Journal of Athletic Training 2020;55(3):282–288
doi: 10.4085/1062-6050-482-18

www.natajournals.org

Sex Differences in Ultrasound-Based Muscle Size and Mechanical Properties of the Cervical-Flexor and -Extensor Muscles

Takashi Nagai, PhD, ATC*; Nathan D. Schilaty, DC, PhD*†; David A. Krause, DSc, PT, OCS‡; Eric M. Crowley, MS, ATC*; Timothy E. Hewett, PhD*†‡

*Biomechanics Laboratories, Department of Orthopedic Surgery, and Sports Medicine Center, †Department of Physiology & Biomedical Engineering, and ‡Department of Physical Medicine & Rehabilitation, Mayo Clinic, Rochester, MN

Context: Neck pain (NP), neck injuries, and concussions are more prevalent in female athletes than in their male counterparts. Females exhibit less neck girth, strength, and stiffness against a perturbation. As part of the clinical examination for individuals with NP, ultrasound (US)–based imaging of the cervical muscles has become common. Muscle size or thickness and stiffness can be measured with US-based B-mode and shear-wave elastography (SWE), respectively. Information on reliability, normative values, and sex differences based on US-based muscle size or thickness and stiffness in young and athletic individuals is limited.

Objective: To evaluate sex differences in US-based muscle size or thickness and biomechanical properties of the cervical-flexor and -extensor muscles.

Design: Cross-sectional study.

Setting: Laboratory.

Patients or Other Participants: A total of 13 women (age = 23.7 ± 1.9 years, height = 167.1 ± 6.1 cm, mass = 63.8 ± 5.6 kg) and 11 men (age = 25.6 ± 4.9 years, height = 178.7 ± 8.3 cm, mass = 78.9 ± 12.0 kg).

Main Outcome Measure(s): The same examiner collected all measures, using US B-mode to scan the cross-sectional area and thickness of the longus colli (LC), sternocleidomastoid (SCM), cervical-extensor muscles, and upper trapezius (UT) muscle. The US SWE-mode was used to measure the stiffness of the SCM and UT. Independent t tests or Mann-Whitney U tests were calculated to determine sex differences. The intraclass correlation coefficient (ICC) measured intrarater test-retest reliability.

Results: Men had thicker SCMs than women ($P = .01$). No sex differences were present for longus colli cross-sectional area, cervical-extensor muscle thickness, or UT thickness ($P > .05$). In addition, no sex differences were evident for SCM ($P = .302$) or UT ($P = .703$) SWE stiffness. Reliability was good to excellent (ICC = 0.715–0.890) except for SCM SWE stiffness (ICC = 0.554).

Conclusions: The only sex difference was in SCM thickness. However, smaller SCMs in women did not result in less SCM SWE stiffness. We provided normative values for US-based imaging of the cervical-flexor and -extensor muscles in young and athletic men and women.

Key Words: cervical spine, neck pain, stiffness

Key Points

- Sex differences in ultrasound (US)–based measurements (size, thickness, and stiffness) of the cervical muscles may contribute to a higher prevalence of neck pain in women than in men.
- Normative values and the reliability of US-based measurements of these cervical muscle properties have rarely been examined in young and athletic individuals.
- Based on our results, future researchers should investigate the effects of intervention strategies for improving the size, thickness, and biomechanical properties of the cervical-flexor muscles in young and athletic women.

Neck pain (NP) is a common and disabling musculoskeletal condition. The Global Burden of Disease 2010 Study listed NP as the fourth most common basis for disability as measured by years lived with disability.[1] Although the prevalence of NP was higher in women and peaked from ages 40 to 60 years in both sexes,[1] young and athletic individuals also experience NP or neck injuries. Wrestlers and ice hockey players had the highest 1-year prevalences of NP (73% and 65%, respectively), but individuals in noncontact sports, such as orienteering, triathlon, and weightlifting, also had a high NP prevalence (38%–52%).[2] Neck strain injuries in collegiate ice hockey players accounted for 5% and 10% of all injuries in the head-face-neck injury category among men and women, respectively, based on data from the National Collegiate Athletic Association Injury Surveillance Program.[3] The authors also identified a higher rate of concussion in females than in males of the same cohorts.[3] In fact, neck pain and stiffness were common symptoms (46% and 26%, respectively) in individuals who sustained concussions.[4] Another common neck-related injury in young individuals was whiplash injury from a motor vehicle accident and, again, females were at a higher risk of developing chronic NP.[5] Potential explanations for a higher prevalence of NP, neck injuries, and concussions in females are multifactorial and complex. Yet, deficits in neck muscle mass or girth and neck strength are 2 of the most commonly reported sex differences in the literature.[5] Although these physical characteristics can easily be measured with a tape and handheld dynamometer, respectively, clinicians and researchers recently began using ultrasound (US)–based imaging of the neck muscles to quantify the muscle size (cross-sectional area and thickness) of specific cervical-flexor and -extensor muscles.

The cross-sectional area (CSA) of the longus colli, one of the deep cervical-flexor muscles, can be reliably measured at the sixth cervical vertebra (C6) with US.[6] Individuals with chronic NP had smaller CSAs of the longus colli than control individuals.[7] In addition, individuals with smaller longus colli muscles had higher self-reported neck disability index scores.[7] Within the control group, the authors reported that females had smaller CSAs of the longus colli than males; however, normalized CSAs (CSA divided by participant's body mass) were not calculated.[7] Thickness of the cervical-extensor muscles (trapezius, splenius capitis, semispinalis capitis, semispinalis cervicis, and multifidus) can also be reliably measured with US.[8–10] Males had thicker cervical-extensor muscles, yet this sex difference was eliminated after the thickness values were normalized to their body masses.[10] Two common body-mass normalization strategies have been used for US-based muscle measurements: ratio scaling and allometric scaling.[11] Because allometric scaling requires many participants, basic ratio scaling with body mass has been used frequently in determining neck muscle size and thickness characteristics.[10,12]

In addition to permitting measurements of the CSA and thickness of the cervical muscles, recent advances in US technology have allowed clinicians and researchers to assess the tissue biomechanical properties (eg, stiffness) of targeted muscles using shear-wave elastography (SWE). Traditionally, head or neck stiffness was measured during dynamic-perturbation tasks in which a participant's head was attached to a cable with a weight, and he or she had to react as soon as the cable was released.[13] Females exhibited less neck stiffness against perturbations, resulting in greater neck displacement and acceleration.[13] Although neck-stiffness testing has provided important findings, less invasive methods using simple devices and standardized procedures would be preferred in clinical practice or large-scale prospective injury-prevention studies. The US-based SWE-stiffness values of the brachialis muscle were validated concurrently with the Young modulus (mechanical stiffness values based on strain and stress during passive stretch of the muscle) using the materials testing system.[14] Clinically, 1 group[15] evaluated US-based SWE stiffness of the sternocleidomastoid (SCM), scalene, upper trapezius (UT), and levator scapulae muscles and found a stiffer UT muscle in individuals with chronic NP. Neck stiffness is also a common symptom after concussions and whiplash injuries.[4,5] However, researchers do not yet know which regions or muscles are involved and how much stiffness is present in individuals with concussions or whiplash injuries. Similarly, possible sex differences in US-based SWE stiffness of the cervical-flexor and -extensor muscles in young and athletic individuals have been largely unexamined. In 1 study,[16] no sex differences were present in SCM SWE stiffness among healthy individuals. More research is needed to confirm these findings.

The aforementioned studies support the clinical use of US-based imaging of the cervical-flexor and -extensor muscles in individuals with NP. This imaging was also used to assess the effects of 2 types of interventions (craniocervical-flexion exercises and standard cervical-flexion exercises) in individuals with NP.[17] However, justification for the use of US-based imaging in young and athletic individuals is scarce. As the first step, it is critical to establish the reliability and normative values of US-based imaging of the cervical muscles in young, athletic men and women. Without such reference values, screening and preventing NP, neck injuries, and concussions in young, athletic individuals will remain difficult. Given the higher prevalences of NP, neck injuries, and concussions in female athletes, it is clinically important to explore sex differences in this population and develop neck injury-prevention strategies.

The first purpose of our investigation was to examine sex differences in US-based neck muscle characteristics of young, healthy women and men. Second, we aimed to establish normative values and intrarater test-retest reliability values. Based on previous studies of sex differences in US-based muscle size,[7,10] we hypothesized that men would exhibit larger CSAs and thicknesses in the absolute values but not in the normalized values. Given the results of 1 study[16] of sex differences in US-based SWE muscle stiffness of the SCM, we proposed that no sex differences would be identified in US-based SWE stiffness of the cervical muscles. Third, good reliability values were reported[6,8] using US-based imaging of the cervical muscles. Therefore, we expected that intrarater test-retest reliability values using the intraclass correlation coefficient (ICC) would be >0.60, based on the recommended values provided by Landis and Koch.[18]

METHODS

Participants

A total of 24 (13 women and 11 men) physically active, young adults participated in the study. The a priori sample size was determined by using the US-based CSAs of the cervical muscles in comparisons of sex differences.[7,10] To estimate sample size, we performed a power analysis using G*Power software (version 3.1.9.2; The G*Power Team, Dusseldorf, Germany). Given power of 0.80 with α set at .05 in the independent *t*-test study design (2 tailed), 10 to 11 participants per group were required. *Physically active* was operationally defined as healthy individuals who engaged in physical activities at least 5 times per week for 30 minutes. Inclusion criteria were (1) age between 18 and 30 years and (2) physically active. Exclusion criteria were (1) any preexisting condition that prohibited neck movements, (2) a history of or current NP, (3) a history of spine surgery, (4) a history of or current upper extremity injury, or (5) current pregnancy. Participants' demographics are shown in Table 1. The study was reviewed and approved by the Mayo Clinic Institutional Review Board. All participants gave

Table 1. Demographics and Sex Differences Based on Independent *t* Tests

Characteristic	Women	Men	*P* Value
Age, y	23.7 ± 1.9	25.6 ± 4.9	.195
Height, cm	167.1 ± 6.1	178.7 ± 8.3	.001
Weight, kg	63.8 ± 5.6	78.9 ± 12.0	.002

consent before the study began. They reported to the laboratory 1 time for 90 minutes. Ultrasound measurements were performed (approximately 30 minutes) during the first session, they took a 20-minute break, and then the measurements were repeated (second session). We used the values from the first session to examine sex differences and the values from both sessions to establish intrarater test-retest reliability. This test-retest interval was chosen because we were interested in evaluating the acute effects of a dynamic warm-up or isometric muscular contractions on neck US measurements as a part of a concussion-prevention project.

Instrumentation and Procedures

All US-based measurements were collected using an Aixplorer Mach 30 Ultrasound System (SuperSonic Imagine, Inc, Bothell, WA) by the same researcher (T.N.) who has used diagnostic musculoskeletal US for research activities for more than 3 years. In addition, structures or shapes of interest in the current study were independently confirmed by a certified sonographer before analysis. For consistency, all measurements were conducted using the same transducer probe (model SuperLinear SL18-5; SuperSonic Imagine) with a bandwidth of 5 to 18 MHz. The test order was kept the same for all participants: (1) the longus colli (LC) and SCM in B mode, (2) the isolated SCM in SWE mode, (3) the cervical-extensor muscles in B mode, and (4) the UT in SWE mode (Figure). Based on a previous study,[16] we anticipated no differences between the right and left sides of the spine in healthy participants; therefore, only the right side was measured, and the resulting data were analyzed.

For the cervical-flexor muscles, the CSA of the LC and thickness of the SCM were measured on the same image.[17] Participants were supine on an examination table with a folded towel under the neck to position it in slight extension. They were asked to relax as much as possible and close their eyes if they preferred. An examiner identified the thyroid below the thyroid cartilage and placed the probe in the transverse position. In this position, the cross-sectional area of the LC and thickness of the SCM were visible, and 3 images were saved for postprocessing. For postprocessing, the CSA of the LC was traced by hand using the preprogrammed measurement tool in the US device, which automatically calculated the CSA in square centimeters. The thickest part (in the anterior-posterior direction in B mode) of the SCM was measured in centimeters. The CSA and thickness were expressed as absolute (square centimeters or centimeters) and normalized (cm^2/kg or cm/kg) values. Simple ratio scaling (simple division by body weight) was used as the normalization strategy to compare sexes in a previous study[10]; therefore, we followed the same strategy.

For the US-based SWE stiffness measurements of the SCM, the muscle was measured at its midpoint (between the mastoid process and the sternoclavicular joint). The probe was oriented longitudinally along the muscle fibers. The US machine recorded 3 frames of muscle stiffness in SWE mode for postprocessing. After scanning, the same examiner (T.N.) adjusted the position of the consistent measurement circle to be within the SCM and recorded SWE stiffness values. The stiffness value of each frame was automatically calculated using the device software and expressed in kilopascals. For all measurements, an average of 3 values was used for statistical analyses.[19]

For the cervical-extensor muscles, participants were in a prone position with a pillow under the chest. The neck was slightly flexed with the head resting on the table. Participants were asked to relax as much as possible and close their eyes if preferred. The cervical-extensor muscles include a layer of the UT, splenius capitis, semispinalis capitis, semispinalis cervicis, and multifidus muscles (Figure). The probe was oriented transversely to capture the thickness of all muscles at the C5 level, slightly lateral to the spinous processes.[8,9] The thicknesses of all muscles were measured together as the cervical-extensor muscle thickness in absolute (centimeters) and normalized (cm/kg) values. For the US-based SWE stiffness measurements of the UT, the distance between C7 and the most lateral part of the acromion process was measured first and then two thirds of the distance from the acromion process was used to scan UT thickness in B mode and stiffness in SWE mode. The transducer probe was oriented parallel to the muscle fibers. The UT thickness was expressed in absolute (centimeters) and normalized (cm/kg) values. Postprocessing of the upper trapezius SWE stiffness was similar to that for SCM SWE stiffness. The SWE stiffness of the UT was expressed in kilopascals. Similar to the cervical-flexor muscles, an average of 3 values was used for statistical analyses.[19]

Data Analysis

All statistical analyses were conducted using SPSS (version 22.0; IBM Corp, Armonk, NY). Descriptive statistics (means and standard deviations) were calculated for each variable in each group and then normality was checked using the Shapiro-Wilk test. Based on the normality result, we used either independent *t* tests or Mann-Whitney *U* tests to examine the effect of sex on the variables of interest (LC CSA, SCM thickness or SWE stiffness, cervical-extensor muscle thickness, and UT thickness or SWE stiffness). The level of significance was set at $P < .05$. Intrarater test-retest reliability was calculated using ICCs [3,1] with 95% confidence intervals. Based on the ICC values and pooled standard deviations, we determined the standard error of measurement (SEM) and minimal detectable change (MDC) with 95% confidence intervals for each dependent variable.

RESULTS

All descriptive statistics and results of sex differences are shown in Tables 1 and 2. Men were heavier and taller than women. Shapiro-Wilk tests were significant for the LC CSA and cervical-extensor muscle thickness in women. Therefore, Mann-Whitney *U* tests were used on these 2

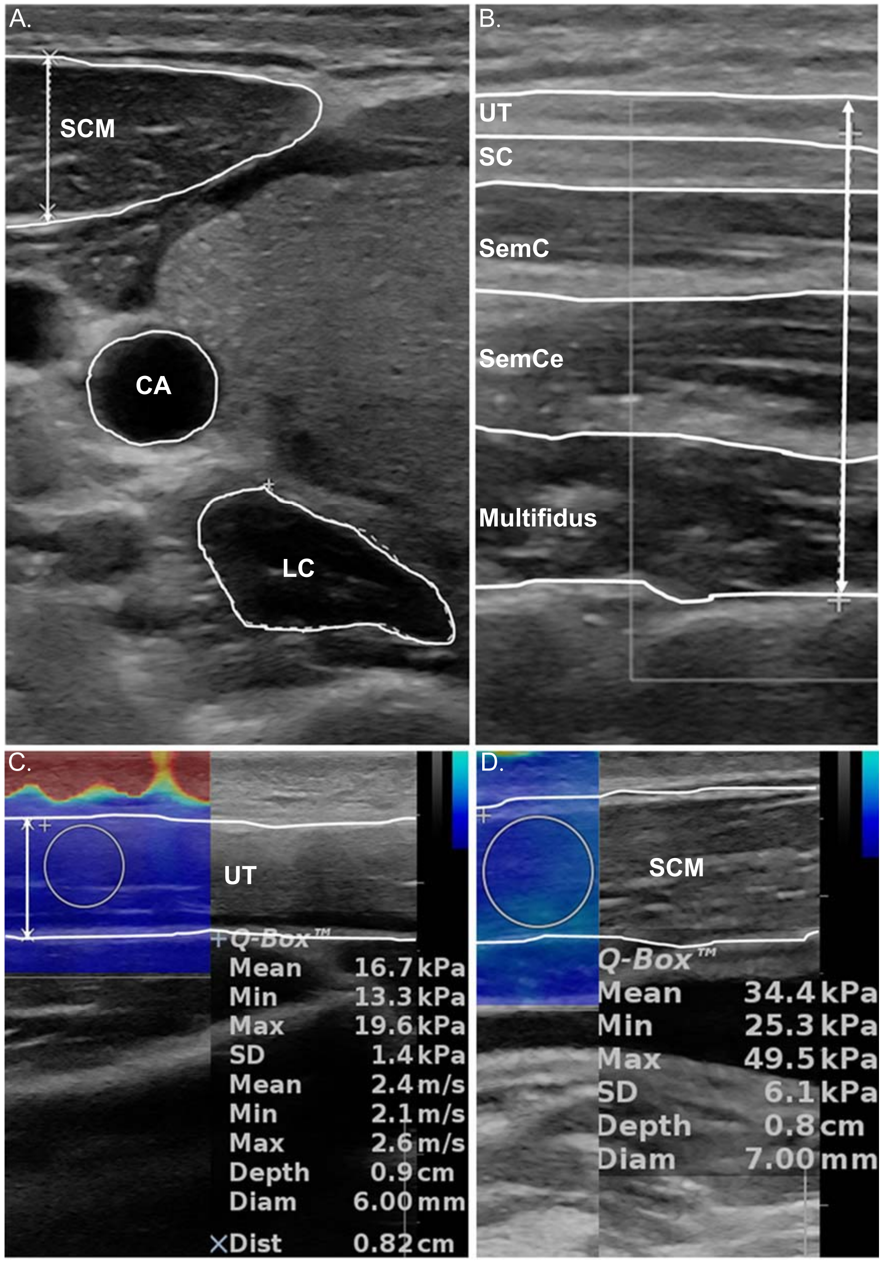

Figure. Ultrasound-based images. A, cross-sectional area of the longus colli (LC), thickness of the sternocleidomastoid (SCM), and carotid artery (CA). B, thickness of the cervical extensor muscles: upper trapezius (UP), splenius capitis (SC), semispinalis capitis (SemC), semispinalis cervicis (SemCe), and multifidus. C, shear-wave elastography (SWE) stiffness of the upper trapezius (UT). D, SWE stiffness of the SCM.

variables for sex comparisons. Men had thicker SCMs than women in both absolute (women = 0.62 ± 0.11 cm, men = 0.91 ± 0.13 cm; $P < .001$) and normalized (women = 0.00978 ± 0.00170 cm/kg, men = 0.01148 ± 0.00114 cm/kg; $P = .010$) values. Similarly, men had thicker cervical-extensor muscles than women (women = 1.90 ± 0.26 cm, men = 2.09 ± 0.31 cm; $P < .026$). However, cervical-extensor muscle thickness was not different between sexes when normalized to body mass ($P = .086$). No sex differences were evident for LC CSA in either absolute or normalized values ($P = .072$–.973). In addition, no sex differences were present for SCM (women = 30.2 ± 7.2 kPa, men = 33.0 ± 5.3 kPa; $P = .302$) or UT (women = 24.9 ± 10.4 kPa, men = 26.3 ± 6.9 kPa; $P = .703$) SWE stiffness. Reliability was good to excellent (ICC = 0.715–0.890) except for SCM SWE stiffness (ICC = 0.554). Reliability (ICC), precision (SEM), and MDC values for all variables are shown in Table 3.

DISCUSSION

We examined sex differences in US-based measures of muscle size and SWE stiffness of the cervical-flexor and -extensor muscles. Men had thicker SCM and cervical-extensor muscles in terms of absolute values, although no sex differences were found in other muscles (LC and UT). When the size or thickness was normalized by a participant's body mass, the SCM was the only variable that remained significantly different ($P = .010$). Therefore,

Table 2. Sex Differences in Size and Stiffness of the Cervical-Flexor and -Extensor Muscles

Muscle	Variable	Mean ± SD		*P* Value
		Women	Men	
Longus colli				
	Cross-sectional area, cm^2	0.69 ± 0.21	0.86 ± 0.28	.072
	Normalized cross-sectional area, cm^2/kg	0.01075 ± 0.00312	0.01079 ± 0.00299	.973
Sternocleidomastoid				
	Thickness, cm	0.62 ± 0.11	0.91 ± 0.13	<.001
	Normalized thickness, cm/kg	0.00978 ± 0.00170	0.01148 ± 0.00114	.010
	Shear-wave elastography stiffness, kPa	30.2 ± 7.2	33.0 ± 5.3	.302
Cervical extensors				
	Thickness, cm	1.90 ± 0.26	2.09 ± 0.31	.026
	Normalized thickness, cm/kg	0.02978 ± 0.00410	0.02677 ± 0.00406	.086
Upper trapezius				
	Thickness, cm	1.11 ± 0.29	1.14 ± 0.29	.833
	Normalized thickness, cm/kg	0.01733 ± 0.00364	0.01455 ± 0.00427	.099
	Shear-wave elastography stiffness, kPa	24.9 ± 10.4	26.3 ± 6.9	.703

our hypotheses were partially supported. These results were in line with those of a previous study[10] that did not show sex differences in muscle size or thickness when normalized to body mass. To further quantify the relationship between the size of the cervical muscles and body mass, we used nonparametric bivariate correlation coefficients (Spearman ρ), which revealed positive relationships (mass versus LC: $\rho = 0.501$, $P = .013$; mass versus SCM: $\rho = 0.704$, $P < .001$; mass versus UT: $\rho = 0.394$, $P = .057$; mass versus cervical-extensor muscles: $\rho = 0.596$, $P = .002$). Significant relationships between the muscle size or thickness and body mass support the continued use of normalized values. Another important finding was the lack of sex differences in US-based SWE stiffness values of the SCM and UT. In addition, stiffness values were not related to body mass. Bivariate correlation coefficients revealed no significant relationship between body-mass and SWE-stiffness values (mass versus SCM SWE stiffness: $\rho = 0.387$, $P = .062$; mass versus UT SWE stiffness: $\rho = 0.220$, $P = .302$).

The SCM is the main dynamic stabilizer against sudden neck-extension forces in sports. Females exhibited greater head acceleration and displacement during a head–neck perturbation test despite earlier onset and activation of the SCM.[20] The authors[20] also reported that females had less neck girth, muscle strength, and stiffness. Our results of less thickness of the SCM in women were in agreement; however, we did not identify any sex differences in SCM SWE stiffness. In a recent review,[13] investigators also reported mixed results for sex differences in neck-stiffness values. Previous researchers[13] used a whole head–neck perturbation test to calculate neck stiffness. Methodologic differences between studies would likely explain the mixed results for neck stiffness and sex differences. Few authors[16] have studied US-based SWE stiffness and sex differences in the cervical-flexor and -extensor muscles. More research is needed to confirm the current findings.

Regulation of joint stiffness is an important topic in the fields of sports medicine, joint stability, preventive medicine, athletic performance, and rehabilitation. For example, clinicians and researchers have evaluated intrinsic mechanisms for reducing sport-related concussions using the "brace-for-impact" strategy.[21] A computer-simulation study[22] has validated this concept. We need to understand if

Table 3. Intrarater Reliability, Precision, and Minimal Detectable Change for Size and Stiffness of the Cervical-Flexor and -Extensor Muscles

Muscle	Variable	Intraclass Correlation Coefficient [3,1] (95% Confidence Interval)	Standard Error of Measurement	Minimal Detectable Change, 95% Confidence Interval
Longus colli				
	Cross-sectional area	0.846 (0.627, 0.936)	0.106 cm^2	0.293 cm^2
	Normalized cross-sectional area	0.817 (0.555, 0.924)	0.00136 cm^2/kg	0.00377 cm^2/kg
Sternocleidomastoid				
	Thickness	0.890 (0.743, 0.952)	0.063 cm	0.176 cm
	Normalized thickness	0.715 (0.332, 0.877)	0.00101 cm/kg	0.00279 cm/kg
	Shear-wave elastography stiffness	0.554 (–0.034, 0.808)	5.122 kPa	14.198 kPa
Cervical extensors				
	Thickness	0.808 (0.564, 0.916)	0.1340 cm	0.387 cm
	Normalized thickness	0.852 (0.663, 0.935)	0.00175 cm/kg	0.00485 cm/kg
Upper trapezius				
	Thickness	0.769 (0.449, 0.903)	0.147 cm	0.410 cm
	Normalized thickness	0.733 (0.364, 0.887)	0.00228 cm/kg	0.00632 cm/kg
	Shear-wave elastography stiffness	0.734 (0.362, 0.888)	4.895 kPa	13.569 kPa

exercises or modalities can actually increase SWE stiffness before practices or games and how long SWE stiffness remains elevated, if at all. The current normative, ICC, SEM, and MDC values can be used as references for young and athletic individuals.

Other neck muscles (LC, cervical-extensor muscles, and UT) were commonly assessed in individuals with NP or chronic pain. Although we examined young, healthy individuals, it was clinically relevant to discuss previous studies on the effects of musculoskeletal conditions (ie, NP and chronic pain) and therapeutic interventions on US-based muscle size. The LC is one of the most frequently targeted muscles for therapeutic exercise interventions because of its role in stabilizing the spine. The LC acts as a local spine stabilizer, whereas the SCM acts as a global neck flexor and contralateral rotator.[23] The LC CSA in our male participants was similar to that in a previous study.[7] In contrast, our larger standard deviations would likely explain why we detected no sex difference.[7] From a clinical perspective, the LC and SCM could be strengthened with craniocervical-flexion exercise (using a pressure cuff to apply downward pressure to a bowed head in a supine position for 10 seconds for 10 repetitions) and cervical-flexion exercise (lifting or flexing the head through the full range of motion for 3 sets of 15 repetitions), respectively, for 10 weeks.[17] The authors[17] reported increases in LC CSA of 0.167 cm^2 and SCM thickness of 0.733 cm in individuals with chronic NP. Based on the current MDC values (Table 3), the change in LC CSA of 0.293 cm^2 and in SCM thickness of 0.176 cm after interventions would be clinically meaningful. In other words, based on the MDC values, the previous results after interventions would not be clinically meaningful. Our data can serve as references when implementing neck-strengthening exercise interventions for young and athletic individuals in future studies.

Compared with the deep cervical-flexor muscles, the deep cervical-extensor muscles have been investigated less frequently. Nonetheless, the roles of the semispinalis cervicis and multifidus muscles have been discussed.[24] The US-based CSA of the cervical multifidus muscle was smaller in individuals with chronic whiplash-associated disorder.[25] However, magnetic resonance imaging–based CSA of the same muscle was larger in individuals with chronic whiplash-associated disorder.[26] The authors[26] suggested that fatty infiltration might contribute to enlargement of the muscle and result in inconsistent findings. The accuracy and precision of US-based images can be operator dependent, and slight changes in neck position can result in large changes in the CSA of the cervical-extensor muscles.[27] To overcome this limitation, 1 examiner performed all scans in our investigation. However, researchers should pay particular attention to standardizing participants' head and neck positions to maintain consistency.

We found that the cervical-extensor muscles were thicker in men than in women. This finding was consistent with a previous study[10] that showed sex differences in the deep posterior muscles and semispinalis. However, this sex difference in thickness of the cervical-extensor muscles was eliminated when thickness was normalized to body mass. Despite a lack of sex differences in muscle size, decreased neck strength in females has been acknowledged.[20] Strength deficits should be addressed with resistance exercises. In particular, specific manual resistance exercises have been shown[28] to activate the deep cervical-extensor muscles. Simple neck-extension exercises with a weight hanging from a headband increased the normalized electromyography amplitude of both the semispinalis cervicis and splenius capitis.[29] Because those muscles are active during cervical rotation, the authors[29] recommended a weighted-pull exercise positioned slightly below the level of the headband. Both groups[28,29] used intramuscular electromyography to quantify muscle activation of the cervical-extensor muscles; however, for clinical use, US-based imaging could serve as an alternative for examining which exercise elicits the largest change in muscle thickness. For example, in a study[9] of the acute effects of isometric contractions of the shoulder muscles in 6 directions (flexion, extension, abduction, adduction, internal rotation, and external rotation), increases were noted in cervical-extensor muscle thickness immediately after isometric contractions in shoulder abduction and external rotation. It is important to recognize the critical role of the cervical-extensor muscles (especially the splenius capitis) as spine stabilizers during (shoulder) muscle contractions at the peripheral joints.[9] Future investigators should address whether US-based imaging can detect changes after different types of therapeutic exercises or resistance training on multiple joints.

No sex differences were demonstrated in SCM or UT SWE stiffness in young, athletic individuals. This finding was in agreement with a previous report[16] of no sex differences in SCM SWE stiffness. Interestingly, in the same study, the authors identified a gradual decrease in SCM muscle SWE stiffness among healthy older individuals.[16] Our results could serve as references for future studies of older participants. In patients with chronic pain, the UT SWE-stiffness values were 23.6% higher than those of control individuals.[15] Another group[30] evaluated US-based SWE stiffness of the cervical-extensor muscles in healthy individuals at rest and during a head-lift; UT stiffness values were 7.7 and 15 kPa, respectively. In participants with myofascial trigger points, US-based SWE-stiffness measurements were 89% higher directly over the trigger points compared with the adjacent fibers within the same muscle.[31] It is interesting to note that our results for SCM and UT SWE stiffness were 2 to 3 times higher than the values reported previously.[30] However, because of the current, less reliable values and the higher coefficient of variance for the SWE-stiffness measurements, further refinement of the technique is required.

The study had a few limitations. The areas of interest during postprocessing were selected by the primary investigator (T.N.). Independent reviewers (additional sonographers) could have conducted postprocessing to remove any potential bias. The size of the circle selected for SWE stiffness depended on the individual's muscle size. In other words, there might have been differences in SWE-stiffness values when smaller or larger areas were compared. Standardized sizes for US-based SWE-stiffness values also added a limitation in that the smallest muscle size would have been used as the reference. Because US-based SWE-stiffness measurement is a relatively new technology, interdevice differences likely exist. Finally, we performed a power analysis and established reliability, but type II error was possible due to multiple variables associated with US-based imaging. Additional participants could confirm the current results.

CONCLUSIONS

We used US-based imaging to measure cervical-flexor and -extensor muscle size and stiffness in young, athletic individuals. Reliability values were good; however, a sex difference was found only for SCM thickness. We provided normative values for US-based imaging of the cervical-flexor and -extensor muscles in young, athletic men and women.

REFERENCES

1. Hoy D, March L, Woolf A, et al. The global burden of neck pain: estimates from the global burden of disease 2010 study. *Ann Rheum Dis*. 2014;73(7):1309–1315.
2. Noormohammadpour P, Farahbakhsh F, Farahbakhsh F, Rostami M, Kordi R. Prevalence of neck pain among athletes: a systematic review. *Asian Spine J*. 2018;12(6):1146–1153.
3. Simmons MM, Swedler DI, Kerr ZY. Injury surveillance of head, neck, and facial injuries in collegiate ice hockey players, 2009-2010 through 2013-2014 academic years. *J Athl Train*. 2017;52(8):776–784.
4. Kennedy E, Quinn D, Tumilty S, Chapple CM. Clinical characteristics and outcomes of treatment of the cervical spine in patients with persistent post-concussion symptoms: a retrospective analysis. *Musculoskelet Sci Pract*. 2017;29:91–98.
5. Stemper BD, Corner BD. Whiplash-associated disorders: occupant kinematics and neck morphology. *J Orthop Sports Phys Ther*. 2016;46(10):834–844.
6. Cagnie B, Derese E, Vandamme L, Verstraete K, Cambier D, Danneels L. Validity and reliability of ultrasonography for the longus colli in asymptomatic subjects. *Man Ther*. 2009;14(4):421–426.
7. Javanshir K, Rezasoltani A, Mohseni-Bandpei MA, Amiri M, Ortega-Santiago R, Fernandez-de-Las-Penas C. Ultrasound assessment of bilateral longus colli muscles in subjects with chronic bilateral neck pain. *Am J Phys Med Rehabil*. 2011;90(4):293–301.
8. Overas CK, Myhrvold BL, Rosok G, Magnesen E. Musculoskeletal diagnostic ultrasound imaging for thickness measurement of four principal muscles of the cervical spine—a reliability and agreement study. *Chiropr Man Ther*. 2017;25:2.
9. Karimi N, Rezasoltani A, Rahnama L, Noori-Kochi F, Jaberzadeh S. Ultrasonographic analysis of dorsal neck muscles thickness changes induced by isometric contraction of shoulder muscles: a comparison between patients with chronic neck pain and healthy controls. *Man Ther*. 2016;22:174–178.
10. Rankin G, Stokes M, Newham DJ. Size and shape of the posterior neck muscles measured by ultrasound imaging: normal values in males and females of different ages. *Man Ther*. 2005;10(2):108–115.
11. Linek P, Saulicz E, Wolny T, Mysliwiec A. Body mass normalization for ultrasound measurements of adolescent lateral abdominal muscle thickness. *J Ultrasound Med*. 2017;36(4):775–782.
12. Goodarzi F, Rahnama L, Karimi N, Baghi R, Jaberzadeh S. The effects of forward head posture on neck extensor muscle thickness: an ultrasonographic study. *J Manipulative Physiol Ther*. 2018;41(1):34–41.
13. Le Flao E, Brughelli M, Hume PA, King D. Assessing head/neck dynamic response to head perturbation: a systematic review. *Sports Med*. 2018;48(11):2641–2658.
14. Eby SF, Song P, Chen S, Chen Q, Greenleaf JF, An KN. Validation of shear wave elastography in skeletal muscle. *J Biomech*. 2013;46(14):2381–2387.
15. Kuo WH, Jian DW, Wang TG, Wang YC. Neck muscle stiffness quantified by sonoelastography is correlated with body mass index and chronic neck pain symptoms. *Ultrasound Med Biol*. 2013;39(8):1356–1361.
16. Herman J, Sedlackova Z, Vachutka J, Furst T, Salzman R, Vomacka J. Shear wave elastography parameters of normal soft tissues of the neck. *Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub*. 2017;161(3):320–325.
17. Javanshir K, Amiri M, Mohseni Bandpei MA, De las Penas CF, Rezasoltani A. The effect of different exercise programs on cervical flexor muscles dimensions in patients with chronic neck pain. *J Back Musculoskelet Rehabil*. 2015;28(4):833–840.
18. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159–174.
19. Koppenhaver SL, Hebert JJ, Fritz JM, Parent EC, Teyhen DS, Magel JS. Reliability of rehabilitative ultrasound imaging of the transversus abdominis and lumbar multifidus muscles. *Arch Phys Med Rehabil*. 2009;90(1):87–94.
20. Tierney RT, Sitler MR, Swanik CB, Swanik KA, Higgins M, Torg J. Gender differences in head-neck segment dynamic stabilization during head acceleration. *Med Sci Sports Exerc*. 2005;37(2):272–279.
21. Eckner JT, Oh YK, Joshi MS, Richardson JK, Ashton-Miller JA. Effect of neck muscle strength and anticipatory cervical muscle activation on the kinematic response of the head to impulsive loads. *Am J Sports Med*. 2014;42(3):566–576.
22. Jin X, Feng Z, Mika V, Li H, Viano DC, Yang KH. The role of neck muscle activities on the risk of mild traumatic brain injury in American football. *J Biomech Eng*. 2017;139(10). doi: 10.1115/1.4037399.
23. Jull GA. Deep cervical flexor muscle dysfunction in whiplash. *J Musculoskelet Pain*. 2000;8(1–2):143–154.
24. Schomacher J, Falla D. Function and structure of the deep cervical extensor muscles in patients with neck pain. *Man Ther*. 2013;18(5):360–366.
25. Kristjansson E. Reliability of ultrasonography for the cervical multifidus muscle in asymptomatic and symptomatic subjects. *Man Ther*. 2004;9(2):83–88.
26. Elliott J, Jull G, Noteboom JT, Galloway G. MRI study of the cross-sectional area for the cervical extensor musculature in patients with persistent whiplash associated disorders (WAD). *Man Ther*. 2008;13(3):258–265.
27. Rezasoltani A, Nasiri R, Faizei AM, Zaafari G, Mirshahvelayati AS, Bakhshidarabad L. The variation of the strength of neck extensor muscles and semispinalis capitis muscle size with head and neck position. *J Bodyw Mov Ther*. 2013;17(2):200–203.
28. Schomacher J, Erlenwein J, Dieterich A, Petzke F, Falla D. Can neck exercises enhance the activation of the semispinalis cervicis relative to the splenius capitis at specific spinal levels? *Man Ther*. 2015;20(5):694–702.
29. Rivard J, Unsleber C, Schomacher J, Erlenwein J, Petzke F, Falla D. Activation of the semispinalis cervicis and splenius capitis with cervical pulley exercises. *Musculoskelet Sci Pract*. 2017;30:56–63.
30. Dieterich AV, Andrade RJ, Le Sant G, et al. Shear wave elastography reveals different degrees of passive and active stiffness of the neck extensor muscles. *Eur J Appl Physiol*. 2017;117(1):171–178.
31. Jafari M, Bahrpeyma F, Mokhtari-Dizaji M, Nasiri A. Novel method to measure active myofascial trigger point stiffness using ultrasound imaging. *J Bodyw Mov Ther*. 2018;22(2):374–378.

Address correspondence to Takashi Nagai, PhD, ATC, Biomechanics Laboratories, Mayo Clinic, 200 First Street SW, Rochester, MN 55905. Address e-mail to nagai.takashi@mayo.edu.