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Investigation of Flexion-Relaxation Ratio Symmetry in Subjects with and without Non-Specific Chronic Neck Pain

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ABSTRACT

Introduction: Neuromuscular imbalance between right and left sides of Cervical Erector Spinae (CES) muscles can induce pain by applying the asymmetric loads on the spine incorrectly. This study evaluated the symmetry of the right and left cervical flexion-relaxation ratio (FRR) in patients with Non-Specific Chronic Neck Pain (NSCNP) and healthy subjects. We aimed to investigate the symmetry of FRR on the right and left sides of the CES muscles in individuals with and without NSCNP.

Materials and Methods: A total of 25 patients with NSCNP and 25 healthy subjects participated in this study. The surface electromyography activity of CES muscles during four phases of flexion and extension tasks were measured and recorded. Unilateral FRR in the right and left sides of CES muscles was calculated and compared in each group.

Results: Only in NSCNP patients, FRR in the right CES muscle was significantly higher than that in the left one ($P<0.05$). Also, FRR for bilateral CES muscles was significantly higher in healthy subjects than in NSCNP patients ($P<0.001$).

Conclusion: The study results indicated a greater FRR asymmetry in CES muscles in NSCNP patients than in healthy subjects. This asymmetry is probably due to the dominance of the limb. Moreover, asymmetric FRR as a kind of neuromuscular imbalance may cause pain due to imposing asymmetric loads on spine structures.

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1. Introduction

Chronic Neck Pain (CNP) is a common problem that affects adults and imposes high economic costs on society; even some patients lose their jobs because of CNP [1, 2]. Every year, $34 billion is spent in Australia to treat Non-Specific Chronic Neck Pain (NSCNP) directly and indirectly [3]. It is estimated that 67% of adults experience neck pain at least once in their lifetime, of whom 15% to 20% of cases become chronic [4]. The chronic phase means that the pain lasts for three months or more [5]. Although patient history and clinical evaluations determine the cause of pain, in many cases, there is no specific pathology for neck pain, so it is labeled NSCNP [6, 7]. Although many studies have examined biomechanical and neuromuscular disorders in patients with neck pain, our knowledge of these disorders is still sketchy [6, 8-10]. Patients with NSCNP display an altered muscle activation pattern. Augmented superficial cervical muscles activation and inhibited deep muscles such as longus colli and longus capitis are common findings in these patients. Also, in NSCNP patients, the onset of deep cervical muscle activity is delayed during rapid arm movement compared with healthy subjects, indicating changes in the central nervous system strategy to control the cervical spine [9, 11]. Previous studies have also shown that strengh and endurance of neck flexor and extensor muscles in patients with NSCNP are reduced compared to healthy subjects [8, 12]. NSCNP patients cannot properly relax their cervical muscles such as anterior scalene following activation [13].

Previous studies have demonstrated that the electrical activity of CES muscles drops after a certain degree of cervical flexion, which is known as the Flexion-Relaxation Phenomenon (FRP) [14, 15]. Floyd and Silver first reported this phenomenon as a reduced or sudden onset of myoelectric silence of erector spinae muscles during full trunk flexion [16]. Some studies reported that FRP in patients with NSCNP is absent or appears with a delay [15]. Although previous studies have shown that FRP occurs less frequently in NSCNP patients than in healthy subjects, all characteristics of cervical FRP are not clear [14, 15]. The absence of this phenomenon in NSCNP patients means that they cannot relax the superficial cervical muscles so that it can impose the vertebral structures to excessive loading resulting from the continuous muscular contraction [15].

Cervical muscle recruitment patterns can affect loading on the spine [17]. Just as imbalances in the strength, endurance, and length of the muscles on both sides of the spine can impose asymmetric loads on the joints, resulting in more muscle pain and injury, neuromuscular imbalances can at least theoretically create the same devastating consequences [18, 19]. The term "neuromuscular imbalance" was introduced by Freiwald et al. [20]. Changed muscle activation can be evaluated via an abnormal FRP. Also, Murphy et al. reported that Flexion-Relaxation Ratio (FRR) is an objective criterion and a reliable marker for assessing neuromuscular impairment, which can discriminate patients with CNP from healthy people [21]. Asymmetric FRR as a kind of neuromuscular imbalance can cause pain due to imposing asymmetric loads on spine structures [22]. Impaired motor control of the cervical spine, such as asymmetric FRR, may lead to poor control of intervertebral joint movements, repeated microtrauma, and finally, pain. For example, inhibiting cervical deep flexor muscles can influence stability and increase the likelihood of neck pain [9].

A recent study examined the asymmetry of FRR on the right and left sides of lumbar erector spinae muscles in healthy subjects and Low Back Pain (LBP) patients. This study showed that the FRR asymmetry is higher in LBP patients than in healthy people. Asymmetric FRR can impose asymmetric loads on the lumbar structure during forward flexion and result in unilateral over-activity of lumbar erector spinae and induce low back pain [22]. In contrast to the low back area, the cervical FRR asymmetry as a part of neuromuscular function has not been examined. Therefore, this study evaluated the symmetry of FRR on the right and left sides of the CES muscles in individuals with and without NSCNP.

2. Materials and Methods

Study participants

In the present study, the sample size was calculated with the following formula:

$$n=\frac{(Z_{1-\alpha/2}+Z_{1-\beta})^2\ \sigma^2)}{(d)^2}$$

Considering a 15% mean difference in FRR, type I error of 0.05, type II error of 0.2 (power=80%), and σ=0.75, 25 patients with NSCNP and 25 healthy subjects participated in this quasi-experimental study. They were recruited from those admitted to physical therapy and orthopedic clinics in Tehran Province, Iran. The present study was accomplished in the Biomechanics Laboratory of the Faculty of Rehabilitation Sciences, Shahid Beheshti University of Medical Sciences in Tehran, Iran. The patient group (12 females and 13 males) was

Figure 1. Placement of surface electrode and thoracic belt

matched with the control group in age, sex, and Body Mass Index (BMI) (frequency matching). All patients were evaluated by a professional physiotherapist and orthopedic surgeon and included in the study if they were diagnosed with NSCNP. All participants were between 20 and 47 years old. The patients were included in this study if they had persistent neck pain without any radiating pain to extremities for at least three months and without any specific pathology (e.g., osteoarthritis, diskopathy, radiculopathy). Also, they had no history of shoulder and LBP during the past year. Both healthy subjects and patients were right-handed. Moreover, patients with a pain score of more than 50 mm based on a Visual Analog Scale (VAS) were excluded from the study. Also, patients would have been excluded from the study if they had participated in a rehabilitation program in the past three months or participants with a history of previous cervical surgery and systemic disease or neck and shoulder trauma.

The study was approved by the Research Ethics Committee of the School of rehabilitation, Shahid Beheshti University of Medical Sciences (Code=IR.SBMU.RETECH.REC.1398.405). We explained all study steps to subjects and took their informed consent before beginning the study.

Experimental protocol

All subjects were evaluated in a 30-min session in a biomechanics laboratory. At first, the pain intensity was determined using VAS to exclude the patients with VAS higher than 50 mm. Then, each subject was asked to sit on an adjustable stool with hips and knees at an angle of 90°, feet on the floor positioned shoulder-width apart, and arms relaxed by their side, looking at an eye-level point [15, 23, 24]. Since different seated postures can affect cervical spine alignment, all subjects were asked to sit with a neutral lumbar lordosis, i.e., the midpoint between full flexion and extension determined by a physiotherapist [25, 26] (Figure 1).

Also, to find the cervical neutral position, all subjects performed cervical full flexion and extension, and then the mid-position was set as a neutral position. To stabilize the upper thoracic area, we immobilized this region by a belt at the T1-T7 spine level [14, 27]. The test protocol was explained to all subjects, and the starting neutral position was determined. The protocol was performed in four phases: each participant was asked to maintain a neutral beginning position for 4 s (phase 1), perform cervical full forward flexion for 4 s (phase 2), sustain relaxation phase for 4 s (phase 3), and finally perform re-extension to starting position for 4 s (phase 4). The protocol was done in three trials [14, 21, 28]. The cadence for the four phases was controlled by a digital metronome. Also, to control the effect of cumulative daily loading on FRR, all participants' tests were performed in the morning [23].

Instrumentation

Surface Electromyography (sEMG)

First, the skin was shaved, abraded, and washed with water to reduce the impedance [29]. According to SENIAM (surface EMG for a non-invasive assessment of muscles) guidelines, bipolar disposal sEMG electrodes (Ag–AgCl) were attached to the skin, 2 cm lateral to the spinous process of C4 [29], parallel to muscle fibers. Inter-electrode distance was 2 cm, and electrode leads were taped on the skin. A ground electrode was attached to the left wrist [30, 31]. sEMG signals in CES muscles were recorded bilaterally (both right and left sides) using an sEMG device (Datalog, UK) and simultaneously with an electrogoniometer during the test. The sampling rate of the EMG device was 1000 Hz, and the band-pass filter frequency was set between 20 and 480 Hz. To determine the exact different phases, cervical flexion and extension angles were recorded by an electrogoniometer sensor (sampling rate of 1000 Hz, Biometrics) synchronized with EMG data.

Visual Analog Scale

VAS (scored from 0-100 mm, a higher score indicates more pain) was used to determine neck pain severity. Patients determined a point along this line as neck pain intensity over the past month.

Data and statistical analysis

Raw EMG data were recorded and filtered. Root Mean Square (RMS) with a 50 ms window of raw EMG (EMGRMS) was employed to calculate electrical muscle activity amplitude (Figure 2).

The EMGRMS provides us with rectified and smoother signals and is a feasible tool for indirectly measuring the amplitude of muscular activity [32]. Visual inspection of the EMGRMS was used to determine muscle activation amplitude. FRR values unilaterally (right and left) were obtained by dividing the maximum EMG in the re-extension phase by the average EMG in the relaxation phase [15]. The formula for calculating FRR is as follows:

$$\frac{EMG\ max\ in\ phase4}{EMG\ average\ in\ phase3} = FRR$$

Bilateral FRR values in each group were obtained by calculating the mean FRR on the right and left sides.

Statistical Analysis

The distribution of demographic variables and bilateral FRR values between the patient and healthy groups was compared with the t-test.

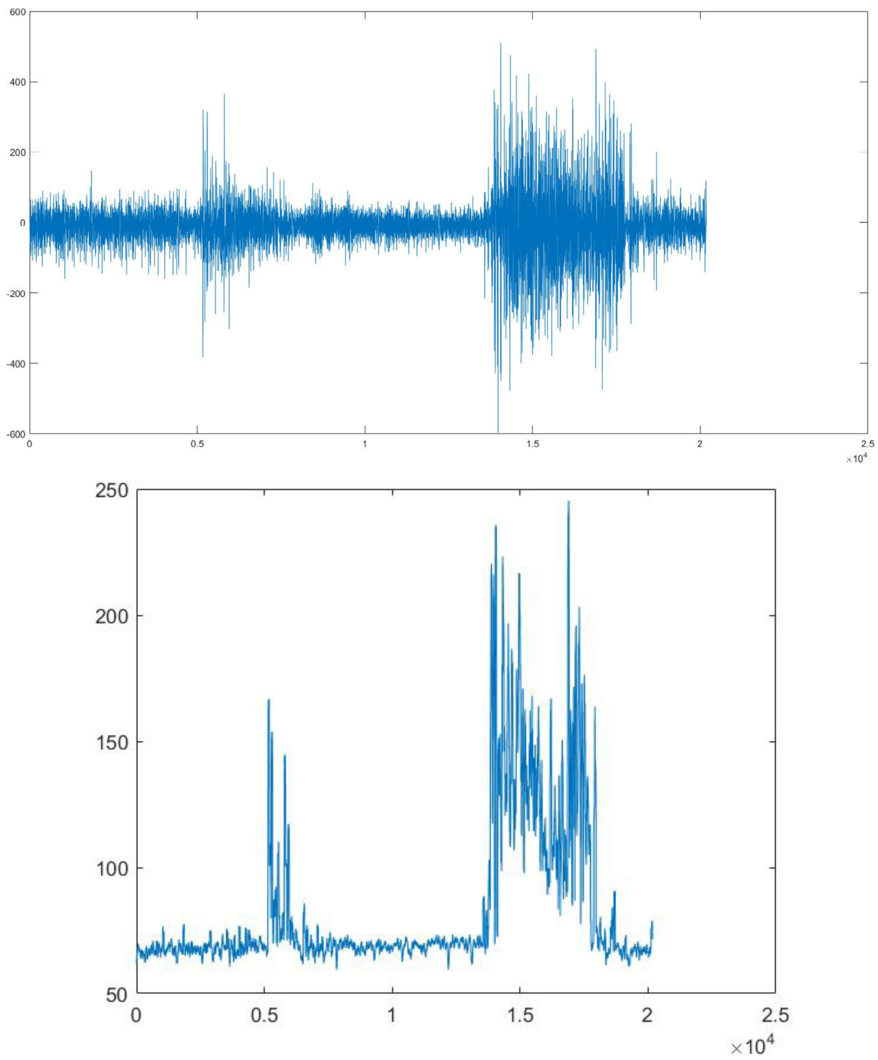

Figure 2. Raw Electromyography trace of Cervical Erector Spinae) (top) during the test protocol

Root mean square (RMS) with a 50 ms window of raw EMG (bottom).

Also, the FRR values of the right and left sides of CES in each group were compared with the paired t-test. Data analysis was performed using Stata software (version 14), and P<0.05 was considered significant statistically.

3. Results

The mean age of 50 participants was 30.64 ± 3.78 years. About 58% of subjects were male (13 healthy subjects and 15 patients). The mean weight and Body Mass Index (BMI) of the patient group were 71.56 ±5.87 kg and 23.86 1.6 kg/m^2, respectively. Table 1 presents the demographics, duration of pain, and a visual analog scale score of participants.

There was no significant association between age and gender with FRR (P<0.05). FRR values of the right cervical erector spinae (RE) was higher than that in the left erector spinae (LE) in both healthy group (mean diff=0.32; 95%CI: 0.5–1.46) and patients (mean diff=1.10; 95%CI: 0.91–1.81); it was statistically significant only in NSCNP patients (P<0.05.04) (Figure 3).

Table 2 presents the mean of FRR in the right and left sides of CES in healthy and patient groups.

Table 1. Distribution of age, weight, and body mass index in healthy and patient groups

Variable	Mean±SD		P*
	Healthy (n=25)	NSCNP (n=25)	
Age (y)	29.68±4.30	31.44±5.71	0.17
Weight (kg)	71.56±5.87	68.64±4.62	0.84
BMI (kg/m^2)	23.86±1.6	23.68±1.75	0.71

Variable	Median(Q1-Q3)
Duration of pain (month)	12 (8–14)
VAS (mm)	50 (25–50)

*Based on the t-test.

BMI: Body Mass Index; VAS: Visual Analog Scale.

Scale; Q1-Q3=lower and upper quartiles.

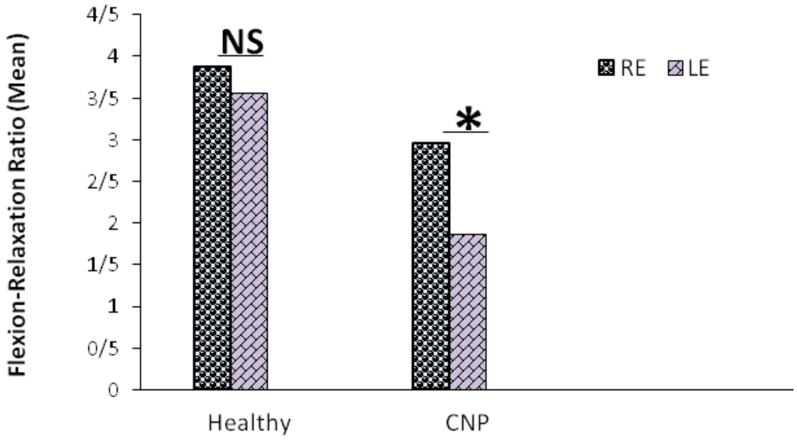

Figure 3. Comparing Flexion-Relaxation Ratio (FRR) on the Right and Left Sides Between Healthy and Patient Groups

*P<0.05. NS: Not Significant (based on the paired t-test); RE: Right Erector spinae; LE: Left erector spinae.

Table 2. Distribution of FRR in cervical erector spinae in each group

Variables	Mean±SD		P*
	FRR_RE	FRR_LE	
Healthy	3.88±1.46	3.56±0.49	>0.05
NSCNP	2.96±1.22	1.86±0.57	0.04

*Based on the t-test.

FRR: FRR: Flexion-Relaxation Ratio; RE: right erector spinae; LE: Left erector spinae; NSCNP: non-specific chronic neck pain.

Also, FRR for bilateral erectile spine was significantly lower in NSCNP patients than in healthy subjects (mean difference=1.32; 95%CI: 0.75-1.91) (P<0.001) (Table 3).

4. Discussion

The current study investigated the asymmetry of FRR on the right and left sides of cervical erector spinae muscles in patients with NSCNP and healthy groups.

FRR is an objective and reliable criterion for studying neuromuscular dysfunction [21]. In the present study, there was a significant difference in FRR between the right and left sides of cervical erector spinae muscles (right FRR=2.96, left FRR=1.86) just in the patients group (P<0.05). Although FRR in healthy individuals was higher on the right side than on the left side (right FRR=3.88, left FRR=3.56), the difference was not statistically significant (P>0.05). In this study, in both the patient and healthy groups, the FRR was higher on the right side than on the left side; limb dominance might contribute to this difference. In the present study, all subjects were right-handed. The dominant side experiences much motion during daily activities, whereas the non-dominant side is usually in a static position for a long time. Therefore, due to the less mobility of the left erector spinae muscles than the dominant side, the accumulation of stress in the left muscles may decrease the FRR. Our findings were similar to the results of the Yoo et al. study. They examined the FRR asymmetry in the CES only in healthy right-handed individuals and found similar results [33]. Pialasse et al. used a cut-off point for FRR as 2.5 to determine of occurrence or non-occurrence of the flexion relaxation phenomenon. Thus, the FRR higher than 2.5 means the occurrence of this phenomenon, and the ratio lower than 2.5 means its non-occurrence [34].

Chronic pain alters motor control via some central mechanisms [35]. In the NSCNP patients, increased superficial neck muscles activity might be a compensatory motor strategy for decreased deep muscles activation. Reorganization of motor control can lead to persistent and awkward symptoms. Pain-induced altered neural control can dispose the superficial muscles to excessive load and, finally, damage them. Furthermore, the reduced contractile capacity of the deep cervical muscles resulting from changed motor control can atrophy specific fiber types. These changes may contribute to the development of chronic symptoms [36].

The new theory of pain introduces the adaptation hypothesis; it considers the relationship between pain and changes in motor and sensory function. The changes in motor function include alterations that occur in the excitability and organization of the motor cortex. Changes in sensory function consist of decreased sensory perception, increased repositioning error, and decreased response to sensory afferents. These changes can affect the control of the musculoskeletal system, especially in painful conditions, and reduced sensory processing can change the motor output [37, 38].

Researchers have shown that pain intensity and avoidance behaviors (pain-related fear) can adversely affect motor control. NSCNP patients may modify their motor control strategies to prevent further pain. So, pain-related anxiety, especially in painful situations, can disrupt sensory integration and alter motor strategy. Patients

Table 3. Distribution of frr for cervical erector spinae between healthy and patient groups

Variable	Healthy (n=25)	NSCNP (n=25)	P*
FRR	3.72 (1.02)	2.41(0.76)	<0.001

* Based on the t-test. FRR: Flexion-Relaxation Ratio; NSCNP: Non-Specific Chronic Neck Pain.

with chronic neck pain lack a proper perception of the forward flexion task due to incorrect sending of sensory information due to impaired sensory function, the presence of pain, and avoidance behaviors (pain-related fear) [39]. So, in NSCNP patients, the movement strategy changes by increasing the electrical activity of the superficial muscles, which eliminates the relaxation phase of these muscles during forward neck flexion, and finally reduces the occurrence of the FRP.

Moreover, the previous studies showed that FRR values in patients with NSCNP are lower than in healthy subjects and FRP incidence in CNP patients is less than in healthy subjects [14, 15, 40, 41]. Also, they showed that NSCNP patients could not relax their erector spinae muscles during neck flexion [14]. In other words, pain-induced altered neural control can decrease or eliminate CES muscles' relaxation time. Therefore, these muscles stay active during the forward flexion movement. This change in motor control may be a strategy to compensate for the inadequate stability provided by the passive system and deep neck muscles [24].

Therefore, not only the FRR is significantly different between healthy and CNP patients, but it is different on the left and right sides of patients with chronic neck pain, too. Furthermore, our findings confirmed the term "neuromuscular imbalance," introduced by Freiwald et al. [20]. Asymmetric FRR in patients with NSCNP is a kind of neuromuscular imbalance. It can alter the control of intervertebral joint movements, increase the neutral zone, cause repeated microtrauma, and finally, pain [2, 20, 41]. The asymmetry of the FRR in patients with NSCNP may be a kind of altered motor control strategy. Pain-induced inhibition of a cervical agonist is probably compensated by the increased activity of synergist and even painless antagonist muscles to achieve the same motor output in less painful conditions. Therefore, FRR asymmetry in patients with chronic neck pain can result from pain and cause pain [36]. Asymmetric FRR can not only result in applying asymmetric loads on the cervical structures during flexion but also may lead to unilateral CES muscle over-activity. Dulcina et al. showed that patients with low back pain exhibited FRR asymmetry in their trunk muscles. Moreover, they reported that FRR asymmetry could induce pain by loading the spine incorrectly due to imbalance muscle activation [22]. To date, asymmetrical FRR in CNP patients has not been defined, and this study provided valuable data on CES muscle behavior in this group.

The current study has some limitations to be considered in future research. The result of this study cannot be generalized to all NSCNP subjects because the patients with VAS> 50 mm were excluded from the study. Further studies are needed to investigate the relationship between pain intensity and asymmetry of the flexion-relaxation ratio in patients with chronic neck pain. Also, in this study, the test protocol was performed in the sitting position. Investigating FRP in different positions, such as standing, may have different results.

5. Conclusion

This study showed a significant difference in FRR between the right and left CES muscles only in NSCNP patients. In addition, it showed that NSCNP patients have altered muscle activation in dynamic tasks in the form of neuromuscular imbalance on the right and left sides of the cervical spinae.

Ethical Considerations

Compliance with ethical guidelines

All procedures performed in studies involving data extraction from articles were in accordance with the ethical standards of the Shahid Beheshti University of Medical Ethics Committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no competing interests.

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