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Alterations in the Mechanical Response of Deep Dorsal Neck Muscles in Individuals Suffering from Whiplash-Associated Disorders Compared to Healthy Controls: An Ultrasound Study

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ABSTRACT

Objective: The purpose of this study was to investigate and compare the mechanical responses of dorsal neck muscles in individuals with whiplash-associated disorders (WAD) versus healthy individuals.

Design: This study included 36 individuals with WAD (26 women and 10 men) and 36 healthy controls (26 women and 10 men). Ultrasound imaging with speckle tracking was used to measure deformation and deformation rate in five dorsal neck muscles during a neck extension task.

Results: Compared to controls, individuals with WAD showed higher deformation of the semispinalis cervicis ($P = 0.02$) and multifidus ($P = 0.002$) muscles and higher deformation rates ($P = 0.03$ and 0.0001 , respectively). Among individuals with WAD, multifidus deformation and deformation rate were significantly associated with pain, disability, and fatigue ($r = 0.31$ – 0.46 , $P = 0.0001$ – 0.01).

Conclusion: These findings indicate that the mechanical responses of the deep dorsal neck muscles differ between individuals with WAD and healthy controls, possibly reflecting that these muscles utilize altered strategies while performing a neck extension task. This finding provides new insight into neck muscle pathology in patients with chronic WAD, and may help to improve rehabilitation programs.

Key Words: Whiplash Injury, Neck Muscle, Cervical Spine, Ultrasonography

INTRODUCTION

Whiplash trauma occurs when rapid acceleration-deceleration of the head and neck causes neck flexion and hyperextension.¹ The annual incidence is 200–300 per 100,000 in the general population, with common causes including car crashes, sport-related trauma, or falling.² Whiplash trauma can lead to whiplash-associated disorders (WAD), potentially including soft tissue, joint, and neuromuscular problems.³ Around 50% of patients with whiplash injury will experience persistent pain and disability. Other clinical symptoms of WAD include headache, dizziness and paresthesia. Patients with WAD may also exhibit fatty infiltration⁴ and altered mechanical response of the dorsal and ventral neck muscles during arm movements.^{3,5,6} Since neck stability strongly depends on proper neck muscle function,⁷ any weakness or change in muscle activity can impair the function of the muscles supporting the cervical spine,⁸ causing sustained pain and disability.

Whiplash-associated disorders symptoms are typically managed with training exercises.⁹ Peterson et al.¹⁰ reported that patients with WAD may benefit from neck-specific exercises, including neck extensor and flexor muscle endurance training.¹⁰ In their study, patients with WAD showed improved dorsal neck muscle endurance (neck extension measured in seconds), although the endurance values remained much lower than reference values obtained in healthy people. In the study by Peterson et al.¹⁰ only clinical measures (endurance time, patients satisfaction) were evaluated and it is not known to what extent different layers of dorsal neck muscles contribute to the performance of a prone endurance task by patients with WAD. Greater knowledge of the dorsal neck muscle changes in WAD is required to understand the pathology contributing to persistent pain and disability. To our knowledge, no prior study has focused on

neck muscle deformation and deformation rates in individuals with WAD during performance of load activities that activate their dorsal neck muscles in the prone position.

The objective of the present study was to investigate, describe, and compare the mechanical responses of dorsal neck muscles while loading the neck via an extension task using speckle tracking ultrasound in individuals with WAD versus healthy individuals. First, dorsal neck muscle deformation (total deformation as well as shortening and elongation components) and deformation rates were measured during a neck muscle extension task (NME) and compared between individuals with WAD and healthy controls. Second, deformation and deformation rates were measured in and compared between each of the five dorsal neck muscle layers (trapezius, splenius capitis, semispinalis capitis, semispinalis cervicis and multifidus). Third, the mechanical responses of the neck muscles were examined with regards to a possible relationship with the patients' perception of neck pain, disability, and fatigue.

MATERIALS AND METHODS

Participants

This case-control study included 36 right-handed adults (26 women and 10 men) who had suffered from right-side-dominant chronic WAD for ≥ 6 months (mean time since injury, 22.8 months; SD, 10.8), as well as 36 age- and sex-matched healthy controls (26 women and 10 men). The patients with WAD were recruited from a population that was already enrolled in a randomized clinical trial (RCT NCT01547624).⁹ The healthy controls were recruited among university and hospital staff, and their families and friends. The two groups showed comparable age, height, weight, and sex distribution ($P > 0.05$) (Table 1).

The inclusion criteria for patients with WAD were persistent signs associated with a whiplash injury that occurred 6 months to 3 years before study enrollment, WAD grade II (neck pain and musculoskeletal signs) or III (neck pain plus neurological signs), neck pain intensity of >20 mm on a visual analog scale (VAS), perceived disability of >20% as measured using the neck disability index (NDI), and aged between 18 and 63 years old. A maximum age of 63 years was chosen to focus the investigation on people of working age. Additional inclusion criteria were right-handedness and right-side-dominant neck pain (or equal-sided neck pain) to eliminate any confounding effects of handedness or side dependency. Exclusion criteria were as follows: patient-reported signs of traumatic head injury at the time of whiplash injury (if the patient was uncertain, their medical records were checked), surgery on the cervical spine, rheumatoid disease, previous neck pain necessitating at least one month of sick leave prior to the whiplash injury, congenital spinal deformities, alcohol or drug abuse, any sign of mental problems, and low back pain that was more severe than the neck pain. Healthy controls were excluded if they reported current or past neck pain, any trauma to their cervical spine or head, or rheumatoid diseases.

All participants were informed about the study aims and procedures, and provided informed written consent prior to participation. The study protocol was conducted according to the Helsinki Declaration, and was approved by the Regional Ethics Board. This study adapts to STROBE guidelines and reports the required information accordingly. (See Supplementary STROBE checklist).

Ultrasound Procedure

Ultrasound imaging was performed using a B-mode (2D) ultrasound Vivid-i scanner (GE Healthcare, Horten, Norway) with a 38-mm, 12-MHz linear array transducer and a frame rate of 235 frames/second. The C4 spinous process was chosen as the level of investigation because it is the center segment of the cervical lordosis, and because less error is associated with ultrasonographic measurement of dorsal neck muscles at this level.¹¹ The C4 spinous process was identified by palpation, marked using an ink pen. Then the transducer was positioned transversely at this level on the spinous process. Next, the examiner tilted the transducer to the right side of the neck until clearly observing the echogenic lamina. During this step the transducer was rotated 90 degrees to the longitudinal position.¹² Imaging was recorded for the five dorsal neck muscles: the upper trapezius, splenius capitis, semispinalis capitis, semispinalis cervicis, and multifidus. All ultrasound imaging was performed at this position while participants performed the NME task.

Speckle Tracking

Custom software was designed to measure the mechanical response of the dorsal neck muscles, using Matlab 2014a (The Math Works, Natick, MA, USA). For each dorsal neck muscle, this software processed the unique speckle pattern formed by the acoustic ultrasound waves that were scattered and reflected upon hitting the muscles.¹³ Five 10-mm lines with rectangular markers at both ends—termed regions of interest (ROIs)—were manually positioned along muscles fibers. One ROI was placed on each dorsal neck muscle (Fig. 1) at the first frame of a video sequence. The recorded video sequence tracked the muscle's mechanical response during its motion while the subject performed the NME task. These ROIs followed and registered longitudinal muscle changes (shortening/elongation) frame by frame throughout the

ultrasound movie sequence. ROI shortening and elongation was interpreted as target muscle shortening and elongation.

Deformation

Deformation (strain) was defined as the relative change in an ROI based on the first frame, and was expressed as % deformation. In this method, a single reference length (here, the ROI length in the first frame) is defined against all following deformation (subsequent frames). This method reportedly shows excellent test-retest reliability, with an ICC of 0.71–0.99.⁵

The software provided graphs of the ROIs longitudinal movements termed deformation curve. The area under the deformation curve was measured as the muscle total deformation (Fig. 2). This area was calculated following the trapezoidal rule as follows:

$$A = \frac{t}{2} (y_1 + 2y_2 + 3y_3 + \cdots \cdots + 2y_{n-2} + 2y_{n-1} + y_n)$$

In this equation, A is the area of the ROI, t is the time between samples, and y_n is the current ROI position at sample point n . The magnitude of each muscle deformation was positively associated with force measurements and progressive electrical stimulation.¹⁴

Deformation Rate

The other measured mechanical response was the deformation rate (also referred to as the strain rate), which was calculated as % deformation per second. The rate was negative during muscle shortening, and positive during elongation. To prevent zeroing due to positive and negative values, deformation rate was reported as the root mean square, which is the square root of mean squares.

Neck Muscle Endurance Task

To perform the NME task, participants were placed in a prone position with their legs straight and their arms resting beside their body. A 2-kg (women) or 4-kg (men) load was applied using a strap wrapped around the participant's head. The examiner monitored and adjusted the test position to ensure that there was no deviation from the desired position. Participants were instructed to extend and raise their head just above the **horizontal examination** table, with no head rotation or lateral bending, such that the tip of the chin pointed towards the floor (Fig. 3).¹⁵ After five seconds, the head was moved back to the starting position, i.e., resting on the examination table. Each participant performed one test trial to become familiar with the test procedure, and then performed the measured task once. Speckle tracking was performed from the start of the NME test until the participant's head was back on the table. A customized trigger switch was placed on the top of the table to enable the examiner to identify when the task started and to check the task period with a stopwatch.

Assessment of Basic Characteristics

A 100-mm visual analog scale was used to assess neck pain intensity before and after the NME task. On this scale, zero indicates no pain at all and 100 indicates the worst imaginable pain.¹⁶ Table 1 presents the pain scores, which are reported as median and interquartile range (IQR).

The neck disability index (NDI) was used to assess the patient's perceived disability.¹⁸ On this index, 0% indicates no disability and 100% indicates severe disability.¹⁷ Perceived disability was assessed 2–3 weeks before the ultrasonographic investigation, while the patient

completed the questionnaire for the large randomized controlled study and was scheduled for ultrasound measurements. NDI scores are reported as mean and standard deviation (SD).

The Borg CR-10 scale was used to rate dorsal neck muscle fatigue before and after ultrasound imaging. On this scale, 0 indicates no fatigue and 10 indicates extreme fatigue.¹⁸ Fatigue scores are reported as median and IQR.

Physical Activity

Participants were asked about their activities of daily life in a typical week, including cycling or walking to work, recreational activities and gardening (household tasks were not included). These answers were scored as 1 for no everyday activity, 2 for low activity (activity at some time during a week), 3 for moderate activity (activity several times per week), and 4 for high activity (almost daily activity).¹⁹ Participants were also asked about their amount of exercise beyond their daily activities. Such sport activities were scored as follows: 1 for no activity, 2 for very little activity, 3 for soft activities (e.g., walking once a week), and 4 for hard activities (e.g., swimming, jogging, or gymnastics at least once a week). The scores from these two questions were combined into one score for further analysis.²⁰ Information regarding physical activity was collected before the NME task.

Statistical Analysis

Data were analyzed using SPSS Statistics for Windows software (Version 20.0; IBM, Armonk, NY, USA). The independent t-test was used for between-group comparisons of age and height data. The Mann-Whitney U test was used to analyze between-group differences in non-normally distributed data, including physical activity, weight, and the indices of perceived

fatigue, pain, and disability. The Wilcoxon test was used for within-group comparisons of fatigue and pain before and after the NME task.

Mixed design analysis of variance (ANOVA) with Bonferroni correction was used to investigate the main effects of the between-subject factor of group (individuals with WAD and controls) and the within-subject factor of muscle (five dorsal neck muscles), as well as the interaction effect of group by muscle with regards to muscle deformation (total deformation, shortening, and elongation) and deformation rate. Task performance times slightly differed among participants; thus, the data were normalized to time to enable comparisons of the deformation of each muscle among participants and between the two groups. For each participant, muscle deformation was divided by task duration and multiplied by the average task duration for all participants. Then the normalized data were transformed to their natural logarithm (Ln) to achieve a normal distribution.²⁰ Ln transformation was also performed to attain a normal distribution for the muscle deformation rate. Spearman's correlation was used to evaluate associations of pain intensity, perceived disability, and fatigue with muscle deformation and deformation rate. The level of significance was set at $P \leq 0.05$.

RESULTS

Two individuals with WAD were excluded from data analyses because they were found outliers while assessing the deformation and deformation rate normality. They were found outliers as their data deviated more than three times the interquartile range. The two participants had higher BMI than the other participants in the study. Therefore, data analysis was performed on 34 individuals with WAD and 36 healthy controls.

Basic Characteristics

Participants suffering from chronic WAD showed a mean pain intensity of 39 (SD, 25.5) and mean NDI of 32 (SD, 14.85). In contrast, the healthy controls reported a mean pain intensity of 1.29 (SD, 1.77) and mean NDI of 0.18 (SD, 0.87). The healthy controls reported that they were highly active, while WAD sufferers were moderately active in their daily lives. Compared to healthy controls, patients with WAD showed significantly higher median fatigue level before the NME task [5.0 (IQR, 3.0) vs. 0 (IQR, 0.5); $P = 0.0001$] and after the NME task [5 (IQR, 3.0) vs. 0 (IQR, 0.5); $P = 0.0001$]. Patients with WAD also showed significantly higher median pain intensity compared to healthy controls both before the NME task [36 (IQR, 40) vs. 0 (IQR, 0) and after the NME task [38 (IQR, 39) vs. 0 (IQR, 0)].

Deformation

There was a significant group $\times$ muscle interaction for deformation ($F = 3.17$ $P = 0.02$), indicating a between-group difference in muscle deformation. The post-hoc group comparison revealed significantly higher deformation of the semispinalis cervicis ($P = 0.02$) and multifidus ($P = 0.002$) muscles in individuals with WAD compared to healthy controls. Moreover, both groups showed significantly higher deformation in the deepest layers (multifidus and semispinalis cervicis muscles) compared to the superficial layers (trapezius and splenius capitis muscles) with P values ranging from 0.0001–0.03 (Fig. 4a). The results also revealed significant main effects of muscle ($F = 28.21$, $P < 0.001$) and group ($F = 6.23$, $P = 0.01$) for deformation. Deformation analyses performed separately for shortening and elongation demonstrated no significant main effect of muscle ($F = 0.96$, $P = 0.43$) or group ($F = 445.42$, $P < 0.0001$) for elongation. However, there was a significant group $\times$ muscle interaction effect ($F = 4.032$, $P =$

0.004), indicating greater muscle elongation in WAD sufferers than in healthy controls. For shortening, there was no significant main effect of muscle ($F = 1.852$, $P = 0.12$) or group ($F = 0.782$, $P = 0.38$), and no group $\times$ muscle interaction effect ($F = 1.898$, $P = 0.11$).

Deformation Rate

The group $\times$ muscle interaction was also significant for the deformation rate ($F = 10.86$, $P < 0.001$), demonstrating significant between-group differences in deformation rates. The post-hoc group comparison showed significantly higher deformation rates in the multifidus ($P < 0.001$) and semispinalis cervicis ($P = 0.03$) muscles among WAD patients compared to healthy controls. Additionally, both groups showed significantly higher deformation rates in the deeper muscles (multifidus and semispinalis cervicis) compared to the superficial ones (trapezius and splenius capitis), with P values ranging from 0.0001–0.002) (Fig. 4b). In table 2 the mean deformation and deformation rates for each muscle in both groups are shown. Deformation rate analysis showed significant main effects of muscle ($F = 181.62$, $P < 0.001$) and group ($F = 7.106$, $P = 0.01$).

Correlation

The deformation and deformation rate of the multifidus muscle showed significant direct positive correlations with neck pain, disability, and fatigue (r ranging from 0.31–0.46, P ranging from <0.001 to 0.01). Additionally, most of the relationships between the deformation and deformation rate of the semispinalis cervicis muscle and neck disability and pain were significant (r ranging from 0.12–0.29, P ranging from 0.01–0.13) (Table 3). No other significant correlations were found for muscles or indices.

DISCUSSION

Comparison of WAD Patients versus Healthy Controls

In the present study, the main finding was that individuals with WAD showed higher deformation and deformation rates of the deep dorsal neck muscles during performance of the NME task compared to healthy controls. Prior findings show altered mechanical responses of these muscles in patients with WAD while performing a series of arm elevations,¹³ but such differences have not previously been reported during neck extensions in a prone position with loading.

Prior reports describe altered interplay between the dorsal and ventral neck muscle layers during repeated arm lifts.^{3,6} This has been interpreted as reflecting lower variability in using neck muscles, and could result in reduced muscular support towards stabilizing the cervical spine in WAD sufferers. Bexander and Hodges reported higher electromyography activities of neck muscles during performance of a balance task, and concluded that these higher activities indicated impaired patterns of sensory feedback and negatively impacted activities of daily life among people with WAD.⁸ Similarly, Peterson et al.⁶ reported a higher deformation rate of deep dorsal neck muscles during 10 arm elevations among WAD sufferers compared to controls, suggesting ineffective muscle function in the WAD group. They concluded that this higher deformation rate reflected less-smooth activation due to less variable interplay of deep dorsal neck muscles in patients with WAD.⁶

The presently observed higher deformation and deformation rates of deep dorsal neck muscles among individuals with WAD might reflect the body's struggle to cope with impaired muscle activity,^{21,22} and could lead to relative overuse followed by fatigue and pain. The deep

dorsal neck muscles, including the multifidus and semispinalis cervicis muscles, are the main stabilizers during neck movements and postural tasks.²³ Therefore, the higher deformation of these muscles in WAD sufferers could be interpreted as protective mechanism of the spinal muscles in this patient population.⁸ Elliot et al.⁴ described fatty infiltration of the cervical multifidus in WAD sufferers, and other studies report morphological changes in the multifidus muscle—specifically, reduced muscle thickness—in patients with chronic neck pain and in WAD sufferers.^{24,25} Thus, the presently observed higher deformation and deformation rates of the deep dorsal neck muscles (including the multifidus and semispinalis cervicis muscles) in WAD sufferers may reflect their responses to altered morphology and function. It could also be interpreted as a protective mechanism in response to altered ventral neck muscles in WAD sufferers.^{5,3} However, it must be noted that deformation may not directly reflect muscle activity, but could be induced by the imposed pressure from neighboring muscles and tissues or even passive muscle elongation.³

The separate analyses of elongation and shortening revealed higher elongation among WAD sufferers compared to healthy controls. This finding may indicate that patients with WAD exhibit eccentric activity of the dorsal neck muscles against increased motion of the lower cervical vertebrae.²⁶ Alternatively, elongation could be induced by passive elongation of neighboring muscles.³ Overall, the present findings support speculation that compensatory eccentric elongation of these muscles occurred in WAD sufferers to protect the cervical structures against the imposed load of NME task. These changes could also result from altered dorsal and ventral muscle interplay in this patient group.^{6,3} Supporting these hypotheses, prior studies have reported decreased head steadiness in individuals with WAD.²⁷

Comparison of Superficial Versus Deep Muscles

Both groups in the present study showed higher deformation and deformation rates in the deep dorsal neck muscles compared to the superficial muscles. Higher activity in the multifidus is consistently reported in healthy individuals.¹⁵ In a magnetic resonance study, Elliot et al.²⁸ described greater T2 shifts in deep dorsal neck muscles compared to in the splenius capitis after a craniocervical extension task. Consistent with the present findings, prior studies have described increased deformation in deep neck muscles compared to superficial neck muscles with regards to flexor muscles during an arm elevation task in both healthy individuals and patients with WAD.⁵ Previous studies have also shown greater fat infiltration in the deep dorsal neck muscles than in superficial muscles among WAD sufferers.⁴ This suggests that the higher deformation and deformation rates of deep muscles compared to superficial ones among WAD sufferers in the current study could reflect morphological changes in the deep dorsal neck muscles of this patient group. Earlier reports describe more notable changes in the activity and morphological alterations of deep dorsal neck muscles compared to superficial muscles.^{29,30}

In contrast, electromyography studies show decreased activation of the semispinalis cervicis in patients with traumatic neck pain.²⁹ These contradictory results could be explained by differences between studies with regards to experimental tasks and evaluation methods (electrical action potential with EMG versus mechanical longitudinal movement with speckle tracking). However, increased coactivation of the semispinalis cervicis was also observed, which may be consistent with the present findings. The increased deformation and deformation rates of deep dorsal neck muscles observed in the current study could result from less-variable interplay of these muscles, potentially reflecting their diminished function in individuals with WAD.⁴

Correlation

Significant weak-to-moderate positive relationships were observed between the multifidus muscle deformation and deformation rate and pain, disability, and fatigue; between the semispinalis cervicis deformation and deformation rate and disability; and between the semispinalis cervicis deformation rate and pain intensity. These correlations may suggest that greater disability, fatigue, and pain tend to be associated with higher deformation and deformation rates in the deep dorsal neck muscles, especially the multifidus muscle. Falla et al.³¹ also reported that pain was positively associated with perceived disability in WAD sufferers. Higher deformation and deformation rates of deep muscles could potentially be a mechanism for the body to cope with disability and fatigue, or even be the cause of disability and fatigue.

Limitations

This study had several limitations. For the NME exercise, we used 2-kg loads for the women and 4-kg loads for the men. Thus, the study design did not consider potential individual differences in the maximal voluntary contraction and fatigability of the dorsal neck muscles, and it is possible that some participants may not have been challenged when they performed the NME task. Moreover, the muscle mechanics might differ between men and women. This could not be investigated in the present study, as there were only 10 men in each group compared to 26 women. Another potential limitation was that even though speckle tracking has been validated for force measurements,^{14,12} the effects of probe pressure and displacement with neck movement cannot be discounted. . Magnetic resonance imaging may provide more accurate images although ultrasound speckle tracking may be preferred as it provides real time images with lower cost and without the exclusion criteria for MRI such as metal in the body or claustrophobia. Additionally, speckle tracking is a 2D imaging modality that measures the longitudinal movements of the target muscles. Rotational movement could not be captured due to its 3D nature. Notably, since

speckle tracking was performed at the C4 vertebral level, the observed results may not be generalizable to other vertebral levels. The other possible limitation is that NDI was questioned 2-3 weeks prior the speckle tracking. Therefore, it might bias the results of correlation analyses as there is some correlation between disability and muscle function. Finally, 11 of the study patients reported neurological signs due to their whiplash injury (WAD III), and this should be considered when interpreting the results.

Despite these limitations, the present investigation was a well-structured and unique study that investigated the deformation and deformation rates of dorsal neck muscles in response to load-bearing tests in individuals with chronic WAD. Such a study has not previously been performed with individuals in a prone position. Moreover, no prior study has examined the different mechanical responses of various dorsal neck muscle layers during performance of this particular exercise. The present findings may increase our understanding of neck muscle function in individuals with chronic WAD, which could improve WAD diagnosis and aid in the development of rehabilitation programs.

Conclusion

The present results showed differences in both deformation and deformation rates of the deep dorsal neck muscles, including the multifidus and semispinalis cervicis, during an NME task in a group of individuals with WAD compared to healthy controls. Specifically, the deep dorsal neck muscles showed higher deformation and deformation rates in the WAD group, likely due to these patient's responses to morphological and functional damage.^{21,22} Moreover, in both participant groups, the degree of deformation and the deformation rates significantly differed between the deep dorsal neck muscles versus the superficial muscles. The results also revealed

that patients with WAD who had greater fatigue, pain, and disability tended to show greater deformation and deformation rates in some deep dorsal neck muscles during an NME task. These findings merit further study and may be relevant to improving WAD rehabilitation and for developing neck-specific exercises for individuals with WAD.

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Figure legends

FIGURE 1. Representative ultrasound image of dorsal neck muscles in an individual with whiplash-associated disorders. From the most superficial to the deepest: trapezius (TP), splenius capitis (SP), semispinalis capitis (Scap), semispinalis cervicis (Scerv), and multifidus (MF).

FIGURE 2. Dorsal neck muscle deformation curves during the neck extension task. Each curve represents the changes in the relative ROI of each dorsal neck muscle. TP, trapezius; SP, splenius capitis; Scap, semispinalis capitis; Scerv, semispinalis cervicis; and MF, multifidus.

FIGURE 3. Neck muscle extension task being performed during ultrasound imaging.

FIGURE 4. Dorsal neck muscle deformation (a) and deformation rate (b) in whiplash-associated disorders (WAD) sufferers and healthy controls during the neck muscle extension task. Ln, logarithm; MF, multifidus; NME, neck muscle extension task; Scap, semispinalis capitis; Scerv, semispinalis cervicis; SP, splenius capitis; TP, trapezius; WAD, whiplash-associated disorders.

1 **Table 1. General characteristics of the participants**

Group	WAD (n=36)	Controls (n=34)	p value
Variable			
Age (years)	37±10.78	37±10.54	0.97
Height (cm)	171±8.19	173±8.60	0.28
Weight (kg)	76±13.09	73±13.96	0.11
NDI (percent)	32±14.85	1.29±1.77	0.0001*
Pain before NME task (mm)	39±25.52	0.18±0.87	0.0001*
Pain after NME task (mm)	38.51±26.21	0.18±0.87	0.0001*
Physical Activity	3.0 (1.0-4.0)	4.0 (2.0-4.0)	0.35
Fatigue	5.0(0.5-52.0)	0.0 (0.0-2.0)	0.0001*

2 Note: Values are mean ± standard deviation

3 *: significant p-value

4 Abbreviations: NDI, neck disability index; WAD, whiplash-associated disorders.

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Table 2. Dorsal neck muscle deformation and deformation rates during a neck muscle endurance task in patients with WAD[†] versus healthy controls

	Deformation (%)			Deformation rate (%/sec)		
	WAD	Healthy	p-value	WAD	Healthy	p-value
Trapezius	0.12±0.09	0.11±0.07	0.97	0.096±0.03	0.089±0.025	0.56
Splenius capitis	0.20±0.18	0.16±0.13	0.69	0.13±0.05	0.12±0.03	0.73
Semispinalis capitis	0.23±0.19	0.20±0.16	0.25	0.18±0.09	0.16±0.04	0.45
Semispinalis cervicis	0.39±0.36	0.24±0.33	0.02	0.36±0.29	0.26±0.20	0.03
Multifidus	0.86±0.86	0.34±0.31	0.002	1.26±1.37	0.67±1.11	0.0001

Note: Values are mean ± standard deviation

*: significant p-value

Abbreviation: WAD, whiplash-associated disorders

Table 3. The association between the muscle mechanical response and neck muscle pain (VAS), disability (NDI), and fatigue (Borg scale)

Patient characteristics		VAS (r, p-value)	NDI (r, p-value)	Borg scale (r, p-value)
Muscle				
Multifidus	Deformation	r=0.31, p=0.01	r=0.40, p=0.001	r=0.33, p=0.005
	Deformation rate	r=0.43, p=0.0001	r=0.46, p=0.0001	r=0.43, p=0.0001
Semispinalis cervicis	Deformation	r=0.18, p=0.13	r=0.29, p=0.01	r=0.12, p=0.31
	Deformation rate	r=0.27, p=0.03	r=0.28, p=0.02	r=0.18, p=0.10

Abbreviations: NDI, neck disability index; VAS, visual analogue scale

*: significant p-value