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A Tissue Velocity Ultrasound Imaging Investigation of the Dorsal Neck Muscles during Resisted Isometric Extension

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ABSTRACT

Persons with neck pain exhibit altered patterns of muscle patterning, but limited investigations have been carried out on these alterations or muscle patterning in healthy volunteers. This study investigated the tissue motion of the dorsal neck muscles at the C4 segmental level in 15 healthy subjects during manually resisted head extension. Doppler-based tissue velocity ultrasound imaging (TVI) was used to detect regional tissue deformation, providing indirect evidence of inter-muscular movement patterning. The deep muscles, multifidus and semispinalis, had different muscular movement patterning than the superficial muscles, especially the trapezius muscle. The semispinalis cervicis was the first deformed upon exercise initiation, followed by multifidus and semispinalis capitis. The semispinalis muscles, notably capitis, exhibited a high rate of deformation during the exercise. The trapezius muscle exhibited the least deformation and the lowest deformation rate. In conclusion, TVI provided detailed information on regional tissue activity and muscle movement patterning among the dorsal neck muscles. In future studies, data from patients with neck disorders will have to be matched to data from healthy volunteers in a variety of situations and activities.

INTRODUCTION

Individuals with neck pain demonstrate less neck muscle strength (Jordan et al., 1997; Peolsson et al., 2002) and endurance (Lee et al., 2003; Peolsson & Kjellman, 2007), greater neck muscle fatigability (Gogia et al., 1994), and altered activation patterns (Falla et al., 2004; Jull et al., 2004) than persons without neck complaints. Strong evidence exists that physical exercise is effective in the rehabilitation of patients with neck disorders (Kay et al., 2005), but a consensus has not been reached regarding the key components of such an intervention. Some investigators have suggested that a key component of neck pain rehabilitation is to exercise the deep dorsal neck muscles, but there is a lack of information as to the dorsal neck muscle activity during specific exercises and movement patterns. Thus, more knowledge about the activation and patterning of these muscles in different clinical settings and populations is needed.

Ultrasound is a well documented imaging method (Hides et al., 1995; Kristjansson, 2004; Fernández-De-Las-Peñas et al., 2008; Lee et al., 2009) that can capture functional movements in real time. The method is highly complementary to magnetic resonance imaging (MRI) and is noninvasive, in contrast to wire electromyogram (EMG). Traditional grey scale ultrasound, which has been used in previous studies of neck muscles (Rezasoltani et al., 1998, 1999, 2002; Kristjansson, 2004; Rankin et al., 2005; Fernández-De-Las-Peñas et al., 2008; Jesus et al., 2008; Lee et al., 2009), provides information about anatomical landmarks and structural information about the tissue. Dorsal (Lee et al., 2007, 2009) and ventral (Jesus et al., 2008) neck muscles have been studied using changes in muscle thickness or cross-sectional area (CSA) as an indication of muscle activity. Lee et al. (2007, 2009) studied the CSA of the multifidus muscle during rest and isometric head extension, finding that ultrasound can detect changes in multifidus during contraction, with acceptable reliability.

Tissue velocity imaging (TVI) uses the Doppler method to study tissue dynamics (Grubb et al., 1995; Mannion et al., 2008; Peolsson et al., 2008; Pulkovski et al., 2008). The Doppler effect is a change in the frequency of a wave when it propagates in a medium and is used for a number of applications, including by bats for navigation, in sonar, and in ultrasound techniques. For ultrasound waves, the frequencies of the waves are relative to the medium in which they are transmitted (skin, fat, connective tissue, muscle, or bone). The received signals result in different scales of grey in the ultrasound picture. Thus, TVI can be used to calculate tissue deformation. Two measuring techniques are used, strain and strain rate. Strain is the momentary tissue deformation expressed as a percentage of the original length, resulting in compression or elongation of the muscle tissue length (Mirsky et al., 1973). Strain rate is the rate at which the deformation occurs expressed as change in deformation per unit of time (Heimdal et al., 1998; D'Hooge et al., 2000), which gives information about the local tissue velocity. Regional strain and strain rate values are calculated frame by frame in the ultrasound loop. Using TVI, active and passive tissues can be separated (Grubb et al., 1995) and different phases in voluntary muscular contractions identified (Grubb et al., 1995), which makes it possible to study skeletal muscle deformation (Peolsson et al., 2008). In addition, TVI can be used to study muscular feed-forward activity (Mannion et al., 2008). Pulkovski et al. (2008) reported good reliability (intra class correlation coefficient (ICC) 0.67-0.99) for the onset of muscle activation when using TVI and found a good correlation for the onset of muscle activation when using TVI and EMG ($r=0.78-0.80$). The TVI technique can be used to differentiate muscle deformation between healthy controls and patients with trapezius disorder (Peolsson et al., 2008) because it assesses tissue motion within various tissue regions, which may be an indicator of muscle patterning. Tissue motion as an indicator of the muscle patterning of the deep dorsal neck muscles, such as the multifidus and semispinalis muscles,

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in relationship to more superficial muscles, such as the splenius and trapezius, has not yet been studied with ultrasound.

This study aimed to investigate and describe the muscle patterning of the dorsal neck muscles at the C4-C5 level in healthy people in a seated position with manual resistance of the head in extension using ultrasound TVI.

METHODS

Participants

Fifteen university student volunteers, 9 women and 6 men (mean age 25 years, standard deviation (SD) 3.8, range 19-33 years), with good neck health participated in the study. Participants were excluded if they had experienced pain (>10 mm on the visual analogue scale (VAS) (Scott and Huskisson, 1976; Croft et al., 1998) or discomfort (>20% on the neck disability index (NDI)) (Fairbank et al., 1980; Vernon and Mior, 1991) in the neck during the preceding 3 months or had a history of repeated neck discomfort, medical treatment for a neck disorder, or neck trauma. Participants were also excluded if they were experiencing severe back pain, generalized myalgia, or had a diagnosis of rheumatologic or neurological disease. Thus, the volunteers were without neck pain or discomfort with a mean VAS of 0.5 mm (SD 2.07, range 0-8) and mean NDI of 1% (SD 1.95, range 0-6). The volunteers also had high physical activity (mean 3.5, SD 0.64, range 2-4 on a 4-point scale) (Peolsson et al., 2007). All procedures were conducted according to the Declaration of Helsinki. The Ethics Committee at the Faculty of Health Sciences, Linköping University approved the study.

Measurements

Ultrasound imaging

A 14.0 MHz linear transducer and Ultrasound Vivid 7 Dimension (GE Healthcare, Horten, Norway) ultrasound imaging system was used to generate images of the dorsal cervical muscles: trapezius, splenius, semispinalis capitis (SSCap), semispinalis cervicis (SSCerv), and multifidus. In the present study, the multifidus and rotatores were not separated in the analysis and are referred to as the multifidus. After an experienced physical therapist identified the C4 level by palpation and marked the skin with a pen, the transducer was positioned in a transverse orientation at a level on the right side of the neck in such a way that

the C4 spinous process was seen within the ultrasound image. Further clarification of the C4 spinal level was provided by identification of the bifurcation of the arteria vertebralis (commonly accepted to be found at the C4 level). Once the operator was comfortable that the C4 spinal level had been identified, the transducer was rotated 90 degrees in a longitudinal orientation to generate the images for analysis, which were imported into EchoPac software (GE Healthcare, Horten, Norway) for offline analysis (Figure 1).

Insert Figure 1 about here

Test procedure

The experimental procedure was designed to be similar to a clinical situation. Before measurements were taken, participants were carefully informed about it and practiced it to ensure an accurate performance.

Volunteers were seated on a stool with a straight back, feet flat on the floor, hands resting on their legs, and were told to perform small ventral flexion in the upper neck. A physiotherapist (manual therapist, AP) held her right hand on the back of the participant's head and requested the participant perform a sub-maximal isometric head extension for approximately 8 seconds, as commonly performed for neck rehabilitation. The volunteers were given instructions by the physiotherapist as follows: "In an upright position, hold your chin in. When the operator has counted to three, you will push your head backward against my hand. It is important to do so with a gentle start and stop and not to push as hard as possible." The physiotherapist gently increased the resistance at the start of the procedure and then gradually decreased the resistance (Figure 2). A medical engineer performed the ultrasound registrations (MP).

Insert Figure 2 about here

Test-retest reliability was determined from two measurements made 2 weeks apart in 10 (4 men and 6 women) individuals from the present study (mean age 25 years, SD 4.3, range 19-33).

Insert Figure 3 about here

Quantification of tissue velocity from images

In order to quantitatively investigate the relative muscle patterns of the dorsal neck muscles during movement, regions of interest were used to capture muscle demarcations within the images. A region of interest is a shape that can be drawn and placed arbitrarily within the images. In this study, an ellipse captured the trapezius, splenius, SSCap, SSCerv, and multifidus muscles. The region of interest was placed in the first frame of the loop and then followed frame by frame, allowing region of interest strain values to be calculated in real time. As a result, the relationship between the individual regions of interest was discerned and presented in one curve per region of interest as a function of the progression of the movement (Figure 4).

Insert Figure 4 about here

Three variables were calculated from the quantitative curves: the root mean square (RMS) for strain rate and the mean and maximal values for strain.

Identification of three phases

In order to describe the course of deformation during the isometric resistance exercise in more detail, three phases were identified in the strain rate curves. The first phase was derived from tissue motion, indicating the activation of the neck muscles as a consequence of maintaining the position of the head during the initial manual resistance compared to the neck muscles at rest. This phase, termed the “initial contraction phase”, is indicated by a rapid increase in activity in the strain rate curve. The second phase refers to the maintenance of muscle deformation during the external hand held resistance. This phase of the strain rate curve was characterized by a flat, low activity level, indicating that the deformation has reached a steady state called the “plateau phase”. The third phase was the letting go of the external hand held resistance and is termed the “end phase”, which is indicated by an inverted strain rate curve compared to the initial contraction phase.

Statistical analysis

For descriptive statistics, the mean, SD, and 95% confidence interval were used. For paired two-group analysis (tests of patterns within the same muscle), a paired two-tailed Student's t-test was used. For unpaired three-group comparisons (tests between the muscles), factorial analysis of variance (ANOVA) with Fisher's protected least significant difference test (as a post-hoc test) was used. F-values from the ANOVA table are presented. Single measure ICC two-way random absolute agreement was used to obtain ICC values for the total sequence. A $p\text{-value} \leq 0.05$ was considered significant.

RESULTS

Test-retest reliability

The procedure was found to have moderate to good test-retest reliability for the dorsal neck muscles with an ICC of 0.88-0.99 for quadratic mean values (RMS strain rate) and 0.63-0.96 for strain (Table 1).

Deformation and deformation rate

The SSCap and SSCerv exhibited more strain than the trapezius in both the initial contraction phase and the plateau phase ($p=0.01-0.003$; Table 2). The SSCap and SSCerv also had more strain than the multifidus in the plateau phase ($p=0.03-0.003$; Table 2).

Except for the mean strain in the initial contraction phase and strain rate in the plateau phase, the splenius muscle had more strain and a higher strain rate than the trapezius ($p=0.03-0.02$). No significant differences were found between the multifidus and trapezius, with the exception of a higher strain rate for the multifidus in the plateau phase ($p=0.002$). The strain rate in all muscles ($p=0.01-0.0003$), except the trapezius ($p=0.06$), decreased from the initial contraction phase to the plateau phase. For strain, aside from the maximum strain of the multifidus ($p=0.07$), the relationship was inverse ($p=0.02- <0.0001$).

Tissue motion as an indication of the order of muscle recruitment

The SSCerv, followed by the multifidus and SSCap, was commonly the first to be deformed as an indication of activation, and thereby muscle patterning, when isometric head extension began. The trapezius was the last to be deformed (Table 3). Significant differences were found between the deep muscles (multifidus, SSCerv, and SSCap) and the trapezius ($p=0.008-$

0.002), but no significant difference was found between the trapezius and splenius ($p=0.13$; ANOVA table $F=3.75$).

DISCUSSION

We found that the deep semispinalis muscles, particularly the SSCap, have high strain and a high strain rate during sub-maximal isometric head extension. The trapezius, the most superficial muscle, was the muscle with the lowest strain and strain rate. The strain rate in all muscles, aside from the trapezius, decreased from the initial contraction phase to the plateau phase. Strain was inversely proportional to increased muscular deformation in the plateau phase. With regard to recruitment order at the start of the exercise, deeper muscles (multifidus and semispinalis) contracted prior to superficial muscles.

Present results compared with earlier results

To the best of our knowledge, inter-muscular tissue displacement as an indication of muscle patterning in deep and superficial dorsal neck muscles during isometric neck extension has not been previously studied, and TVI has not been previously utilized to study dorsal neck muscles. In earlier studies, muscle size, shape, and symmetry, and the change in these parameters during activity compared to a resting state, were studied using ultrasound to describe reference values or capture abnormalities due to muscle atrophy or hypotrophy (Rezasoltani et al., 2002; Kristjansson et al., 2004; Rankin et al., 2005; Lee et al., 2007, 2009; Fernández-De-Las-Peñas et al., 2008). However, the ultrasound technique cannot be used as a direct measure of activity and recruitment. The results of the present study contribute to the knowledge of physiotherapy and neck rehabilitation, as the clinical hypothesis that deep dorsal muscles contract during the exercise appears to be true, particularly for SSCap.

Rezasoltani et al. (2002) studied changes in the size of the SSCap at the C3 level during maximal isometric extension compared to rest in six junior hockey players and found that the multiplied linear dimension increases with maximal isometric contraction. Lee et al. (2009)

showed that the thickness of the multifidus increases in isometric extension but reaches a plateau after 50% maximal contraction. These studies (Rezasoltani et al., 2002; Lee et al., 2009) support our findings that both the SSCap and multifidus contract during isometric neck extension and play a role in segmental stabilization. The SSCap extends the head bilaterally as well as ipsilaterally (Kapandji, 1990). When ipsilaterally contracted, lateral flexion is minimal and the SSCap muscle is considered to be the main neck muscle balancing the head (Kapandji, 1990). This activity could explain the result in the present study in which SSCap was found to have high deformation during isometric neck extension. Conley et al. (1995) used exercise-induced shifts on T2-weighted MRI to study increased CSA in seven healthy adults performing sets of neck extension exercise against gravity compared to rest, finding that the SSCap has the highest signal-induced shift. The SSCerv and splenius also showed a signal shift, as did the multifidus in a relative sense, and the trapezius showed less of a shift (Conley et al., 1995). Contrary to TVI, the MRI technique used by Conley et al. (1995) could not measure muscular deformation in real time, but measured it as a signal-induced shift. Despite the differing measurement techniques and exercises used, the results of the present study support the findings by Conley et al. (1995) and are valuable information for future work that can be seen as a validation of TVI for studying neck muscles.

TVI strain rate and strain

Strain rate is the deformation rate parameter and can be related to the rate of contraction, whereas strain is a description of the consequences expressed in terms of muscle expansion as a consequence of muscle contraction. The colorization of these parameters gives visual qualitative information about the progression of the specific muscle deformation, as well as an indication of the time-related inter-muscular coordination pattern during exercise. The curves, on the other hand, provide quantitative graphical information about these items. Therefore, the

benefit of strain and strain rate is that they identify regional tissue deformation in relation to nearby tissues. However, all deformations are angle-dependant, and tissue velocities are measured in an axial direction to the probe and not along the fascicles. There is a principle of muscle volume incompressibility, meaning that if a muscle is shortened (contracted) in one dimension, the muscle volume has to expand in the other two dimensions; thus, the measurement carries relative information that cannot be used as an absolute value. Aside from muscle deformation, the angle of the transducer relative to the surface of the skin and muscles investigated is a possible factor that could result in alteration of the strain and strain rate. Due to individual differences in the configuration of the neck, in order to obtain the optimal ultrasound picture small differences could be present in the projection angle among individuals.

Another drawback is that TVI provides an indirect measure of the tissue movement patterning of the dorsal neck muscles. Activation and recruitment pattern are neurophysiological terms implying that electrical parameters were monitored (e.g., EMG). In this study, TVI provides a method to assess tissue motion patterns within various muscles, which is argued to be an indicator of tissue contraction patterning. However, due to the lack of a possibility of non-invasive EMG registrations of the deep dorsal neck muscles, TVI appears to be useful.

As with all medical imaging, the issue of quality must be considered, and analysis is time-consuming. This is also the case when performing post-process analyses. Yet, we argue that the benefits dominate. It is a safe, non-invasive technique, cheap compared to MRI, and has the benefit of allowing an investigation of the muscle tissue response in real-time during functional movements.

Manual resistance and biomechanical parameters

In the present study, sub-maximal non-standardized resistance was used to imitate the clinical rehabilitation technique used by physical therapists. In patients with severe neck pain, one repetition maximum in isometric extension could be contra-indicated due to pain or fear of movement and due to high segmental load (Choi et al., 2000). The outcome of this study could have been affected if a different load had been applied, such as maximal resistance, or if measurements had been done at a different segmental level. However, the function of the neck muscles is primarily to stabilize the neck and resist load during daily activities. Lee et al. (2009) showed that the multifidus reaches a plateau in change of thickness after 50% maximal contraction. However, the superficial neck muscles, in particular, could have acted differently if a greater load had been applied. Not unexpectedly, large variations were seen between participants (Rankin et al., 2005). Using a strain gauge to control for potential differences in resistance could have been advantageous. Also, the average of two or three measurements could have been used to minimize potential error. However, the reliability of the measurements was found to be good to very good (ICC 0.61-0.99) and could indicate the usefulness of the results.

Biomechanical parameters, such as the length of each muscle, the location of origins and insertions, and the location where the force was applied relative to the muscles, are factors that could influence the results. However, these parameters are impossible to capture with the methodology used.

Statistics

The small sample size and single measurement (two measurements in the reliability part of the study) in participants were chosen for pragmatic reasons as analyses of the “video

sequences” are very time consuming. Future work needs to be done to improve and accelerate image analysis. The study could be looked upon as a pilot study in order to learn more and provide valuable information concerning both the implication of the technique and dorsal neck muscle activation. Due to the small sample size, one can argue that non-parametric statistics should have been used. The results of the measurements did not differ when nonparametric and parametric analyses were compared, demonstrating result stability. Despite the small sample size and the wide inter-individual range, some patterns and differences were detected in the study. A large study possibly could have found more clear differences between muscles.

Representativeness of the population

In the present study, only young adults were included. Elliot et al. (2007) found a weak correlation between age and relative CSA at the C5 level using MRI. Rankin et al. (2005) presented reference values for the size of the semispinalis, multifidus, and rotators muscles in healthy adults of different ages and gender and found gender differences in the size and shape, but no altered muscle size with age. This fact indicates that our young healthy adults are representative of healthy muscle function.

Volunteers in the present study had a high physical activity level. This fact makes it easier to study the muscles because it is easier to identify the fascia layer dividing the muscles (Kristjansson et al., 2004), but this does not give a representative picture of muscular tissue motion to indicate muscular patterning in the general population. Elliott et al. (2007), using MRI of the semispinalis muscles and splenius, reported that physical activity levels have an impact on muscle size. In this study, most participants reported regular jogging, aerobics, or

spinning without specific neck exercises, which is suggestive of having less influence on the neck muscles.

If the present study had included patients with neck disorders, one can speculate that the muscular deformation and muscular patterning would have been altered according to decreased tonic deep muscle deformation and increased deformation in the superficial torque-produced muscles. Such findings have been seen in the neck flexors (Jull et al., 2004; Falla et al., 2004, 2006, 2007) and the lumbar spine (Hides et al., 1996). Kristjansson (2004) found it more difficult to visualize the fascia dividing the multifidus and SSCerv in patients with a whiplash-associated disorder than in healthy people, and suggested that these findings were due to hypotrophy and dysfunction of the multifidus. Fernández de las peñas et al. (2008) found the CSA of the multifidus to be smaller in patients with bilateral mechanical neck pain compared to healthy controls, which is consistent with the results of other studies that found inhibition of the deep ventral neck muscles following pain (Jull et al., 2004, Falla et al., 2004). Elliot et al. (2007) found, in contrast to others (Kristjansson et al., 2004; Fernández-de-las-peñas et al., 2008), that patients with whiplash-associated disorders have a larger CSA (C3-C7) on MRI than controls. This finding was interpreted as reflecting fatty infiltration in the muscles (Elliott et al., 2007). The disturbance in deep neck muscles after trauma and pain demonstrate the need for additional understanding of muscular patterning in healthy and diseased persons, and a better understanding of how to optimize rehabilitation. Ultrasound TVI could be a useful tool in these studies.

CONCLUSION

The deep semispinalis muscles, particularly the SSCap, have high strain and a high strain rate during sub-maximal isometric head extension. The trapezius, the most superficial muscle, has the lowest strain and strain rate. The strain rate in all muscles, aside from the trapezius, decreases from the initial contraction phase to the plateau phase. Strain was inversely related to higher muscular deformation in the plateau phase. The SSCerv, followed by the multifidus and SSCap, was the first to be deformed when isometric head extension started. The trapezius was the last to be deformed. The TVI technique provided detailed information about tissue motion that may be an indicator of muscle patterning between the dorsal neck muscles. To expand the knowledge regarding dorsal neck muscle patterning and rehabilitation methods, future studies should compare data from patients with neck disorders across ages and match them with healthy volunteers in a variety of situations and activities. TVI could prove to be a useful and important tool in such studies.

Tables

Table 1. Test-retest reliability.

	Strain rate (RMS)^a	Strain mean	Strain max
MUF	0.99	0.61	0.63
SSCerv	0.88	0.75	0.82
SSCap	0.94	0.94	0.92
SP	0.95	0.74	0.96
TP	0.97	0.65	0.80

Data was obtained from two measurements made 2 weeks apart in 10 (4 men and 6 women) persons (age 25 years, SD 4.3, range 19-33 years).

^aThe intraclass correlation coefficient values of the root mean square (RMS) strain rate.

Max, maximal strain; MUF, multifidus; SSCerv, semispinalis cervicis; SSCap, semispinalis capitis; SP, splenius; TP, trapezius.

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Table 2. Root mean square (RMS) of strain rate measurements and mean and maximal (max) strain of dorsal neck muscles in 15 healthy volunteers.

	MF	SSCerv	SSCap	SP	TP	F	p-value	
Contraction phase								
Strain rate (RMS)								
Mean (SD)	0.11(0.07)	0.19(0.12)	0.22(0.16)	0.18(0.11)	0.10(0.06)	3.83	MF-SSCerv p=0.04 MF-SSCap p=0.006 SSCerv-TP p=0.02 SSCap-TP p=0.002 SP-TP p=0.03	
95% CI	(0.07-0.15)	(0.13-0.26)	(0.14-0.31)	(0.12-0.24)	(0.06-0.13)			
Strain Mean								
Mean (SD)	4.9(4.10)	7.1(6.6)	8.04(8.3)	6.3(6.2)	2.5(4.04)	1.90		
95% CI	(2.7-7.2)	(3.5-10.8)	(3.4-12.6)	(2.9-9.8)	(0.27-4.7)		SSCerv-TP p=0.04 SSCap-TP p=0.01	
Max								
Mean (SD)	9.6(6.7)	15.5(10.6)	17.0(13.4)	15.0(11.7)	6.3(7.6)	2.89	SSCerv-TP p=0.02 SSCap-TP p=0.006 SP-TP p=0.02	
95% CI	(5.9-13.3)	(9.6-21.4)	(9.6-24.4)	(8.4-21.5)	(2.1-10.5)			
Plateau phase								
Strain rate (RMS)								
Mean (SD)	0.04(0.02)	0.06(0.04)	0.07(0.03)	0.08(0.03)	0.07(0.03)	4.19	MF-SSCerv p=0.04 MF-SSCap p=0.003 MF-SP p=0.0007 MF-TP p=0.002	
95% CI	(0.02-0.05)	(0.04-0.08)	(0.06-0.09)	(0.06-0.09)	(0.06-0.09)			
Strain Mean								
Mean (SD)	10.6(7.3)	17.0(10.3)	19.7(14.2)	18.0(12.0)	7.4(10.3)	3.42	MF-SSCap p=0.03 SSCerv-TP p=0.02 SSCap-TP p=0.003 SP-TP p=0.02	
95% CI	(6.6-14.7)	(11.3-22.7)	(11.9-27.5)	(11.4-24.7)	(1.7-13.1)			
Max								
Mean (SD)	11.4(8.4)	18.0(11.1)	21.8(14.4)	20.0(13.7)	10.4(12.8)	2.64	MF-SSCap p=0.02 SSCap-TP p=0.01 SP-TP p=0.03	
95% CI	(6.7-16.0)	(11.8-24.1)	(13.8-29.7)	(12.4-27.6)	(3.3-17.4)			

MF, multifidus; SSCerv, semispinalis cervicis; SSCap, semispinalis capitis; SP, splenius; TP, trapezius.

Descriptive statistics are given as mean values with standard deviation (SD) and 95% confidence interval (95%

CI). F and p-values are presented from factorial analysis of variance.

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Table 3. The most common order of tissue deformation as an indicator of activation in the dorsal neck muscles in 15 healthy volunteers from the start of the contraction phase during isometric head extension against manual resistance

Individual	MF	SSCerv	SSCap	SP	TP
1	2	1	3	4	5
2	5	3	2	1	4
3	2	1	3	4	5
4	2	4	1	5	3
5	1	3	1	5	4
6	4	2	1	3	5
7	1	2	3	4	5
8	1	2	3	4	5
9	3	5	4	2	1
10	3	5	4	2	1
11	2	1	3	4	5
12	3	2	5	1	4
13	5	1	3	2	4
14	3	1	2	4	5
15	1	3	2	5	4
Σ	38	36	40	50	60
Most common order of tissue deformation ^a	2	1	3	4	5

MF, multifidus; SSCerv, semispinalis cervicis; SSCap, semispinalis capitis; SP, splenius; TP, trapezius

^a1=the first muscle to be deformed, 5=last to be deformed.

Video sequences obtained by Doppler-based tissue velocity ultrasonographic imaging were analysed according to the color-coded activity maps and strain-rate curves with respect to regional tissue velocity alternations correlating to the progress of movement. The TP had a significantly lower deformation rate than the MF, SSCerv, and SSCap ($p=0.008-0.002$) and insignificantly less deformation than the SP ($p=0.13$).

Figure legends

Figure 1. The longitudinal ultrasound projection covering the C4 – C5 cervical segments (probe length 4.5 cm). The specific anatomical landmarks are numbered as follows: 1, M trapezius; 2, M splenius; 3, semispinalis capitis; 4, M semispinalis cervicis; 5, M multifidus.

Figure 2. Test position of sub-maximal head extension during manual resistance.

Figure 3. Placement of the ultrasound transducer.

Figure 4. Quantification of inter-muscle tissue motion in the neck.

The left part of the left image shows five regions of interest (ROIs) inserted in the separate muscles. From superficial to the deep muscle layer: M trapezius, M splenius (SP), M semispinalis capitis (SSCap), M semispinalis cervicis (SSCerv), and M multifidus (see Figure 1 for anatomical landmarks).

The right part of the image presents the calculated curves corresponding to the specific ROIs in the left images. Each grey shaded curve (representing different bright colors in the original) shows the resulting tissue deformation during exercise. The curve has a positive slope indicating an increase in tissue deformation (phase 1) when going from a relaxed neck position to pressing the head backwards towards light hand held resistance. The second phase (2) is the plateau phase in which the degree of deformation is maintained. The third phase (3) has a negative slope, which corresponds to decreased tissue deformation. The curves show the relative degree of deformation for the specific ROI.

Figures

Figure 1.

Figure 2.

Figure 3.

Figure 4.

References

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