



Technical Note

Shear wave elastography for assessing the anterior scalene elasticity in patients with neck pain

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ABSTRACT

Purpose: Shear-wave elastography (SWE) provides quantitative and absolute metrics for analyzing the elasticity of soft tissues. Despite the anterior scalene muscle (AS) is a key structure in patients with neck pain and nerve compressive syndromes, the majority of SWE studies only included asymptomatic subjects. This study aimed to analyze the Young's modulus and shear wave speed test-retest reliability in a sample of patients with neck pain symptoms to characterize the AS stiffness.

Methods: A diagnostic accuracy study acquiring a set of ultrasound images at C7 level in 42 patients with mechanical neck pain by one experienced examiner. After blinding the participants' identity, trial and side, the Young's modulus and shear wave velocity were measured by an independent experienced rater in randomized order. Intra-class correlation coefficients (ICC), standard error of measurement (SEM), minimal detectable changes (MDC) and coefficient of variation (CV%) were calculated.

Results: The sample reported moderate pain intensity (5.9/10 points) and disability (17.38/100 points). AS stiffness metrics assessed showed no significant differences between males and females, left and right side nor painful and non-painful side. (all, $p > 0.05$). Intra-examiner reliability was excellent for calculating the Young's modulus for shear wave speed (ICC > 0.90).

Conclusion: The results support the use of this procedure for assessing the AS stiffness in populations with mechanical neck pain as excellent reliability estimates were obtained. However, future research should analyze case-control differences and the association between SWE metrics with clinical severity indicators.

1. Introduction

The scalene muscles have a high clinical interest due to the anatomical relationships and its role in specific musculoskeletal impairments. In fact, the inter-scalene triangle is particularly relevant as it serves as the pathway for the roots and trunks of the brachial plexus and the subclavian artery [1,2]. Histological and functional AS muscle changes has been found associated with neck pain [3] as evidence demonstrated fiber conversion [4] and greater electromyographic activity pain-side specific during low-load tasks [5]. Despite these

findings, US research investigating this muscle is lacking in contrast with other neck muscles [6].

Since previous studies reported a considerable prevalence of active myofascial trigger points (MTrPs) located at the AS muscle in patients with upper thoracic spine pain [7] and whiplash associated disorders [8], and considering the nature of MTrPs (defined as a hyperirritable palpable nodule located in a taut band which produces sensorimotor dysfunctions and autonomic phenomena [9]), the use of stiffness measurements with objective and reliable tools may assist clinicians during the diagnostic procedure and treatment decision making [10].

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Previous studies used included SWE to assess both general muscle stiffness and specific locations within the muscles such as myofascial trigger point (MTrP) [11] and stiffness changes after specific interventions to MTrPs [11]. However, most of SWE research targeting neck muscles focused on the upper trapezius muscle [11] and reliability studies targeting the AS muscle are limited to small sample sizes in asymptomatic populations [12,13]. Therefore, the aim of this study is to establish a more specific, detailed and reproducible SWE protocol for identifying and measuring the anterior scalene muscle's stiffness in individuals with neck pain symptoms.

2. Methods

2.1. Study design

Between October 2022 and April 2023, a diagnostic accuracy designed cross-sectional observational study was conducted at a private University in Madrid, Spain. To improve the quality of this report, the study adhered to the Reporting Reliability and Agreement Studies (GRRAS) guidelines [14]. The Ethics Committee of Rey Juan Carlos University provided oversight and approval for the study protocol prior to data collection.

2.2. Participants

After posting local announcements around the campus, a sample consisting of volunteers with neck pain symptoms was recruited through convenience sampling. Inclusion criteria were being aged from 18 to 65 years old, experiencing neck pain symptoms at the moment of the exams, a pain duration of at least 6 months since the onset, a Neck Disability Index (NDI) score > 8 out of 100 and a Numeric Pain Rating Scale (NPRS) score > 3 out of 10 as these are the reported cut-off points to discriminate asymptomatic subjects from those with neck pain [15,16]. Participants were excluded if reported being under medical, pharmacological or physiotherapy treatments affecting pain perception or muscle tone 6 months previous to their inclusion, traumatic origin compatible with the symptoms (e.g., whiplash associated disorders, fractures or fissures), previous history of neck surgeries, radiculopathies, myelopathies and any other medical condition (e.g., fibromyalgia or oncologic conditions). Reading and signing an informed written consent before being included in the data collection was a mandatory request to be met by all participants.

2.3. Sample size calculation

The minimum sample size for this study was estimated according to the guidelines presented by Walter et al., [17] calculating it using the intraclass correlation coefficients (ICCs) provided in previous studies.

Given that: 1) an expected ICC value of 0.9 was hypothesized (as the protocol described in this study is more precise than the procedure described by Bedewi et al., [13]); 2) a power of 80 % and a significance level of 5 % were established; and 3) 10 % losses were assumed due to the longitudinal nature of the study, the minimum sample size required for this study was determined to be 65 SWE images.

2.4. Examiners

For conducting this study, one examiner with over 10 years of US and clinical experience in musculoskeletal conditions acquired and codified all the images while one blinded rater with comparable experience conducted all the image measurements. The imaging acquisition was conducted randomizing the volunteers' participation order and the sides firstly examined. The first session was conducted from 9:00 AM to 1:00 PM and the second trial was conducted from 3:00 PM to 17:00 PM. The rater was not aware of the side or trial as all images were previously codified and assigned in randomized order.

2.5. Shear wave elastography: Anterior scalene stiffness

The US device used for collecting all the images was a Logiq E9 device, using a linear transducer 6–15 MHz ML-6–15-D (General Electric Healthcare, Milwaukee, WI, USA). The console settings were also standard for all the acquisitions.

Participants were placed in the supine position with a pillow under their knees to minimize the lumbar lordosis. All volunteers received instructions to relax their neck muscles for reducing muscle stiffness variability attributable to muscle contraction.

After placing the transducer on the supraclavicular region beside the cricoid cartilage, a lateral glide was performed until locating the carotid artery in the lateral border of the image. Then, the transducer was glided in the cranial and caudal directions until locating the C6 transverse process in a short-axis view (characterized by a prominent the anterior tubercle and a smaller posterior tubercle) [18]. Then, the probe was caudally glided until locating the transverse process of C7 (characterized by a prominent posterior tubercle [18]). To blind the side examined, the posterior tubercle was consistently orientated to the left side of the image.

Finally, all images were analyzed onsite the US device measuring software. The blinded rater used the caliper to contour the anterior scalene perimeter (avoiding the inclusion of osseous, nervous and connective tissues as shown in Fig. 1) to calculate automatically both the Young's Modulus and the Shear Wave Velocity measurements.

2.6. Statistical analysis

The Statistical Package for the Social Sciences (SPSS v.27, Armonk, NY, USA) for Mac OS was used for conducting all data processing and analysis, using two-tailed tests with a significance level of $p < 0.05$. After corroborating the normal distribution of the sample using histograms and Shapiro-Wilk tests (if $p > 0.05$), the sample's characteristics were reported using descriptive analyses.

Sociodemographic and clinical data were reported by total sample and by gender while SWE features were reported by total sample, gender, left/right side and painful/non-painful side. Between-group differences (gender, side and pain presence) were analyzed using the Student's T-test for independent samples.

For test-retest reliability analyses, a calculation of 1) the mean average of both trials, 2) the absolute error between measurements 3), the intraclass correlation coefficients (ICC_{3,1} with a 2-way mixed model consistency type), 4) the standard error of measurement (SEM, calculated as the standard deviation of the mean average multiplied by the square root of 1 minus ICC, and 5) the minimal detectable changes (MDC, calculated as 1.96 times the square root of 2 times SEM) was conducted [19].

3. Results

From a total of 45 volunteers interested in collaborating with the study, 3 were excluded since they reported being under pharmacological treatment. Therefore, 42 volunteers with neck pain were included in the data collection, analyzing left and right sides from all participants. This led to a total of 84 anterior scalene muscles being examined, obtaining a total of 168 SWE images.

Table 1 compares the sociodemographic and clinical characteristics of the sample by gender. Although males were significantly taller and heavier than women (both, $p < 0.001$), body mass index and age were comparable between sexes ($p > 0.05$). Regarding the clinical characteristics of the sample, no significant differences were observed between males and females ($p > 0.05$), who reported a mild-to-moderate mean pain intensity [15] and moderate disability associated with neck pain [16].

The AS stiffness (assessed with SWE) is described in Table 2. The analyses revealed that the AS Young's modulus and shear wave speed

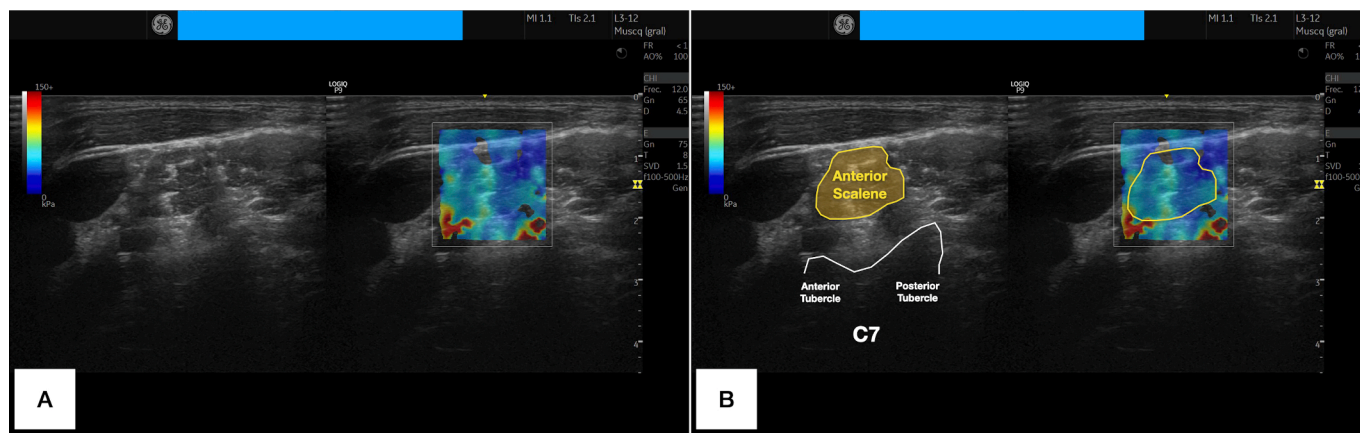


Fig. 1. Illustrative example of raw image (B-mode and Shear Wave Elastography) acquired at C7 level (A), identifying the anterior scalene muscle contour for calculating the stiffness metrics (B).

Table 1
Participants' sociodemographic characteristics.

Variables	Total sample (n = 42)	Gender		Difference
		Male (n = 15)	Female (n = 27)	
Age (y)	21.07 ± 2.75	21.60 ± 3.06	20.77 ± 2.57	0.82 (-0.97; 2.61) p = 0.360
Height (m)	1.68 ± 0.09	1.78 ± 0.07	1.63 ± 0.05	0.14 (0.10; 0.19) p < 0.001
Weight (kg)	68.10 ± 14.75	76.03 ± 16.63	63.70 ± 11.73	12.32 (3.44; 21.21) p < 0.001
Body Mass Index (kg/m ²)	23.85 ± 4.34	23.75 ± 4.09	23.90 ± 4.54	-0.14 (-3.00; 2.71) p = 0.917
Numeric Pain Rating Scale (0–10)	5.90 ± 1.60	5.66 ± 1.39	6.03 ± 1.72	-0.37 (-1.42; 0.68) p = 0.480
Neck Disability Index (0–100)	17.38 ± 9.74	17.60 ± 8.98	17.25 ± 10.30	0.34 (-6.07; 6.75) p = 0.915

^aReported values are obtained by calculating the mean average of both trials.

Table 2
Anterior scalene stiffness description by gender, side and painful side.

	Young's Modulus (kPa)	Shear Wave Speed (m/s)
Mean	18.99 ± 11.43	2.40 ± 0.72
Gender		
Males (n = 30)	16.86 ± 7.83	2.29 ± 0.56
Females (n = 54)	22.51 ± 13.50	2.61 ± 0.80
Difference	-5.64 (-13.35; 2.05) p = 0.094	-0.31 (-0.79; 0.15) p = 0.185
Side		
Left (n = 42)	17.46 ± 10.74	2.30 ± 0.70
Right (n = 42)	20.49 ± 12.00	2.50 ± 0.73
Difference	-3.03 (-1.94; 8.01) p = 0.229	-0.19 (-0.11; 0.51) p = 0.212
Pain side		
Painful side (n = 35)	17.89 ± 10.53	2.33 ± 0.69
Non-painful side (n = 49)	19.76 ± 12.07	2.44 ± 0.74
Difference	-1.86 (-6.96; 3.22) p = 0.486	-0.10 (-0.43; 0.21) p = 0.802

was comparable between genders (both, p > 0.05). In addition, no significant differences were found between the painful side and the asymptomatic side (p > 0.05) nor the left and right side (p > 0.05).

Finally, the test-retest reliability estimates for assessing the AS muscle stiffness in patients with neck pain are summarized in Table 3.

Table 3
Test-retest reliability for assessing the anterior scalene muscle stiffness.

Variables	Young's Modulus (kPa)	Shear Wave Speed (m/s)
Mean	18.99 ± 11.43	2.40 ± 0.72
Test	18.95 ± 10.92	2.41 ± 0.70
Retest	19.03 ± 12.93	2.39 ± 0.79
Absolute Difference	4.21 ± 5.69	0.27 ± 0.29
ICC _{3,2} (95 % CI)	0.904 (0.851;0.938)	0.922 (0.879;0.949)
SEM	3.54	0.20
MDC ₉₅	5.00	0.28
CV (%)	22.17 %	11.25 %

SEM and MDC₉₅ are expressed in the units described for each metric.

Good-to-excellent ICCs were found for assessing the Young's modulus (ICC = 0.851–0.938) and shear wave velocity (ICC = 0.879–0.949). In accordance with ICC results, shear wave speed demonstrated to be a more accurate metric than Young's modulus as SEM (3.54 kPa for Young's Modulus and 0.20 m/s for shear wave speed), MDC (5.0 kPa for Young's Modulus and 0.20 m/s for shear wave speed) and CV percentage (22.17 % for Young's Modulus and 11.25 % for shear wave speed) were relatively better considering the mean scores.

4. Discussion

The main strength of this study is that, to our knowledge, is the first research investigating the test-reliability of a US-based procedure for assessing the anterior scalene stiffness in patients with neck pain symptoms, finding good to excellent reliability for both metrics (Young's modulus and shear wave speed). Although Bedewi et al., [13] conducted a similar study, the sample consisted of 15 asymptomatic subjects and only the Young's modulus reliability was calculated. As the authors recognize, their study included a small sample size with no sample size calculation (therefore those results should be cautiously interpreted) and with limited clinical applicability as only asymptomatic individuals were assessed.

One limitation overcome in this study is the procedure detail in comparison with previous studies [13,20]. For instance, Bedewi et al., [13] designed a hardly replicable procedure because of its ambiguity as the authors only defined the patients' positioning as supine position (body positioning seems to have a direct impact on US reproducibility [21,22]) and the probe placement was described to be beside the thyroid lobe (since the average length of this gland was reported to be around 4.22 to 4.32 cm [23], a considerable error could be expected). On the other hand, Kuo et al., [20] assessed the shear wave speed (but not the Young's modulus) in a sample of 20 asymptomatic subjects. The procedure described consisted of placing the transducer at the lower fourth

of the anterolateral aspect of the neck. Likewise, the lack of details may involve a considerable risk of low reproducibility. However, this hypothesis cannot be confirmed as the authors did not provide reliability data.

If a comparison between the reliability estimates between this study and the results reported by Bedewi et al., [13] is made, a considerable increase in the procedure reliability has been got. The most reasonable rationale is that this study provides a considerably specific location to place the transducer. Additionally, it should be noted that generally intra-examiner reliability is generally better during the assessments of asymptomatic individuals in comparison with clinical populations [24], as it has been proposed that histological changes associated with pain may difficult the muscle contouring.

However, a precise location reduces considerably the measurement error. This hypothesis was confirmed since the reliability estimates obtained in this study were comparable to those reported in two recent studies [25,26] following the same procedure in asymptomatic individuals (ICC = 0.881 to 0.912 for Young's modulus and ICC = 0.850 to 0.923 for shear wave speed).

Finally, a discussion regarding the stiffness differences between the values obtained from asymptomatic individuals in previous studies [13,20] with the results obtained in patients with pain symptoms may assist on future research as the sociodemographic differences among the samples seems to be not associated with stiffness scores. It should be pointed that this study aimed to assess the procedure reliability and, since the sample size calculation was made for this purpose, the statistical power might not be enough to support the descriptive values reported nor the differences between sides, genders or painful and non-painful sides.

Thus, the lack of studies assessing the elastic properties of the AS muscle (even if other procedures such as myotonometry or tensiomyography are available and widely used for other muscles) also difficulted a direct comparison. In fact, a recent *meta*-analysis published by Opara et al., [27] describing which muscles exhibit increased stiffness in people with chronic neck pain found that the only supported conclusion was that the upper trapezius stiffness was elevated in patients with chronic neck pain compared to their counterparts without CNP while the data for other muscles (i.e., levator scapulae, splenius capitis, sternocleidomastoid and cervical multifidus) remained inconclusive.

Considering these cautions, the greater stiffness scores of our sample compared with asymptomatic individuals assessed in other articles [24,25] suggest that both the objective (SWE) and subjective (reported by the patients) measures of muscle stiffness can offer deeper insights into CNP's underlying mechanisms. Although these mechanisms are still unknown, the hypothesis proposed by Opara et al., [27] is that increased stiffness in these patients may be influenced by factors such as pain and inflammation activating specific sensory endings, potentially leading to altered muscle spindle excitability and increased muscle tone. Most studies have assessed passive muscle stiffness, indicating possible enhanced muscle activity at rest as a response to pain or as a protective strategy against painful movements. This complexity is further influenced by factors like muscle length and neck posture. Future research, integrating methods like EMG with shear-wave elastography, could provide more definitive insights into whether stiffness is due to passive mechanical characteristics or active muscle behavior, which would be crucial for determining effective treatment strategies.

4.1. Limitations

A limitation of our study is that we restricted the sample to patients with mechanical neck pain. As multiple neck pain classifications are described (neck pain with mobility deficits, with headaches, with radiating pain, with movement coordination impairments...) [28], the stiffness characteristics of this muscle may differ depending on the pain etiology. Secondly, we only assessed one cervical level and employed a single US device with a single experienced examiner acquiring the

images. As such, additional research that includes multiple cervical levels, various US devices and more examiners with different experience in the use of US is required to validate our findings.

5. Conclusion

The results obtained in this study supports the use of this US-based procedure for assessing the AS muscle stiffness in populations with neck pain symptoms. The intra-examiner reliability estimates indicated a good-to-excellent test-retest reliability. Although both metrics were similarly reliable, the shear wave speed demonstrated slightly better accuracy, being the most recommended metric for longitudinal studies. Further observational research is needed to corroborate the discriminative capacity of SWE and its correlation with clinical severity indicators.

6. Patient and public involvement Statement

Participants were not involved in the design, conduct, reporting or dissemination plans of our research.

7. Institutional review board statement

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Clinical Ethics Committee of Universidad Rey Juan Carlos (ID: URJC 1602202307923).

8. Informed consent statement

Informed consent was obtained from all subjects involved in the study.

9. Authors' contributions

All the authors equally contributed on 1) concept/idea/research design, 2) acquisition of data, 3) analysis and interpretation of data, 4) writing/review/editing of manuscript, 5) final approval of the manuscript, 6) providing facilities and 7) providing subjects.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

All data derived from this study are presented in the text.

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