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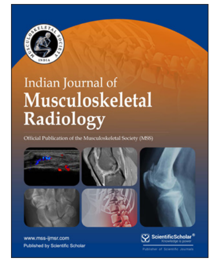

Original Article

Shear wave elastography of ulnar nerve in arm: An observational study for evaluation of performance

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Received : 13 February 2021
Accepted : 31 May 2021
Published : 30 June 2021

DOI
10.25259/IJMSR_7_2021

Quick Response Code:

ABSTRACT

Objectives: The performance of shear wave elastography (SWE) for peripheral nerve pathology, predominantly compressive neuropathy, has been studied with the median nerve, sciatic nerve, and tibial nerve. However, studies for ulnar nerve are limited in literature. The aim of the study was to study the performance of SWE for ulnar nerve in arm by analyzing the correlation of elasticity value by two transducers of the same ultrasound system.

Material and Methods: This was a prospective observational study. Elasticity of ulnar nerve was measured in the mid-arm and supracondylar region in longitudinal and transverse planes with two different transducers of the same ultrasound system. The reliability of measurement was assessed by interclass correlation of values obtained.

Results: Ninety-two ulnar nerve measurement sets were analyzed. The ages of the patients ranged from 14 years to 76 years, with a median age of 50. The SWE values obtained by two probes showed a weak interclass correlation coefficient value <0.5.

Conclusion: Quantitative SWE measurements of the ulnar nerve in the arm by two transducers showed a weak interclass correlation. It should be used with caution as a diagnostic tool with a universally acceptable cut off values.

Keywords: Ulnar nerve, Shear wave elastography, Reliability

INTRODUCTION

The elasticity of soft tissues is defined as tissue deformability, and is determined by its structure and composition. Ultrasound (US) elastography is a method that can assess the mechanical properties of soft tissue through US imaging. Since its introduction in 1991, US elastography has evolved considerably. It has found clinical application in neoplastic and non-neoplastic disorders, including neuromuscular diseases.[1-4]

Different elasticity measurement techniques depend on the type of stress applied and the method used to detect tissue deformability. Shear wave elastography (SWE) measures the directional shear wave's velocity produced by an US pulse. It allows both qualitative color-coded image and quantitative information of elasticity (in kilopascals [kPa]) or shear wave velocity (in cm s^{-1}).[5]

The introduction of SWE into commercially available US systems has allowed its use in various clinical conditions despite reservation raised by an *in vitro* study that reported considerable difference in SWV on different transducers and machines, limiting its use with the absolute values.[6] SWE has been validated in breast, liver, prostate, and thyroid diseases.[7-12] It also holds promise for several musculoskeletal disorders and has complemented conventional B-mode US and Doppler imaging.[1,2,13,14] However, there are concerns about using this method for very superficial structures, as a certain depth of US penetration is needed for shear waves to be produced.[15,16]

Electrodiagnostic studies have been the primary diagnostic modality for providing insight into peripheral nerve dysfunction. Recently elastography has been explored as a non-invasive way to evaluate nerve parenchyma. There have been some reports about the performance of SWE for peripheral nerve pathology, predominantly compressive neuropathy in the median nerve, ulnar nerve, sciatic nerve, and tibial nerve.[17-19]

The SWE measurements have been reported to be reproducible, with high inter-rater agreement rates for median nerve stiffness.[17] These arguments support its routine use in suspected entrapment neuropathies. However, these studies also documented a considerable variance in the absolute values of nerve's stiffness, both in cases and healthy controls.[17,19] To overcome this limitation, the ratio of measurements at two sites was evaluated, and it provided high accuracy in distinguishing between the two groups.[19] SWE studies for the ulnar nerve are limited, and data do not establish the role of elastography in the diagnosis of ulnar neuropathy at the elbow.[20-22] This may be attributed to fewer studies or due to the under performance of this tool in the ulnar nerve.

This study investigates the performance of SWE for the ulnar nerve in the arm regarding its measured value by two different US transducers of the same US system. *In vivo* reliability in terms of SWE values correlation of two different transducers has not been reported in the literature to the best of our knowledge. The *in vitro* study reporting difference in SWV by two probes is silent about the correlation of the values obtained by two probes in the same experimental settings.

MATERIAL AND METHODS

Subjects

This study was designed as a cross-sectional observational study. The study was approved by the institutional ethics committee. It was a sample of convenience with all consecutive patients referred for sonographic evaluation of ulnar nerve for different clinical conditions, from September 2019 to March 2020, was enrolled after informed consent from each participant for use of this data for the study. There were no specific inclusion criteria as study related to measurements by two probes in same clinical setting. However, ulnar nerves of the arm with a history of trauma, any operative procedure in the supracondylar region or deformity were excluded from the study.

Sonographic examinations

Sonographic examinations were performed with SuperSonic Imagine-Aixplorer®-Innovative UltraFast™ US Imaging system with SuperLinear™ SLH20-6 probe of bandwidth 6–20 MHz and SuperLinear™ SL18-5 probe of bandwidth 5–18 MHz by a radiologist of more than 15 years of experience in peripheral nerve ultrasonography. Examiner was blinded to the clinical condition of the patient.

The examination was done in the supine position with the arm abducted for 15–30°, elbow extended and palm facing the ceiling on the right side. On the left side, it was examined in cobra position. The nerve is relaxed on the right and semi stretched on the left side [Figure 1].

The course of the ulnar nerve at each level was localized on B-mode scans. The transducer was always kept parallel to the skin surface, and special attention was paid to minimize the pressure and avoid a disruption of the hydrogel layer. Elastographic measurements were taken in a transverse scan and longitudinal scan with both the probes one after the other in the same sitting at the level just above the medial epicondyle and about 7 cm proximal to it.[23] Shear wave imaging was done in standard setting at 1.1 Hz in 20–6 MHz probe and 2.0 Hz in 18–5 MHz probe. Any abnormal shadowing from superficial structure/septa was avoided. Q-Box was placed at least 5 mm deep to surface, and measurements were

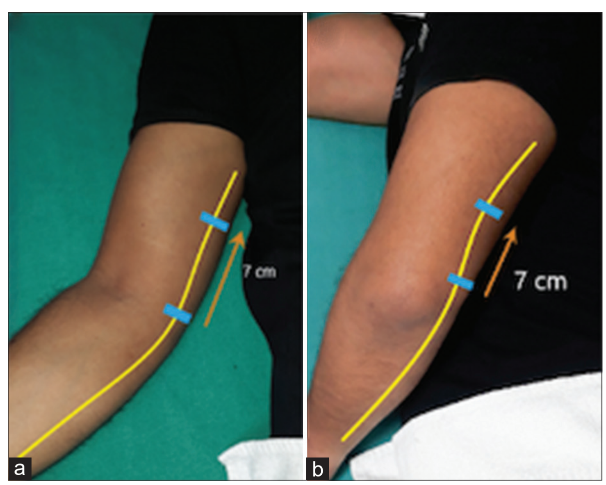

Figure 1: Photograph showing the position of the elbow. Extended on the right (a) and flexed on the left (b). Note the position of the probe along the course of ulnar nerve.

taken with an area of the circle being 1 sq mm and SD <4. During the examination, supersonic shear imaging pulse was focused at the nerve stroma by positioning the ulnar nerve in the center of the SWE box and stabilized for 3–4 s to get good SWE map that is stable and not pixelated. Care was taken so that no surface jell layer or underlying bone surfaces were included in the SWE box.[24,25] Shear modulus data for the Q-Box, (one sq. mm) were acquired automatically by the ultrasonographic software, and the results were recorded in kPa. Representative elastography map is presented in Figure 2.

Elastographic measurements were taken at two sites, as mentioned above. In a transverse scan, the shear wave velocity was measured in the nerve stroma, in the peripheral epineurium (marginal), and the subcutaneous fat (as close to deep fascia as possible). In a longitudinal scan, two measurements were taken in the nerve stroma, and the average was calculated, and one measurement was taken in subcutaneous plane. Shear wave elasticity ratio was calculated at each site using the value measured in the nerve stroma and value in subcutaneous fat in longitudinal sonogram as numerator and denominator, respectively. In the transverse sonogram, two ratios were calculated. The first was the ratio between the elasticity values in nerve stroma and epineurium, and second between the values in nerve stroma and subcutaneous fat. Ratio of elasticity measured at mid arm and supracondylar region was also calculated for agreement between two probes.

Analysis

Initially, the data were checked for errors. Outliers were detected. Descriptive statistics to summarize the characteristics of the study group after including means and SD were done after the deletion of outliers. The agreement was assessed by the intraclass correlation (ICC) (two-way, random measures, for absolute agreement, and for single measurements). For association of measurements in longitudinal and transverse plane with same probe Pearson's correlation coefficient was used. An ICC usually varies between 0 and 1. Values close to 1 indicate excellent reliability, while values close to zero are considered to be completely unreliable.[26] All analyses were conducted using R statistical environment, version 3.6.0, along with the "rel" package.

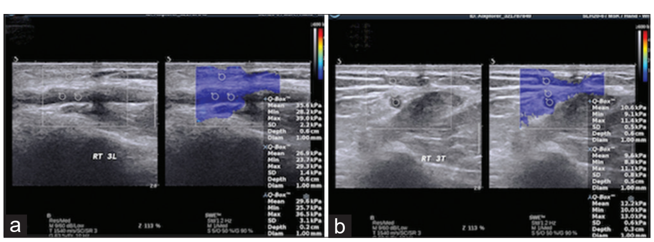

Figure 2: Elastogram map images showing the shear wave elastography box placement and point of measurements in longitudinal plane (a) and transverse plane (b).

RESULTS

Fifty-three subjects referred for evaluation of ulnar nerve for different clinical conditions were enrolled. There were 93 sets of measurements of the ulnar nerve (measurements taken on one arm constitutes a set). One set showed significant outliers interfering with results, and was excluded from the analysis. So a total of 92 nerve measurement sets were analyzed. There were 37 males, and 16 females with 25 males and 14 females had both arm measurements, and rest had a measure of single nerves. The ages of the patients ranged from 14 years to 76 years, with a median age of 50 years.

The description of the measurements taken is given in Table 1.

The ICCs for agreement between the values both absolute and ratios were low for almost all parameters studied, with not a single measure having even an ICC of 0.5 [Table 2]. The correlation of agreement between two probes in the longitudinal plane at the midarm was (0.42) with 95% CI 0.26–0.59, and in supracondylar region was 0.42 with 95% CI of 0.23–0.57. ICC for agreement in ratio of elasticity value at two sites between two probes was 0.017 and 0.272 in longitudinal and transverse plane. Pearson's correlation coefficient for association between values taken in two planes at each site and probes is listed in Table 3.

DISCUSSION

This study has been undertaken to determine the reliability of SWE quantitative imaging in peripheral nerve. The present study was done for the ulnar nerve in arm, as it is one of the most commonly affected neuropathies in clinical practice. The measured value for ulnar nerve elastography has a limited publication.[21,22] Study by Shin *et al.*, on phantom reported significant difference in SWV on US elastography depending on the machines, transducers, and acquisition depth. However, they did not mention about the strength of correlation between the values obtained by two transducers with other parameters being same.[6] The research is ongoing with use of elastography in the diagnosis of peripheral nerve lesions especially the median nerve with good outcome in terms of interobserver reliability and repeatability. However, in a review concerning the use of elastography for evaluation of peripheral nerve lesion by Wee *et al.*, the author highlights the paucity of data available in literature to assign any role of elastography for ulnar nerve pathology. They were silent on the reason for the same, as the instrumental limitation as mentioned by Shin *et al.*, are equally relevant for all other nerve as well. They also stressed the need for study on this subject as the future area of interest.[20]

Table 1: Measurements by the two probes in longitudinal and transverse planes.

			Mean (SD)	Median (Range)
Mid arm	L18	Mean intraneural value	45.2 (22.1)	39.3 (10.2–148.1)
		Subcutaneous	31.4 (19.1)	27.6 (6.6–133.3)
		Ratio of mean intraneural and subcutaneous fat	1.9 (1.6)	1.3 (0.7–12.6)
	L20	Mean intraneural value	41.3 (20)	37 (15.5–116)
		Subcutaneous	32.4 (17.2)	27.7 (10.1–85.5)
		Ratio of mean intraneural and subcutaneous fat	1.4 (0.6)	1.3 (0.5–4.2)
Supracondylar	L18	Mean intraneural value	43.3 (22)	39.9 (3.5–130.1)
		Subcutaneous	32.2 (19.2)	28.3 (7–112.4)
		Ratio of mean intraneural and subcutaneous fat	1.7 (1.1)	1.3 (0.1–6.1)
	L20	Mean intraneural value	42.8 (20.1)	39.3 (6.3–106.3)
		Subcutaneous	35.7 (17.7)	30.7 (10.9–89.9)
		Ratio of mean intraneural and subcutaneous fat	1.3 (0.5)	1.2 (0.1–3.4)
Mid arm	T18	Intraneural	20.5 (11.8)	17.1 (4.6–64.1)
		Marginal	21.6 (10.1)	20.1 (6–43.5)
		Subcutaneous	20.2 (10.8)	18.5 (0.7–57.2)
		Ratio: intraneural to marginal	0.9 (0.2)	0.9 (0.5–1.8)
		Ratio: intraneural to SC	1.6 (4.4)	1 (0.3–41)
	T20	Intraneural	26.1 (12.3)	22.7 (7.6–77.1)
		Marginal	28.1 (12.5)	25.5 (7.8–81)
		Subcutaneous	26.3 (13.2)	23.2 (4.8–76.3)
		Ratio: intraneural to marginal	0.9 (0.2)	0.9 (0.4–1.3)
		Ratio: intraneural to SC	1.1 (0.5)	1 (0.3–3.2)

(Contd...)

Table 1: *(Continued).*

			Mean (SD)	Median (Range)
Supracondylar	T18	Intraneural	23.7 (15.3)	19.3 (3–67.1)
		Marginal	26.3 (15.9)	21.5 (7–79.6)
		Subcutaneous	23.5 (13.6)	18.6 (7.8–65.1)
		Ratio: intraneural to marginal	0.9 (0.3)	0.9 (0.2–1.8)
		Ratio: intraneural to SC	1.1 (0.7)	1 (0.3–5)
	T20	Intraneural	22.7 (11.2)	20.2 (5.2–73)
		Marginal	27 (12.4)	24.5 (6.6–70.9)
		Subcutaneous	25.8 (13)	22.9 (7.6–67)
		Ratio: intraneural to marginal	0.9 (0.2)	0.9 (0.3–1.7)
		Ratio: intraneural to SC	0.9 (0.4)	0.9 (0.2–2.4)

*L is measurement taken in longitudinal plane and T is measurements taken in transverse plane. 18 and 20 refers to SL5-18 and SLH 20-6 probes. SC: Subcutaneous fat

In the present study, the performance of SWE to measure the elasticity of the ulnar nerve in arm has been evaluated by two different US transducers of the same unit, at the same site and imaging planes, and in the same sitting. Thus, we have avoided inter-observer, inter-instrumental, temporal, and positional factors in this analysis. Chang *et al*. observed that, of all physical factor extrinsic to US beam, probe pressure is an important determinant to changes the speed of propagation in superficial tissue by increasing the density, and so the propagation speed. This has been overcome in the study design by adequate gel layer avoiding any compression.[27]

There was poor agreement of absolute values of elasticity in two transducers. This is in agreement with the observation by Shin *et al*.[6] Similar observation has been reported in Median nerve by Bedewi *et al*. Moreover, different studies have quoted different value of elasticity in a healthy median nerve.[17,28,29]

The speed of shear wave propagation decreases at greater source-to-target distances, paralleling the progressive attenuation of the pulses generating the shear waves as they travel within tissues. Thus, lower values are obtained in deeper tissue. Two sites were chosen in present study so as

Table 2: The ICC between two probes at different sites with the 95% confidence intervals.

	ICC (95% CSI)
Mid arm	
L18 vs. L20: Mean Intraneural	0.44 (0.26–0.59)
L18 vs. L20 Subcutaneous	0.2 (0–0.39)
L18 vs. L20: Ratio of mean intraneural and subcutaneous fat	0.02 (−0.17–0.21)
Supracondylar	
L18 vs. L20: Average	0.42 (0.23–0.57)
L18 vs. L20 Subcutaneous	0.28 (0.08–0.46)
L18 vs. L20: Ratio of mean intraneural and subcutaneous fat	0.29 (0.09–0.46)
Mid arm	
T18 vs. T20: Intraneural	0.34 (0.14–0.52)
T18 vs. T20: Marginal	0.26 (0.06–0.45)
T18 vs. T20: Subcutaneous	0.22 (0.03–0.4)
T18 vs. T20: Ratio Intraneural-marginal	0.12 (−0.09–0.32)
T18 vs. T20: Ratio Intraneural-subcutaneous	0.01 (−0.19–0.22)
Supracondylar	
T18 vs. T20: Intraneural	0.21 (0.01–0.4)
T18 vs. T20: Marginal	0.38 (0.19–0.55)
T18 vs. T20: Subcutaneous	0.19 (−0.01–0.38)
T18 vs. T20: Ratio Intraneural-marginal	0.19 (−0.01–0.38)
T18 vs. T20: Ratio Intraneural-subcutaneous	0.01 (−0.19–0.21)
Ratio of mid arm and supracondylar intraneural measurement 18 vs. 20	
Longitudinal	0.17 (−0.18, 0.21)
Transverse	0.27 (0.07, 0.44)

*L is measurement taken in longitudinal plane and T is measurements taken in transverse plane. 18 and 20 refers to SL5-18 and SLH 20-6 probes. ICC: Intraclass correlation coefficients, vs.: versus

Table 3: Association between nerve stromal elastography values observed in longitudinal and transverse plane.

Site	Probe*	Pearson's correlation (95% CI)
Mid arm	18	0.04 (−0.15, 0.24)
Mid arm	20	0.35 (0.16, 0.52)
Supracondylar	18	0.38 (0.19, 0.54)
Supracondylar	20	0.27 (0.08, 0.45)

*18 and 20 refers to SL5-18 and SLH 20-6 probes.

to include a very superficial location, and an intermediate depth. However, the values obtained in our study were not showing any significant lower values in deeper course of the nerve (mid arm) as compared to supracondylar region. This may be attributed to relatively lower depth of both sites in comparison to depth associated with liver elastography in experimental model.[27,30,31] Moreover, other reason could be that shear waves are expected to meet more architectural disturbances in heterogenous tissue.[32] On a similar note, Palmeri *et al*. observed that nerves surrounded by fat typically displaces less and are relatively stiffer than their adjacent tissues. These same nerves can appear more compliant when surrounded by substantial volumes of skeletal muscle.[33] Thus, more fat surrounding the supracondylar part of ulnar nerve may have compensated for its more superficial location and hence not much of a difference in values at two sites.

The mean values of elasticity were higher in longitudinal plane in both transducers, as compared to transverse plane. A similar observation was made by Paluch *et al*., attributing such discrepancies to different transducer frequencies and plane of the tissues.[22,28] At least two categories of anatomical factors strongly influence the propagation of the shear waves, the tissue architecture, and anisotropy. The anisotropy reflects the direction dependence of certain properties. Most of the current knowledge about the effects of anisotropy on the transmission of shear waves derives from an experimental work by Gennisson *et al*. on an animal model using supersonic shear waves imaging.[34] Similar anisotropic effect in elasticity has been seen in other tissues. In a study by Arda *et al*., the mean elasticity value of Achille's tendon in longitudinal and transverse plane was different with significantly different ranges, consistent with this anisotropic concept of tissue elasticity.[9]

The ICC of stromal elasticity measured showed mild correlation between the two transducers. However, the level of agreement was higher in longitudinal plane (0.44–0.42) than in transverse plane (0.34–0.21) at both sites. This is similar to observation made by Paluch *et al*. that measurements from the nerve cross-section are characterized by lower repeatability.[28]

Use of ratio of the elasticity of nerve tissue and subcutaneous fat has been evaluated in line with the strain ratio equivalent in strain elastography. Our observation shows that the use of elasticity equivalent ratio between the ratio of fat and nerve elasticity values obtained by two probes had poor ICC (<0.3). This lower ICC is in sync with law of statistics where the negative factors are exaggerated in ratio, and so a relatively higher discordance.

The ratio of elasticity of ulnar nerve at mid arm and supracondylar region has been advocated in some of the studies due to the limitations of variability in observation. Paluch *et al*., proposed wrist to forearm ratios to be independent of patient age or weight and exhibit excellent diagnostic accuracy regardless of where on the forearm the second measurement is taken.[19] However, our study showed poor ICC 0.017 in longitudinal and 0.272 in transverse plane making this ratio a less reliable tool in case of ulnar nerve in distal arm. This can also be explained with effect of probe frequency, depth, heterogeneity, and anisotropy being significantly high due to its anatomy.

CONCLUSION

Quantitative SWE measurements of the ulnar nerve in the arm by two transducers showed weak interclass correlation, suggesting complex non-linear interaction of instrumentation, anatomy, and tissue architecture. Hence, the absolute values or the ratios of elasticity of ulnar nerve as a diagnostic tool by SWE need to be used with caution.

This study design has some inherent limitations including evaluation by single observer with lack of inter- and intra-observer reliability assessment. Simultaneous study of any deeper nerve could have added much insight and served as control for some of the ambiguity. Methodology could have included measurement with larger Q-Box tool so as to get a better average value.

Acknowledgments

Dr. Anup Kumar Thacker, Professor Neurology, for constant support and guidance during the study.

Compliance with ethical standards

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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How to cite this article: Narayan S, Choudhury N, Singh AK, Anand T, Raj G, Agarwal D. Shear wave elastography of ulnar nerve in arm: An observational study for evaluation of performance. Indian J Musculoskelet Radiol 2021;3(1):3-9.