Neck Muscle Stiffness in Participants With and Without Chronic Neck Pain: A Shear-Wave Elastography Study

Serkan Taş, PhD, PT,[a] Feza Korkusuz, PhD, MD,[b] and Zafer Erden, PhD, PT[c]

Abstract

Objectives: The purpose of the present study was to investigate differences in neck muscle stiffness between patients with chronic neck pain and asymptomatic control group.

Methods: Thirty-five patients with chronic neck pain and 35 age-matched asymptomatic participants enrolled in the study. Shear wave velocity (SWV) of upper trapezius, levator scapulae, splenius capitis, and sternocleidomastoid muscles were obtained using an ACUSON S3000 Ultrasonography Device (Siemens Medical Solutions, Mountain View, California). In patients with chronic neck pain, pain intensity was measured by Numerical Rating Scale and disability level was measured by Neck Disability Index.

Results: The SWV of splenius capitis was similar in both groups ($P = .985$); however, SWV of upper trapezius ($P = .001$), levator scapulae ($P = .038$), and sternocleidomastoid ($P = .001$) of the patients with chronic neck pain were higher compared with the asymptomatic controls groups. Numerical Rating Scale and Neck Disability Index scores did not correlate with the SWV of the selected muscles ($P > .05$).

Conclusions: Stiffness of upper trapezius, levator scapulae, and sternocleidomastoid muscles in patients with neck pain were higher compared to asymptomatic participants. In addition, severity of pain and disability did not correlate to stiffness of these muscles in patient with chronic neck pain. (J Manipulative Physiol Ther 2018;41:580-588)

Key Indexing Terms: *Elasticity Imaging Techniques; Pain; Spine*

Introduction

Neck pain globally has an annual prevalence rate of 30%, and it is one of the leading causes of disability following back pain, depression, and arthralgia.[1] Most patients with acute neck pain recover with or without treatment; however, neck pain still occurs at varying degrees in 50% of these patients.[2-4] Even though various factors have been associated with neck pain, skeletal muscle mechanical properties and muscular function abnormalities have been cited among the leading causes of neck pain.[5-7] Changes in skeletal muscle stiffness may be related to chronic neck pain, and these changes may be associated with the severity of pain and disability in patients with chronic neck pain. Muscle stiffness is one of the essential indicators of the shock absorption feature of the muscle-tendon unit and joint.[8] In addition, increase in muscle stiffness can limit motion and potentially affect joint control.[9,10]

Changes in muscle stiffness in individuals with neck pain have been investigated in only 1 study. Ishikawa et al[7] reported that trapezius muscle stiffness in patients with neck pain increased; however, levator scapulae and rhomboid major stiffness were found to be similar with those of the asymptomatic controls. However, the changes in muscle stiffness were interpreted using the strain ratio, and they did not calculate the actual elastic modulus. There is limited information on changes in neck muscles stiffness of patients with chronic neck pain. In addition, to our knowledge, there exists no study investigating differences in neck muscle stiffness between patients with chronic neck pain and asymptomatic individuals using the shear wave elastography (SWE) method. Furthermore, the literature review shows that the relationship of muscle stiffness with pain and disability in individuals with neck pain has not been investigated. Any insight into the changes in muscle stiffness in individuals wi2th neck pain may shed light on the factors causing neck pain or may provide important information on the pathomechanics of neck pain.

[a] Department of Physiotherapy and Rehabilitation, School of Health Sciences, Toros University, Mersin, Turkey.
[b] Departments of Sports Medicine, School of Medicine, Hacettepe University, Ankara, Turkey.
[c] Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Hacettepe University, Ankara, Turkey.
Corresponding author: Serkan Taş, PhD, PT, Department of Physiotherapy and Rehabilitation, School of Health Sciences, Toros University, Bahçelievler Campus, 1857th Street, Apt 12, Yenişehir, Mersin, 33140, Turkey. Tel.: +90 324 325 33 00.
(e-mail: *serkan.tas@toros.edu.tr*).
Paper submitted August 27, 2017; in revised form January 8, 2018; accepted January 9, 2018.
0161-4754

https://doi.org/10.1016/j.jmpt.2018.01.007

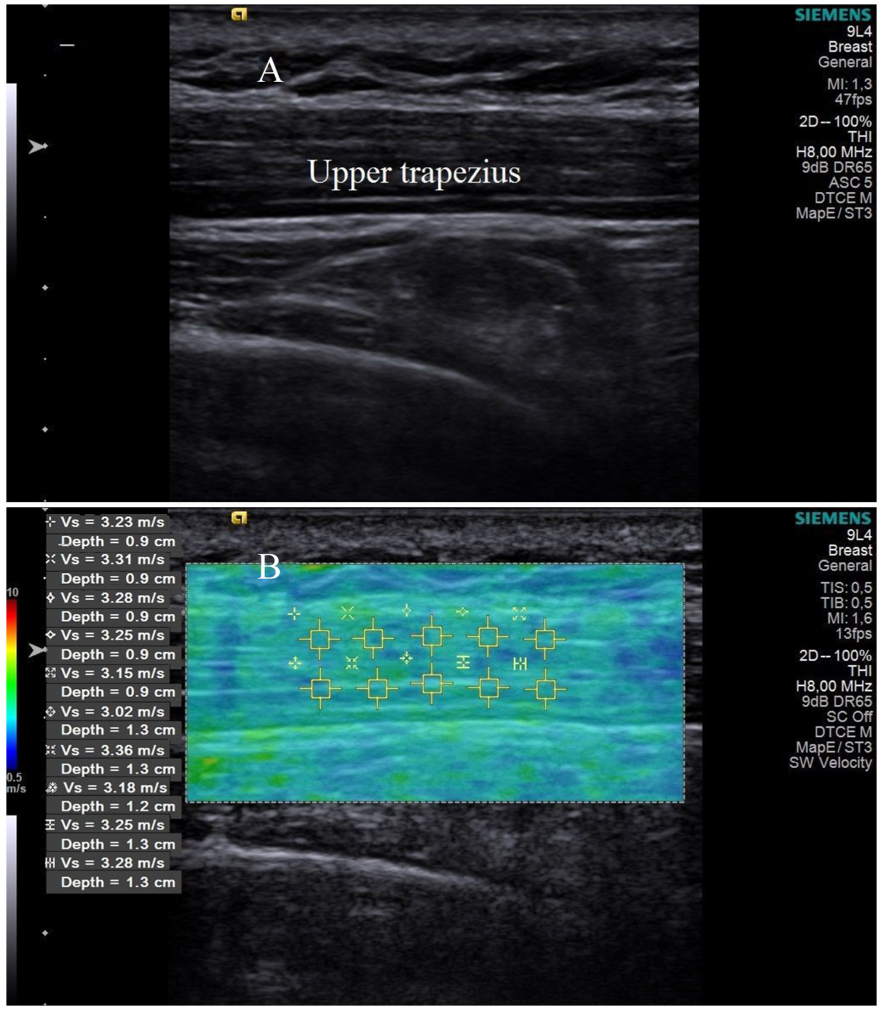

Fig 1. *Two-dimensional ultrasound image of the upper trapezius muscle (A). Color map shear wave elastography image of the upper trapezius muscle in the longitudinal plane (B). Ranges of image were placed in the muscle, and corresponding shear wave velocity (m/sec) values were recorded. The shear wave velocity of the tissues increases in the order of blue-green-red color-coded areas.*

Muscle stiffness is evaluated by different methods such as simple palpation, B-mode ultrasound, and magnetic resonance elastography. However, these methods have some disadvantages, for example, the structure of simple palpation has a subjective nature, magnetic resonance elastography is expensive and takes a long time, and standard ultrasonography gives only indirect information about muscle hardness. Shear wave elastography is a relatively new ultrasonography-based method. Using SWE, mechanical characteristics of a tissue are estimated by measuring both temporary deformation and displacement of the soft tissue caused by acoustic radiation force.[11] Shear wave elastography enables the measurement of soft tissue stiffness to be done easily, cheaply, quickly, reliably, and validly.[12-14]

The purpose of the present study was to investigate the differences in upper trapezius, splenius capitis, levator scapulae, and sternocleidomastoid muscle stiffness between patients with chronic neck pain and asymptomatic controls. Another purpose of the study was to investigate the relationship of muscle stiffness with the severity of physical disability and pain in patients with chronic neck pain. We hypothesized the following: (1) upper trapezius, levator scapulae, splenius capitis, and sternocleidomastoid muscle stiffness would be higher in patients with chronic neck pain compared with asymptomatic controls; and (2) an increase in muscle stiffness would correlate with the severity of disability and pain in patients with chronic neck pain.

Materials and Methods

Participants

The chronic neck pain group included 35 patients, with an age range of 19 to 50 years (35.7 ± 8.3 years), who had been experiencing neck pain for at least 3 months before the study. The control group included 35 healthy individuals, with an age range of 18 to 49 years (35.2 ± 9.0), who had never experienced

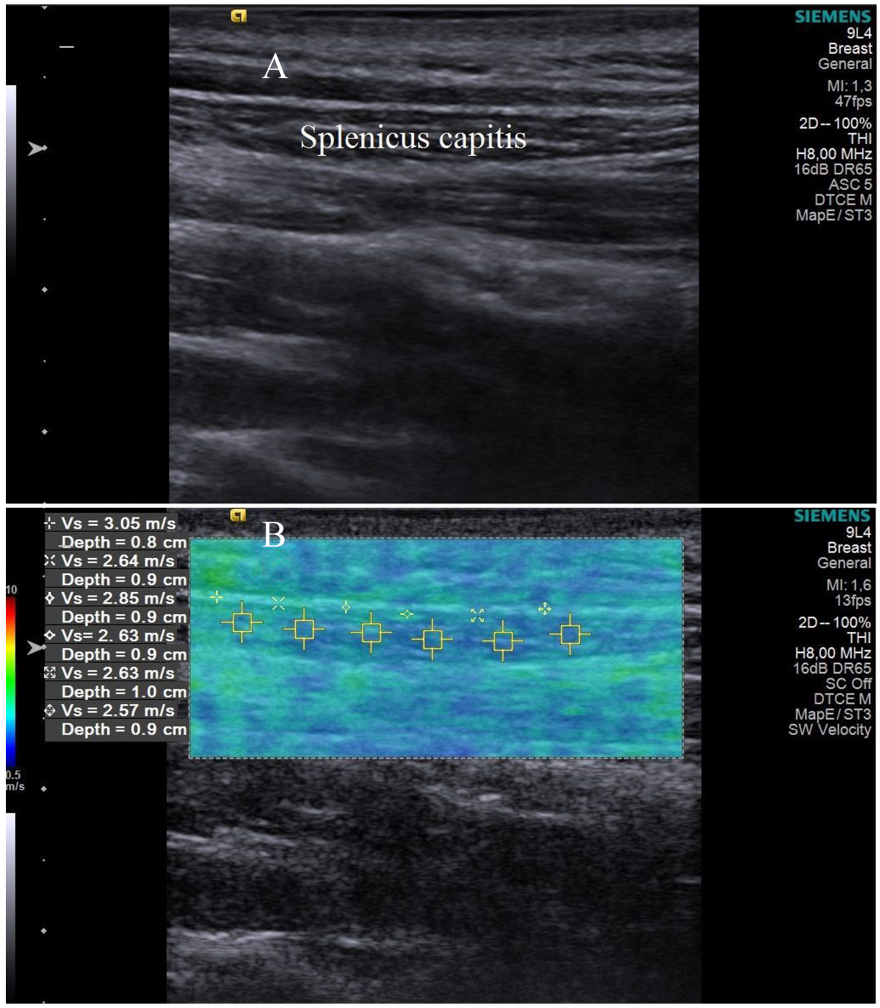

Fig 2. *Two-dimensional ultrasound image of the splenius capitis muscle (A). Color map shear wave elastography image of the splenius capitis muscle in the longitudinal plane (B). Ranges of image were placed in the muscle, and corresponding shear wave velocity (m/sec) values were recorded. The shear wave velocity of the tissues increases in the order of blue-green-red color-coded areas.*

neck pain for at least 1 year before the study. Participants were excluded if they met any of the following exclusion criteria: (1) diagnosed with neurological, vestibular, rheumatic, or endocrine disorders; (2) had previous spinal surgery, neck trauma associated with post-traumatic amnesia or concurrent head injury, or cervical fracture or dislocation; or (3) currently receiving treatment for neck pathology. Required permission was obtained from Hacettepe University Non-Invasive Clinical Research Ethics Board. Informed consent was obtained from all participants in the study.

Pain and Disability Assessments

Pain severity of the patients with chronic neck pain was obtained via the Numerical Rating Scale (NRS), which is reported in the literature as a reliable and valid scale for the detection of pain severity.[15,16] In the NRS, 0 indicates no pain and 100 indicates an unbearable pain. The Neck Disability Index (NDI) was used to assess the neck pain-related disability level. The NDI is a reliable and valid scale for identifying the disability level of patients with chronic neck pain.[17,18] The NDI is composed of 10 sections, namely: pain intensity, personal care, lifting, reading, headaches, concentration, work, driving, sleeping, and recreation. In each section, the score ranges between 0 (no disability) and 5 (total disability). The total score ranges between 0 (no disability) and 50 (total disability). The present study included patients with a pain intensity level of 20 or more based on the NRS and a total disability level of 10 or more based on the NDI.

Muscle Stiffness Measurement

Shear wave velocity (SWV) measurements in the selected muscles were performed using an ACUSON S3000 Ultrasound System and a 9L4 probe (4-9 MHz)

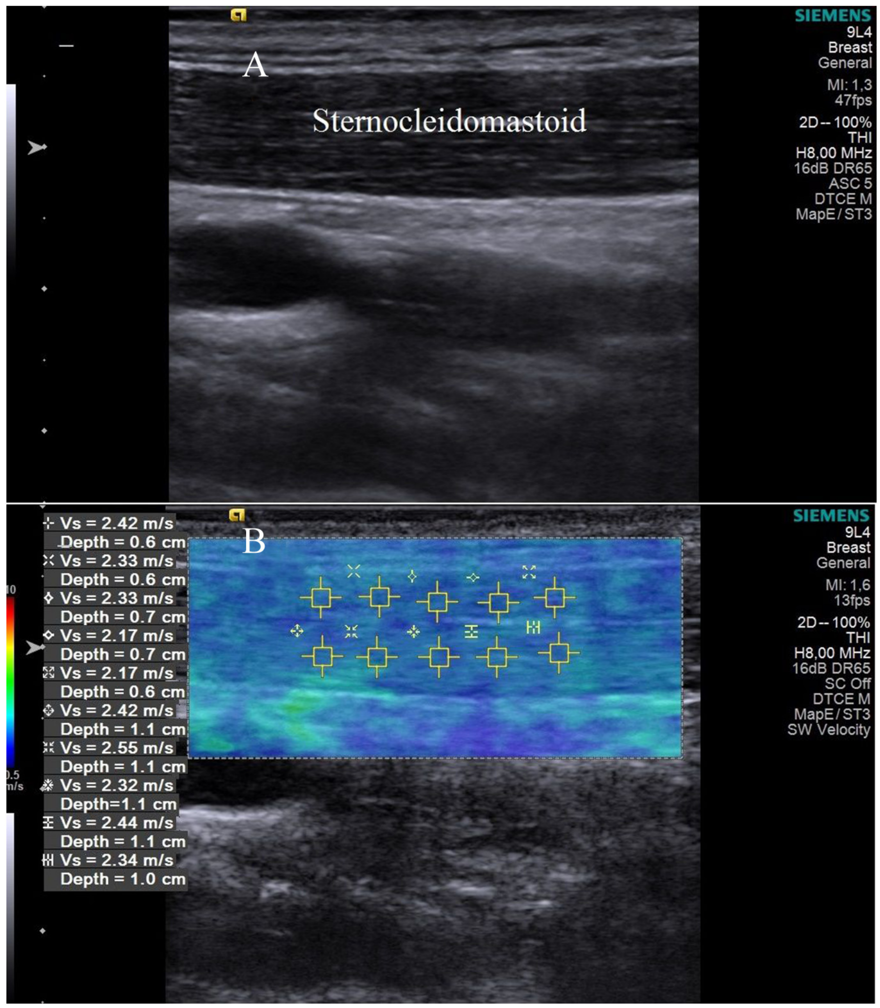

Fig 3. *Two-dimensional ultrasound of the sternocleidomastoid muscle (A). Color map shear wave elastography image of the sternocleidomastoid muscle in the longitudinal plane (B). Ranges of image were placed in the muscle, and corresponding shear wave velocity (m/sec) values were recorded. The shear wave velocity of the tissues increases in the order of blue-green-red color-coded areas.*

(Siemens Medical Solutions, Mountain View, California). In healthy individuals, muscle stiffness was measured at the dominant side. In patients with neck pain, muscle stiffness measurements were performed on the side where pain occurred most. If the pain intensity was similar on both sides, measurement was performed at the dominant side.

Longitudinal axial B-mode images of the upper trapezius, splenius capitis, levator scapulae, and sternocleidomastoid were obtained by scanning each muscle. Similar to previous studies,[7,19] assessments of trapezius and splenius capitis were performed with the individuals in lying prone position on an examination couch, with their arms relaxed at their sides and their wrists pronated as their forehead is on a U-shaped pillow. For the SWV measurement of the upper trapezius muscle, the transducer was positioned at 2 cm lateral of the midway between the lateral edge of the acromion and spinous process of C7. For the SWV measurement of the splenius capitis muscle, the transducer was positioned at 2 cm lateral of the spinous process, centering the fourth cervical vertebra. For the SWV of the levator scapulae muscle, the transducer was positioned at the plumpest section of the muscle between the superior angle of the scapula and the midpoint between the transverse processes of C1 and C4.

Assessments of the sternocleidomastoid muscle were performed with individuals lying in supine position on an examination couch, with a soft pillow underneath the neck. For the SWV measurement of the sternocleidomastoid muscle, the transducer was positioned at the midway between the sternum and the mastoid process. The SWVs of the muscles were calculated by taking the average of 3 successive measurements performed at intervals of at least 20 seconds. Mean SWV measurement was obtained using customized software, Virtual Touch Imaging and

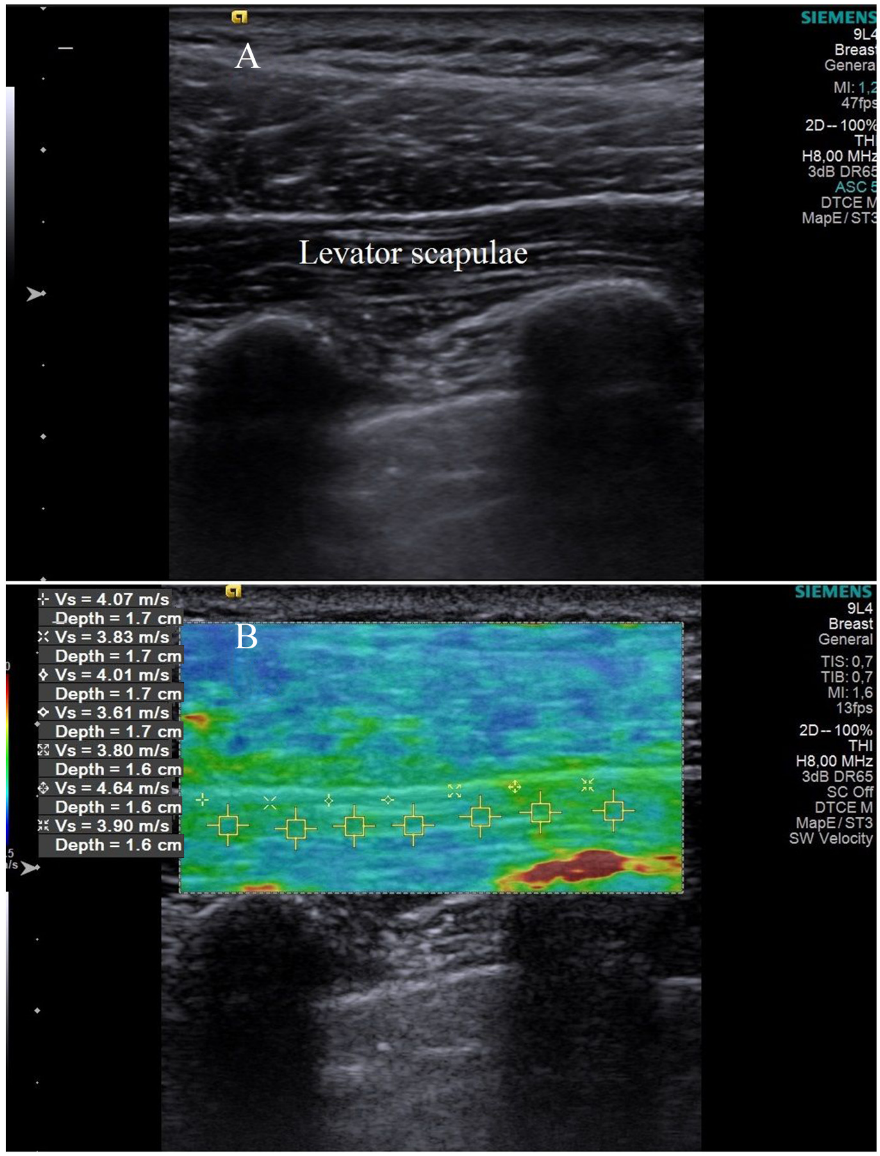

Fig 4. *Two-dimensional ultrasound of the levator scapulae muscle (A). Color map shear wave elastography image of the sternocleidomastoid muscle in the longitudinal plane (B). Ranges of image were placed in the muscle, and corresponding shear wave velocity (m/sec) values were recorded. The shear wave velocity of the tissues increases in the order of blue-green-red color-coded areas.*

Quantification (Siemens Medical Solutions, Mountain View, California). The SWVs of the muscles were calculated as the average value obtained from a series of fixed sample regions positioned in the area of interest and recorded as meter per second (Figs 1-4).

Statistical Analysis

No previous data were available to estimate sample size (means and standard deviations) for this type of comparison; thus, we estimated a large effect size. The hypothesized effect size is 0.90 and significance level of 0.01 (type 1 error). On the basis of these criteria, at least 30 participants per group were necessary.[20] Statistical analyses were carried out using SPSS for Windows, version 18 (SPSS Inc, Chicago, Illinois). Variables were investigated using visual (histograms, probability plots) and analytical methods (Kolmogorov-Smirnov or Shapiro-Wilk tests) to determine distribution. Demographic data and the assessed parameters were presented using mean and standard deviation for normally distributed variables. As the assessed parameters were normally distributed, intergroup comparisons were carried out by the Student's *t* test. Upper trapezius, splenius capitis, levator scapulae, and sternocleidomastoid stiffness were compared by the Paired Student's *t* test. Correlation coefficients for relations between parameters and statistical

Table 1. *Demographic Data and Results of Ultrasonic Evaluations of the Patients With Chronic Neck Pain and Asymptomatic Individuals*

	Neck Pain Patients	Asymptomatic Controls	
Parameters	Mean ± SD	Mean ± SD	P
Age (y)	35.6 ± 8.3	35.2 ± 9.2	.847
Sex (male/female)	8/27	11/24	
Height (m)	1.66 ± 0.09	1.65 ± 0.08	.558
Weight (kg)	68.4 ± 10.7	68.0 ± 9.4	.878
BMI (kg/m^2)	24.9 ± 3.6	24.6 ± 3.3	.743
SWV of upper trapezius (m/sec)	3.2 ± 0.5	2.8 ± 0.4	.001
SWV of sternocleidomastoid (m/sec)	2.5 ± 0.3	2.2 ± 0.3	.001
SWV of levator scapulae (m/sec)	4.0 ± 0.8	3.7 ± 0.6	.038
SWV of splenius capitis (m/sec)	2.6 ± 0.4	2.6 ± 0.4	.985
Numerical Rating Scale (mm)	46.3 ± 19.8		
Neck Disability İndex (score)	22.8 ± 7.8		

BMI, body mass index; *SD*, standard deviation; *SWV*, shear wave velocity.

significance in patients with neck pain were calculated using the Pearson test. For statistical significance, type I error level was set as 5%.

Results

Both groups were similar in age (*P* = .847), height (0.558), body mass (0.878), and body mass index (*P* = .743). The SWV of the splenius capitis muscle was similar in both groups (*P* = .985); however, SWV of the upper trapezius (*P* = .001), levator scapulae (*P* = .038), and sternocleidomastoid (*P* = .001) of the patients with chronic neck pain were higher compared with the asymptomatic controls. The results of the statistical analyses belonging to patients with chronic neck pain and asymptomatic controls are presented in Table 1.

The SWV of the levator scapulae muscle was found to be higher than that of the upper trapezius, sternocleidomastoid, and splenius capitis muscles (*P* < .001). The SWV of the upper trapezius muscle was found to be higher than that of the sternocleidomastoid and splenius capitis (*P* < .001) muscles; however, SWV of the sternocleidomastoid and splenius capitis muscles were found similar for all individuals (*P* = .198).

The correlation analysis revealed that the NRS score did not correlate with the SWV of the upper trapezius (*r* = -0.27, *P* = .123), levator scapulae (*r* = -0.14, *P* = .422), sternocleidomastoid (*r* = -0.03, *P* = .878), and splenius capitis (*r* = 0.07, *P* = .970) muscles. Similarly, the NDI score did not correlate with the SWV of the upper trapezius (*r* = -0,08 *P* = .650), levator scapulae (*r* = -0.08, *P* = .642), sternocleidomastoid (*r* = 0.09, *P* = .591), and splenius capitis (*r* = 0.02, *P* = .917) muscles.

Discussion

The present study was conducted to investigate changes in the stiffness of neck muscles in patients with chronic neck pain. The results demonstrate that stiffness of the splenius capitis muscle in patients with chronic neck pain was similar to asymptomatic controls; however, the upper trapezius, levator scapulae, and sternocleidomastoid stiffness was higher compared with asymptomatic controls. Similar to our results, Ishikawa et al[7] assessed muscle stiffness using strain elastography and was based on strain ratio and reported that trapezius muscles stiffness increased in patients with neck pain, which is in line with the results of the present study, but unlike our results, they reported that levator scapulae stiffness was similar to asymptomatic controls. Potentially, this difference might be due to the methodological differences between the studies. In the present study, muscles were assessed by SWE, but Ishikawa et al performed their muscle stiffness measurements using strain elastography. The increase in muscle stiffness in patients with chronic neck pain may be associated with the changes in the γ-motor activity. The following was hypothesized: (1) chemical mediators are released because of inflammation, ischemic muscle contraction, or fatiguing, which stimulates group III and IV afferents; (2) the stimulation of group III and IV afferents stimulates γ-motor neurons and reflexively increases the muscle spindle afferent Ia and II spindle outputs; (3) an increase in the muscle spindle afferent activity results in an increase in muscle stiffness.[21,22]

Another cause of the results obtained in the present study might be the morphologic and histologic changes occurring in the muscle structures of the patients with neck pain. An increase in fatty infiltration and changes in muscle fiber type and cross section area of neck muscles in patients with chronic neck pain have been reported in literature.[23-27] It is well established that morphologic and histologic changes in muscle structure could affect muscle stiffness.[28,29] On the other hand, increased muscle stiffness may be an adaptation or motor strategy in patients with chronic neck pain. An increase in muscle stiffness could increase joint stabilization and resistance against external loads during functional performance.[9,10]

One of the hypotheses of the present study is that there is a positive correlation of the increase in muscle stiffness with the severity of pain and disability in patients with chronic neck pain. This hypothesis was established based on the idea that nociception activity stemming from the injuries in local tissues would affect the flexor reflex activity and the sensitivity in ɣ motor neurons. The ɣ-muscle spindle system sensitivity and reflex activity during pain may become disturbed because of the chemosensitive type III and IV afferents (nociceptors). The stimulation of ɣ motor neurons causes an increase in the muscle spindle activity, which increases muscle stiffness.[21,22] Contrary to our hypothesis, our results suggest that the severity of pain and disability did not relate to stiffness of these muscles in patients with chronic neck pain. However, the fact that muscle stiffness values obtained in both healthy controls as well as in patients with chronic neck pain were laid out in a wide spectrum might have inhibited establishing a correlation between parameters. The correlation between parameters that is examined by correlation analysis is directly examined. In this method, deviations from normal values cannot be determined because the individuals' standardized values are not known. Having these values would have been useful in identifying correlations. In addition, the fact that the values obtained were laid out in a wide spectrum may not influence unilateral conditions, such as lateral epicondylitis or plantar fasciitis; however, it may hinder the differentiation of a pathologic case with a normal one by the SWE method in patients with neck pain. In most unilateral conditions, the comparison of the affected side and the healthy one may be a suitable method to overcome this limitation. However, in patients with neck pain, each side of the neck may be affected at different levels. Therefore, further studies or methods are warranted to standardize neck muscles stiffness on an individual basis.

Another result of the present study was that upper trapezius and levator scapulae muscle stiffness were higher compared to the sternocleidomastoid and splenius capitis muscles. Potentially, it may be associated with the anatomic feature of the upper trapezius and levator scapulae muscles. Unlike sternocleidomastoid and splenius capitis, trapezius and levator scapulae muscles have an important task involving scapula and shoulder joint stabilization and regarding the weight bearing of the upper extremities. Excessive stiffness of the trapezius and levator scapulae muscles may increase passive stabilization, and thus it may decrease weight bearing of the muscle.

Limitations

The assessments were not performed by a researcher blinded to the groups. However, standardized instructions were used in muscle stiffness measurements to minimize the bias. The study included only patients with current chronic neck pain. Patients with acute neck pain or those in the silent period of the condition were not included in the study. Involving such patients could have been useful in having insight into the pathomechanics of neck pain. Finally, in the present study, muscle stiffness measurements were performed on the side where pain occurs most in the patients with neck pain. Assessing muscle stiffness of contralateral side of patients with chronic neck pain could have been useful in having insight into the pathomechanics of chronic neck pain.

Conclusions

In conclusion, the splenius capitis muscle stiffness was found similar in both groups, but the stiffness of upper trapezius, levator scapulae, and sternocleidomastoid muscles were found increased in patients with neck pain. In addition, the severity of pain and disability did not relate to the stiffness of these muscles in patients with chronic neck pain.

Funding Sources and Conflicts of Interest

No funding sources or conflicts of interest were reported for this study.

Contributorship Information

Concept development (provided idea for the research): S.T., F.K., Z.E.

Design (planned the methods to generate the results): S.T., F.K., Z.E.

Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): S.T., F.K., Z.E.

Data collection/processing (responsible for experiments, patient management, organization, or reporting data): S.T., F.K., Z.E.

Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): S.T., F.K., Z.E.

Literature search (performed the literature search): S.T., F.K., Z.E.

Writing (responsible for writing a substantive part of the manuscript): S.T., F.K., Z.E.

Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): S.T., F.K., Z.E.

Practical Applications

- Stiffness of upper trapezius, levator scapulae, and sternocleidomastoid muscles in patients with neck pain were higher compared with asymptomatic participants.
- Stiffness of upper trapezius and levator scapulae were higher compared with sternocleidomastoid and splenius capitis muscle for all participants.
- Severity of pain and disability did not relate to stiffness of selected muscles in patient with chronic neck pain.

References

1. Cohen SP. Epidemiology, diagnosis, and treatment of neck pain. *Mayo Clin Proc.* 2015;90(2):284-299.
2. Vasseljen O, Woodhouse A, Bjorngaard JH, Leivseth L. Natural course of acute neck and low back pain in the general population: the HUNT study. *Pain.* 2013;154(8):1237-1244.
3. Vos CJ, Verhagen AP, Passchier J, Koes BW. Clinical course and prognostic factors in acute neck pain: an inception cohort study in general practice. *Pain Med.* 2008;9(5):572-580.
4. Hogg-Johnson S, van der Velde G, Carroll LJ, et al. The burden and determinants of neck pain in the general population: results of the Bone and Joint Decade 2000-2010 Task Force on Neck Pain and Its Associated Disorders. *J Manipulative Physiol Ther.* 2009;32(2 Suppl):S46-S60.
5. De Pauw R, Coppieters I, Kregel J, De Meulemeester K, Danneels L, Cagnie B. Does muscle morphology change in chronic neck pain patients? - A systematic review. *Man Ther.* 2016;22:42-49.
6. Lindstroem R, Graven-Nielsen T, Falla D. Current pain and fear of pain contribute to reduced maximum voluntary contraction of neck muscles in patients with chronic neck pain. *Arch Phys Med Rehabil.* 2012;93(11):2042-2048.
7. Ishikawa H, Muraki T, Morise S, et al. Changes in stiffness of the dorsal scapular muscles before and after computer work: a comparison between individuals with and without neck and shoulder complaints. *Eur J Appl Physiol.* 2017;117(1):179-187.
8. Watsford ML, Murphy AJ, McLachlan KA, et al. A prospective study of the relationship between lower body stiffness and hamstring injury in professional Australian rules footballers. *Am J Sports Med.* 2010;38(10):2058-2064.
9. Butler RJ, Crowell HP, Davis IM. Lower extremity stiffness: implications for performance and injury. *Clin Biomech (Bristol, Avon).* 2003;18(6):511-517.
10. Eiling E, Bryant AL, Petersen W, Murphy A, Hohmann E. Effects of menstrual-cycle hormone fluctuations on musculotendinous stiffness and knee joint laxity. *Knee Surg Sports Traumatol Arthrosc.* 2007;15(2):126-132.
11. Taljanovic MS, Gimber LH, Becker GW, et al. Shear-wave elastography: basic physics and musculoskeletal applications. *Radiographics.* 2017;37(3):855-870.
12. Tas S, Onur MR, Yılmaz S, Soylu AR, Korkusuz F. Shear wave elatography is a reliable and repeatable method for measuring the elastic modulus of the rectus femoris muscle and patellar tendon. *J Ultrasound Med.* 2017;36(3):565-570.
13. Miyamoto N, Hirata K, Kanehisa H, Yoshitake Y. Validity of measurement of shear modulus by ultrasound shear wave elastography in human pennate muscle. *PLoS One.* 2015;10(4)e0124311.
14. Lacourpaille L, Hug F, Bouillard K, Hogrel JY, Nordez A. Supersonic shear imaging provides a reliable measurement of resting muscle shear elastic modulus. *Physiol Meas.* 2012;33(3):N19-N28.
15. Price DD, McGrath PA, Rafii A, Buckingham B. The validation of visual analogue scales as ratio scale measures for chronic and experimental pain. *Pain.* 1983;17(1):45-56.
16. Bolton JE, Wilkinson RC. Responsiveness of pain scales: a comparison of three pain intensity measures in chiropractic patients. *J Manipulative Physiol Ther.* 1998;21(1):1-7.
17. Vernon H, Mior S. The Neck Disability Index: a study of reliability and validity. *J Manipulative Physiol Ther.* 1991;14(7):409-415.
18. Telci EA, Karaduman A, Yakut Y, Aras B, Simsek IE, Yagli N. The cultural adaptation, reliability, and validity of Neck Disability Index in patients with neck pain: a Turkish version study. *Spine (Phila Pa 1976).* 2009;34(16):1732-1735.
19. Akagi R, Kusama S. Comparison between neck and shoulder stiffness determined by shear wave ultrasound elastography and a muscle hardness meter. *Ultrasound Med Biol.* 2015;41(8):2266-2271.
20. Cohen J. *Statistical Power Analysis for the Behavioral Sciences.* 2nd ed. Mahwah, NJ: Lawrence Erlbaum Associates; 1988.
21. Johansson H, Sojka P. Pathophysiological mechanisms involved in genesis and spread of muscular tension in occupational muscle pain and in chronic musculoskeletal pain syndromes: a hypothesis. *Med Hypotheses.* 1991;35(3):196-203.
22. Knutson GA. The role of the gamma-motor system in increasing muscle tone and muscle pain syndromes: a review of the Johansson/Sojka hypothesis. *J Manipulative Physiol Ther.* 2000;23(8):564-572.
23. Elliott JM, Pedler AR, Jull GA, Van Wyk L, Galloway GG, O'Leary SP. Differential changes in muscle composition exist in traumatic and nontraumatic neck pain. *Spine (Phila Pa 1976).* 2014;39(1):39-47.
24. Jesus-Moraleida FR, Ferreira PH, Pereira LS, Vasconcelos CM, Ferreira ML. Ultrasonographic analysis of the neck flexor muscles in patients with chronic neck pain and changes after cervical spine mobilization. *J Manipulative Physiol Ther.* 2011;34(8):514-524.

25. Hallgren RC, Greenman PE, Rechtien JJ. Atrophy of suboccipital muscles in patients with chronic pain: a pilot study. *J Am Osteopath Assoc.* 1994;94(12):1032-1038.
26. Lindman R, Eriksson A, Thornell LE. Fiber type composition of the human female trapezius muscle: enzyme-histochemical characteristics. *Am J Anat.* 1991;190(4):385-392.
27. Uhlig Y, Weber BR, Grob D, Muntener M. Fiber composition and fiber transformations in neck muscles of patients with dysfunction of the cervical spine. *J Orthop Res.* 1995;13(2):240-249.
28. Schleip R, Naylor IL, Ursu D, et al. Passive muscle stiffness may be influenced by active contractility of intramuscular connective tissue. *Med Hypotheses.* 2006;66(1):66-71.
29. de Bruin M, Smeulders MJ, Kreulen M, Huijing PA, Jaspers RT. Intramuscular connective tissue differences in spastic and control muscle: a mechanical and histological study. *PLoS One.* 2014;9(6)e101038.