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Neck Muscle Stiffness Measured With Shear Wave Elastography in Women With Chronic Nonspecific Neck Pain

Between 27% and 48% of working adults complain of neck pain annually.[1,2] The prevalence of neck pain is higher in women,[12,24] peaks in middle age,[5,24] and is influenced by psychosocial,[9,22] environmental,[28,32,46] and physical[22,32] conditions. The majority of people with neck pain fall into the category of nonspecific neck pain, which includes a mix of nociceptive and neuropathic pain mechanisms.[35] Besides pain, sensations of tense, tight, or stiff neck muscles are common complaints accompanying neck pain[27,37,52] and are the target of various therapeutic approaches.[42,60,62]

Shear wave elastography provides an objective measure of muscle stiffness that may or may not be related to self-reported stiffness. More specifically, shear wave elastography enables noninvasive measurements of tissue stiffness in the form of images (elastograms) that represent maps of localized stiffness[7,20,25] (**FIGURE 1A**). A focused ultrasound beam, the "push-beam," induces a remote, minimal displacement of tissue and thereby the propagation of transverse shear waves.[7,20] The velocity of the propagating shear waves (V_s) is linked to the tissue's shear modulus ($\mu = \rho \times V_s^2$, where ρ is the material's density), which provides an estimate of the tissue's stiffness.[20]

Increasing evidence questions whether muscles in regions of perceived stiffness are objectively stiffer than those of asymptomatic individuals.[1,13,29,51,58] Indeed, the existing evidence of altered objective stiffness of the neck muscles in people with chronic neck pain is conflicting. Increased stiffness of the upper trapezius muscle has been reported in some[27,33,53] but not all studies,[1,13] and similar stiffness of the splenius capitis was observed in those with and without neck pain.[53] Objective stiffness of the deeper neck muscles has only been examined in pain-free participants.[14,18] Studies in healthy individuals have demonstrated higher stiffness in the deep compared to the superficial neck muscles,[14,18] suggesting a depth-dependent organization

OBJECTIVE: Utilizing shear wave elastography, we compared the stiffness of the neck extensor muscles and the stiffness in muscle-specific regions between women with chronic nonspecific neck pain and asymptomatic controls.

DESIGN: Cross-sectional observational study.

METHODS: We measured the average muscle stiffness over multiple neck extensor muscles and in regions corresponding approximately to the trapezius, splenius capitis, semispinalis capitis, semispinalis cervicis, and multifidus muscles using ultrasound shear wave elastography in 20 women with chronic nonspecific neck pain and 18 asymptomatic women during multiple tasks. The measurements were automatically quality controlled and computer processed over the complete visible neck region or a large muscle-specific region.

RESULTS: Pooled over all tasks, neck muscle stiffness was not significantly different between those with neck pain and asymptomatic controls (neck pain median, 11.6 kPa; interquartile range, 8.9 kPa and control median, 13.3 kPa; interquartile range, 8.6 kPa; $P = .175$). The measure of neck muscle stiffness was not correlated with the intensity of neck pain or perceived disability.

CONCLUSION: Shear wave elastography revealed similar muscle stiffness in people with and without chronic neck pain, despite the sensation of increased neck stiffness in those with chronic neck pain. Therapeutic interventions aiming to reduce neck muscle tone are often based on the assumption that perceived neck stiffness corresponds to objective muscle stiffness. The current results question this assumption. *J Orthop Sports Phys Ther 2020;50(4):179-188. Epub 6 Jan 2020. doi:10.2519/jospt.2020.8821*

KEY WORDS: *cervical spine, chronic pain, muscle tension, shear modulus, ultrasound shear wave elastography*

of neck muscle stiffness.[14] Altered organization and extent of muscle stiffness may partially explain perceived stiffness. Given the discrepancies within the current literature, we aimed to compare the average stiffness of the neck extensor muscles between middle-aged women with chronic nonspecific neck pain who report the sensation of increased neck muscle stiffness and asymptomatic controls. Additionally, we compared stiffness in specific muscle regions between groups. As a further aim, we examined the reliability of stiffness measurements of the neck extensor muscles in a subgroup of our participants with and without chronic nonspecific neck pain. Although fair to excellent reliability of shear wave elastography measurements of muscle stiffness has been reported,[31,38] a recent study observed a significant between-day variation in neck muscle stiffness measurements.[18] Further investigation of the between-day reliability of shear wave elastography measures of the neck extensor muscles is warranted.

We hypothesized that (1) shear wave elastography would provide reliable measurements of neck extensor muscle stiffness, and (2) women with chronic nonspecific neck pain reporting perceived neck muscle stiffness would demonstrate increased objective stiffness of their neck muscles, as revealed by shear wave elastography, compared to asymptomatic participants. The evaluation of objective neck muscle stiffness in individuals with neck pain is expected to inform clinical practice and may aid in intervention selection.

METHODS

Participants

This cross-sectional, observational study included 38 women with a median age of 50.5 years (interquartile range [IQR], 9.0 years). Twenty participants had chronic nonspecific neck pain accompanied by sensations of neck muscle stiffness and 18 were healthy, asymptomatic individuals. Participants were recruited from the University Hospital Göttingen pain clinic and through advertisement in local newspapers. Inclusion criteria for the neck pain group were nonspecific neck pain for longer than 6 months, with periods of symptom aggravation of at least 1 week in duration, the sensation of neck stiffness, and a score of 10/50 or greater on the Neck Disability Index (NDI).[44,56] The control group was required to have no history of recurrent neck or low back pain and no neck pain that limited function or required treatment from a health care professional in the past year. Exclusion criteria for both groups were major circulatory, neurological, or respiratory disorders; current or recent pregnancy; previous cervical spine surgery; participation in neck muscle training in the past 6 months; body mass index (BMI) greater than 30 kg/m^2 (due to suspected loss of imaging quality); and intake of medications that could affect muscle stiffness, such as muscle relaxants or antidepressants. No pain medication was allowed on the days when data were collected. Selection criteria were confirmed in a telephone interview. The study was approved by the Medical Ethics Committee of the University Medical Center Göttingen (23/10/15). Participants provided written informed consent prior to study participation, and all procedures were performed in accordance with the Declaration of Helsinki.

Ultrasound Shear Wave Elastography

Participants were positioned in upright sitting within a Multi-Cervical Unit (BTE Technologies, LLC, Greenwood Village, CO) (**TABLE 1**). Using the fourth cervical

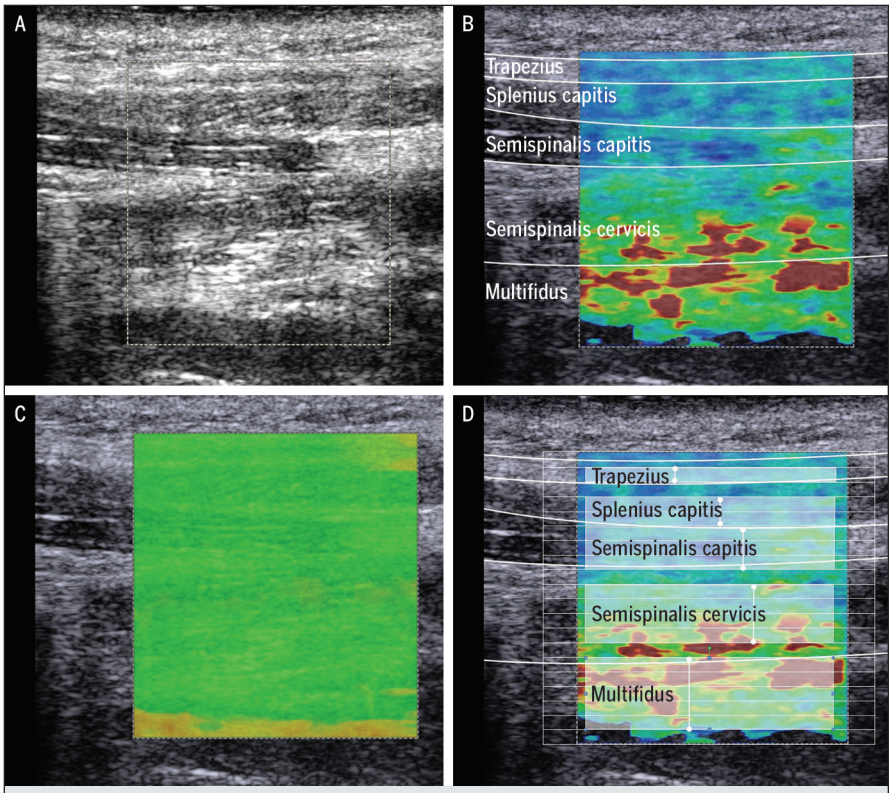

FIGURE 1. Raw grayscale ultrasound image and superimposed elastograms obtained from a control participant during an isometric neck extension at 36 N. (A) Longitudinal scan of the neck extensor muscles (during elastography, postprocessing of the grayscale ultrasound data is automatically turned off, which explains the coarse appearance of the grayscale ultrasound image). (B) Local shear wave velocities (note the higher stiffness in the deep-lying muscles). (C) Quality map that indicates good quality of shear wave tracking. (D) Segmentation of the regions of interest into 20 horizontal subsections allocated to muscle-specific regions (shaded areas).

spinous process (C4) as an anatomical landmark, 2 cross-sectional brightness-mode ultrasound images (ACUSON S3000 and 9L4 linear transducer with a 4-cm footprint; Siemens, Munich, Germany) of the right neck extensor muscles were recorded for the identification of muscle layers.[14] System settings were a transducer frequency of 9 MHz, gain of 16 to 20 dB, dynamic range of 45 dB, and image depth between 3.5 and 4 cm, with a single focus zone at 2 cm. The elastograms were recorded 1 cm to the right of the spinous processes along the main common axis of extensor muscle short-

TABLE 1 The Included Tasks and Their Detailed Descriptions

Task	Detailed Description	Photograph
Graded isometric neck extension	The Multi-Cervical Unit is adjusted for upright and comfortable sitting, with full contact with the backrest, the arms and feet supported, the neck in neutral, and the head in contact with the dynamometer. A feedback screen in front of the participant indicated the exerted force and the target force levels. Neck muscle stiffness was recorded in relaxed sitting and during 4 series, each involving 3 trials of isometric neck extension sustained over 4 seconds at target force levels of 12 N, 24 N, 36 N, and 48 N, sequenced from low to high force. Next, participants rotated their head 30° to the right, as indicated on the halo of the Multi-Cervical Unit, and exerted a pressure of 24 N. Finally, instructions were given to preserve the spinal posture without limb support during 3 attempts to produce the maximal individual neck extension force	
Office task	Participants sat at a common office desk, with a paper print-out of the D2 stress test[8] at a comfortable reading distance. The D2 stress test requires marking letters according to slightly distinct features while stopwatch measurements induce permanent time pressure.[8] The test was explained and performed in 3 minutes. Without a change of the participant's posture, neck stiffness was scanned directly following the test and 60 and 120 seconds later	
Prone relaxation and isometric head lift	Participants lay comfortably in prone on a plinth with armrests and an opening for the face, which was adjusted for a neutral neck position. After a few minutes of relaxation, during which muscle stiffness was recorded, participants were prompted to slowly lift the weight of their head while maintaining skin contact with the headrest (quasi-isometric performance), and to sustain the head lift over 4 seconds, during which muscle stiffness was recorded. Alternating between relaxation and head lift, each condition was recorded 3 times	
Balancing sandbags (weight of 1 kg) on the head in free sitting	Participants were instructed to sit relaxed and upright on a chair without a backrest. Stepwise, 2 sandbags (15 × 25 cm) of 0.5-kg weight were positioned on top of the participant's head, and these were balanced on the head while 3 elastograms were recorded. This was repeated 3 times	

ening centered at C4,[14] using a custom-programmed modification of the thyroid preset, with shear wave velocity measurements between 0.5 and 10 m/s. To ascertain a repeatable transducer position, the measurement location was framed by adhesive foam plates that were kept in place for the duration of the recording session. The elastograms covered a depth of 2.5 cm over a length of 2 cm, provided a spatial resolution of approximately 1 mm^2, and were positioned individually to include the trapezius muscle at the upper border and the multifidus at the lower border (**FIGURES 1A** and **1B**). The elastography system provided quality maps to control for the quality of the shear wave tracking.[53,61] Quality maps were generated for each elastogram (**FIGURE 1C**).

Procedure

Data were collected in a laboratory at the university pain clinic. Participants with neck pain rated their pain intensity on a numeric rating scale (NRS; 0-10)[50] and completed the NDI, which includes 10 items related to pain, sleep, and daily activities.[56] The NDI provides a score of neck pain–related disability between 0 (no disability) and 50 (maximal disability).[56]

Following instrumented measures of cervical flexion and rotation range of movement in the Multi-Cervical Unit,[10] participants performed 4 tasks (**TABLE 1**) in a fixed sequence, arranged to facilitate the completion of all tasks by the participants with neck pain. A setup of graded force production was used to observe the increase of muscle stiffness with neck extension force. Following practice trials, neck muscle stiffness was recorded in relaxed sitting and during 4 series of isometric neck extension at target force levels of 12 N, 24 N, 36 N, and 48 N, sequenced from low to high force (**TABLE 1**). Fixed force levels, instead of percentages of individual maximal force, were selected because the main function of the neck extensor muscles is to manage the weight of the head, which remains the same with neck pain or weaker muscles. The average adult female head is 31 to 36 N.[11] A deskwork task under time pressure[8] was used to simulate a stressful office work condition (**TABLE 1**). Relaxation and head lift in prone were used to capture a situation of relaxation and the capacity to manage the weight of the head (**TABLE 1**). A head-balancing task in upright free sitting was used to address finely adjusted neck muscle activity (**TABLE 1**). All efforts were sustained over 4 seconds, of which 3 seconds were needed for the acquisition of the elastogram. Each condition (task) was repeated 3 times, and each time an elastogram was captured (**TABLE 1**). Eleven participants, 6 with neck pain and 5 controls, repeated the study procedure within 10 days to allow estimation of the between-day reliability of the elastography measurements.

Image Processing

The small measurement regions of the elastography measures were not used due to the uncertain representativeness.[3] A MATLAB script (Version R2014a; The MathWorks, Inc, Natick, MA) was programmed to ensure a reliable, quality-controlled, and time-efficient evaluation of the elastograms over large muscle regions. Each pixel's color was detected and was included in the analysis when the respective quality map (**FIGURE 1C**) indicated a tracking quality greater than 50%, a threshold based on our experience, as no quantitative quality assurance was found in comparable studies. Pixels from the right and left edges of the elastogram were excluded due to occasional color delineation artifacts. In the semi-transparent elastograms (**FIGURE 1B**), the colors are biased by the hue of the underlying grayscale image. The true color values of each pixel were estimated based on the Commission Internationale de I'Eclairage (CIE) 94 standard.[40] Using linear scaling, shear wave velocities between 0.5 and 10.0 m/s were assigned to the 256-bit RGB color scale and served as an unbiased color reference. The shear wave velocity of each pixel was identified by the smallest difference between the actual (grayscale-biased) pixel color and the unbiased RGB colors.[21,26] For the evaluation of averaged neck muscle stiffness, the "grand mean" (mean shear wave velocity over all included pixels) was calculated. Maximal shear wave velocity was controlled for values greater than 9.98 m/s, which suggests saturated measurements.[39] For the evaluation of stiffness in regions corresponding approximately to the trapezius, splenius capitis, semispinalis capitis, semispinalis cervicis, and multifidus muscles, the elastogram was divided into 20 parallel horizontal subsections (**FIGURE 1D**). The subsections of muscles were visually determined and allocated on 224 images for each task (**FIGURE 1D**). Shear wave velocities of repeated trials of the same condition were averaged. The shear modulus (μ) was calculated from the recorded shear wave velocities (V_s) ($\mu = \rho \times V_s^2$)[20] based on a density (ρ) of 1000 kg/m^3, which is generally assumed for soft tissue.[17,43]

Statistical Analysis

Due to a lack of data on expected group differences at the time of data collection, a sample size comparable to relevant reference studies[19,27] was considered. Between-day reliability of averaged neck muscle stiffness and of stiffness in muscle-specific regions was estimated from 6 participants with neck pain and 5 controls, who repeated the study procedure within 10 days. Using a fully computed image analysis, the focus of the reliability analysis was the between-day reliability of the stiffness measure, when slight differences in the setup, variation of performance, and measurement error accumulate. Between-day reliability is described using the intraclass correlation coefficient (ICC; model 3,3), that is, a 2-way mixed model on averaged measures[30] and the standard error of measurement ($SEM = SD \times \sqrt{1 - ICC}$). Further, the minimal detectable change at the 95% confidence level (MDC_{95}) ($SEM \times \sqrt{2} \times 1.96$)[16] was determined.

The Shapiro-Wilk test indicated several skewed distributions, in particular for

the data from the neck pain group (**FIGURE 2**); therefore, nonparametric statistics were used. The main objective, the comparison of averaged neck extensor muscle stiffness between groups, was examined by a Mann-Whitney *U* test comparing the pooled stiffness measurements of each group with the level of significance (set to $\alpha = .05$). Further, Mann-Whitney *U* tests were used to explore group differences in muscle stiffness for the different tasks and muscle regions. Using the Bonferroni adjustment for multiple hypothesis testing (α/n, where n is the number of tested hypotheses), an adjusted level of significance of $\alpha = .003$ was used for testing group differences in the 5 muscle levels and 9 tasks (**FIGURE 2**). The Spearman correlation coefficient (rho) served to examine relations of muscle stiffness with BMI and with self-reports of pain and disability. Statistics were computed using SPSS Version 24 (IBM Corporation, Armonk, NY).

RESULTS

The participants with neck pain demonstrated less neck range of motion (**TABLE 2**). Data availability was 96% for single trials and 100% for averaged results.

Between-Day Reliability of Neck Muscle Stiffness Measurements

The between-day reliability of averaged neck muscle stiffness was moderate to good, with ICCs between 0.629 and 0.809 (moderate, 0.5 or greater; good, 0.75 or greater)[47] for all tasks except "relaxation in prone" (ICC = 0.138), which was therefore excluded from the group comparison (**TABLE 3**). The small sample of 11 participants generated wide confidence intervals. The reliability of stiffness in muscle-specific regions was moderate to good, with ICCs between 0.732 and 0.845, depending on the muscle region (**TABLE 3**). The SEM and MDC for measures of the neck extensor muscles were similar or lower than those of the back extensor muscles[31] (**TABLE 3**).

Group Differences for Averaged Neck Muscle Stiffness

No group differences in median neck stiffness were evident for any of the individual tasks($P = .141$ to $.988$) (**FIGURE 2**). Additionally, median neck muscle stiffness pooled over all tasks was similar between groups (neck pain median, 11.6 kPa; IQR, 8.9 kPa; controls, 13.3 kPa; IQR, 8.6 kPa; $P = .175$). In the control group, active muscle stiffness during all levels of graded neck extension was negatively correlated with BMI ($\rho = -0.583$ to -0.703, $P<.05$). A significant correlation between BMI and active neck muscle stiffness was also observed for the neck pain group, but only for neck extension at 48 N ($\rho = -0.475$, $P<.05$). There was no significant correlation between averaged stiffness of the neck muscles and the intensity of pain or disability for the neck pain group.

Group Differences in Muscle-Specific Regions

Pooled over all tasks, the largest difference between groups was observed for the

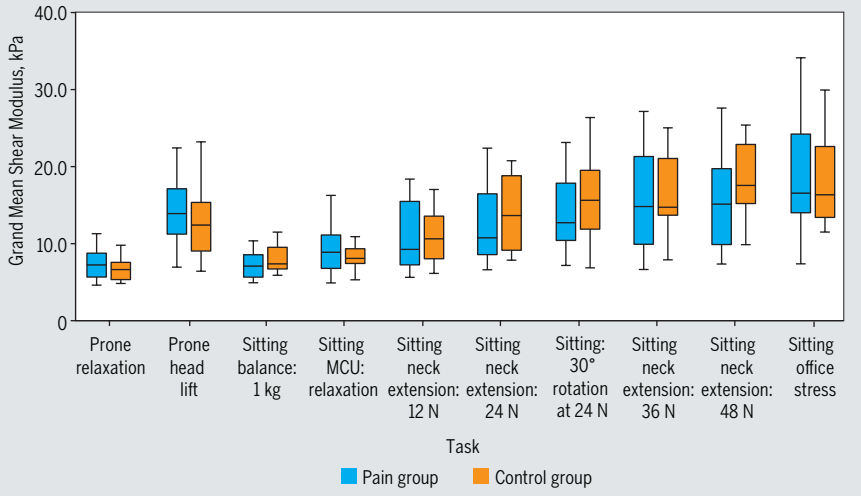

FIGURE 2. Averaged neck muscle stiffness (grand mean) during relaxation and multiple active tasks. Abbreviation: MCU, Multi-Cervical Unit.

TABLE 2 Group Characteristics[a]

Characteristic and Distribution[b]	Neck Pain (n = 20)	Control (n = 18)	*P* Value[c]
Age, y[d]	52.5 (12.0)	48.5 (9.0)	.361
Body mass index, kg/m^2	23.8 ± 3.2	22.2 ± 2.4	.103
Neck flexion ROM, deg	50.6 ± 12.4	69.4 ± 10.8	<.001
Neck rotation ROM (left plus right), deg	115.5 ± 14.3	145.5 ± 26.6	<.001
Neck extension MVIC, N	56.3 ± 18.5	64.0 ± 19.2	.219
Pain: today (0-10 NRS)	3.6 ± 2.2	0	<.001
Pain duration, y[d]	8.0 (16.3)	...	...
Neck Disability Index, %[e]	32.5 ± 12.3	...	...

Abbreviations: MVIC, maximal voluntary isometric contraction; NRS, numeric rating scale; ROM, range of motion.
[a]*Values are mean ± SD unless otherwise indicated.*
[b]*Distributions are normal unless otherwise indicated.*
[c]*Independent 2-sided t test (normal distribution) or Mann-Whitney U test (skewed distribution).*
[d]*Values are median (interquartile range).*
[e]*Scored from 0% to 100%.*

semispinalis cervicis region (neck pain, 12.2 kPa; IQR, 10.7 kPa; controls, 14.5 kPa; IQR, 13.2 kPa; P = .019) (**TABLE 4**). None of the differences were significant after adjustment for multiple testing, and no difference exceeded the MDC_{95}. In the control group, the measure of stiffness in the semispinalis cervicis region was negatively correlated with BMI (ρ = −0.531 to −0.662, P<.023), but this association was not present for the neck pain group. There was no significant correlation between the measure of stiffness in the semispinalis cervicis region and the intensity of neck pain or disability.

DISCUSSION

When comparing muscle stiffness measurements in middle-aged women from 2 different days, shear wave elastography provided reliable measurements of neck muscle stiffness during most tasks. Contrary to our hypothesis, women with chronic nonspecific neck pain, moderate pain-related disability, and the perception of increased neck muscle stiffness demonstrated neck muscle stiffness similar to that of asymptomatic women. The objective muscle stiffness differed most in the region of the semispinalis cervicis muscle; however, the difference between groups was not statistically significant after adjustment for multiple testing and did not exceed the MDC_{95}.

The reliability of the shear wave elastography measures of neck extensor muscle stiffness during active tasks was within the range previously reported in the literature.[31,38] Consistent with a previous study, the ICC was lower for measurements of relaxed muscles, likely due to lower variation of performance. In the current study, the SEM and MDC determined for the neck extensor muscles were higher than those reported previously for the abdominal muscles,[38] but lower than those for the lumbar extensor muscles.[31] The MDCs observed in the current study suggest difficulties in using this measure to detect changes, for example, following an exercise intervention. Notably, shear wave elastography measurements are not normalized to account for individual baseline differences, as is done for electromyography measurements.

Previous shear wave elastography studies on the neck muscles have largely focused on the trapezius muscle. During prone relaxation, Taş et al[53] investigated the stiffness of the trapezius and splenius capitis muscles in participants with and without neck pain and reported values of 10.2 kPa (neck pain group) versus 7.8 kPa (control group) for the trapezius at the level of C7 and 6.8 kPa (both groups) for the splenius capitis at the level of C4. Consistent with our current results, no correlation between neck muscle stiffness and the extent of pain or disability was identified.[53] Heizelmann et al[23] reported

TABLE 3 Reliability of the Grand Mean Shear Modulus Over All Tasks and for Selective Tasks, and in Muscle-Specific Regions Over All Tasks

		Session 1			Session 2
Task/Region	**Retest Reliability: $ICC_{3,3}$[a]**	**Median (IQR) kPa**	**SEM**	**MDC_{95}**	**Median (IQR) kPa**
MCU: relaxed sitting	0.808 (0.227, 0.952)	10.94 (5.58)	1.68	4.65	8.45 (3.24)
MCU: isometric neck extension					
12 N	0.676 (0.000, 0.913)	15.15 (2.86)	1.97	5.45	14.79 (4.32)
24 N	0.629 (0.000, 0.900)	17.31 (4.64)	2.66	7.38	18.35 (6.89)
36 N	0.809 (0.291, 0.949)	20.69 (6.58)	2.53	7.00	21.45 (8.62)
48 N	0.793 (0.229, 0.944)	19.44 (5.83)	2.43	6.74	22.90 (5.69)
MCU: 30° of rotation at 24 N	0.743 (0.045, 0.931)	17.72 (7.44)	3.03	8.41	15.07 (6.60)
Prone relaxation	0.138 (0.000, 0.768)	7.12 (3.41)	2.15	5.97	8.01 (2.58)
Prone head lift	0.768 (0.138, 0.938)	13.22 (5.95)	2.32	6.42	15.51 (6.14)
Desk stress	0.799 (0.253, 0.946)	21.15 (11.79)	3.03	8.41	22.08 (12.54)
Sitting and balancing 1 kg	0.654 (0.000, 0.914)	8.54 (2.15)	1.18	3.27	8.69 (3.59)
Over all tasks	0.870 (0.813, 0.910)	14.54 (9.93)	2.29	6.35	14.52 (10.77)
Stiffness in muscle-specific regions over all tasks					
Trapezius	0.736 (0.617, 0.818)	5.91 (2.31)	3.04	8.43	6.01 (2.44)
Splenius capitis	0.763 (0.657, 0.836)	8.12 (6.48)	3.35	9.28	7.89 (6.11)
Semispinalis capitis	0.828 (0.752, 0.881)	8.99 (7.49)	2.62	7.26	8.96 (7.14)
Semispinalis cervicis	0.845 (0.776, 0.893)	11.4 (9.28)	2.59	7.19	10.7 (9.48)
Multifidus	0.732 (0.613, 0.815)	10.9 (7.46)	2.96	8.19	11.8 (7.78)

Abbreviations: ICC, intraclass correlation coefficient; IQR, interquartile range; MCU, Multi-Cervical Unit; MDC, minimal detectable change; SEM, standard error of measurement.
[a]*Values in parentheses are 95% confidence interval.*

the average stiffness of the trapezius as 7.3 kPa when measured in 278 healthy individuals during prone relaxation. In the current study, during prone relaxation we recorded lower stiffness for both the trapezius region (neck pain, 5.5 kPa; controls, 5.1 kPa) and splenius capitis region (neck pain, 5.9 kPa; controls, 5.5 kPa). In 10 healthy participants during relaxed sitting, Ewertsen et al[18] measured stiffness as 10.2 kPa for the trapezius, 9.2 kPa for the splenius capitis, and 11.3 kPa for the semispinalis capitis. In the current study, trapezius stiffness during relaxed sitting was 7.0 kPa in the neck pain group versus 6.5 kPa in the control group. The variation in stiffness values reported across studies is likely explained by differences in the recording site within the muscles and the varying methods of data extraction across studies. We used a fully computed data extraction over the complete visible extent of the muscle regions. Taş et al[53] and Heizelmann et al[23] used multiple small measurement regions. Ewertsen et al[18] measured single, manually placed, circular regions.[29] In accordance, the current and 2 previous studies[23,53] document increased stiffness of the trapezius muscle or muscle region in people with neck pain during relaxed sitting and relaxation in prone, but the difference in the current study was small and within measurement error.

This is the first study to evaluate stiffness measurements of the deep neck muscles in individuals with chronic neck pain. Because measurements of active muscle stiffening relate to active force production,[3,6,61] findings of studies that examined deep neck muscle activation may be compared to the current findings and may, together with the current findings, guide future analyses. A fine-wire electromyography study demonstrated reduced semispinalis cervicis activity during isometric contractions in participants with chronic neck pain.[49] A functional magnetic resonance imaging study also suggested less activation of the semispinalis/multifidus muscles during active neck extension in participants with neck pain.[44] Functionally, the semispinalis cervicis muscle is designed to support and move the cervical spinal segments.[14] Decreased deep neck muscle stiffness may compromise the control of spinal movement.[59] Mechanically less precise muscle activation in people with chronic neck pain[49] and other chronic pain conditions[15,55] has been reported. In the current study, the reduced correlation with BMI, the large stiffness ranges, and higher stiffness during some tasks (overshooting) may be interpreted in line with a reduced mechanical precision of muscle use. The current study confirmed increasing stiffness of the neck muscles toward the spine, replicating the results of a study using a different elastography system in healthy young individuals.[14]

In the current study, all participants with neck pain confirmed sensations of neck stiffness, but higher muscle stiffness was not measured. A discrepancy between perceived and objective muscle stiffness has been documented before with regard to neck and shoulder stiffness,[1] to tension-type headache,[29] and to rheumatoid arthritis.[57] This discrepancy leads to a clinical dilemma: interventions to reduce muscle tone appear appropriate to alleviate reported neck stiffness, but are not endorsed by objective measurements. Why do patients feel stiffness? The conscious sensation of stiffness during neck movement implies that the sensory feedback that is received during the motion does not fit the unconscious expectations of how it should feel.[48] Usually, the sensation of movement does not come into awareness because it fits with learned expectations. Only when discrepancies arise do we perceive a central interpretation of the incongruous response to action.[48,54] Hypothetically, a resistance to neck movement may be perceived if the orderly organization of muscle stiffness, with stiffer muscles close to the spine and more flexible muscles toward the surface,[14] is disturbed; superficial neck muscles may feel too stiff compared to deep muscles of low stiffness. Alternatively, a resistance to neck movement may be perceived when movement occurs with a delay. Low muscle stiffness has been reported to lengthen the electromechanical delay between motor unit excitation and the mechanical muscle contraction.[36] Osumi et al[45] induced the perception of increased limb heaviness through an experimentally delayed feedback of motor action. The central nervous system may interpret a minimally delayed neck movement as the result of a resistance to movement, that is, stiffness. Further research is required to gain a deeper understanding of the relationship between perceived and objective muscle stiffness.

TABLE 4 Stiffness in Muscle-Specific Regions Over All Tasks[a]

Muscle	Neck Pain	Control	*P* Value[b]
Trapezius	6.7 (2.6)	6.9 (2.5)	.266
Splenius capitis	8.1 (6.1)	8.3 (6.3)	.353
Semispinalis capitis	8.8 (6.2)	9.3 (8.4)	.140
Semispinalis cervicis	12.2 (10.7)	14.5 (13.2)	.019
Multifidus	15.5 (14.9)	17.1 (16.2)	.312

[a]*Values are median (interquartile range) kilopascals.*
[b]*Mann-Whitney U test for between-group differences.*

Limitations

Muscle displays an anisotropic mechanical behavior, meaning that its stiffness differs depending on the direction of measurement.[17,18,20] In the present study, the fiber direction of the splenius capitis muscle (origin at the nuchal ligament, directed cranially and laterally toward the occiput and mastoid) is oblique to the transducer orientation. Further, parts of the multifidus muscle[2] and, to a lesser ex-

tent, of the semispinalis cervicis muscle deviate from the transducer direction. Ultrasound shear wave elastography has been validated for measurements along the main axis of the muscle, irrespective of fiber pennation.[17,41] The current measurements provide information about the muscle's mechanical properties along its main shortening direction, corresponding to the stiffness that is measured using a material testing machine on isolated muscles.[17] The shortening direction of the muscle can be considered the most relevant direction with respect to muscle biomechanics.[4,34] The measurement variation in the current study was high. Shear wave elastography demonstrates an inhomogeneous within-muscle distribution of stiffness[18] (**FIGURE 1B**). This contributes to variation and questions the representativeness of small measurement regions.[3] Further, there is no accepted method for normalizing muscle stiffness measurements to reduce variation. Presumably, a normalization procedure would decrease the measurement variation between participants and thus facilitate the detection of group differences. Additional limitations are that the current analysis does not include measures of perceived stiffness, and that it evaluated only stiffness averages, not local inhomogeneities ("trigger points").

CONCLUSION

The comparison of shear wave elastography–measured stiffness in muscle-specific regions revealed similar averaged stiffness of the neck muscles in middle-aged women with long-standing chronic neck pain. The current finding highlights the discrepancy between the sensation of stiffness and an objective measure of neck muscle stiffness. ◉

KEY POINTS

FINDINGS: Women with chronic neck pain and perceived neck muscle stiffness present with similar objective stiffness of the neck extensor muscles compared to asymptomatic women.

IMPLICATIONS: Therapeutic interventions that aim to reduce neck extensor stiffness in individuals with chronic neck pain are questionable.

CAUTION: The physiology behind the sensation of stiff neck muscles and the complexity of influencing factors is not well understood.

STUDY DETAILS

AUTHOR CONTRIBUTIONS: Drs Dieterich, Petzke, and Falla designed the study. Dr Petzke facilitated the loan of an elastography system. Dr Dieterich recorded the data, Dr Yavuz developed the program for the analysis, and Drs Dieterich and Yavuz analyzed the data. Dr Dieterich performed the statistical analysis and wrote the manuscript, which was reviewed and complemented by Drs Nordez, Yavuz, and Falla. All authors approved the manuscript for publication.

DATA SHARING: The elastograms recorded during this study are available on request from the corresponding author via e-mail. Two publications on further analyses of the study data are pending (2020).

PATIENT AND PUBLIC INVOLVEMENT: The development of the research question and the choice of tasks performed for data acquisition were informed by patients' priorities and treatment experiences derived from working with patients with neck pain over many years in the clinic. Study participants were individually informed about the study outcomes. Patients and the public were not systematically involved in contributing to the study process.

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