced by the probe propagating through the tissue of interest waves in a shear manner and presented in kilopascals (kPa, Young modulus). SWE is less operator dependent, reproducible, and provides semiquantitative, and qualitative evaluation of tissue elasticity without manual compression artifacts.

The other main type of sonoelastography is strain elastography, where mild compression of the probe causes tissue displacement. This results in color scaled qualitative and semiquantitative evaluation of elasticity. SWE could easily assess increased nerve stiffness in the setting of peripheral neuropathy, and was reported by several authors to diagnose compressive neuropathies of the median, sciatic, and tibial nerves.[6–18] It is believed that SWE could have a role in the future in predicting injury risk, and/or tracking healing progress.[19] Both common sites of ulnar nerve entrapment were studied previously by SWE.[3–5] Measuring the stiffness of the ulnar nerve at the forearm could be a part of future studies of ulnar nerve SWE to compare the stiffness proximal and distal to the site of

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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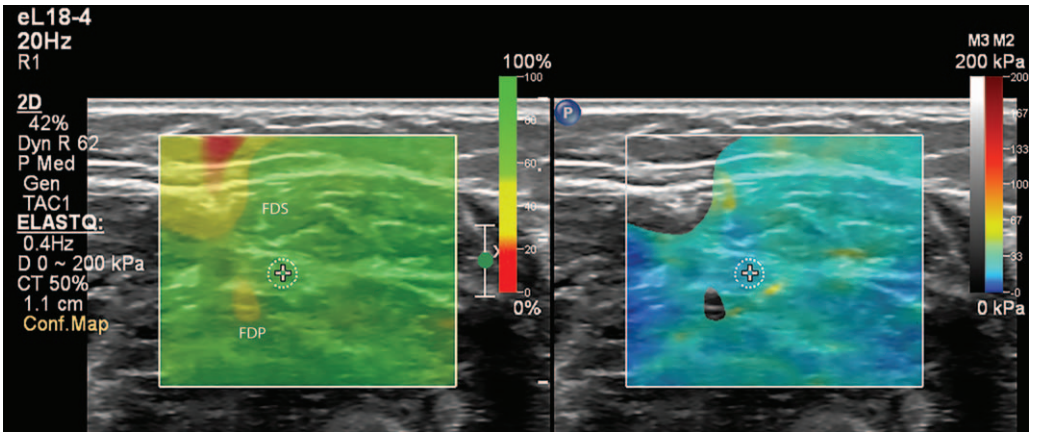

Figure 1. Short axis view of the ulnar nerve shear wave elastography, with confidence map on the left, color map scale on the right, for measurement of stiffness in kPa. FDP = flexor digitorum profundus muscle, FDS = flexor digitorum superficialis muscle.

entrapment. The aim of this work is to study the sonoelastographic features of the ulnar nerve at the forearm.

2. Methods

2.1. Participants

Thirty-eight ulnar nerves were evaluated in 20 healthy adult subjects. After institutional review board approval, the participants of the study were recruited between September 2019 and October 2019, and written consent was obtained. Inclusion criteria included: being healthy, male or female, age range (25–46). Exclusion criteria included: peripheral neuropathy, history of numbness or upper limb pain, weakness, or paresthesias, and injury to the upper limb. For each participant, data including sex, age, weight, BMI, and height were recorded. Subjects enrolled in this study were free from any diseases related to neuromuscular system, as indicated by and clinical examination and electrophysiologic methods.

2.2. Technique

Ultrasound examination was performed by an L18-4, MHZ linear-array transducer (EPIQ Elite SW 5.0.1, Ultrasound system: Philips, Bothell). A radiologist (MAB, 19 years of experience) performed all examinations, images were reviewed by neurologist (MK). All the participants were examined in the sitting position, with the participant resting his arm on the thigh, the elbow extended, slightly abducted, and the wrist supinated. The ulnar nerve was first identified at the medial side of the mid forearm (in short axis 10 cm above the wrist crease). Then the cross-sectional area (CSA) was measured in mm^2. For the SWE measurements, each subject was scanned 3 times with removal of the probe from the skin between measurements. To increase the reliability of the reported stiffness values, a confidence map was used to mask areas below a specific confidence level. Large amount of gel was used with light touch of the probe to decrease pressure effect on the skin. First, the ulnar nerve was identified in short axis and SWE measurements were taken, then the probe was rotated 90° to acquire longitudinal SWE measurements. In each examination, and after identifying the nerve, the probe was held stationary for 3 to 4 seconds and a 2 mm diameter region of interest (ROI) circle was placed within the hyperechoic epineurium. After viewing the color map, real-time shear wave images were recorded with color coding. The readings consisted of median elasticity, maximum elasticity, and average elasticity with standard deviation (SD) and were reported in kPa. The color scale was mapped to a 0 kPa to 200 kPa range. The spectrum of scale colors ranges from blue for softer tissues through red for stiffer tissues (Figs. 1, 2).

2.3. Electrophysiologic methods

Nerve conduction studies were performed with Nihon-Cohden Neuropack device. All studies were performed under standard room temperature of 25°C. Hand temperature was maintained at ≥32°C. Electrodiagnostic studies were performed on both hands and feet in all subjects by an expert neurologist.

2.4. Statistical analysis

Statistical analysis was performed using Statistical Package for the Social Sciences (SPSS) version 21 software (SPSS Inc, Chicago, IL). Data were presented as mean ± standard deviation (SD) and range. Intraobserver variability was measured using Kohen's Kappatest. Independent sample test was used to assess the differences between mean elasticity of the right and left ulnar nerves. The correlations between the mean elasticity bilaterally and age, weight, height, and BMI were calculated by Pearson correlation coefficient test.

3. Results

The study included 38 nerves in 20 healthy adult subjects, with a mean age of 32.9 ± 6.6 [range 25–46], mean height 156.6 cm ± 8.3 [range 140–171], mean weight 59.7 kg ± 10.4 [range 43–85], mean BMI 24.3 ± 3.5 [range 19–31.6]. The mean cross-sectional area of the nerve was 7.1 mm^2 [range 4.4–12.3 ± 1.7]. The mean shear elastic modulus of the nerve in the short axis was 27.4 kPa [range 15.6–37.5 ± 5.7]. The mean shear elastic modulus of the nerve in long axis was 24.7 kPa [range 13.5–37.3 ± 5.9]. Table 1 shows the demographic characteristics of study participants. Table 2 shows the CSA and stiffness values of the nerve. The

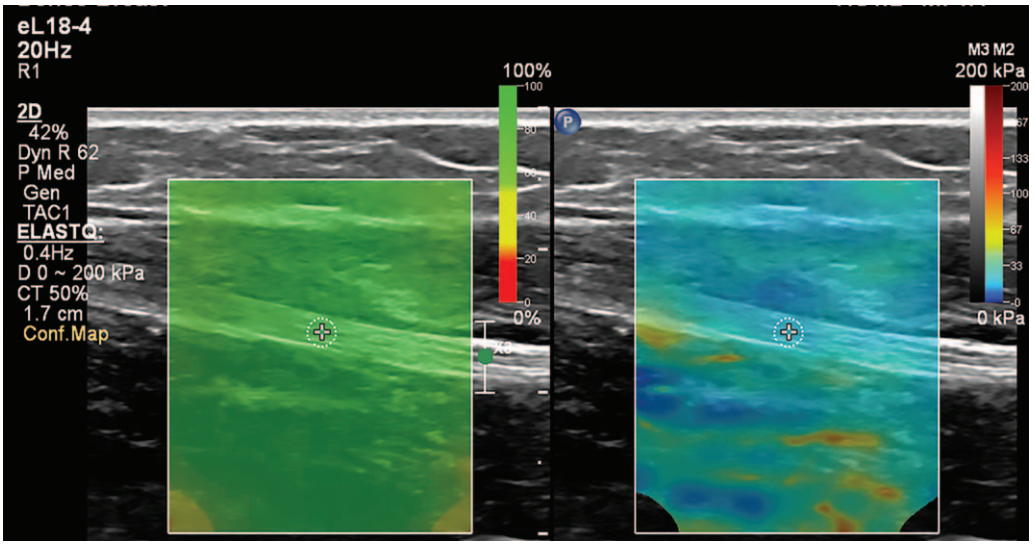

Figure 2. Long axis view of the ulnar nerve shear wave elastography, with confidence map on the left, color map scale on the right, for measurement of stiffness in kPa.

intra-observer reliability calculations resulted in an overall intraclass correlation coefficient of 0.78. No statistical differences were noted between the right and left sides regarding the CSA ($P = .433$), shear wave elastic modulus of the nerve in short axis ($P = .832$), and shear wave elastic modulus of the ulnar nerve in the long axis ($P = .267$). No statistical correlation could be noted between shear modulus and demographic factors. No statistical relation could be noted between elasticity measurements in long and short axes. The ulnar nerve elastic modulus also showed no correlation with CSA neither in the long axis nor short axis. Age, height, weight, and BMI showed no correlation with the ulnar elastic modulus in short or long axes. Table 3 shows the correlation between the CSA, stiffness, and demographic characteristics in our study.

Table 1

The demographic characteristics of study participants (mean ± standard deviation).

	Mean	±SD	Number	Percentage
Age in year	32.9	6.6		
Gender				
Male			6	
Female			14	70
Height (cm)	156.6	8.3		
Weight (kg)	59.7	10.4		
Body mass index	24.3	3.5		

SD = standard deviation.

Table 2

CSA and stiffness values of the ulnar nerve (mean ± standard deviation).

	Minimum	Maximum	Mean ± SD
Ulnar CSA	4.4	12.3	7.1 ± 1.7
Ulnar SA	15.6	37.5	27.4 ± 5.7
Ulnar LA	13.5	37.3	24.7 ± 5.9

CSA = cross sectional area, LA = long axis, SA = short axis, SD = standard deviation.

4. Discussion

We studied the ulnar nerve in at the forearm in healthy adult subjects by SWE. The relationship between elasticity and height, weight, body mass index, gender, were also studied. The CSA measurements of the ulnar nerve at the forearm obtained in our study were 7.1 mm^2 [range 4.4–12.3 ± 1.7], were comparable to Cartwright et al (6.3 mm^2 ± 1.0), and slightly lower than Kerasnoudis et al (5.46 mm^2 ± 1.26), and Bedewi et al (5.5 mm^2 ± 1.9).[20–22] The mean stiffness of the ulnar nerve in the longitudinal axis in our study was (26.1 ± 6.4 kPa). Paluch et al reported much higher level of mean stiffness of the ulnar nerve at the forearm (49 kPa range 23–68). This same group also reported a mean stiffness of (51 kPa range 20–69) at the level of the Guyon's canal. In another study, Paluch et al reported a mean stiffness reaching (33.1 ± 10.13 kPa, range 19–51) for the ulnar nerve at the level of the cubital tunnel.[3,4] These values were also

Table 3

Correlations between demographic factors, cross sectional area, and stiffness in the long and short axes.

	Ulnar CSA	Ulnar SA	Ulnar LA	
Age	Pearson correlation	.188	.057	.042
	Sig. (2-tailed)	.259	.734	.803
Weight in kg	Pearson correlation	.117	.226	.116
	Sig. (2-tailed)	.486	.173	.492
Height in cm	Pearson correlation	.130	−.032	−.079
	Sig. (2-tailed)	.438	.846	.642
BMI	Pearson correlation	.072	.286	.195
	Sig. (2-tailed)	.668	.082	.246
Ulnar CSA	Pearson correlation		−.001	−.114
	Sig. (2-tailed)		.997	.502
Ulnar SA	Pearson correlation	−.001		.225
	Sig. (2-tailed)	.997		.181
Ulnar LA	Pearson correlation	−.114	.225	
	Sig. (2-tailed)	.502	.181	

BMI = body mass index, CSA = cross sectional area, LA = long axis, SA = short axis, SD = standard deviation.

much higher than the results obtained by Cornelson et al who reported a mean stiffness for the ulnar nerve at the cubital tunnel (13.2 ± 11.26 kPa).[5] One explanation of this variability of the results is the axis of the transducer during SWE measurement. Both studies of Paluch et al took measurements in the long axis, while Cornelson et al took his measurements in the short axis. Some authors experienced difficulty in obtaining reliable results when measurements were taken in the short axis. Others reported higher stiffness values in the long axis compared with the short axis.[15,23] In our study we measured the SWE at both axes, and we found minor differences that were not statistically significant between mean elasticity in the short axis (27.4 kPa) and the long axis (24.7 kPa). Other factors could also influence the reliability of nerve stiffness measurements. Substantial variability of nerve stiffness with different limb positions was reported by especially in the upper limb nerves. This could have a clinical impact on patients with chronic limb posture (like spasticity and muscle contracture) resulting in increased nerve stiffness on the affected side.[24,25] Proximity of the examined nerve to some anatomical structures like bone, and synovial fluid could lead to unreliable SWE readings.[26] The use of different machines, different acquisition depths, and different transducers was reported by Shin et al to result in different elasticity values of the same phantom.[27] Excellent inter and intra observer agreement was demonstrated with the median nerve SWE, and could be another important factor affecting nerve stiffness.[28] This study has several limitations. First, small sample size decreases the statistical significance of our results. Second, the number of males is not equal to females. Third, only healthy subjects were involved without inclusion of nerve pathologies, especially ulnar neuropathy. Future studies on a larger sample size, with even sex distribution, could help to increase the validity of SWE measurements. These further studies should include studying the elasticity in patients with different types of compressive neuropathy and comparing them to the elasticity values of the normal ulnar nerve. We believe that to establish cut-off limits for discriminating normal healthy nerves from diseased ones, knowledge of the normal elasticity values is necessary. In conclusion, we believe that shear wave elastography of the ulnar nerve could be a useful future tool to aid in studying change of the stiffness of the ulnar nerve in different pathologies for diagnostic and therapeutic purposes.

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