original article

Isometric muscle fatigue of the paravertebral and upper extremity muscles after whiplash injury

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Ann Saudi Med 2017; 37(4): 297-307

DOI: 10.5144/0256-4947.2017.297

BACKGROUND: Whiplash-associated disorders (WAD) result from injury of neck structures that most often occur during traffic accidents as a result of rapid acceleration-deceleration. The dominant symptoms manifest in the musculoskeletal system and include increased fatigue. Because of the frequency of whiplash injuries, a simple, cheap and useful diagnostic tool is needed to differentiate whiplash injury from healthy patients or those faking symptoms.
OBJECTIVES: To determine muscle fatigue in patients with whiplash injury in six body positions.
DESIGN: Analytical cross-sectional study.
SETTING: Emergency center, university hospital.
PATIENTS AND METHODS: We studied patients with whiplash injury from vehicular traffic accidents who presented to the emergency center within 6 hours of sustaining the injury. We determined whiplash injury grade according to the Quebec Task Force (QTF) classification and measured isometric muscle endurance in six different body positions. Control subjects for each patient were matched by age, gender and anthropomorphic characteristics. Cut-off values were determined to distinguish patients with whiplash injury from controls and for determination of injury grade .
MAIN OUTCOME MEASURE(S): QTF grade, time to muscle fatigue in seconds.
RESULTS: From September 2013 to September 2016, we enrolled 75 patients with whiplash injury and 75 matching control subjects. In all six positions, the patients with whiplash injury felt muscle fatigue faster than equivalent controls ($P<.05$) and the time to onset of muscle fatigue decreased with increasing injury grades in all six positions. Assignment to the patient or control group and to injury grade could be predicted with more than 90% accuracy on the basis of time to muscle fatigue. The most efficient position was the highest injury grade, by which 99.9% of the patients were accurately categorized. Isometric muscle endurance correlated with whiplash injury grade in all six positions ($P<.01$).
CONCLUSION: Under clinical conditions, muscle endurance and the appearance of isometric muscle fatigue during testing can be a useful indicator of whiplash injury and grade.
LIMITATIONS: The size of the sample was small. An objective parameter such as electromyography is needed to confirm isometric muscle fatigue.

Whiplash injury is an injury to the soft and/or bony tissues of the cervical spine and neck structures that most frequently occurs in the course of traffic accidents, usually at low speed.[1] The incidence varies—the frequency is higher in the Scandinavian countries and generally in the countries of the West, as opposed to countries such as Greece and Lithuania.[2] This difference may be related to the practice of compensation for injuries by insurance companies in Western countries.[3-5] In a study conducted in Croatia, which included 1077 persons with a neck injury from the region of Rijeka, 94.8% had whiplash injury, which translates to an incidence of 0.11% to 0.39% injured persons per year.[6] Whiplash injury results from acceleration-deceleration or laterolateral forces that strain and injure neck structures, with the specific injuries dependant on various biomechanical conditions.[1] The most common mechanism of injury is a rear-end vehicle collision involving a stopped car. The driver's body movements in the collision result from the state of inertia before the collision and transmission of force depending on velocity and mass, which in this case refers to a rapid movement with the injury dependant on the amount of absorbed energy.[1,7,8] The point of highest strain is at the C6-C7 dynamic segment of the cervical spine. Normally, the movement of the cervical spine begins in the area of the upper vertebrae.[7-9] Panjabi et al published a frequently cited paper in which they opposed the hypothesis that hyperextension of the cervical spine was the main cause of damage to neck structures during whiplash injuries. During a simulation of a whiplash injury mechanism on cadaveric human spines, they noticed that the cervical spine forms into a non-physiological S-shape which injures the structures in the lower part, while hyperextension occurs later resulting in injury to structures of the upper part of cervical spine.[10]

The symptoms that develop due to whiplash injury are called whiplash-associated disorders (WAD). The most dominant symptoms are those of the musculoskeletal system—pain, unease, cramps and strain.[1] In normal physiological conditions, muscle fatigue develops after long-term and/or strong contraction, which is manifested in weakening and inability to perform further muscle labor as a result of biochemical processes on the level of the muscle cell.[11,12] James and Doe tested neck muscle endurance, measured in seconds, in 19 young and asymptomatic, healthy examinees in the lying position as the head was in flexion. The average time endured was 126.42 seconds, and the test reliability was 0.983. The authors suggested that clinicians perform similar tests on patients with neck pathology as a means to define the range for normal and abnormal results.[13] Patients with whiplash injury had time-to-fatigue of the paravertebral muscles 3-5 times shorter than controls. Subjects are placed into a certain position to measure how much isometric stress they can endure.[14] Standardization of testing varies from the use of highly sophisticated instruments to a subjective assessment by an examiner. The current criteria for evaluating whiplash injuries are mostly derived from a review of the current methodology in studying muscle fatigue with various neck pathologies by de Koning et al in 2008.[15] Few studies have dealt with other muscles and groups of muscles in the context of endurance and fatigue in patients with WAD, and particularly in injuries that do not have a direct anatomic relationship with the head and neck. It seems that soreness in certain muscles of the neck region, particularly in the semispinalis capitis muscle, is what affects the speed of muscle fatigue in patients with whiplash injury; soreness also affects biochemical processes in neuromuscular connections.[16] The aim of this study was to determine isometric muscle fatigue in six positions which induce muscle strain of the neck and upper extremities of patients with whiplash injury, and compare the time to onset with controls. Also, we wanted to investigate how muscle fatigue correlates with the degree of whiplash injury, as muscle fatigue can serve as a diagnostic tool in clinical practice.

PATIENTS AND METHODS

In this analytical cross-sectional study conducted from September 2013 to September 2016, participants were selected by deliberate or purposive sampling, a form of nonprobability sampling from patients with suspected whiplash injury after a traffic accident, who reported to the UHC Mostar Center for Emergency Medicine within 6 hours of sustaining the injury. The test group consisted of patients injured in vehicular traffic accidents who had isolated whiplash injury divided into subgroups (grade 1, 2 or 3) according to the criteria of the Quebec Task Force (QTF).[17] The controls consisted of compatible, healthy subjects, mostly employees of the University Clinical Hospital (UCH) Mostar and students of the University of Mostar, who were matched with individuals in the test group according age, gender, weight, height, BMI and neck circumference. Potential participants were fully informed verbally and in writing that testing might be uncomfortable, but harmless. The study was conducted in accordance with the Helsinki Declaration and principles of quality clinical practice, with approval of the Ethics Committee of UCH Mostar (reference number 767/13, 6 February 2013).

After admission to the emergency department, patients underwent the usual procedures, which included taking a medical history, physical examination and x-ray of the cervical spine in two standard projections. Afterwards, we determined the whiplash injury grade according to the QTF criteria (the study encompassed patients who had whiplash injury of grade 1, 2 or 3, according to QTF, without concomitant injuries). Isometric muscle endurance was then determined in muscles and groups of muscles of the neck and upper extremities, which were examined in the following positions (muscles activated indicated in parentheses):

Position 1: Sitting position with arms in abduction up to 30° retroflexion with outward rotation (supraspinatus muscle, infraspinatus muscle, teres minor muscle, trapezius muscle);

Position 2: Sitting position with arms in adduction, retroflexion and inward rotation (subscapularis muscle, teres major muscle);

Position 3: Sitting position with arms in abduction up to 90° with outward rotation (deltoid muscle, supraspinatus muscle, infraspinatus muscle);

Position 4: Sitting position with arms in abduction up to 120° with outward rotation (deltoid muscle, supraspinatus muscle, infraspinatus muscle, ascending part of trapezius muscle, serratus anterior muscle);

Position 5: Lying position on the back with head in semiflexion up to 30° (longus colli muscle, longus capitis muscle, rectus capitis anterior muscle, sternocleidomastoid muscle);

Position 6: Lying position on the stomach with head in extension up to 20° (trapezius muscle, splenius capitis muscle, longissimus cervicis muscle, longissimus capitis muscle).

The subjects remained in position until the limits of endurance were reached and muscle fatigue appeared, which was determined by head or extremity movement by 5° and a statement by the subject that they could not endure the forced position anymore and felt unable to continue. Time of endurance in the position was measured with a standard stopwatch in seconds. Testing began after setting the subject into one of the forced positions, and ended after the appearance of muscle fatigue. Testing in each subsequent position came after a three-minute break from the previous test.

Statistical analysis

Independent *t* tests were used to analyze time of onset of muscle fatigue with one-way ANOVA for independent samples. After the variance analyses, Tukey post-hoc test was used to determine differences between three groups. To predict grade of injury based on time-to-onset of muscle fatigue, cut-off values were established by receiver operating characteristic (ROC) curve analysis. Analyses were conducted for all six test positions in patients and controls, as well as between subgroups after division into the three grades based on QTF definitions. The ability to distinguish the grade of injury by compromise between sensitivity and specificity was defined by area under the curve (AUC): >0.9- excellent distinction; 0.9-0.8−good distinction; 0.7-0.8−moderate distinction; 0.7-0.6−low distinction. For the binary logistic regression, values less than or equal to cut-off values were coded 1 and more likely represented the patient group, while the values above the cut-off were coded 2 and more likely represented the control group. Binary logistic regression assessed whether classification into the patient or control group. The Spearman rho was used determine correlation of isometric muscle fatigue with grade of whiplash injury according to QTF. A probability of <.05 was taken as statistically significant. SPSS statistical software, version 20.0, was used for all statistical analyses (SSPS Inc., Chicago, IL).

RESULTS

During the study period, we enrolled 75 patients with whiplash injury and 75 matching control subjects. There were more men (n=44, 58.7%) than women (n=31, 41.3%). There were no statistically significant differences in any anthropometric measurement (**Table 1**). Patients developed muscle fatigue earlier than controls (P<.01) (**Table 2**). The time-to-onset of muscle fatigue decreased with increasing injury grades in all six positions (**Table 3**). Muscle fatigue onset developed most rapidly in patients with whiplash injury grade 3 and was slowest in patients with injury grade 1.

Assignment to patient or control group

ROC curves for the six test positions indicated that assignment to the patient or control group could be readily predicted (more than 95% accuracy) on the basis of time to muscle fatigue (**Figure 1**). The most efficient position was position 6, by which 99.9% of the patients were accurately categorized. The optimum cut-off values based on time of isometric muscle fatigue in the test positions were determined for each test position (**Table 4**). In almost all positions there was excellent differentiation between groups with AUC greater than 0.9. The binary logistic regression analysis confirmed the ability to predict injury in patients as indicated by large and statistically significant odds ratios (**Table 5**).

Assignment to injury grade

For all test positions, there was a statistically signifi-

Table 1. Anthropometric measurements.

	Patients (n=75)	Controls (n=75)
Age (years)	34.6 (11.1)	34.1 (11.1)
Height (cm)	178.9 (10.3)	179.5 (9.9)
Weight (kg)	82.0 (19.5)	82.2 (19.5)
BMI (kg/m^2)	25.4 (4.8)	25.2 (4.7)
Neck circumference (cm)	38.3 (4.8)	38.5 (4.9)

Data are mean (standard deviation).

Table 2. Time of onset of isometric muscle fatigue for patients with whiplash injury and controls for each test position.

Test position	Group	Time of onset (s)	df	t statistic
1	Patients	52.9 (44.8)	148	-21.514
	Controls	266.4 (73.3)		
2	Patients	42 (35)	148	-17.473
	Controls	212 (76.6)		
3	Patients	50.6 (42.3)	148	-15.540
	Controls	202 (64)		
4	Patients	45.6 (41)	148	-17.102
	Controls	217 (86.2)		
5	Patients	28.1 (26.4)	148	-14.896
	Controls	121.7 (47.6)		
6	Patients	41.4 (41.1)	148	-24.360
	Controls	309.4 (85.9)		

Time of onset values are mean (standard deviation). Statistical analysis by independent *t* test. $P<.01$ for all comparisons.

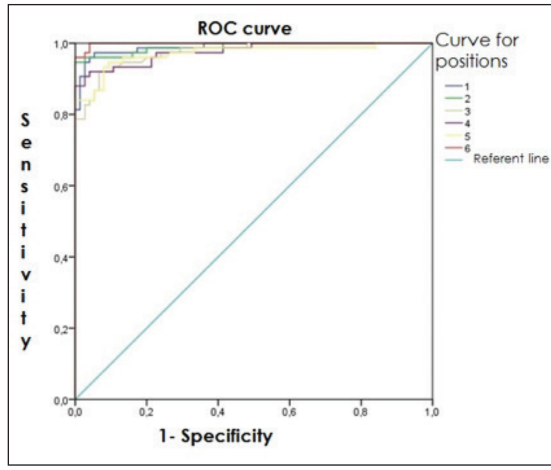

Figure 1. ROC curve for time-to-isometric muscle fatigue onset. 1-6 refers to Position 1 to 6.

cant prediction of assignment to injury grade with an accuracy of more than 90%. The highest accuracy was detected for position 6, in which a total of 97.3% subjects were classified correctly. For position 6, only one control subject was misclassified as a patient out of 150 subjects while three patients were classified as controls (**Table 6**). ROC curves predicted affiliation to the subgroup of patients by injury grade (**Figure 2, Figure 3**). Cut-off values for differentiation QTF grade 1 from QTF grade 2 subgroup showed limited, but significant "accurate" possibilities in classification of patients into subgroups with the best distinction for positions 3, 4, 5, and 6 (**Tables 7 and 8**). The best positions for distinguishing QTF grade 2 from QTF grade 3, were positions 1, 2, 3, 4 and 6 (**Tables 9 and 10**). Correlation was statistically significant (*P*<.01) between the QTF grades of whiplash injury and onset of muscle fatigue in the six positions (**Table 11**).

DISCUSSION

In patients with WAD, isotonic contractions lead to a more rapid muscle fatigue.[18] In our study, isometric muscle fatigue in positions 3 and 4 occurred more rapidly than in controls. In addition, the speed of fatigue was related to whiplash injury grade according to QTF score. No other studies have used our methodology so comparison is difficult, but similar studies have also discovered that patients with WAD have increased muscle tension in the humeroscapular and trapezius muscles. Since no comparable studies exist for these positions, we refer to similar papers which tested the mobility of the shoulder and sternoclavicular joint in the context of WAD, which assumes muscles included in movements as in positions 3 and 4.[19] Helgadottir et al examined the activity of trapezius and serratus anterior muscles by electromyography in patients with WAD during abduction of the arm, which is similar to position 3 in our study. The results showed reduced endurance, which affects the stability of the shoulder blade.[20] It was interesting that in positions 1, 2, 3 and 4 in our study, the majority of the activated muscles did not have a vertex or a starting point in the cervical spine, and yet they showed faster isometric muscle fatigue in patients with whiplash injury. Soreness in those muscles is a well-known phenomenon, which affects mobility in the activated muscles and in the cervical spine. Even in the case when there is no active movement in the neck, soreness in this region is present, due to proven activation of the muscles serving as spine stabilizers.[21] It is believed that

Table 3. Time to onset of isometric muscle fatigue in patients with whiplash injury and controls by injury grade for each test position.

Test position	QTF grade	Patients		Controls	
		Time to onset (s)	F statistic	Time to onset (s)	F statistic
1	1	82.6 (54.4)‡,§	15.895†	271.2 (72.9)	.100
	2	46 (27)‡,‖		264.7 (82)	
	3	23 (16.7)§,‖		262.2 (66)	
2	1	63.1 (39.1)‡,§	11.196†	201.1 (49.6)	.623
	2	35 (23.1)‡,‖		224.7 (87.5)	
	3	23.1 (26.9)§,‖		211.3 (91.8)	
3	1	81.3 (44)‡,§	18.028†	225.7(67.7)§	4.139*
	2	38.1 (24.2)‡,‖		198.6 (52.1)	
	3	25.6 (32.1)§,‖		175.8 (62.8)§	
4	1	79.2 (44.8)‡,§	27.603†	243.8 (97.7)	2.450
	2	34 (24.8)‡,‖		208.5 (77)	
	3	15.9 (9.8)§,‖		192.6 (73.9)	
5	1	47.4 (28.9)‡,§	19.433†	130 (47.2)	.686
	2	21.5 (20.5)‡,‖		115.9 (51.2)	
	3	10.9 (5.9)§,‖		117.7 (44.5)	
6	1	71.7 (38.4)‡,§	22.129†	337.5 (94.4)	2.616
	2	34.7 (38.8)‡,‖		298.4 (72.5)	
	3	10.6 (6.1)§,‖		286.1 (82.4)	

Statistical analysis by ANOVA with Tukey post hoc test results. Degrees of freedom for patients: between groups 2 and within groups 74 ; for controls: between groups 2 and within groups 73

Tukey post hoc test: *<.05; †<.01; ‡<.05 between QTF1 and QTF2; §<.05 between QTF1 and QTF3; ‖<.05 between QTF2 and QTF3 (QTF: Quebec Task Force)

latent and active points of soreness in not only muscles of the neck, but also in others, such as the trapezius muscle, can be a source of altered muscle activity in patients with a whiplash injury.[22] As for testing position 5, muscle fatigue in patients appeared also more rapidly in comparison with controls. A statistically significant difference was shown in rapidity of fatigue considering injury grade according to QTF and in comparison with controls. In a study similar to ours, Kumbhare et al, tested fatigue of the neck flexor as we did, in 71 patients with whiplash injury grade 2 according to QTF, and compared them with controls from a local sports club, who were of similar age and gender. This simple test discriminated patients with whiplash injury, with different tests used to measure the effects of whiplash injury. The average time of isometric muscle fatigue onset was similar to our patients with whiplash injury grade 3. Values in control subjects were also similar to ours. The results indicated large individual variability among examinees, as in our study. Results differed because

Table 4. Area under the receiver operating characteristic curve for isometric muscle fatigue onset in patients and controls for each test position.

Test position	Area under the curve	Standard error	*P*	Reliability interval (95%)		Cut-off value (s)	Sensitivity	1-Specificity
				Lower limit	Upper limit			
1	0.989	0.006	<.001	0.977	1.000	115	0.907	0.013
2	0.989	0.007	<.001	0.976	1.000	111.25	0.960	0.027
3	0.974	0.010	<.001	0.954	0.994	114	0.920	0.067
4	0.977	0.011	<.001	0.956	0.997	119.3	0.933	0.107
5	0.971	0.013	<.001	0.945	0.997	65.3	0.933	0.093
6	0.999	0.001	<.001	0.996	1.000	156.8	0.987	0.040

Table 5. Prediction of assignment to patient or control group by binary logistic regression for each test position.

Test position	B	SE	Wald	*P*	OR (95% CI)
1	6.578	1.082	36.945	<.001	718.8 (86.2-5994.8)
2	6.775	0.928	53.321	<.001	876 (142.1-5398.8)
3	4.913	0.610	64.903	<.001	136 (41.2-449.4)
4	4.764	0.595	64.082	<.001	117.3 (36.5-376.5)
5	4.913	0.610	64.903	<.001	136 (41.2-449.4)
6	7.482	1.167	41.141	<.001	1776 (180.5-17473.3)

they had stricter criteria for the onset of muscle fatigue, and controls were well-trained young athletes.[23] Woodhouse et al also detected faster muscle fatigue in patients with WAD in comparison with patients who had chronic pains in the neck of other etiology, as well as in controls when endurance under large and small stresses was tested. Subjects were placed in a position similar to position 5 in our study. With the head in semiflexion up to 40 seconds under increasing stress, only 70% subjects with WAD succeeded, unlike almost all subjects with chronic neck pain of other etiology or controls. Their patients with chronic WAD had QTF grades 1 and 2 injuries, so results can be compared to ours to a certain degree, bearing in mind that the subjects in their study were under stress and had chronic difficulties.[24] In our study, the largest difference in testing isometric muscle fatigue between the patients and controls was obtained in testing position 6, where patients developed isometric muscle fatigue faster, depending on QTF grade. It seems that this test is the best one for detecting whiplash injury.

In other studies, results were less similar to ours. Edmondston et al[25] tested the fatigue in neck muscles in extension, in a way similar to our method, with different results that identified a cut-off value, which differentiates the patients from the controls with 97.3% accuracy, which would mean that their results are somewhat similar to the results obtained in our study for QTF grade 1 group, even though fatigue appeared much more rapidly in patients. A pilot study from 2011 studied the endurance of neck muscles in 148 patients with chronic neck pain, mostly caused by whiplash injury.[26] The patients were exposed to tests in various positions and from additional manual stress by the examiner. One of the set positions was similar to position 6 in our study. They reported that 32.4% patients with neck pain had a certain level of weakness, unlike 2% of controls. They estimated the specificity of this test at 93.7% for patients and 70% for controls. Similarly, we found a high specificity of 97.3% for position 6. Limitations of our study were the small sample, especially in subgroups. Another limitation was the lack of objective parameters to assess the onset of muscle fatigue such as electromyography.[27]

Muscle fatigue in whiplash patients affects many aspects of their life, aggravating common activities such as driving a car, which requires mental effort to compensate.[28] There is no doubt that whiplash injury

Table 6. Prediction of assignment to patient or control group on the basis of dichotomous values for time to isometric muscle fatigue for each test position by binary logistic regression.

Assignment		Nagelkerk R square (%)	Predicted assignment		Correct predictions (%)
			Patients n (%)	Controls n (%)	
Position 1	Patients		68 (90.6)	7 (9.3)	90.7
	Controls		1 (1.3)	74 (98.6)	98.7
Total		**89.9**			**94.7**
Position 2	Patients		72 (96)	3 (4)	96
	Controls		2 (2.6)	73 (97.3)	97.3
Total		**88.7**			**96.7**
Position 3	Patients		68 (90.6)	7 (9.3)	90.7
	Controls		5 (6.6)	70 (93.3)	93.3
Total		**75.2**			**92**
Position 4	Patients		70 (93.3)	5 (6.6)	93.3
	Controls		8 (10.5)	67 (90.5)	89.3
Total		**73.4**			**91.3**
Position 5	Patients		70 (93.3)	5 (6.6)	93.3
	Controls		7 (9.3)	68 (90.6)	90.7
Total		**75.2**			**92**
Position 6	Patients		74 (98.6)	1 (1.3)	98.7
	Controls		3 (4)	72 (96)	96
Total		**91.0**			**97.3**

Bolded values are the average for correct predictions.

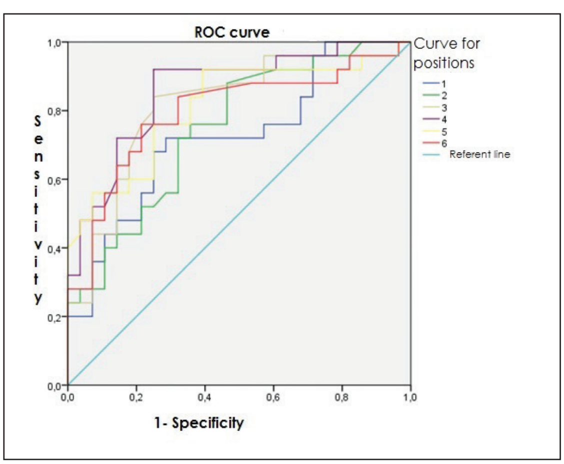

Figure 2. ROC curve for time-to-isometric muscle fatigue onset in patients with QTF1 and QTF2 grade whiplash injury.

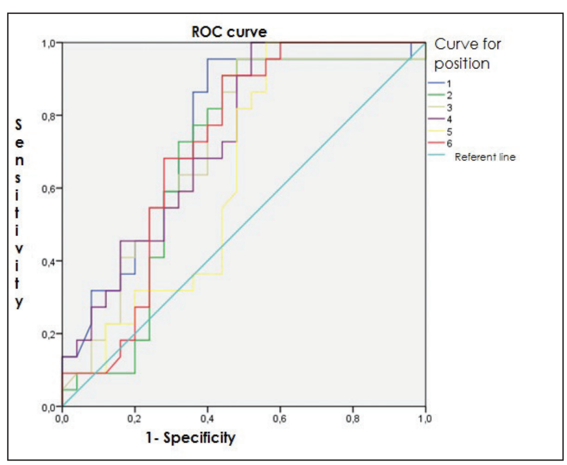

Figure 3. ROC curve for time-to-isometric muscle fatigue onset in patients with QTF2 and QTF3 grade whiplash injury.

Table 7. Area under the ROC curve for isometric muscle fatigue onset in patients with QTF grade 1 and QTF grade 2 injury for each test position.

Test position	Area under curve	Std. error	*P*	Reliability interval (95%)		Cut-off value(s)	Sensitivity	1-Specificity
				Lower limit	Upper limit			
1	0.723	0.071	.005	0.584	0.861	59	0.720	0.286
2	0.747	0.067	.002	0.616	0.878	44	0.720	0.321
3	0.821	0.058	.000	0.707	0.935	59.5	0.840	0.250
4	0.859	0.052	.000	0.758	0.960	57.8	0.880	0.250
5	0.812	0.061	.000	0.692	0.932	30.3	0.760	0.286
6	0.796	0.065	.000	0.669	0.922	45.1	0.760	0.214

Table 8. Predictions of assignment to QTF grade 1 or QTF grade 2 based on dichotomous values for isometric muscle fatigue onset for each test position by binary logistic regression.

Assignment		Nagelkerk R square (%)	Predicted assignment		Correct predictions (%)
			QTF2	QTF3	
Position 1	QTF1		20	8	71.4
	QTF2		7	18	72
Total		**23.6**			**71.7**
Position 2	QTF1		19	9	67.9
	QTF2		7	18	72
Total		**20.1**			**69.8**
Position 3	QTF1		21	7	75
	QTF2		4	21	84
Total		**41.7**			**79.2**
Position 4	QTF1		21	7	75
	QTF2		2	23	92
Total		**53.5**			**83**
Position 5	QTF1		20	8	71.4
	QTF2		6	19	76
Total		**27.8**			**73.6**
Position 6	QTF1		21	7	75
	QTF2		6	19	76
Total		**31.8**			**75.5**

Bolded values are the average for correct predictions.

Table 9. Area under the ROC curve for isometric muscle fatigue onset in patients with QTF grade 2 and QTF grade 3 injury for each test position.

Test position	Area under curve	Std. error	*P*	Reliability interval (95%)		Cut-off value (s)	Sensitivity	1-Specificity
				Lower limit	Upper limit			
1	0.753	0.073	.003	0.610	0.896	34.3	0.955	0.400
2	0.689	0.082	.027	0.528	0.850	27.3	0.818	0.400
3	0.714	0.077	.012	0.563	0.865	30.7	0.773	0.400
4	0.736	0.072	.006	0.595	0.878	19.6	0.682	0.400
5	0.639	0.083	.103	0.476	0.803	14.7	0.818	0.480
6	0.717	0.077	.011	0.566	0.869	12.8	0.682	0.280

Table 10. Predictions of assignment to QTF grade 2 or QTF grade 3 based on dichotomous values for isometric muscle fatigue onset for each test position by binary logistic regression.

Assignment		Nagelkerk R square (%)	Predicted assignment		Correct predictions (%)
			QTF2	QTF3	
Position 1	QTF2		15	10	60
	QTF3		1	21	95.5
Total		**43.4**			**76.6**
Position 2	QTF2		15	10	60
	QTF3		4	18	81.8
Total		**23.1**			**70.2**
Position 3	QTF2		15	10	60
	QTF3		5	17	77.3
Total		**18.2**			**68.1**
Position 4	QTF2		14	11	56
	QTF3		7	15	68.2
Total		**7.7**			**61.7**
Position 5	QTF2		12	12	50
	QTF3		4	18	81.8
Total		**16.1**			**65.2**
Position 6	QTF2		18	7	72
	QTF3		7	15	68.2
Total		**20.4**			**70.2**

Bolded values are the average for correct predictions.

Table 11. Correlation between grade of whiplash injury and onset of muscle fatigue for each test position.

Test position	Position 1	Position 2	Position 3	Position 4	Position 5	Position 6
Spearman coefficient for all QTF grades	-.623*	-.578*	-.656*	-.739*	-.653*	-.685*

*P<.01 for all correlations

is often pathological, but factitious disorder or simulation for manipulative purposes is common.[5,6] This can make the work of doctors more difficult as they deal with many patients who attempt to submit fraudulent insurance claims.[6] Modification of insurance policies in response to this issue have resulted in changes in the incidence of whiplash injury.[5] Because of the frequency of whiplash injuries, a simple, cheap and useful diagnostic tool is needed, which can differentiate whiplash injury patients from the healthy. Under clinical conditions, muscle endurance and the appearance of isometric muscle fatigue during testing can be a useful indicator of whiplash injury and grade.

Conflict of interest

The authors report no conflicts of interest.

REFERENCES

1. Pavic R. Literature review of whiplash injuries of the cervical spine. Lijec Vjesn 2011;133(9-10):327-9. URI: http://hrcak.srce.hr/171851
2. Obelieniene D, Schrader H, Bovim G, Miseviciene I, Sand T. Pain after whiplash: a prospective controlled inception cohort study. J Neurol Neurosurg Psychiatry. 1999 Mar;66(3):279-83. PubMed PMID: 10084524; PubMed Central PMCID: PMC1736255.
3. Styrke J, Stlnacke BM, Bylund PO, Sojka P, Bjornstig U. A 10-year incidence of acute whiplash injuries after road traffic crashes in a defined population in northern Sweden. PM&R 2012;4(10):739-47. doi:10.1016/j.pmrj.2012.05.010. Epub 2012 Jul 21.
4. Quinlan KP, Annest JL, Myers B, Ryan G, Hill H. Neck strains and sprains among motor vehicle occupants-United States, 2000. Accid Anal Prev 2004;36(1):21-7.
5. Binder A. The diagnosis and treatment of nonspecific neck pain and whiplash. Eura Medicophys 2007;43(1):79-89.
6. Girotto D, Ledi? D, Strenja-Lini? I, Peharec S, Grubesi? A. Clinical and medicolegal characteristics of neck injuries. Coll Antropol 2011;35(Suppl 2):187-90.
7. Erbulut DU. Biomechanics of neck injuries resulting from rear-end vehicle collisions. Turk Neurosurg 2014;24(4):466-70. doi:10.5137/1019-5149.JTN.9218-13.1.
8. Crowe HE. Injuries to the Cervical Spine. Paper Presented at the Meeting of the Western Orthopedic Association. San Francisco 1928.
9. Bogduk N, Yoganandan N. Biomechanics of the cervical spine Part 3: minor injuries. Clin Biomech (Bristol, Avon) 2001;16(4):267-75.
10. Panjabi MM, Cholewicki J, Nibu K, Grauer JN, Babat LB, Dvorak J. Mechanism of whiplash injury. Clin Biomech (Bristol, Avon) 1998;13(4-5):239-249.
11. Lindstedt SL. Skeletal Muscle Tissue in Movement and Health: Positives and Negatives. J Exp Biol 2016;219(Pt 2):183-8. doi:10.1242/jeb.124297.
12. Ortenblad N, Westerblad H, Nielsen J. Muscle glycogen stores and fatigue. J Physiol 2013;591(18):4405-13. doi:10.1113/jphysiol.2013.251629. Epub 2013 May 7.
13. James G, Doe T. The craniocervical flexion test: intra-tester reliability in asymptomatic subjects. Physiother Res Int 2010;15(3):144-9. doi:10.1002/pri.456.
14. Peolsson A, Ludvigsson ML, Wibault J, Dedering , Peterson G. Function in Patients with Cervical Radiculopathy or Chronic Whiplash-Associated Disorders Compared with Healthy Volunteers. J Manipulative Physiol Ther 2014;37(4):211-8. doi:10.1016/j.jmpt.2014.01.003. Epub 2014 Apr 18.
15. de Koning CH, van den Heuvel SP, Staal JB, Smits-Engelsman BC, Hendriks EJ. Clinimetric evaluation of methods to measure muscle functioning in patients with non-specific neck pain: a systematic review. BMC Musculoskelet Disord 2008;9:142. doi:10.1186/1471-2474-9-142.
16. Ettlin T, Schuster C, Stoffel R, Brderlin A, Kischka U. A distinct pattern of myofascial findings in patients after whiplash injury. Arch Phys Med Rehabil 2008;89(7):1290-3. doi:10.1016/j.apmr.2007.11.041. Epub 2008 Jun 13.
17. Scientific approach to the assessment and management of activity-related spinal disorders. A monograph for clinicians. Report of the Quebec Task Force on Spinal Disorders. Spine (Phila Pa 1976). 1987 Sep;12(7 Suppl):S1-59. Review. PubMed PMID: 2961086.
18. Elert J, Kendall SA, Larsson B, Mnsson B, Gerdle B. Chronic Pain and Difficulty in Relaxing Postural Muscles in Patients with Fibromyalgia and Chronic Whiplash Associated Disorders. J Rheumatol 2001;28(6):1361-8.
19. Helgadottir H, Kristjansson E, Mottram S, Karduna AR, Jonsson H Jr. Altered Scapular Orientation during Arm Elevation in Patients with Insidious Onset Neck Pain and Whiplash-Associated Disorder. J Orthop Sports Phys Ther 2010;40(12):784-91. doi:10.2519/jospt.2010.3405. Epub 2010 Oct 22.
20. Helgadottir H, Kristjansson E, Einarsson E, Karduna A, Jonsson H Jr. Altered activity of the serratus anterior during unilateral arm elevation in patients with cervical disorders. J Electromyogr Kinesiol 2011;21(6):947-53. doi:10.1016/j.jelekin.2011.07.007. Epub 2011 Sep 1.
21. Rahnama L, Rezasoltani A, Zavieh MK, NooriKochi F, Baghban AA. Differences in cervical multifidus muscle thickness during isometric contraction of Shoulder Muscles: a comparison between patients with chronic neck pain and healthy controls. J Manipulative Physiol Ther 2015;38(3):210-7. doi:10.1016/j.jmpt.2014.11.008. Epub 2015 Mar 11.
22. Fernandez-Prez AM, Villaverde-Gutirrez C, Mora-Snchez A, Alonso-Blanco C, Sterling M, Fernndez-de-Las-Peas C. Muscle Trigger Points, Pressure Pain Threshold, and Cervical Range of Motion in Patients with High Level of Disability related to Acute Whiplash Injury. J Orthop Sports Phys Ther 2012;42(7):634-41. doi:10.2519/jospt.2012.4117. Epub 2012 Jun 7.
23. Kumbhare DA, Balsor B, Parkinson WL, Harding Bsckin P, Bedard M, Papaioannou A, et al. Measurement of Cervical Flexor Endurance following Whiplash. Disabil Rehabil 2005;27(14):801-7.
24. Woodhouse A, Liljebck P, Vasseljen O. Reduced Head Steadiness in Whiplash Compared with Non-Traumatic Neck Pain. J Rehabil Med 2010;42(1):35-41. doi:10.2340/16501977-0484
25. Edmondston S, Bjornsdttir G, Plsson T, Solgrd H, Ussing K, Allison G. Endurance and fatigue characteristics of the neck flexor and extensor muscles during isometric tests in patients with postural neck pain. Man Ther 2011;16(4):332-8. doi:10.1016/j.math.2010.12.005. Epub 2011 Jan 20.
26. Cuthbert SC, Rosner AL, McDowall D. Association of Manual Muscle Tests and Mechanical Neck Pain: Results from a Prospective Pilot Study. J Body Mov Ther 2011;15(2):192-200. doi:10.1016/j.jbmt.2010.11.001. Epub 2010 Dec 15.
27. Stapley PJ, Beretta MV, Dalla Toffola E, Schieppati M. Neck muscle fatigue and postural control in patients with whiplash injury. Clin Neurophysiol 2006 Mar;117(3):610-22. Epub 2006 Jan 19.
28. Takasaki H, Treleaven J, Johnston V, Van den Hoorn W, Rakotonirainy A, Jull G. A description of neck motor performance, neck pain, fatigue, and mental effort while driving in a sample with chronic whiplash-associated disorders. Am J Phys Med Rehabil 2014 Aug;93(8):665-74.