J Musculoskelet Neuronal Interact 2022; 22(1):52-61

Journal of Musculoskeletal and Neuronal Interactions

Original Article

Comparison of ultrasonographic characteristics of deep abdominal muscles in women with and without chronic neck pain: a case-control study

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Abstract

Objectives: To compare ultrasonography (USG) parameters of deep abdominal muscles (transversus abdominis-TrA, internal obliques-IO) between women with and without chronic neck pain (CNP). **Methods**: Women with CNP (n=18; mean-age=37.7 years; mean-BMI=22.7 kg/m^2) and asymptomatic individuals (n=18; mean-age=36.1 years; mean-BMI=21.8 kg/m^2) participated in the study. The activation of the deep neck flexors (ADNF) was measured using cranio-cervical flexion test. Muscle thickness, changes in thickness (ΔT), and contraction ratio (CR) of deep abdominal muscles were evaluated by ultrasonography device in two conditions: standard-protocol and during ADNF. For each condition, ultrasound image of abdominal muscles was captured at rest and during abdominal draw-in manoeuvre (ADIM). **Results**: Comparative statistics revealed no significant difference between groups regarding ultrasonography parameters in the standard-protocol ($p>0.05$). Besides, there was no difference in the CR of TrA and IO between groups in the two conditions. However, women with CNP showed less muscle thickness of TrAADIM during ADNF than the asymptomatic participants ($p<0.05$). The CNP group also had decreased ΔT of TrA(ADIM-rest) during ADNF compared to the asymptomatic group ($p<0.05$). **Conclusions**: The ultrasonography parameters of TrA suggest that motor control in the lumbar region is altered in women with CNP. The combination of cervical stabilization exercises with ADIM can be a novel strategy in the treatment of CNP.

Keywords: Abdominal Draw-In Manoeuvre, Deep Neck Flexors, Neck Pain, Transversus Abdominis, Ultrasonography

Introduction

Neck pain is a widespread and burdensome musculoskeletal problem that affects approximately 30-50% of the general population annually, and it is two times more common in women than in men. Pain becomes chronic in almost fifty percent of the patients[1-3]. The mechanism of chronic neck pain (CNP) is heterogeneous with multiple causes and symptoms, including reduced cervical muscle strength, poor proprioception, and decreased control of the deep stabilizers[4-6]. Deep spinal muscles play a vital role in providing functional segmental stability for the whole spine. Deep neck flexors (longus capitis, longus colli) are the cervical spine's primer stabilizers[7]. These deep featured muscles continue as the transversus abdominis (TrA), internal obliques (IO), lumbar multifidus, diaphragm, and pelvic floor muscles in the lumbar region[8-10]. Over the past decade, studies have found late activation of the deep neck flexors (ADNF) in individuals with CNP due to motor control alterations, while patients with chronic low back pain had delayed deep abdominal muscle activity in the abdominal draw-in manoeuvre (ADIM)[11-15]. The decreased ADNF indicates a significant sign for delayed automatic feed-forward control of the cervical spine[15]. Therefore, it is reasonable that the altered motor strategy of the cervical spine leads to reorganization of the activity among agonist, antagonist, and synergist muscles and causes substantial differences in load sharing in spinal muscles[16,17].

The measurement of ultrasonography (USG) imaging

The authors have no conflict of interest.

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Edited by: G. Lyritis
Accepted 17 September 2021

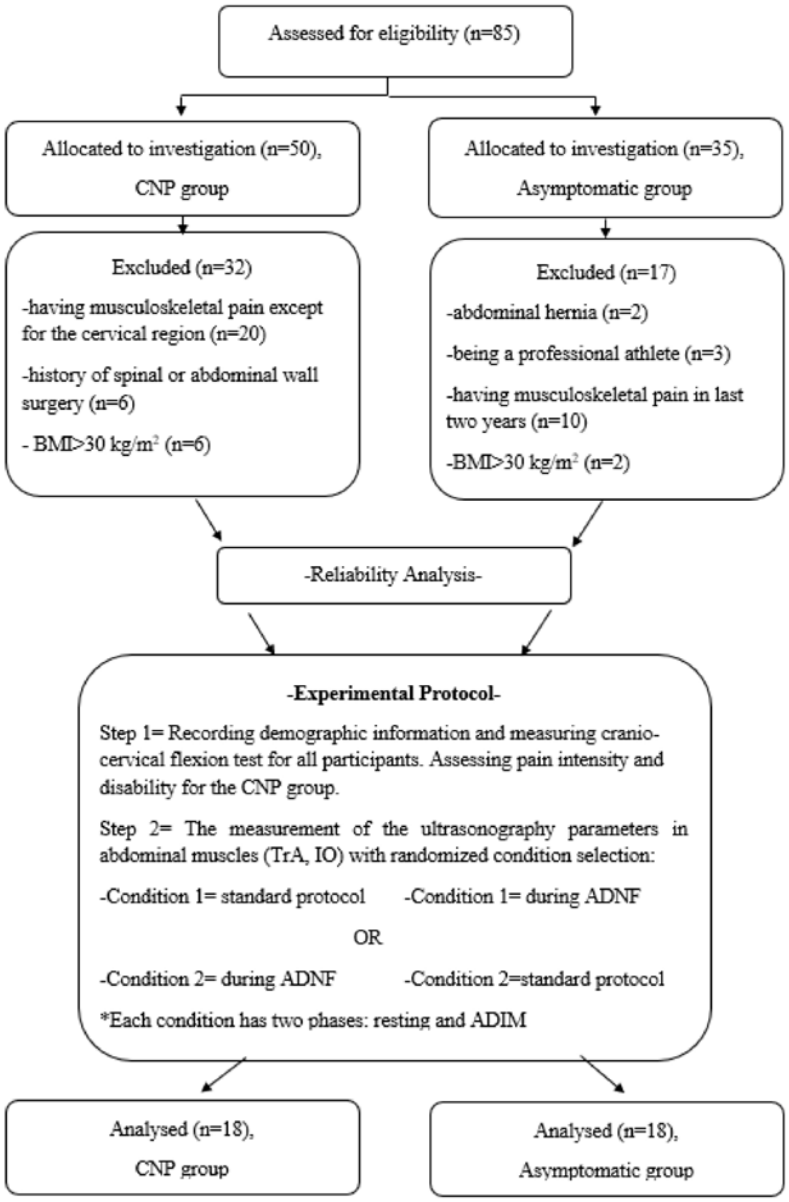


Figure 1. Flow diagram of the study.

has been used in many studies evaluating trunk muscle morphology in individuals with chronic low back pain[12,13,18-22]. The ADIM is primarily used for determining TrA muscle function, and patients with low back pain have impaired control of ADIM compared to pain-free participants[18,21], while patients with CNP have altered control of the ADNF in the cranio-cervical flexion test[15,16]. Up to date, several studies have examined the interaction between the cervical and lower spinal regions[17,23,24]. Thongprasert et al. (2019) reported abnormal performance of the deep cervical stabilizers in patients with low back pain, just like in the individuals with CNP. Thus, the authors mentioned a potential relationship between cervical and lumbar motor strategy[24]. On the other hand, Falla et al. (2017) established that patients with CNP had stiffer thoracic movements than the asymptomatic sample in the walking task[17]. In another study, individuals with neck pain were more predisposed to develop low back pain in the next two years regarding their decreased abdominal draw-in task capability[23]. Accordingly, CNP may negatively affect lower spine segments, thereby causing pain to expand towards the other spinal region. However, it is not known whether deep abdominal muscles are altered or not in people with CNP.

Overall, the present study aimed to compare USG characteristics (muscle thickness, muscle thickness change in ADIM, and contraction ratio) of the deep abdominal muscles (TrA, IO) between women with CNP and asymptomatic

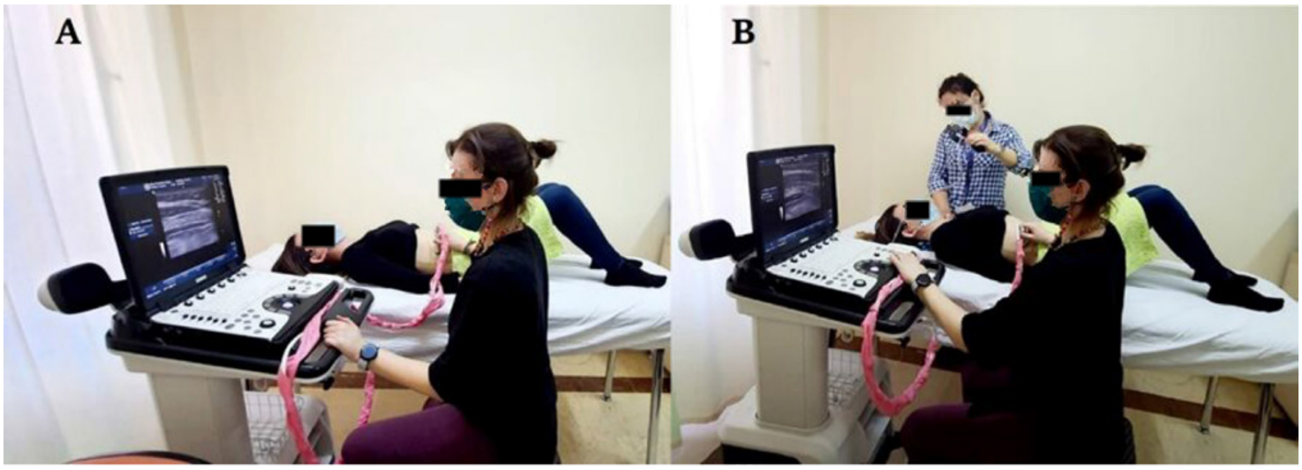


Figure 2. A) Ultrasonographic measurement of the deep abdominal muscles in the standard protocol. B) Ultrasonographic measurement of the deep abdominal muscles during the ADNF.

participants in the standard protocol and ADNF. We hypothesized that women with CNP would have altered USG characteristics of the deep abdominal muscles compared to their asymptomatic peers.

Materials and Methods

This case-control study was conducted in the Dokuz Eylul University School of Physical Therapy and Rehabilitation between October 2019 and February 2020. The ethical approval was obtained from the Non-Invasive Research Ethics Committee of Dokuz Eylul University (No: 2019/ 25-32, Date: 14.10.2019) before the study, and all procedures were conducted in accordance with the Declaration of Helsinki.

Participants

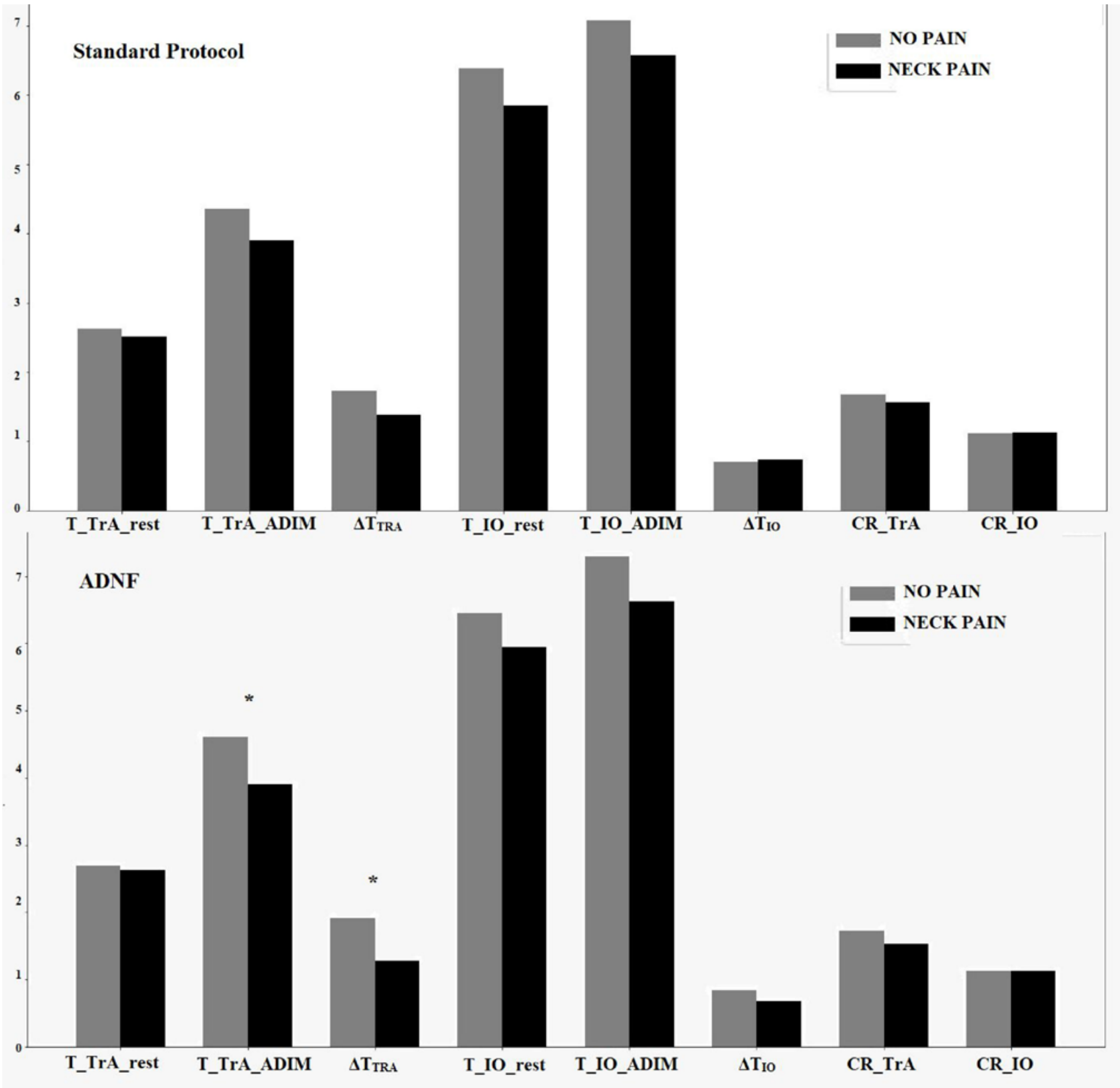
A total of eighty-five participants were assessed, of which forty-nine participants were excluded according to the eligibility as described in the flow chart (Figure 1). The minimum required sample size was determined via G*Power (version 3.1.9.4, Düsseldorf University, Germany) as 36 (18 for each group) with the power of 85%, alpha error probability of 0.05. The reference value was provided from the pilot study finding of the TrA muscle thickness change in ADIM due to the smallest difference between study groups (32), which included ten women with CNP group (mean age=38.3±9.1; mean neck pain intensity=6.3±1.3) and ten asymptomatic women (mean age=42.6±11.4).

The inclusion criteria for the CNP group were as follows: (1) having neck pain for more than six months, (2) having no pain in the other regions of the body in the previous two years, (3) willing to participate in the study, (4) age between 25-50 years, and (5) body mass index ≤30 kg/m^2. The inclusion criteria of the asymptomatic group were as follows: (1) having no musculoskeletal pain in the last two years, (2) willing to participate in the study. Exclusion criteria for both groups included the followings: (1) history of spinal or abdominal wall surgery, (2) severe visual problems, (3) having signs of radicular cervical pain (positive sign of neck distraction test, Spurling's neck compression test, and Adson's test), (4) being a professional athlete, (5) traumatic cervical injuries, (6) chronic musculoskeletal pain except for the cervical region, (7) pregnancy in the past one year, abdominal hernia, or diastasis recti, and (8) severe comorbidities (neurological, neuromuscular, or cognitive) (9) scoliosis. A written informed consent was obtained from all participants included in the study prior to the evaluations. The study was conducted at School of Physical Therapy and Rehabilitation, Dokuz Eylul University.

Experimental Procedure

Two physiotherapists were involved in the data recording process. One was responsible for recruiting the participants, retrieving demographic information, assessing pain intensity and disability, and estimating participants' activation scores based on the cranio-cervical flexion test whereas the other was blinded to the assigned group and evaluated the USG characteristics of the deep abdominal muscles. All steps of the procedure were also summarized in the flow chart (Figure 1).

Deep abdominal muscle thickness was evaluated under two conditions. Randomized selection of the beginning state was used for the elimination of the positive or negative learning effect. In the standard protocol, the measurement was determined at rest and during ADIM in the hook lying position. The participant was instructed to perform ADIM with standardized instruction: "*Take a*



Graph 1. Comparison of the deep abdominal muscles ultrasonographic parameters between the study groups.

deep breath in and, as you exhale, pull your belly button up and in towards your spine"[25]. In the second condition, the same evaluations were made as in the standard protocol with the ADNF (Figure 2) with an interval was 10 minutes between the two conditions.

Outcome Measures

Pain and Disability Characteristics

The worst neck pain intensity in the past week was assessed using a visual analogue scale[26]. The distance from zero to the marked point was recorded in cm on a 10 cm horizontal line. Neck disability level of the participants was assessed according to the Neck Disability Index-Turkish version, which has very high test-retest reliability (ICC=0.97)[27]. The questionnaire contained ten sections and each item was scored from zero to five.

Strength of the cervical stabilizer muscles

Cranio-cervical flexion test was used to define the activation score of the deep cervical stabilizers. The participants were positioned in hook-lying and the uninflated pressure sensor of the stabilizer (Chattanooga Stabilizer Group Inc., Hixson, TN, USA) was placed beneath the occiput. The pressure sensor was inflated to a stable baseline value of 20 mm-Hg, then participants have performed the nodding movement (as if to say "yes"). The participants gradually increased the nodding value (20-22-24-26-28-30 mm Hg) until they achieved the score holding ten repetitions of 10-second duration without activation of superficial neck flexors. The activation score was determined using the described method of "Achieved value-20 mm Hg" by Jull et al. (1999, 2008) with high inter-rater reliability (ICC=0.81) (7,28).

The measurement of the USG parameters in the deep abdominal muscles

The thickness measurement of the deep abdominal muscles (TrA, IO) was evaluated by two-dimensional USG device (LOGIQ-e, GE Healthcare, Milwaukee, WI, USA). A multi-frequency linear array transducer (GE 12L-RS, bandwidth 5–13 MHz, footprint 12.7 x 47.1mm) at a central frequency of 10 MHz was used for capturing B-mode images. All images were collected and processed by a single investigator with five years of experience in musculoskeletal USG imaging (accredited by The Royal College of Radiologists, British Medical Ultrasound Society, European Society of Musculoskeletal Radiology).

Aqua sonic gel was applied to the transducer head-skin interface to optimize acoustic transmission. The evaluations were carried out by placing the transducer on the right anterolateral abdominal wall in the transverse axis along an axillary line midway between the inferior angle of the rib cage and the iliac crest. With the transducer in transverse orientation (aligned perpendicular to the long axis of the body), the investigator glided the probe slowly over the abdominal wall toward the umbilicus until the anterior fascial attachment of TrA muscle was fully visualized (Figure 2)[29]. Additionally, special attention was paid to the pressure imposed on the transducer to avoid compressing the underlying tissue. Therefore, minimal and consistent probe pressure was used to obtain the view of the target muscle. The scanning depth was adjusted to the thickness of a study participant's tissues, and to get the image with the best quality possible; depth was set at up to 45 mm.

To control the effect of breathing and to standardize the imaging procedure, all images were captured at the end of the calm expiration[30]. The thickness of the TrA and IO muscles were measured between the superficial and deep hyperechoic fascial lines for both conditions, at approximately 2-2.5 cm apart from the anterior fascial insertion of the TrA muscle using caliper-based tools included in the ultrasound imaging software. Measurements were conducted perpendicular to the fascial lines and recorded in mm. Three measurements were taken, and their average was used for the statistical analysis. Also, the contraction ratio of TrA and IO muscles was determined with the formula of "muscle thickness during ADIM/muscle thickness at rest" to evaluate the relative change of muscles' thicknesses[31].

The explanation of USG parameters' abbreviations

$T_{TRA\ (rest)}$: Muscle thickness of TrA in rest
$T_{TRA\ (ADIM)}$: Muscle thickness of TrA in ADIM
$T_{IO\ (rest)}$: Muscle thickness of IO in rest
$T_{IO\ (ADIM)}$: Muscle thickness of IO in ADIM
ΔT_{TRA}: Muscle thickness of TrA in ADIM- Muscle thickness of TrA in rest
ΔT_{IO}: Muscle thickness of IO in ADIM- Muscle thickness of IO in rest
CR_{TRA}: Muscle thickness of TrA in ADIM/Muscle thickness of TrA in rest
CR_{IO}: Muscle thickness of IO in ADIM/Muscle thickness of IO in rest

Statistical Methods

Statistical analyses were performed using the Statistical Package for the Social Sciences 22.0 (SPSS) software for Windows (Lead Technologies Inc. SPSS Inc., Chicago, IL, USA). Normal distribution was utilized with the Shapiro-Wilk test and histograms. Descriptive analyses were presented as the means and standard deviations (Table 1). The USG parameters of the deep abdominal muscles were compared between groups using independent samples T-tests as all variables had a normal distribution. The effect sizes were estimated using Cohen's d, interpreting values in the range 0-0.40 as small, 0.41–0.70 as moderate, 0.71 or higher as large effect size[32]. Negative values of the Cohen's d indicated that the CNP group have lesser mean values than the asymptomatic group[33].

Intra-rater reliability of the USG measurement was calculated by intraclass correlation coefficient ($ICC_{3,3}$) for all phases (In rest, ADIM, Rest with ADNF, ADIM with ADNF), both muscles (TrA, IO), and groups separately (CNP group and asymptomatic group) for 36 participants. An interval of four days was provided between two measurements. Standard error of measurement (SEM) and the minimum detectable change (MDC) were calculated with the formulas of $SD \times \sqrt{1-ICC}$ and $1.96 \times SEM \times \sqrt{2}$, respectively. A p-value of less than 0.05 was considered to show statistical significance.

Results

The sample of the study consisted of 18 women with CNP (mean age=37.72±9.94 years; mean body mass index (BMI)=22.73±2.16 kg/m^2) and 18 asymptomatic women (mean age=36.11±12.11 years; mean BMI=21.82±2.64 kg/m^2). The CNP and asymptomatic groups were similar in terms of age, weight, height, BMI, and gender (p>0.05) and general demographics of both groups were presented in Table 1. The activation score values of the CNP group were significantly less than the asymptomatic group (p<0.001) (Table 1). Also, CNP group characteristics of pain intensity, pain duration, and disability were reported in Table 1. Intra-rater reliability of the USG evaluations showed significantly

Table 1. General characteristics of the chronic neck pain and asymptomatic groups.

	CNP Group (n=18) Mean±SD	Asymptomatic Group (n=18) Mean±SD	p
Age (y)	37.72 ± 9.94	36.11 ± 12.11	0.670
Weight (kg)	59.88 ± 4.99	58.11 ± 7.49	0.414
Height (cm)	162.44 ± 5.22	163.23 ± 6.61	0.696
BMI (kg/m²)	22.73 ± 2.16	21.82 ± 2.64	0.268
ADNF score (mmHg)	5.08 ± 0.86	7.61 ± 0.76	<0.001*
Worst pain in the last week (VAS, cm)	5.86 ± 1.42	NA	NA
Pain Duration (month)	43.22 ± 26.86	NA	NA
NDI (score)	17.66	NA	NA

*Abbreviations: CNP, Chronic Neck Pain; SD, Standard Deviation; p, statistical significance in the Independent-samples T test; BMI, Body mass index; ADNF, Activation of deep neck flexors; NDI, Neck disability index; NA, Not applied, *p<0.05 and statistically significant.*

Table 2. Comparison of abdominal muscles ultrasonographic parameters between the groups in the standard protocol.

USG Parameter	CNP Group (n=18) Mean ± SD	Asymptomatic Group (n=18) Mean ± SD	Mean Difference (95 % CI)	Cohen's d	p
$T_{TRA\ (rest)}$, mm	2.51 ± 0.52	2.62 ± 0.59	-0.11 (-0.49 to 0.27)	-0.19	0.556
$T_{TRA\ (ADIM)}$, mm	3.90 ± 0.82	4.35 ± 0.94	-0.45 (-1.06 to 0.15)	-0.51	0.139
$T_{IO\ (rest)}$, mm	5.84 ± 0.92	6.38 ± 1.48	-0.53 (-1.37 to 0.30)	-0.43	0.207
$T_{IO\ (ADIM)}$, mm	6.57 ± 0.97	7.07 ± 1.72	-0.50 (-1.45 to 0.45)	-0.35	0.294
ΔT_{TRA}, mm	1.39 ± 0.58	1.73 ± 0.58	-0.34 (-0.74 to 0.05)	-0.58	0.093
ΔT_{IO}, mm	0.73 ± 0.53	0.69 ± 0.83	0.03 (-0.44 to 0.51)	0.05	0.889
CR_{TRA}	1.57 ± 2.32	1.67 ± 2.29	-0.10 (-0.26 to 0.05)	-0.04	0.188
CR_{IO}	1.13 ± 0.97	1.11 ± 1.36	0.01 (-0.06 to 0.10)	0.01	0.654

Abbreviations: USG, Ultrasonography; CNP, Chronic Neck Pain; SD, Standard deviation; T, Muscle thickness; TrA, Transversus Abdominis; IO, Internal Obliquus; ADIM, Abdominal draw-in manoeuvre; $\Delta T_{TRA} = TrA_{ADIM} - TrA_{rest}$; $\Delta T_{IO} = IO_{ADIM} - IO_{rest}$; *CR, Contraction ratio; *p<0.05 and statistically significant.*

Table 3. Comparison of abdominal muscles ultrasonographic parameters between the groups during the activation of deep neck flexors.

USG Parameter	CNP Group (n=18) Mean ± SD	Asymptomatic Group (n=18) Mean ± SD	Mean Difference (95 % CI)	Cohen's d	p
$T_{TRA\ (rest)}$, mm	2.62 ± 0.65	2.69 ± 0.65	-0.06 (-0.51 to 0.38)	-0.10	0.761
$T_{TRA\ (ADIM)}$, mm	3.90 ± 0.85	4.61 ± 1.14	-0.70 (-1.39 to -0.01)	-0.70*	0.046*
$T_{IO\ (rest)}$, mm	5.94 ± 1.11	6.45 ± 1.45	-0.50 (-1.39 to 0.38)	-0.39	0.256
$T_{IO\ (ADIM)}$, mm	6.63 ± 0.93	7.29 ± 1.95	-0.66 (-1.70 to 0.37)	-0.43	0.204
ΔT_{TRA}, mm	1.28 ± 0.85	1.91 ± 0.85	-0.63 (-1.22 to -0.05)	-0.74*	0.034*
ΔT_{IO}, mm	0.68 ± 0.73	0.83 ± 0.78	-0.15 (-0.67 to 0.36)	-0.19	0.543
CR_{TRA}	1.53 ± 0.30	1.73 ± 0.30	-0.19 (-0.40 to 0.01)	-0.66	0.061
CR_{IO}	1.12 ± 0.12	1.12 ± 0.10	0.004 (-0.07 to 0.08)	0.001	0.917

Abbreviations: USG, Ultrasonography; CNP, Chronic Neck Pain; SD, Standard deviation; T, Muscle thickness; TrA, Transversus Abdominis; IO, Internal Obliquus; ADIM, Abdominal draw-in manoeuvre; $\Delta T_{TRA} = TrA_{ADIM} - TrA_{rest}$; $\Delta T_{IO} = IO_{ADIM} - IO_{rest}$; *CR, Contraction ratio; *p<0.05 and statistically significant.*

very high reliability in all conditions for both the CNP group (ICC=0.90-0.99) (Appendix 1) and the asymptomatic group (ICC=0.97-0.99) (Appendix 2).

Comparative statistics of the USG parameters in the deep abdominal muscles between the groups were shown in Tables 2, 3 and Graph 1 via independent samples T-test. The independent samples T-test revealed no significant difference in abdominal muscle thickness in the standard protocol between the groups. However, there was a significant difference between the study groups' muscle thickness of TrA_{ADIM} during the ADNF (p=0.046) with a moderate effect size (Cohen's d=-0.70). The women with CNP (3.90±0.85 mm) showed less muscle thickness of TrA_{ADIM} during the ADNF than the asymptomatic participants (4.61±1.14 mm). The CNP group (ΔT_{TRA}=1.28±0.85 mm) had also decreased thickness change of TrA during the ADNF compared to the asymptomatic group (ΔT_{TRA}=1.91±0.85 mm) (p=0.034) with a large effect size (Cohen's d=-0.74). Furthermore, the contraction ratio of TrA and IO was similar between the CNP and asymptomatic groups in both conditions (standard protocol and during ADNF) (p>0.05).

Discussion

The primary result of the present study was that women with CNP had less muscle thickness of TrA_{ADIM} than asymptomatic controls during ADNF. The other finding was that the CNP group had less ability to change muscle thickness of TrA during the ADNF than the asymptomatic group. Besides, there was no significant difference in USG parameters of the deep abdominal muscles between groups in the standard protocol. Also, no difference was found in the contraction ratio of the deep abdominal muscles between groups.

Wong et al. (2013) and Unsgaard-Tøndel et al. (2012) revealed limited evidence regarding the relationship between temporal changes in low back pain and the contraction ratio of TrA (18,19). In contrast, Pulkovski et al. (2012) indicated that the contraction ratio of TrA does not differentiate between patients with low back pain and healthy controls[31]. Moreover, many studies evaluating trunk muscle morphology in individuals with chronic low back pain had a common view was that only the contraction ratio of the TrA could not be efficient to determine the difference between low back pain and control groups[13,18,21,22]. Similarly, our findings did not show a significant difference between CNP and asymptomatic groups in the contraction ratio of TrA. There should be an additional function such as standing, forward bending, bridging, or straight leg raise to reveal the different USG patterns of abdominal muscles in patients with low back pain, according to the aforementioned studies[11,13,34]. Thus, we took the USG measurement of deep abdominal muscles, adding the condition of ADNF, which was the primary stabilization function of the cervical spine, in our experimental procedure. Accordingly, our findings showed decreased muscle thickness of TrA_{ADIM} during ADNF in women with CNP, although no difference was found between the groups in the standard protocol. We could speculate that while women with CNP perform a condition (ADNF) to provide cervical stabilization, their preferential activity in TrA might be reduced. Therefore, a holistic approach that considers cervical and lower segments could be beneficial. Besides, Shaikh et al. (2021) reported potential benefits of USG imaging as a feedback tool for the further rehabilitative exercise models in the current systematic review[35]. In this manner, we thought that USG imaging of deep abdominal muscles in the management of CNP could provide both the sensorimotor system's voluntary control and improve the self-awareness of the synergistic deep spinal muscle activities.

Prior to the study, we hypothesized that the ability to change the deep abdominal muscle thickness was less in the CNP than in the asymptomatic controls. Our results showed no difference between the groups regarding the thickness change of the deep abdominal muscle in the standard condition. However, the CNP group had less ability to change muscle thickness of TrA during the ADNF than the asymptomatic group. Also, Pulkovski (2012) and Chritchley et al. (2002), indicated that there was no statistical difference between chronic low back pain and asymptomatic groups regarding the muscle thickness of TrA and IO[22,31]. However, Unsgaard-Tøndel et al. (2012) showed an association between the lateral slide of the abdominal muscles and long-term pain reduction in patients with chronic low back pain. They discussed the importance of non-contractile tissue on spinal stability[19]. Moreover, Shimizu et al. (2020) found a significant relationship between the elasticity of TrA and lumbar stability in healthy participants[36]. Thus, it has been advocated that the transfer moment of the lumbar region via intra-abdominal pressure and fascial tightening depends on the connective tissue and interaction with other spinal muscles. Accordingly, the motor control of the spine might depend on both the sliding ability and strength variables of the deep structured muscles.

Subjects with CNP have restricted thoracic motor control patterns compared to healthy controls[17]. For instance, Alsultan et al. (2020) found reduced trunk movement in individuals with neck pain during dual-task (cervical rotation) gait compared to healthy individuals, while there was no difference between groups in the single gait task[37]. We thought that patients with CNP could not execute multiple spinal tasks in both the cervical and lumbar region. Thus, our findings also similarly pointed out the lumbar region's motor control alteration in women with CNP, indirectly. Nevertheless, only two studies were pertaining to the interaction between the cervical and lumbar musculoskeletal control[23,24]. Moseley found reduced abdominal draw-in task performance in people with subacute neck pain compared to control subjects. The findings above showed that when patients with neck pain had an abnormal abdominal draw-in task, they were more likely to develop low back pain in the next two years[23]. In contrast to the aforementioned study, our present findings did not show a difference between study groups in the standard measurement in terms of the deep abdominal muscle thickness in ADIM. However, this discrepancy might be due to the different experimental procedures. Moseley determined the comparative findings in prone four-point kneeling position via stabilizer, while we used the USG in our main assessments in the supine position. Another possible explanation about the supine test position also might be that this position does not effectuate much of a challenge on spinal stability[31]. Additionally, Moseley also emphasized the necessity of adding a functional task during the evaluation of abdominal muscles in the neck pain group[23]. Similarly, there was a significant difference between CNP and asymptomatic groups in the muscle thickness of TrA_{ADIM} during the ADNF condition. Our results might suggest that it is preferable to measure deep abdominal muscle with USG by adding a specific function to understand the difference between painful and painless subjects.

The results of the second previous study conducted by Thongprasert et al. (2019) demonstrated the abnormal performance of cervical stabilizers in patients with low back pain[24]. They concluded that there was an alleged relationship in muscle control between cervical and lumbar regions. Similarly, our study showed that women with CNP had less ability to change TrA muscle thickness during ADNF. Although our CNP group had no lower back pain, the less thickness change of TrA might have indicated that they had also possible impaired motor control of the lumbar spine. Consequently, repetitive movements through this potentially impaired motor control could cause pain in another spinal region in people with CNP. Also, decreased control of the segmental stabilization is only one part of the CNP. There are substantial biomechanical, postural, or somatosensorial changes that occur in a patient with CNP. Thus, future longitudinal studies should evaluate this cumulative process to find the trigger for this bidirectional connection between CNP and lower spinal segments.

This study had certain limitations that should be specified. Our study sample consisted of only female participants. Previous reports indicated that women have superior motor control than men due to greater activation patterns of TrA[20,29,38]. Besides, Teyhen et al. (2007) found a specific gender difference in absolute thickness values of the abdominal muscles[29]. The fact that our study consisted of only female participants may have ensured data homogeneity. However, these results are difficult to generalize in population with CNP. Additionally, we evaluated USG parameters of abdominal muscles only from the right side. As to our knowledge, abdominal muscular asymmetry is commonly seen in the problems such as abdominal hernia, musculoskeletal problems of lower extremity problems, or scoliosis[29,39], and the exclusion criteria of the present study had already involved these issues. However, future studies should evaluate the abdominal muscles' symmetry to ensure the explanation of this potential alteration in patients with CNP. In the present study, women with CNP had moderate levels of neck disability, so different results would be possible if the participants had severe disabilities. We evaluated only the USG characteristics of the deep abdominal muscles except for the external obliques muscle. An additional electromyography analysis and data about the external obliquus muscle could provide a deeper understanding of our hypothesis. On another hand, our reliability analysis of the ultrasonographic methodology contained only the intra-rater reliability. Thus, future studies could be done regarding inter-rater reliability and validity analysis for guiding more objective findings.

Overall, the present results defined one aspect of the muscular difference in women with CNP, which was decreased muscle thickness of TrA_{ADIM} during ADNF. These findings provided possible hypotheses to the role of abdominal muscle characteristics in CNP for future research. Furthermore, our results support the proposed idea of using ADNF with ADIM as a therapeutic exercise in CNP patients. We thought that it might be advisable to evaluate lumbar stabilizers for providing long-term benefit in managing CNP. The additional ADIM might be considered a clinical strategy or a measurement tool for different motor learning stages in the rehabilitation process. Future studies may also use this USG observation for defining new exercise designs in patients with CNP.

Acknowledgement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors would like to thank the Department of Scientific Research Projects of Dokuz Eylul University for their financial support in the PhD project [Grant ID: 2018/69]. The authors would also like to thank Aybuke Cansu Kalkan and Biron Onur Ugut for their help of the shooting proper images.

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Appendix 1. Intra-rater reliability of ultrasonographic muscle thickness measurement in the CNP group.

	Resting			ADIM			Resting with ADNF			ADIM with ADNF		
Muscle	ICC	SEM	MDD	ICC	SEM	MDD	ICC	SEM	MDD	ICC	SEM	MDD
TrA	0.99	0.005	0.013	0.95	0.019	0.052	0.99	0.007	0.019	0.93	0.015	0.041
IO	0.99	0.001	0.002	0.96	0.021	0.057	0.99	0.012	0.033	0.90	0.021	0.057

Abbreviation: ADIM, Abdominal draw-in; ADNF, Activation of deep neck flexors; ICC, Intraclass correlation coefficient; SEM, Standard error of measurement; MDD; Minimum detectable change; TrA, Transversus abdominis; IO, Internal oblique.

Appendix 2. Intra-rater reliability of ultrasonographic muscle thickness measurement in the asymptomatic group.

	Resting			ADIM			Resting with ADNF			ADIM with ADNF		
Muscle	ICC	SEM	MDD	ICC	SEM	MDD	ICC	SEM	MDD	ICC	SEM	MDD
TrA	0.98	0.008	0.022	0.98	0.013	0.035	0.99	0.007	0.019	0.98	0.015	0.041
IO	0.97	0.028	0.077	0.99	0.020	0.055	0.99	0.016	0.044	0.99	0.022	0.060

Abbreviation: ADIM, Abdominal draw-in; ADNF, Activation of deep neck flexors; ICC, Intraclass correlation coefficient; SEM, Standard error of measurement; MDD; Minimum detectable change; TrA, Transversus abdominis; IO, Internal oblique.