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Clinical Research Article

Effect of pain on cranio-cervico-mandibular function and postural stability in people with temporomandibular joint disorders

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ABSTRACT

Background: Neck and jaw pain is common and is associated with jaw functional limitations, postural stability, muscular endurance, and proprioception. This study aimed to investigate the effect of jaw and neck pain on cranio-cervico-mandibular functions and postural stability in patients with temporomandibular joint disorders (TMJDs).
Methods: Fifty-two patients with TMJDs were included and assessed using Fonseca's Questionnaire and the Helkimo Clinical Dysfunction Index. An isometric strength test was performed for the TMJ depressor and cervical muscles. The TMJ position sense (TMJPS) test and cervical joint position error test (CJPET) were employed for proprioception. Total sway degree was obtained for the assessment of postural stability. Deep neck flexor endurance (DNFE) was assessed using the craniocervical flexion test. The mandibular function impairment questionnaire (MFIQ) was employed to assess mandibular function, and the craniovertebral angle (CVA) was measured for forward head posture.
Results: Jaw and neck pain negatively affected CVA (R^2 = 0.130), TMJPS (R^2 = 0.286), DNFE (R^2 = 0.355), TMJ depressor (R^2 = 0.145), cervical flexor (R^2 = 0.144), and extensor (R^2 = 0.148) muscle strength. Jaw and neck pain also positively affected CJPET for flexion (R^2 = 0.116) and extension (R^2 = 0.146), as well as total sway degree (R^2 = 0.128) and MFIQ (R^2 = 0.230).
Conclusions: Patients with painful TMJDs, could have impaired muscle strength and proprioception of the TMJ and cervical region. The jaw and neck pain could also affect postural stability, and the endurance of deep neck flexors as well as mandibular functions in TMJDs.

Keywords: Jaw; Muscle Strength; Neck; Pain; Posture; Proprioception; Temporomandibular Joint Disorders.

INTRODUCTION

Pain and dysfunction related to musculoskeletal disorders are common and constitute a significant public health problem [1]. Temporomandibular joint disorders (TMJDs) or craniomandibular dysfunctions refer to a

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group of nonspecific related disorders of the muscles of mastication and the temporomandibular joint (TMJ) structures related to the teeth and associated structures that encompass the head and neck region [2]. Neck pain is one of the most common musculoskeletal disorders, with an age-standardized prevalence rate of 27.0 per 1,000 population in 2019 [3]. TMJDs are also an important public health problem affecting approximately 5% to 12% of the overall population. Considering the jaw pain may have a high impact on patients' lives, the importance of knowledge is not only about the prevalence of TMJ pain in the general population but also about its relationship with biopsychosocial variables [4]. In one study, 83% of people with TMJDs reported one comorbid pain condition and 59% reported at least two pain conditions [5]. In another study, it was stated that the most frequently reported accompanying painful conditions in people with TMJDs were headache, neck pain, and back pain [6]. While there were studies showing that jaw and, neck pain were associated with jaw functional limitations, postural stability, muscular endurance and strength [7,8], there were also opposing studies which showed that these variables were not associated [9,10].

The relationship between jaw pain and the cervical region (muscles, joints, *etc*.) is complex and interconnected. Since there are more mechanoreceptors in the cervical region than in the thoracic and lumbar regions, this is important in terms of proprioceptive input. In particular, the special mechanoreceptors in the atlanto-occipital joint and in the corresponding muscles controlling this joint are critical for proprioceptive sensation. Indeed, experimental studies have verified the existence of neurological circuits enabling the link between proprioceptive and nociceptive afferences from C1–C4 to the trigeminal nucleus. These studies also highlight the close functional relationship between the cervical spine and the masticatory system in activities such as swallowing, chewing, and head movement [11]. Based on the results of these experimental studies, TMJDs may alter the neuromuscular control of the cranio-cervico-mandibular (CCM) system, leading to the formation of abnormal afferent information that negatively affects muscles in the cervical region and mandibular positions [12,13].

Jaw and neck pain often involves increased muscle tension and causes muscle imbalances. These muscle imbalances can lead to postural changes [14]. Maintaining a poor head position for a long time due to excessive use of computers and smartphones in offices and homes leads to changes in the length of the anterior and posterior neck muscles and to musculoskeletal dysfunction due to constant loading on the cervical spine [15]. This condition may reversely cause jaw, neck and shoulder pain and may also indirectly affect joint position sense and postural stability [16]. Functional jaw movements involve the simultaneous mandibular and head-neck movements, which occur by activating the jaw and neck muscles in tandem. Studies suggest that painful TMJDs can modulate postural control mechanisms through the jaw sensorimotor system [17,18]. Consequently, individuals with TMJDs may have altered joint position sense in the craniomandibular and craniocervical regions. However, in a recent meta-analysis, five of the included studies have controversial results. Of the five studies, three concluded that there was not any relationship between TMJD and TMJ position sense. In their study, Dahlström et al. [19] measured a group of patients with craniomandibular disorders of arthrogenic or myogenic origin, however, they have found no difference between the experimental and normal groups for the joint position perception of the TMJ. The other study from the abovementioned meta-analysis concluded that mandibular movement accuracy can not be a predictor of the degree of TMJ dysfunction [20]. Another study by van den Berghe et al. [21] also concluded that oral proprioception was not affected in patients with TMJ disorders; hyperactivity of the oral muscles was not caused by erroneous proprioceptive information arising from muscle and joint proprioceptors.

Although specific associations between TMJ pain and muscle strength and proprioception have not been elucidated, there is some indirect evidence which suggests that the maximal voluntary contraction in painful muscles is decreased because of increased activity of the antagonistic muscle, which is likely to serve as a protection for the painful muscle [8]. From a biomechanical standpoint, it has also been suggested that the masticatory muscles are closely related to the cervical muscles as a synergist or antagonist, and serve as extensors or flexors of the cervical spine [11].

As there is significant interest in exploring the connection between the TMJ and the cervical spine, establishing a deeper understanding of this relationship could pave the way for further clinical strategies targeting both areas. Consequently, it emphasizes the importance of a comprehensive approach in managing patients experiencing alterations in the stomatognathic system, particularly those with TMJD. To delve into this connection, this study aimed to find out whether jaw and neck pain affect muscle strength, muscular endurance, postural stability, mandibular functions, the TMJ, and the cervical joints' proprioception in individuals with TMJDs. The authors' hypothesis posits that increased jaw and neck pain in individuals with TMJD would correspond to deteriorated muscle strength and endurance, postural stability and proprioception.

MATERIALS AND METHODS

1. Study design and subjects

This study was performed as part of a larger project in accordance with the Declaration of Helsinki. All participants were informed about the study, and written informed consent was obtained. The study was approved by the Eastern Mediterranean University Scientific Research and Publication Ethics Committee (Number: 2022-0232; Date: 25.10.2022). The clinical trial registration number is "NCT05966103".

Patients were selected from a group of individuals recruited for a larger project, who applied to the Cyprus International University physiotherapy department. Since the prevalence of TMJD was found to be higher in the younger population [22], the authors have selected the participants ages between 18 to 45 who met the inclusion criteria. Individuals with a sedentary lifestyle, a Fonseca questionnaire score of 20–100 and a Helkimo clinical dysfunction index score of 1–25 were included in the study. Individuals with serious musculoskeletal problems of the cervical and thoracic spine, chronic disease, neurological disease affecting balance and postural control, dental and jaw problems, and dental prosthesis were excluded.

2. Sample size

The sample size was calculated with the G*Power program (version 3.1.9.2). When the power analysis was performed, the number of participants to be included in the study was calculated as 42 when the type I error (alpha value) was 0.05, the power (1-β error) was 0.8, and the estimated effect size (Cohen's d) was 0.5. However, a total of 52 participants have been included to reduce bias and increase the accuracy of the findings.

3. Data collection and outcome measures

The participants' age, weight, height, body mass index (BMI), history, physical activity levels, dominant chewing sides, presence of chronic disease and parafunctional habits were recorded.

1) TMJDs

The Fonseca Questionnaire and Helkimo Clinical Dysfunction Index, which were reported to be valid and reliable for the presence of TMJD, were used [23,24]. The validity and reliability study of the Turkish version of the Fonseca questionnaire was performed by Kaynak et al. [25], and the intraclass correlation coefficient (ICC) values were found to be 0.73–0.89. The Fonseca questionnaire consists of 10 questions about joints, head and neck pain, pain during masticatory activity, parafunctional habits, decreased joint movement, impaired occlusion, and emotional stress. The Helkimo clinical dysfunction index is used to detect the presence of clinical findings such as limitation of jaw movements, dysfunction of the TMJ, pain with palpation of the masticatory muscles and the TMJ, and pain with lower jaw movements. The dysfunction index score ranges from 0 (no symptoms) to 25 (severe symptoms). It has been stated that the Helkimo clinical dysfunction index has a sensitivity of 86.67% and a specificity of 68.09% for TMJD prediction [23].

2) Pain assessment

The visual analog scale (VAS) was used for assessment of pain intensity that was created by performing manual palpation with a pressure of approximately 1.0 kgf and 0.5 kgf on the TMJ and on the nape and suprascapular region, respectively. Then the patient indicated the perceived pain intensity on the VAS. The VAS has demonstrated reliability and validity for the measurement of pain intensity [26].

3) Forward head posture (FHP)

Craniovertebral angle (CVA) measurement was used in the evaluation of FHP. To determine the CVA, the lateral photographing method was used by placing markers on the ear tragus and the spinous process of the seventh cervical vertebra (C7). The digital camera recorded the CVA at a distance of 200 cm from the participant, with the height of the camera at the level of the acromion. The camera was fixed on a tripod. This technique shows high reliability (ICC = 0.94). Individuals with a CVA less than 50° as an indicator of FHP were included in the study [27].

4) Temporomandibular joint position sense (TMJPS)

For the TMJPS measurement, a 6 mm-thick wooden reference stick and 9 wooden test sticks from 4 mm to 8 mm

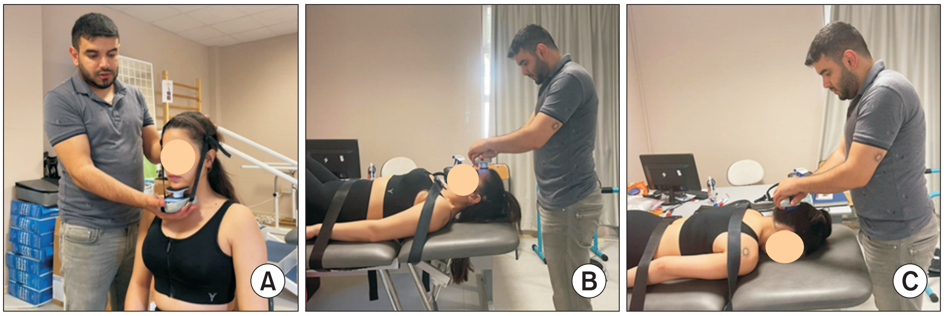

Fig. 1. Assessment of isometric muscle strength. (A) Temporomandibular joint depressors. (B) Cervical flexors. (C) Cervical extensors.

in thickness (increment 0.5 mm) were used. First, the participants were asked to sense the position by biting the 6 mm thick reference test stick with their front teeth for 1 minute. Then, they were asked to randomly bite each of the 9 test sticks and compare each of them with the 6 mm reference test stick. Each of the test sticks was administered in a random order 5 times (45 tests in total). The participants were asked how thick they felt compared to the reference stick that they had bitten down on and indicated their answers as "thinner", "thicker" or "equal" [28,29]. During the test, the participant's eyes were closed, and the answers given about the stick thicknesses were recorded as true (1 point) or false (0 points).

5) Cervical joint position error test (CJPET)

CJPET measurements were performed with an AOS PropPoint® device with a laser apparatus. A validity and reliability study of the AOS PropPoint® device was performed by Köseoğlu et al. [30], and according to the results obtained, it was found that the device is a valid and reliable method for the measurement of cervical proprioception. A 180° platform drawn with 1° intervals was used with the help of a small laser fixed to the head apparatus. Participants were seated in a chair with back support, and the laser starting point was adjusted. For cervical flexion and extension movements, 30° angles were determined as the target point, and the patients were passively taught to find these positions by moving their neck. Afterward, they were asked to actively find these positions with their eyes closed. The error rate between the final position of the laser and the target position was recorded in degrees for flexion and extension movements [31].

6) Assessment of isometric muscle strength

The isometric muscle strength test was performed on the TMJ depressor and cervical region muscles. A digital dynamometer (Model-01165; Lafayette Instruments®) was used for measurements. A measurement method based on the literature was used for isometric muscle strength of the TMJ depressor muscles. Participants were asked to sit in a 90-degree upright position on a chair with a backrest. To prevent compensation during the test, a chin-supported head apparatus was used (**Fig. 1A**). The part of the digital dynamometer compatible with the chin area was placed under the chin of the individual. In this position, the participants were asked to open their mouth strongly against the resistance without disturbing the neutral position of the head [32].

Isometric strength measurement of the cervical flexor and extensor muscles (**Fig. 1B, C**) was performed as it was explained elsewhere [33].

7) Postural stability

The PROKIN-PK200W* (Tecnobody) device was used for postural stability assessment. The Prokin device has a mobile circular platform, which detects angular movements thanks to the chip on the platform and transfers the information from the platform to the computer. Four different parts can be placed under the mobile platform: easy, medium, hard, and rectangular. Changes in stability can be tracked on a computer [34]. For assessment, 2 measurements were made during 30 seconds of standing on both legs with the easy mode of the device, and the average values were recorded. Total sway degree (the number of total degrees reached during the test) data was obtained.

8) Deep neck flexor endurance (DNFE) test

A muscular endurance measurement of deep neck flexors was performed using a stabilizer device (Chattanooga Group Inc.). The measurement was made in the supine position with the head in a neutral position and both knees flexed. The pressure cell was placed under the occipital bone and inflated to 20 mmHg to support cervical lordosis. To minimize the activities of the jaw muscles, the participants were asked to place their tongue on the palate and connect their lips but keep their teeth slightly apart. Afterward, the participants were asked to press their chin to their neck without raising their head and to apply a force above 20 mmHg at 5 different pressure levels (22, 24, 26, 28, 30 mmHg). At each level, the application was made to provide 10 contractions of 10 seconds each. The tests of participants who could sustain 10 contractions for 10 seconds were continued, but the tests of participants who could not sustain 10 contractions for 10 seconds were terminated. A rest period of 10 seconds was given between repetitions. At the end of the test, the "Activation Score" and "Performance Index" values were calculated, and the cumulative performance index was recorded in mmHg. **Table 1** shows how this was calculated [35].

9) Mandibular function impairment questionnaire (MFIQ)

The MFIQ was developed to assess the level of impairment in jaw function in patients with TMJD. This questionnaire consists of 17 questions and two dimensions that score 0–4 points for difficulty in a particular jaw function ranging from 0 (no difficulty) to 4 (severe difficulty or impossible without help). The first 11 items constitute the "functional capacity" dimension, and the next six items form the "nutrition" dimension. A high total score obtained from the questionnaire indicates a high level of impairment in jaw function. The validity and reliability of this questionnaire were determined by Yıldız et al. [36], and it was stated that it is a valid and reliable measurement tool in terms of determining the severity of TMJ-related dysfunctions (ICCs > 0.90).

Table 1. Calculation of cumulative performance index

Pressure (mmHg)	Performance index (activation score = repetitions)	Range of possible scores at this level	Added score[a]
20			
22	2 × (1–10) repetitions	0–20	0
24	4 × (1–10) repetitions	24–60	20
26	6 × (1–10) repetitions	66–120	60
28	8 × (1–10) repetitions	128–200	120
30	10 × (1–10) repetitions	210–300	200

[a]The added score is equivalent to 10 repetitions of the levels below that of the current activation score. The total score therefore includes all attempts at all activation scores achieved.

4. Statistical analysis

IBM Statistical Package for Social Sciences (SPSS) 26.0 software was used for statistical analysis of the data obtained from the individuals included in the study. The normal distribution of the variables was analyzed with the Kolmogorov–Smirnov test. The Pearson test was used for correlation analysis of normally distributed data, and the Spearman test was used for nonnormally distributed data. The correlation coefficients were classified as negligible (0–0.10), weak (0.10–0.39), moderate (0.40–0.69), strong (0.70–0.89), and very strong (0.90–1.00). "Multiple linear regression analysis" was used to determine the effects of independent variables on dependent variables. The results were assessed at a 95% confidence interval, and $P < 0.05$ was considered to indicate statistical significance.

RESULTS

This study was carried out to investigate the relationship between jaw and neck pain and CVA, TMJPS, CJPET for flexion-extension movements, TMJ depressor, cervical flexor and extensor muscles strength, total sway degree, DNFE, and MFIQ in participants with TMJD. A total of 52 participants who met the inclusion criteria among 176 screened individuals were included in the study (**Fig. 2**). The prevalence was found to be 29.54%, which was in line with an earlier study [22].

The age, height, weight, BMI, physical activity levels, jaw and neck pain, and Fonseca and Helkimo scores of the participants are shown in **Table 2**. The median age was 22 years. While the average jaw pain was 2.7 ± 1.3, the average neck pain was 3.7 ± 1.7 cm according to the VAS.

The distribution of the sex, dominant chewing side, parafunctional habits, and TMJD classifications according to Fonseca and Helkimo scores are presented in **Table 3**. The study population included 29 females (55.8%) and 23 males (44.2%). The dominant chewing side of 44 participants was right, and 8 participants were left. The prevalence of TMJD diagnosis, according to the Fonseca Anamnestic Index, was 57.7%, while, according to the Helkimo Clinical Dysfunction Index, it was 57.8%, with moderate as the most frequently seen grade (**Table 3**).

The results of CVA, TMJPS, CJPET for flexion and extension movements, postural stability, TMJ depressor, cervical flexor and extensor muscles isometric strength, DNFE, and MFIQ measurements are shown in **Table 4**.

There was a negative and weak correlation between

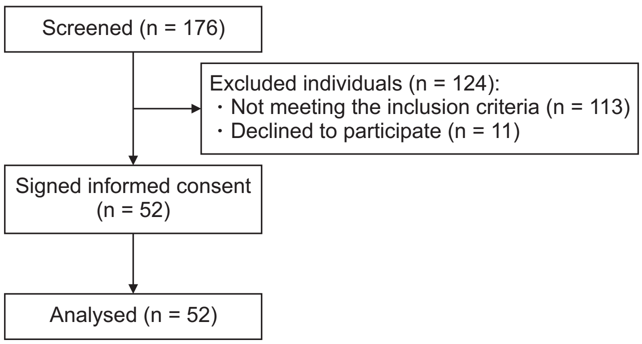

Fig. 2. Flow chart of the participants included in the study.

Table 2. Participants' age, anthropometric characteristics, IPAQ, and TMJD scores

Variable	n	Mean ± SD	Median (Min–Max)
Average age (yr)	52	22.6 ± 2.5	22.0 (19.0–31.0)
Height (m)	52	1.7 ± 0.1	1.7 (1.5–1.9)
Body weight (kg)	52	68.7 ± 12.6	68.0 (50.0–98.0)
BMI (kg/m^2)	52	23.0 ± 3.0	22.9 (18.6–29.4)
IPAQ	52	386.7 ± 124.9	405.5 (99.0–598.0)
Jaw pain-VAS (cm)	52	2.7 ± 1.3	2.4 (0.9–7.0)
Neck pain-VAS (cm)	52	3.7 ± 1.7	3.6 (0.6–8.8)
Fonseca score	52	47.2 ± 15.0	45.0 (20.0–85.0)
Helkimo score	52	5.6 ± 2.6	5.0 (2.0–13.0)

TMJD: temporomandibular joint disorder, IPAQ: international physical activity questionnaire, BMI: body mass index, VAS: visual analogue scale, SD: standard deviation.

Table 3. Sex, dominant chewing side, parafunctional habits, and TMJD classification distributions of the participants

Variable	n	%
Sex		
Female	29	55.8
Male	23	44.2
Dominant chewing side		
Right	44	84.6
Left	8	15.4
Parafunctional habits		
None	3	5.8
Bruxism	11	21.1
Lip biting	4	7.7
Nail biting	2	3.8
2 habits	25	48.1
3 habits	7	13.5
Fonseca category		
Mild TMJD (20–40)	16	30.8
Moderate TMJD (45–65)	30	57.7
Severe TMJD (70–100)	6	11.5
Helkimo category		
Mild TMJD (1–4)	18	34.6
Moderate TMJD (5–9)	30	57.8
Severe TMJD (10–25)	4	7.6

TMJD: temporomandibular joint disorder.

CVA and jaw (r = –0.319, P = 0.021) and neck pain (r = –0.338, P = 0.014). There was a negative and moderate correlation between TMJPS and jaw (r = –0.500, P < 0.001) and neck pain (r = –0.472, P < 0.001). There were positive and weak correlations between CJPET for flexion and jaw (r = 0.309, P = 0.026) and neck pain (r = 0.312, P = 0.024); CJPET for extension and jaw (r = 0.347, P = 0.012) and neck pain (r = 0.350, P = 0.011). There was also positive and weak correlation between total sway degree and jaw (r = 0.339, P = 0.014) and neck pain (r = 0.310, P = 0.025) (**Table 5**).

A moderate negative correlation was found between jaw pain and TMJ depressor muscle strength (rho = –0.406, P = 0.004). There was a negative and weak correlation between jaw pain and cervical flexor muscle strength (rho = –0.309, P = 0.026) and a negative and moderate correlation with cervical extensor muscle strength (rho = –0.414, P = 0.002). There was a negative moderate correlation between jaw pain and DNFE results (rho = –0.548, P < 0.001) and a positive moderate correlation with MFIQ results (r = 0.467, P < 0.001) (**Table 6**).

There were negative and weak correlations between neck pain and TMJ depressors (rho = –0.380, P = 0.005), cervical flexors (rho = –0.387, P = 0.005) and cervical extensors (rho = –0.380, P = 0.005) muscle strength. There was a negative moderate correlation between neck pain and DNFE results (r = –0.538, P < 0.001) and a positive weak correlation with MFIQ results (r = 0.388, P = 0.004) (**Table 6**).

The results of multiple linear regression analysis performed to investigate the effects of jaw and neck pain separately and together on CVA and TMJPS variables are shown in **Fig. 3**.

Jaw pain had an explanatory effect of 9.5% (R^2 = 0.095), and neck pain had an explanatory effect of 9.7% (R^2 =

Table 4. Results of CVA, TMJPS, CJPET, postural stability, TMJ depressor, cervical flexor and extensor muscles' isometric strength, DNFE and MFIQ measurements

Variable	n	Mean ± SD	Median (Min–Max)
CVA (°)	52	45.8 ± 1.9	45.6 (41.1–49.5)
TMJPS (number of correct answers)	52	32.9 ± 3.6	32.0 (24.0–38.0)
CJPET for flexion (°)	52	5.2 ± 1.6	5.2 (2.0–8.5)
CJPET for extension (°)	52	5.4 ± 2.0	5.0 (1.5–12.5)
TMJ depressors muscle strength (kg)	52	7.9 ± 1.8	7.5 (4.3–14.0)
Cervical flexors muscle strength (kg)	52	5.7 ± 1.6	5.5 (3.6–10.4)
Cervical extensors muscle strength (kg)	52	8.3 ± 1.9	8.3 (4.0–12.9)
Total sway degree (°)	52	302.8 ± 59.0	295.5 (171.2–448.7)
DNFE (cumulative PI/mmHg)	52	129.5 ± 56.9	136.0 (32.0–260.0)
MFIQ total score	52	12.6 ± 5.5	12.5 (3.0–27.0)

CVA: craniovertebral angle, TMJPS: temporomandibular joint position sense, CJPET: cervical joint position error test, TMJ: temporomandibular joint, DNFE: deep neck flexor endurance, MFIQ: mandibular function impairment questionnaire, SD: standard deviation, PI: performance index.

Table 5. Correlations between pain and results of CVA, TMJPS, CJPET and postural stability measurements

Variable		CVA (°)	TMJPS (correct answers)	CJPET for flexion (°)	CJPET for extension (°)	Total sway degree (°)
Jaw pain	Correlation	−0.319[a]	−0.500[a]	0.309[a]	0.347[a]	0.339[a]
	P value	0.021*	< 0.001*	0.026*	0.012*	0.014*
Neck pain	Correlation	−0.338[a]	−0.472[a]	0.312[a]	0.350[a]	0.310[a]
	P value	0.014*	< 0.001*	0.024*	0.011*	0.025*

CVA: craniovertebral angle, TMJPS: temporomandibular joint position sense, CJPET: cervical joint position error test.
**P* < 0.05. [a]Pearson r.

Table 6. Correlations between pain and results of TMJ depressor, cervical flexor and extensor muscles' isometric strength, DNFE and MFIQ measurements

Variable		TMJ depressor muscle strength (kg)	Cervical flexor muscle strength (kg)	Cervical extensor muscle strength (kg)	DNFE (mmHg)	MFIQ
Jaw pain	Correlation	−0.406[b]	−0.309[b]	−0.414[b]	−0.548[a]	0.467[a]
	P value	0.004*	0.026*	0.002*	< 0.001*	< 0.001*
Neck pain	Correlation	−0.380[b]	−0.387[b]	−0.380[b]	−0.538[a]	0.388[a]
	P value	0.005*	0.005*	0.005*	< 0.001*	0.004*

TMJ: temporomandibular joint, DNFE: deep neck flexors endurance, MFIQ: mandibular function impairment questionnaire.
**P* < 0.05. [a]Pearson r. [b]Spearman's rho.

0.097) on CJPET for flexion (**Fig. 4**). Jaw pain had an explanatory effect of 12.1% (R^2 = 0.121), and neck pain had an explanatory effect of 12.2% (R^2 = 0.122) on CJPET for extension. On the other hand, jaw and neck pain together explained 11.6% (R^2 = 0.116) of the variance in CJPET for flexion and 14.6% (R^2 = 0.146) of the variance in CJPET for extension (**Fig. 4**).

Jaw pain had an explanatory effect of 13.7% (R^2 = 0.137) on TMJ depressors, 8.6% (R^2 = 0.086) on cervical flexors and 9.6% (R^2 = 0.096) on cervical extensor muscle strength variance (**Fig. 5**). Similarly, neck pain had an explanatory effect of 9.7% (R^2 = 0.097) on TMJ depressors, 14% (R^2 = 0.140) on cervical flexors and 14.1% (R^2 = 0.141) on cervical extensor muscle strength variance. Jaw and neck pain together explained 14.5% (R^2 = 0.145) of the variance in TMJ depressors, 14.4% (R^2 = 0.144) of the variance in cervical flexors and 14.8% (R^2 = 0.148) of the variance in cervical extensors (**Fig. 5**).

Jaw pain had an explanatory effect of 11.5% (R^2 = 0.115) on total sway degree, 30% (R^2 = 0.300) on DNFE and 21.8%

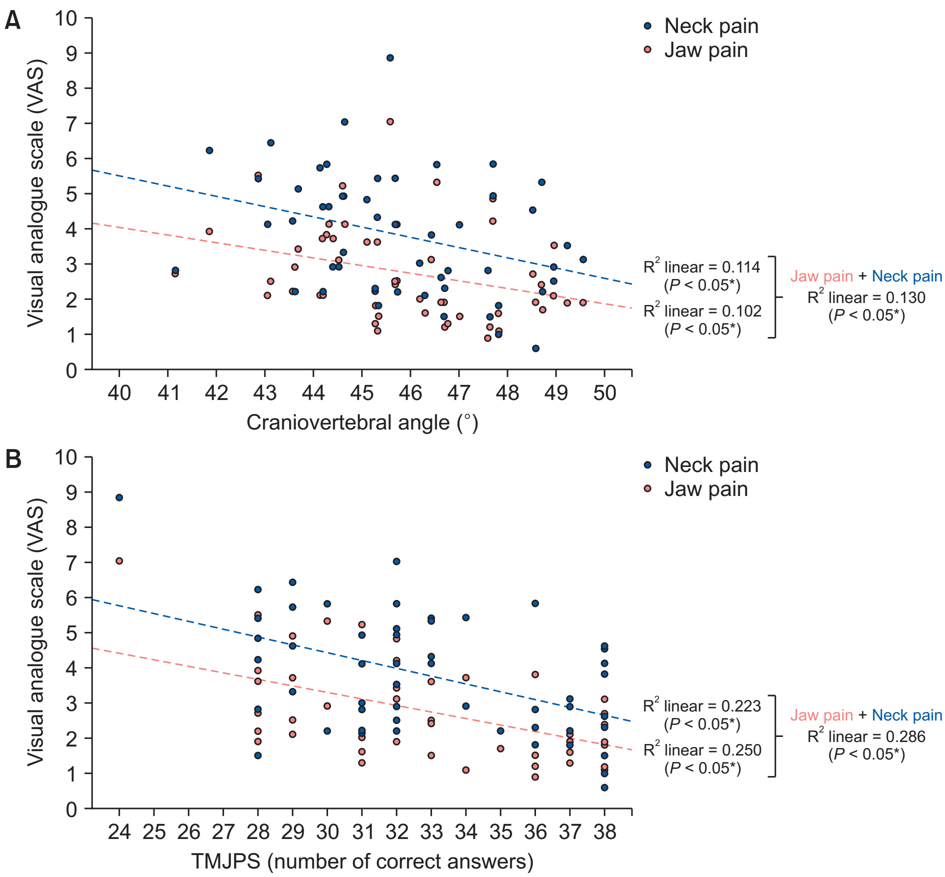

Fig. 3. Linear regression analysis results between pain and CVA (A) and TMJPS (B). CVA: craniovertebral angle, TMJPS: temporomandibular joint position sense.

(R^2 = 0.218) on MFIQ measurement variance (**Fig. 6**). It was also found that neck pain had an explanatory effect of 9.6% (R^2 = 0.096) on total sway degree, 28.9% (R^2 = 0.289) on DNFE and 15.1% (R^2 = 0.151) on MFIQ measurement variance. However, jaw and neck pain together had an explanatory effect of 12.8% (R^2 = 0.128) on total sway degree, 35.5% (R^2 = 0.355) on DNFE and 23% (R^2 = 0.230) on MFIQ measurement variance (**Fig. 6**).

DISCUSSION

The results of the study showed that jaw and neck pain in patients with TMJDs reduces TMJ depressor, cervical flexor strength and endurance, as well as extensor muscle strength; increases total body sway, and negatively affects mandibular functions, the TMJ, and cervical joint position sense.

The Fonseca Questionnaire and Helkimo Clinical Dysfunction Index were used to determine and classify the severity of TMJD [23,24]. It was found that 57% of the patients ages 18 to 45 years diagnosed with TMJD had cases of moderate severity, therefore mild and severe cases were included (**Table 3**) in the analysis.

Anatomic, physiologic, biomechanical, and clinical connections have been established between the craniomandibular and cranio-cervical region. Understanding the relationships between pain in different parts of the body and the CCM system is important for planning a faster and more effective treatment for patients at the initial stage [37]. TMJDs refer to a group of conditions involving the CCM system divided into those affecting the surrounding muscles and TMJ, and cervical region [38]. In individuals with TMJDs, changing the position of the mandible, may lead to a change in the position of the cervical region, and may cause painful conditions. These problems may result in muscular imbalance, deteriorated strength and endurance and reduced range of motion in the TMJ and cervical region. Additionally, the early occurrence of degenerative changes in muscle, ligament, bone structure, and neural elements may also cause the above-mentioned conditions [39]. Superficial muscles such as the trapezius and sternocleidomastoid are expected to take over postural control with excessive loading due to the decrease in the activation of the suprahyoid muscles and masticator muscles, and weakening of the deep neck

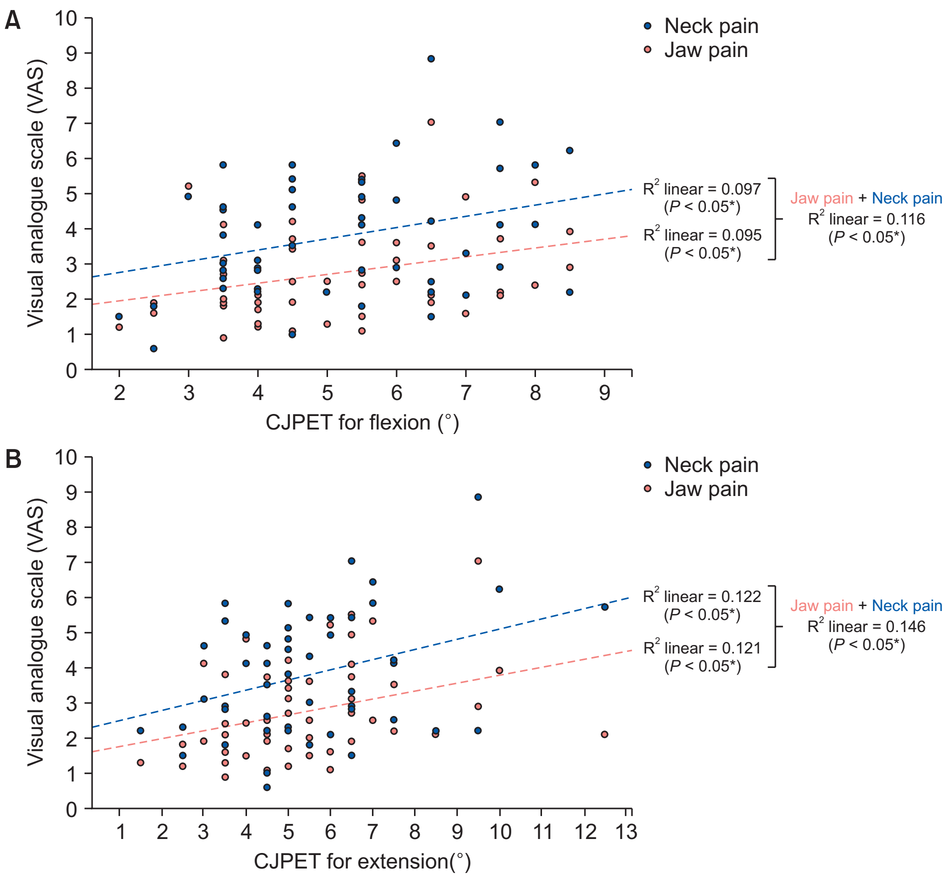

Fig. 4. Linear regression analysis results between pain and CJPET for flexion (A) and CJPET for extension (B). CJPET: cervical joint position error test.

flexors [27]. Indeed, studies have shown that there is a decrease in muscle strength and muscular endurance, as well as mandibular dysfunction and compromised postural control in TMJDs, which may be linked to pain-related reflex inhibition [40, 41]. The results of the present study are in line with the previous studies showed that the strength of the TMJ depressor, as well as the cervical flexor and extensor muscles and the endurance of the deep neck flexors decreased in patients with severe jaw and neck pain. Mandibular functions were also found to be poor in patients with excessive pain.

TMJDs constitute a significant public health problem and are the leading cause of chronic headaches and jaw and neck pain, which can greatly interfere with daily activities [42]. Earlier studies point out the importance of planning treatments according to the biopsychosocial model with a holistic approach, which suggests that disease symptoms are generally not isolated and any problem in one part of the body may affect other areas [37,43]. Individuals experiencing jaw and neck pain may adopt altered postures and head and mandibular positions in an attempt to relieve discomfort. These changes in head position can disrupt the optimal alignment of the body, and negatively impact proprioceptive inputs and postural stability [14,16,17]. Hence, proprioception and postural stability are likely to be affected due to abnormal somatosensory inputs, dysfunction of receptors and impaired sensorimotor control in patients with neck and jaw pain [44]. Indeed, a moderately significant negative correlation between TMJPS, and jaw and neck pain was found (**Table 5**). This result may be explained by the existence of the neurological circuit that enables the link between proprioceptive and nociceptive pathways from the upper cervical region to the trigeminal nucleus [11]. This mechanism may also modify the neuromuscular control in the CCM system and negatively affect the muscles in the cervical region, resulting in impaired postural stability. Previous studies have also concluded that neck and jaw pain cause impairments in dynamic postural stability [39,45]. In a study, it was stated that a symmetrical mandibular position leads to a more symmetrical contraction pattern in the sternocleidomastoid muscle and reduces postural sways [46], while another study emphasized that there were greater changes in the center of pressure that resulted in larger postural sway in patients with painful TMJDs [47]. The results of this study were similar to

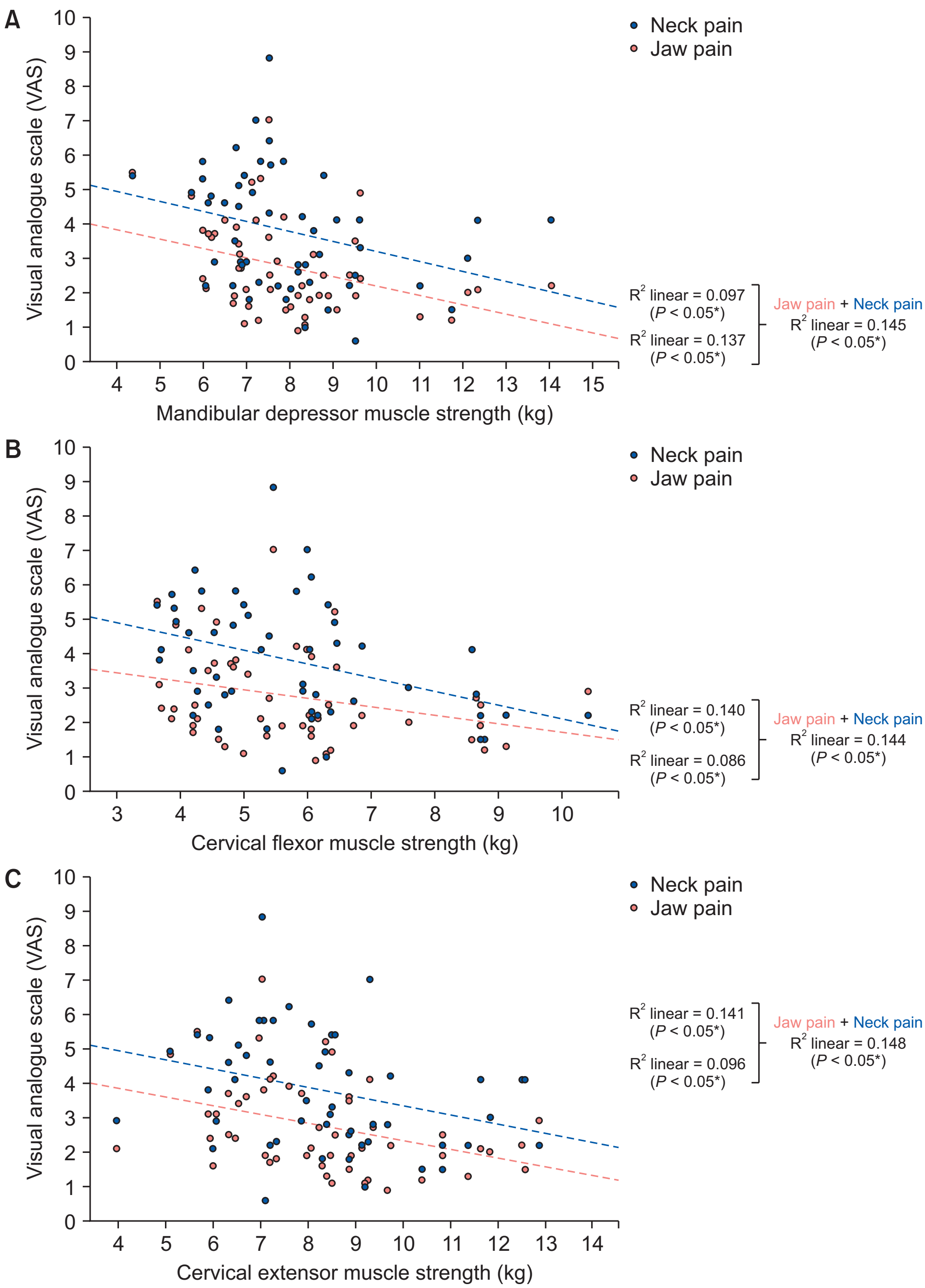

Fig. 5. Linear regression analysis results between pain and temporomandibular joint depressor (A), cervical flexor (B) and cervical extensor (C) muscles strength.

those of earlier studies and showed reduced TMJPS and a higher cervical joint position error rate and total sway in individuals with TMJDs. Despite to moderate and negative correlation that has been shown, explanatory effects of jaw and neck pain on total sway degree, DNFE, MFIQ, and CJPET were found to be lower than expected. The relatively low intensity of pain measured using the VAS in the current study and the subjective nature of the pain could be the major explanation for this outcome. This is also in line with a meta-analysis that was unable to confirm whether joint position sense was associated with jaw and neck pain [7]. The effect of the pain on muscle endurance could also not be confirmed in the scope of the current result. The association between proprioception and muscle strength in the TMJ and cervical region has not been investigated in earlier studies and was not analysed in the current study. However, it has been agreed that if a false posture is erroneously perceived to be correct, it probably will result in irrelevant motor responses and alter muscle activity [48]. This condition may reversely

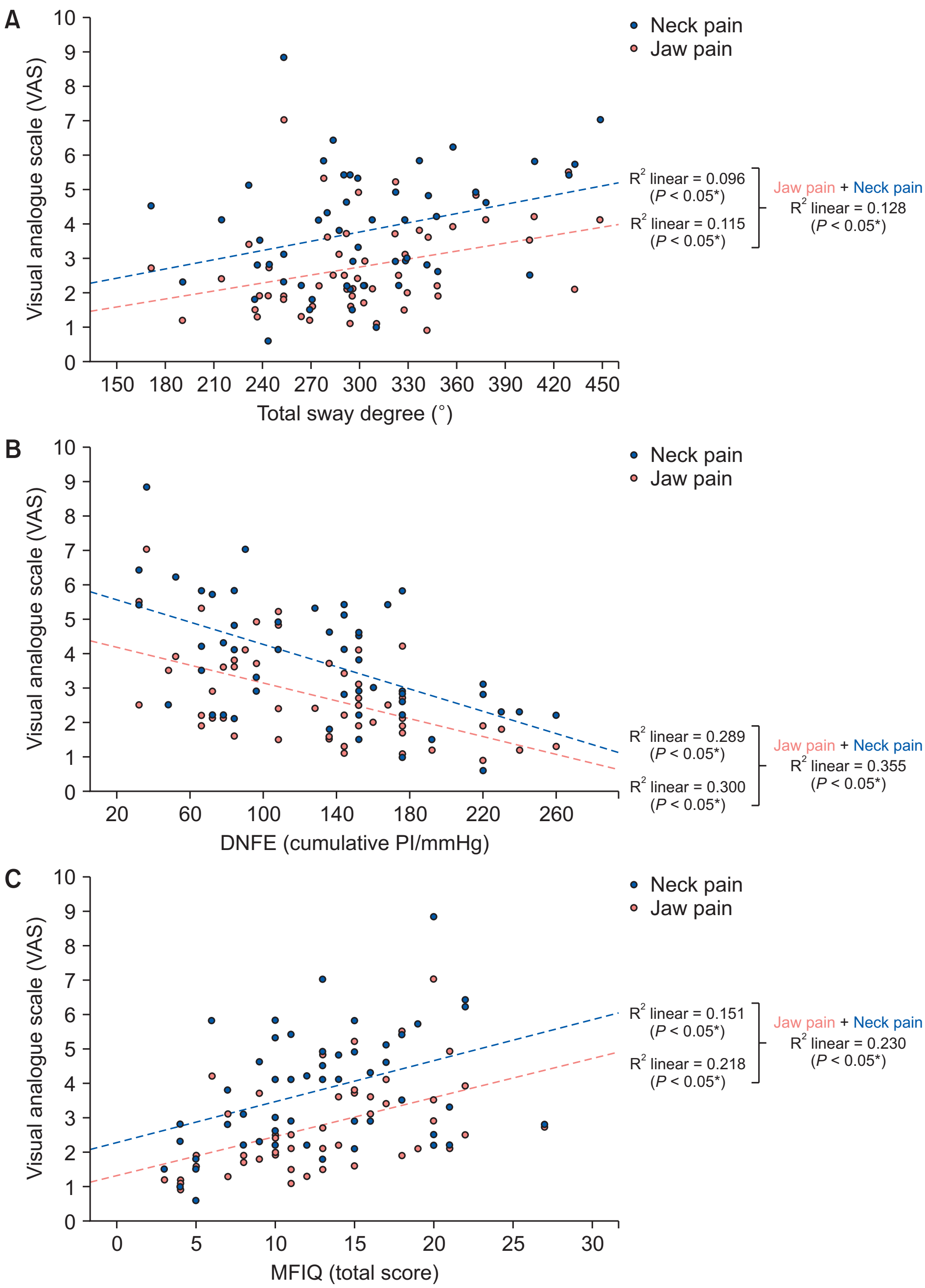

Fig. 6. Linear regression analysis results between pain and total sway degree (A), DNFE (B) and MFIQ (C). DNFE: deep neck flexor endurance, MFIQ: mandibular function impairment questionnaire.

cause jaw, neck and shoulder pain and may also further deteriorate joint position sense and postural stability. Although the biomechanical and neuroanatomic relationship between the cervical spine and the CCM system has been verified in clinical and experimental studies [49,50], the link between the dysfunctions affecting these systems remains in dispute and further studies could be warranted. From a clinical point of view, however, overall postural stability, and the proprioception and muscle function of neighbouring segments could also be included in the treatment intervention when the surrogate effect of the TMJD is concerned.

This study has some limitations. A healthy control group might be added to the authors' study for comparison. Additionally, a comparison with a group with painless TMJDs might highlight whether the effects were caused by pain. Although no particular differences between the types of TMJD have been found [22], the authors did not classify the different types of TMJDs such as myogenic, disc displacement, and arthrogenic, which must be counted as a limitation. The generalisability of the result could be limited due to the relatively smaller sample size with a particular age range.

It has been concluded that TMJDs with jaw and neck pain seem to negatively affect muscle strength and proprioception of the TMJ and cervical region, postural stability, endurance of deep neck flexors and mandibular functions. Considering the strong connections between the TMJ and the neck region, evaluating not only jaw pain but also neck pain in patients with TMJDs is clinically important in terms of improving proprioception and postural stability. Hence, an efficient treatment program may be planned and implemented within the frame of this holistic approach.

DATA AVAILABILITY

Data files are available from Harvard Dataverse: https://doi.org/10.7910/DVN/AUSMDA.

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CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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AUTHOR CONTRIBUTIONS

MM, IY, and SA participated in the conception and design of the study. MM was responsible for data acquisition. MM, IY, and SA analysed and interpreted the data. MM drafted the manuscript and IY, MM, and SA critically revised the manuscript for important intellectual content. All authors approved the final version of the manuscript.

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