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Original article

Altered ventral neck muscle deformation for individuals with whiplash associated disorder compared to healthy controls – A case-control ultrasound study

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ABSTRACT

Previous studies have shown altered neck muscle function in individuals with chronic whiplash associated disorder (WAD). However, we lack real-time investigations with non-invasive methods that can distinguish between the different ventral neck muscle layers. This study investigated deformations and deformation rates in the sternocleidomastoid (SCM), longus capitis (Lcap), and longus colli (Lco) muscles with real-time ultrasonography. Twenty-six individuals with WAD were compared with 26 controls, matched for age and sex. Ultrasound imaging of the SCM, Lcap, and Lco were recorded during 10 repetitive arm elevations. The first and tenth arm elevations were post-process analyzed with speckle tracking. There were few significant differences in the deformations or deformation rates in the SCM, Lcap, and Lco between the WAD and control group. In controls, deformations and deformation rates showed linear positive relationships between SCM/Lcap, SCM/Lco, and Lcap/Lco which increased from the first arm elevation ($R^2 = 0.14–0.70$); to the tenth arm elevation ($R^2 = 0.51–0.71$). The WAD group showed similar or weaker linear relationship ($R^2 < 0.19$) during the tenth compared to the first ($R^2 < 0.44$) arm elevation except for deformations in Lcap/Lco ($R^2 = 0.13–0.57$). This result indicated that deformations and deformation rates in one muscle were correlated by similar deformations and deformation rates in other neck muscles in the control group, but this interplay between muscles was not found in the WAD group.

1. Introduction

Some long-lasting symptoms associated with whiplash-associated disorders (WAD) (Berglund et al., 2001; Kongsted et al., 2007; Carroll et al., 2009) may be due to impaired neck muscle function with altered motor control patterns (Jull et al., 2004; Woodhouse and Vasseljen, 2008; O'Leary et al., 2011). Changed activation of the deep muscle layer (Falla et al., 2004a), which is thought to stabilize the spine (Panjabi, 1992; Mayoux-Benhamou et al., 1994), might increase neck disability. Magnetic resonance imaging can non-invasively distinguish between the deep cervical flexors, longus capitis (Lcap), and longus colli (Lco) (Cagnie et al., 2008, 2010; Elliott et al., 2010); but cannot be used to investigate muscles during movement. Surface electromyography (EMG) has demonstrated increased activity in the sternocleidomastoid (SCM) muscle (Jull et al., 2004; Falla et al., 2004b) and invasive EMG studies (electrode contacts inserted through the nose) reported a delayed activation of the deep cervical flexors in chronic neck pain (Falla et al., 2004a; Falla et al. 2004c). Nevertheless, EMG investigations run a risk of cross-talk between muscles, and cannot distinguish between the Lcap and Lco. Still image ultrasonography can measure the thickness of deep ventral neck muscles (Cagnie et al., 2009; Javanshir et al., 2011), but it provides no information about neck muscle function during real-time motion. With ultrasound, the muscle of interest may be influenced by

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neighboring tissues or external pressure from the probe. Nevertheless; the ability to investigate deep and superficial muscle functions together, during real time activations (Lopata et al., 2010; Peolsson et al., 2010; 2014a) makes this method interesting. Speckle tracking is a post-process method for analyzing ultrasound images; it facilitates measuring muscle deformations (elongations and shortenings) and deformation rates, and this information has improved our understanding of real time (Lopata et al., 2010) mechanical neck muscle function in different muscle layers (Peolsson et al., 2012). To our knowledge, this approach has not been previously applied in individuals with chronic WAD. The objective of the present study was to compare deformations and deformation rates in the SCM, Lcap, and Lco in individuals with WAD vs. control subjects, during repetitive arm elevations. In addition, we aimed to determine if the interplay of the three muscles differed between the WAD and control groups. We hypothesized that deformation and deformation rates would be increased in the SCM and decreased in the Lcap and Lco for individuals with chronic WAD compared to healthy controls.

2. Methods

2.1. Participants

Twenty-six individuals, 20 women and 6 men (mean age 37 years, SD; 10.6) with persistent neck pain after a whiplash injury and 26 controls, matched for age and sex, participated in the study (Table 1). As no previous study has compared deformation and deformation rate between WAD and controls, the sample size was arbitrary.

Individuals with WAD were consecutively recruited for ultrasound investigation from a larger, ongoing, randomized controlled trial (Peolsson et al., 2013).

For study eligibility, individuals had to report neck pain in the right side of the neck, right-handedness, and fluency in Swedish. Study inclusion criteria were positive manual examination findings that corresponded to WAD grade II (neck pain and musculoskeletal signs) or III (neck pain plus neurological signs) (Spitzer et al., 1995); persistent neck pain rated greater than 20 mm on a visual analogue scale (VAS), and/or neck disability greater than 20% (MacDermid et al., 2009), measured with the neck disability index (NDI); aged 18–63 years; and ongoing symptoms associated with a whiplash injury that started six months to three years prior to study entry.

Exclusion criteria were signs of traumatic brain injury at the time of whiplash injury; known or suspected serious pathology; previous fracture or luxation in the cervical spine; contraindication to exercise; neuromuscular diseases; rheumatologic disease; previous serious neck pain that warranted more than 1 month of sick leave in the year prior to their whiplash injury; severe mental illness; or current alcohol or drug abuse.

The healthy controls were recruited from university staff, hospital staff, and acquaintances. Exclusion criteria were current or past neck problems; trauma to the neck or head including whiplash injury; neck or low back pain; rheumatologic or neurologic disease; or generalized myalgia. The study was approved by the Regional Ethics Review Board and was conducted according to the Declaration of Helsinki. Written informed consent was obtained from all participants.

Table 1
Characteristics of participants in the study.

	WAD ($N = 26$)	Healthy controls ($N = 26$)	P
Gender, female (number and %)	20 (77%)	20 (77%)	1.0
WAD grade II/III (number)	18/8	0	0.001
Age (years; mean and SD)	37 (10.9)	37 (10.9)	0.96
Injury duration[a] (months, mean and SD)	22 (7.7)	0	<0.001
BMI[b] male (mean and SD)	25 (6.6)	25 (3.5)	0.81
BMI female (mean and SD)	25 (5.4)	22 (2.4)	0.01
Physical activity level[c] (median and range)	2 (2–3)	4 (3–4)	0.001
Neck Disability Index[d] (mean and SD)	34 (13.4)	1 (1.6)	0.001
Pain previous week[e] (VAS; mean and SD)	50 (18.8)	1 (1.0)	0.001

[a] Months since whiplash injury, range 6–36 months.
[b] BMI; Body Mass Index (kg/m^2).
[c] Physical activity level over the prior 12 months (1 = inactivity, 2 = low activity, 3 = moderate activity, 4 = high activity).
[d] Neck Disability Index Score (0–100%) was based on 10 items; higher scores represented higher disability.
[e] VAS; Visual analogue scale, average pain in the prior week, range 0–100 mm, higher rating represented higher pain intensity.

2.2. Ultrasound measurements

The ventral neck muscles were recorded with a B-mode, 2-D ultrasound Vivid-I scanner (GE Healthcare, Horten, Norway). The ultrasound was equipped with a 12 MHz linear transducer (38 mm) with high frame rate (235 frames/s). Ultrasound measurements of the SCM, Lcap, and Lco were recorded during repetitive arm elevations. Each test included 10 arm elevations, and ultrasound images ("video" sequences) were acquired during the first and tenth arm elevations. The ultrasound probe was positioned at the C4 level on the right side of the neck (Fig. 1a). The segmental level was verified with a transverse ultrasound projection of the bifurcation of the carotid artery, commonly observed at the C4 level. The transducer was then rotated to a longitudinal position, which allowed optimal imaging of the SCM, Lcap, and Lco muscles. All ultrasound measurements were acquired in this longitudinal position (Fig. 1b).

2.2.1. Speckle tracking

Ultrasound of muscle results in reflection of sound waves, which serve as acoustic markers because they form a unique speckle pattern. Briefly, a region of interest (ROI) was manually placed in the first frame of the video sequence of each muscle. Tracking the unique speckle pattern of the respective ROI was based on an algorithm developed by Kanade–Lukas–Tomasi (KLT) (Lucas and Kanade, 1981; Tomasi and Kanade, 1991), which was further enhanced (Farron et al., 2009). Accordingly, when the muscle speckle pattern changes length, the tracked ROI also changes in length, and the unique pattern can be followed frame by frame throughout the ultrasound images. The ROI comprises a large number of points placed equidistant between the two endpoints. The frame to frame displacement can then obtained with a least squares fit, assuming a linear strain model. The displacement of all points within the ROI was summed, to obtain a cumulative sum from all frames in the movie which provided quantitative information of muscle behavior during the arm elevation.

Muscle Deformation was defined as a change in ROI length (elongation or shortening), calculated as the percentage change (% deformation) from the original length; provided information about local tissue dynamics. The *Muscle Deformation Rate* was defined as the rate of the change in deformation, expressed as the amount of deformation per time unit (% deformation/s). Three ROIs (each ROI was 10 × 3.3 mm) were positioned longitudinally in each of the muscles (i.e., oriented longitudinal to the muscle fibers); together, the three ROIs covered 30 mm of the unique speckle pattern in each muscle (Fig. 2). The magnitude of muscle deformation measured with speckle tracking was positively related to other measurements