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RESEARCH

# Muscle elasticity and thickness of the sternocleidomastoid and transversus abdominis in patients with chronic non-specific neck pain and cervical hypolordosis: an ultrasound elastography study

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## Abstract

**Background** Chronic non-specific neck pain (CNP) may extends beyond the cervical region, affecting trunk stability through altered function of the transversus abdominis (TrA). Biomechanical links suggest an interaction between the TrA and sternocleidomastoid (SCM) muscles in maintaining spinal stability. This study aimed to assess SCM and TrA elasticity using shear-wave elastography in individuals with CNP due to cervical hypolordosis and examine their associations with pain, disability, and physical activity.

**Methods** A cross-sectional observational study was conducted to investigate the relationship between sternocleidomastoid (SCM) and transversus abdominis (TrA) muscle properties using shear-wave elastography (SWE) in individuals with chronic neck pain and asymptomatic controls. Twenty patients with cervical hypolordosis and 21 matched asymptomatic individuals were included. Demographic data, pain intensity (VAS), disability (Neck Pain and Disability Scale), and physical activity levels (IPAQ) were recorded. Muscle thickness and elasticity were measured in resting supine positions with SWE. Elastic modulus was calculated from shear wave velocity ($E = 3 \cdot \rho \cdot SWV^2$). Group comparisons were performed using independent t-tests or the Mann–Whitney U test, and Pearson correlation analyses explored the associations between muscle properties and clinical outcomes. Statistical significance was set at $p < 0.05$.

**Results** Groups were similar in demographic characteristics. Compared with controls, the CNP group demonstrated significantly greater TrA thickness (0.32 ± 0.03 vs. 0.28 ± 0.05 cm, $p = 0.03$) and higher TrA elasticity (12.99 ± 0.42 vs. 12.06 ± 1.06 kPa, $p = 0.001$), while SCM parameters did not differ between groups. Correlation analyses revealed that TrA thickness and elasticity were positively associated with IPAQ, whereas TrA elasticity showed a moderate negative correlation with VAS ($r = -0.50$) and NPDS ($r = -0.55$), and a moderate positive correlation with IPAQ ($r = 0.52$). No significant correlations were observed for SCM parameters.

**Conclusion** Individuals with chronic non-specific neck pain exhibit altered transversus abdominis thickness and elasticity, which are associated with physical activity, pain, and disability, while sternocleidomastoid characteristics remain unaffected. These findings emphasize the potential of core stabilization training in managing chronic neck pain with hypolordosis.


**Keywords** Ultrasound elastography · Cervical hypolordosis · Transversus abdominis · Sternocleidomastoideus · Chronic non-specific neck pain

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## Introduction

Chronic non-specific neck pain (CNP) is a prevalent health problem that significantly reduces health-related quality of life [1]. Approximately 70% of individuals experience neck problems at some point in their lives, and 10–40% report neck pain annually due to various factors [2, 3]. Furthermore, 10–15% of individuals develop chronic neck pain persisting for more than six months. Among individuals

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over 40, approximately 20% report neck pain, and 5% experience pain that significantly limits daily activities [4]. Weerakoon et al. [5] found that hypolordosis was detected in 44.9% of patients with chronic neck pain and in 12.3% of individuals without neck pain.

Recent research indicates that dysfunction in CNP may extend beyond the cervical region to involve the trunk [6]. Specifically, studies have reported altered transversus abdominis (TrA) function in individuals with CNP, characterized by reduced muscle thickness and impaired activation during abdominal draw-in maneuvers [7]. From an anatomical perspective, the cervical, thoracic, and lumbar regions of the spine are interlinked in terms of structure and function [8]. Activation of the TrA provides core and trunk stability, enabling the sternocleidomastoideus (SCM) to regulate head and cervical positioning more effectively. Conversely, alterations in SCM activity may increase the demand on the TrA to maintain spinal stability [9]. Due to this interconnection, mechanical dysfunction in the thoracic spine may lead to compensatory changes in the cervical spine and vice versa [10]. Supporting this concept, Treleaven et al. [11] reported increased thoracic stiffness as a compensatory mechanism for neck pain, along with a reduction in the speed of head-body coordination movements, such as thoracic rotation. Similarly, Kang et al. [12] stated that a reduced cranio-vertebral angle due to forward head posture was significantly associated with reduced TrA thickness. Yalcinkaya Colak et al. [13] emphasized that trunk muscle endurance should be considered when designing interventions for CNP to effectively address pain and disability. Yalcinkaya et al. [14] further revealed that there is a moderate relationship between the thickness of the TrA muscle, particularly during the abdominal draw-in maneuver, and pain pressure thresholds of the upper trapezius.

Shear-wave elastography (SWE) is an ultrasound-based imaging technique that quantitatively evaluates tissue stiffness by measuring shear wave velocity (SWV), expressed as elasticity in kilopascals [15]. SWE reflects the mechanical properties of soft tissues and may complement traditional ultrasound measures such as muscle thickness by providing information on tissue stiffness and viscoelastic behavior [16]. Increased muscle stiffness on SWE is represented by higher shear wave velocity (m/s) or elasticity (kPa) values, indicating greater resistance of the tissue to deformation [17].

Despite evidence of functional interdependence between cervical and trunk muscles in postural control, to the best of our knowledge, no previous studies have sequentially quantified the mechanical properties of the SCM and TrA muscles using SWE in individuals with CNP due to hypolordosis. Additionally, the potential associations between these mechanical properties and clinical outcomes such as pain, disability, and physical activity levels remain unexplored. This study aimed to investigate the elasticity and thickness of the SCM and TrA muscles in individuals with chronic non-specific neck pain, and to explore their associations with pain, disability, and physical activity. We hypothesized that individuals with cervical hypolordosis-related CNP would show altered SCM and TrA elasticity and thickness compared to controls, as compensatory activation of the TrA may occur to maintain trunk stability when cervical alignment and muscle efficiency are impaired.

## Materials and methods

This cross-sectional observational study adhered to the STROBE (STrengthening the Reporting of OBservational studies in Epidemiology) [18] to ensure an appropriate level of methodological quality and transparency. The study protocol, including ethical considerations and participants' rights, was reviewed and approved by the Non-Interventional Clinical Research Ethics Committee of İstanbul Medipol University (Approval No: 10840098-604.01.01.01.01-E.10301) prior to data collection.

### Participants

Patients presenting with neck pain and diagnosed with cervical hypolordosis by a radiologist at the İstanbul University, together with asymptomatic controls without cervical hypolordosis, were recruited and evaluated at the Sports Medicine Outpatient Clinic of İstanbul University between May and August 2017.

The study included individuals who experienced pain between the C1 and T1 cervical vertebrae, reported stiffness or tightness in the neck region, were diagnosed with cervical hypolordosis, had measurable bilateral transversus abdominis muscle thickness via ultrasound, demonstrated no cognitive or psychological impairments affecting comprehension, and voluntarily provided informed consent.

Exclusion criteria, identified through participant interviews and medical record reviews, included a history of cervical surgery, progressive neurological deficits, fractures, cancer, infections, systemic diseases, a history of abdominal surgery, torticollis, radiculopathy, or cervical disc herniation.

### Sample size estimation

The sample size calculation was conducted to ensure sufficient statistical power for detecting significant differences between the control and CNP groups. Based on previous ultrasound elastography studies assessing muscle mechanical properties in neck pain populations [19] an expected effect size of 0.81 was used, corresponding approximately to a minimum detectable difference of 0.25–0.30 cm in muscle thickness and 0.5–0.7 m/s in elasticity values between groups. With a significance level (alpha) of 0.05 and a desired power of 80%, the analysis indicated that at least 20 participants per group (40 total) would be required to detect such differences reliably, thereby minimizing the risk of Type II errors.

## Outcome measurements

### Demographic and clinical data

All participants completed a standardized form to collect demographic and clinical data, including age (years), height (cm), and weight (kg), from which body mass index (BMI) was later calculated for analysis. Pain intensity was assessed using the Visual Analog Scale (VAS), a valid and reliable tool consisting of a 100 mm horizontal or vertical line with endpoints labeled 0 (no pain) and 100 (worst possible pain) [20]. Participants were asked to mark a point on the line corresponding to the pain they were experiencing, and the distance from the zero end to the marked point was measured in millimeters to quantify pain intensity, which was then converted to centimeters. Functional disability was evaluated using the Neck Pain and Disability Scale (NPDS), originally developed by Wheeler et al. [21] and validated in Turkish by Biçer et al. in 2004 [22]. Additionally, participants' health-related physical activity levels were assessed using the International Physical Activity Questionnaire (IPAQ), which evaluates physical activity across five domains to provide a comprehensive activity score [23].

### Ultrasonographic evaluation of muscle thickness and elasticity

Shear Wave Elastography (SWE) was used to evaluate the mechanical properties of muscles (Toshiba Aplio 500, SuperCurved 6 − 1, SuperSonic Imagine, Aix-en-Provence, France). Before measurements, patients were positioned comfortably and asked to maintain this position for 10 min to allow their muscles to relax. For SCM muscle measures, participants were positioned supine with a pillow beneath their heads, slightly extended, and minimally rotated to the contralateral side. The probe was placed in the midpoint of the SCM muscle at an angle of approximately 45° in the longitudinal plane. For TrA muscle measurements, participants were positioned in the supine hook-lying position, that is, lying supine with the hips and knees flexed at approximately 90°, and feet flat on the examination table to ensure abdominal relaxation and minimize compensatory activation of the trunk muscles [24]. The TrA muscle was visualized by positioning the probe transversely along the midline between the sacrococcygeal prominence and the lower ribs, with the probe's anterior superior iliac spine (ASIS) located at the lateral third of the line between the ASIS and the umbilicus. Muscle thickness was assessed during exhalation at rest. Three measurements were taken from the right side for standardization, as previous reliability studies have shown minimal side-to-side differences in TrA thickness among healthy and symptomatic individuals [25]. None of the CNP participants presented unilateral pain symptoms; therefore, the right side was selected for consistency. Similarly, SCM measurements were performed unilaterally on the right side following the same rationale. Muscle thickness was determined as the vertical distance between the inner and outer fascial borders in B-mode [26]. In SWE mode, shear wave velocity (m/s) was measured by placing the region of interest in the middle of the muscle and maintaining a constant probe position until a homogeneous color map was obtained. The elasticity of the muscles was calculated from the shear wave velocity measurements using the formula $E = 3 \cdot \rho \cdot (SWV)2$ ($\rho \approx 1000$ kg/m³), and expressed in kilopascals (kPa) [27].

## Statistical analysis

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 22.0 (Lead Technologies Inc., SPSS Inc., Chicago, IL, USA). Descriptive statistics were presented as means, standard deviations, and percentages, as appropriate. The normality of data distribution for all variables, including sternocleidomastoid (SCM) and transversus abdominis (TrA) muscle thickness, elasticity, pain intensity, disability scores, and physical activity levels, was assessed using the One-Sample Kolmogorov–Smirnov test. A p-value greater than 0.05 was interpreted as normally distributed data, whereas $p < 0.05$ indicated non-normal distribution. For comparisons between the chronic non-specific neck pain (CNP) group and the control group, the Independent Samples t-test was used for normally distributed data, and the Mann–Whitney U test was applied for non-normally distributed data. Correlation analyses were conducted to explore the relationships between the mechanical properties of the SCM and TrA muscles and clinical variables, including pain intensity (VAS), disability (NPDS), and physical activity levels (IPAQ). Pearson's correlation coefficients were used for normally distributed variables, while Spearman's rank correlation coefficients were applied for non-normally distributed variables to ensure analytical robustness. The strength of correlations was interpreted as follows: 0.00–0.10 = negligible, 0.10–0.39 = weak, 0.40–0.69 = moderate, 0.70–0.89 = strong, and 0.90–1.00 =

**Table 1** Demographic characteristics and neck pain manifestations

| Variables | CNP ($n$=20) Mean±SD | Control ($n$=21) Mean±SD |
|---|---|---|
| Age (year) | 28±6,39 | 26,76±6,46 |
| Height (cm) | 170,2±6,81 | 169,5±7,12 |
| Weight (kg) | 71,4±9,32 | 69,8±8,53 |
| BMI (kg/m$^2$) | 24,7±3,16 | 24,2±2,94 |
| Sex (Female) | 12 (60%) | 13 (61,9%) |
| Intensity of neck pain (VAS) | 5.50±1.31 | 0.57±1.16 |
| Duration of pain (months) | 4,5±1,2 | Not applicable |
| NPDS (score) | 56.50±12.91 | 5.57±12.37 |
| IPAQ (MET-min/week) | 564.10±103.29 | 541.96±41.30 |

CNP: chronic non-spesific neck pain; SD: standard deviation; BMI: body mass index; VAS: visual analog scale; NPDS: neck pain and disability scale; IPAQ: international physical activity questionnaire; MET: metabolic equivalent task

very strong. Effect sizes (Cohen's d) were also calculated to quantify the magnitude of between-group differences, providing a measure of practical significance beyond p-values. According to Cohen's conventional thresholds, d values of 0.2, 0.5, and 0.8 represent small, medium, and large effects, respectively. A significance level of $p < 0.05$ was considered statistically significant for all analyses [28].

## Results

### Demographic information and clinical data

Forty-one participants were involved in the study, including 20 individuals with CNP (mean age: 28.00±6.39 years, BMI: 24.70±3.10 kg/m²) and 21 asymptomatic controls (mean age: 26.76±6.46 years, BMI: 24.20±2.90 kg/m²). The mean pain intensity for the last week in the CNP group was 5.50±1.32 cm according to the VAS, with an average neck pain duration of 4.5±1.2 years. All demographic characteristics and clinical findings of the participants are summarized in Table 1.

**Table 2** Comparison of SCM and TrA muscle parameters between groups

| Muscle/parameter | CNP ($n$=20) Mean±SD | Control ($n$=21) Mean±SD | $p$ | Cohen's d |
|---|---|---|---|---|
| SCM/thickness (cm) | 1.08±0.26 | 1.13±0.67 | 0.29 | 0.31 |
| SCM/elasticity (kPa) | 20.33±2.64 | 20.98±3.57 | 0.51 | 0.19 |
| TrA/thickness (cm) | 0.32±0.03 | 0.28±0.05 | **0.03** | 0.49 |
| TrA/elasticity (kPa) | 12.99±0.42 | 12.06±1.06 | **0.01** | 0.90 |

CNP: chronic non-spesific neck pain; SD: standard deviation; SCM: sternocleidomastoideus muscle; TrA: transversus abdominis

### Evaluation of SCM and transversus abdominis

In total, 20 participants with CNP and 21 asymptomatic controls were assessed for muscle thickness and elasticity of the SCM and TrA muscles. No significant differences were found between groups for SCM parameters ($p$>0.05). The CNP group demonstrated significantly greater TrA thickness (mean difference=0.04 cm, 95% CI: 0.01–0.07, $p$=0.032, d=0.49, medium effect) and higher TrA elasticity (mean difference=0.93 kPa, 95% CI: 0.42–1.44, $p$=0.001, d=0.90, large effect) compared to the control group. No significant between-group differences were observed for SCM parameters (all $p$>0.05). Adjusted analyses controlling for BMI and physical activity level yielded similar results, indicating that these variables did not substantially confound the associations. Physical activity was analyzed as a continuous variable (MET-min/week) to preserve statistical power (Table 2).

Correlation analyses (Pearson or Spearman) revealed no significant associations between SCM parameters and clinical outcomes. In contrast, TrA parameters demonstrated significant relationships. TrA thickness was positively correlated with TrA elasticity and IPAQ, while TrA elasticity was positively correlated with IPAQ but negatively correlated with VAS and NPDS. Additionally, a strong positive correlation was observed between VAS and NPDS scores (Fig. 1) (Table 3).

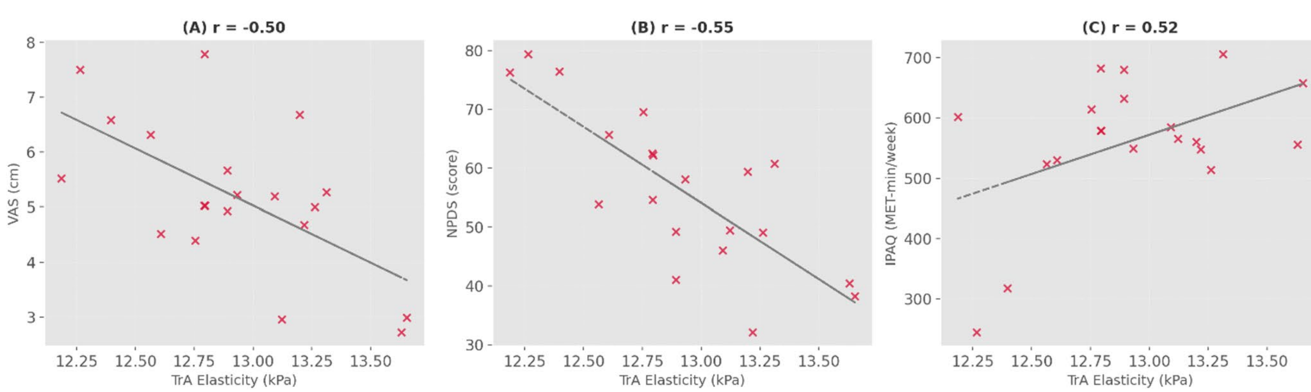


**Fig. 1** Correlation between TrA elasticity and clinical outcomes

**Table 3** Correlations between muscle parameters and clinical outcomes

| Variables | SCM thickness | SCM elasticity | TrA thickness | TrA elasticity | VAS | NPDS | IPAQ |
|---|---|---|---|---|---|---|---|
| SCM/thickness | 1 | | | | | | |
| SCM/elasticity | 0.21 | 1 | | | | | |
| TrA/thickness | 0.15 | 0.12 | 1 | | | | |
| TrA/elasticity | 0.10 | 0.14 | **0.52*** | 1 | | | |
| VAS | 0.05 | 0.10 | −0.38 | **−0.50*** | 1 | | |
| NPDS | 0.08 | 0.12 | −0.42 | **−0.55*** | **0.85**** | 1 | |
| IPAQ | −0.12 | −0.15 | **0.45*** | **0.52*** | −0.45 | −0.50 | 1 |

SCM: sternocleidomastoideus muscle; TrA: transversus abdominis; VAS: visual analog scale; NPDS: neck pain and disability scale; IPAQ: international physical activity questionnaire. Correlation coefficients were computed using Pearson or Spearman tests, depending on the normality of data distribution. $p<0.05$ was considered significant. *$p<0.05$; **$p<0.01$

## Discussion

The present study investigated the elasticity of the SCM and TrA muscles using shear-wave elastography in individuals with CNP associated with cervical hypolordosis, and examined their relationships with pain, disability, and physical activity. This study demonstrated that individuals with chronic non-specific neck pain and cervical hypolordosis exhibited significantly increased TrA thickness and elasticity compared with asymptomatic controls, while no significant differences were found in SCM parameters. Furthermore, TrA thickness showed positive correlations with TrA elasticity and physical activity levels, while TrA elasticity correlated positively with physical activity levels and negatively with pain intensity and disability scores. In addition, a strong positive correlation was found between pain intensity and disability scores, indicating that greater pain intensity was associated with higher functional disability. The medium to large effect sizes and narrow 95% confidence intervals suggest that these differences are both statistically robust and clinically relevant.

A previous study reported that hypolordosis may cause elongation of the SCM muscle, thereby altering its length–tension relationship and decreasing its mechanical efficiency in cervical stabilization [29]. This maladaptive elongation compromises the force-generating capacity of the muscle and diminishes its contribution to maintaining cervical posture [30]. Although no significant differences were found in SCM elasticity or thickness, the lack of change in SCM parameters may reflect limited mechanical adaptation of this muscle in CNP. This finding suggests that TrA alterations, rather than SCM changes, may play a more dominant role in compensatory postural strategies among individuals with cervical hypolordosis [31–34]. The observed decrease in elasticity in the CNP group may be related to postural alterations potentially associated with cervical hypolordosis; however, this interpretation should be made cautiously since hyperlordosis was not examined in this study.

The TrA plays a pivotal role in spinal stability by regulating intra-abdominal pressure and transmitting force to the lumbar spine via the thoracolumbar fascia [35]. Enhanced TrA activity in the presence of pain suggests a compensatory mechanism aimed at improving core stability and maintaining postural control in the presence of cervical dysfunction [36]. In our study, the TrA muscle demonstrated increased thickness and elasticity in the CNP group compared with asymptomatic controls. The positive correlation between TrA thickness and elasticity, and IPAQ scores, further supports the functional importance of TrA activation in maintaining activity levels despite chronic pain. Importantly, these associations remained significant after adjusting for body mass index and physical activity level, indicating that the observed alterations in TrA mechanical properties are unlikely to be confounded by these variables. Moreover, the negative correlations between TrA elasticity and both pain and disability scores, together with the positive association with physical activity, highlight the clinical importance of maintaining TrA function in individuals with cervical dysfunction. In addition, increased shear-wave velocity observed in the TrA of individuals with CNP highlights an elevated activation level, potentially reflecting heightened recruitment of this deep stabilizing muscle to counteract impaired cervical stability. This finding is consistent with the concept of compensatory activation reported in previous studies on postural control in musculoskeletal disorders [37]. Although TrA inactivity has been frequently reported in sedentary individuals, such as office workers with prolonged static postures, the presence of pain in our cohort appears may reflect compensatory activation of the TrA muscle [38]. This adaptive mechanism may function to maintain cervical and trunk stability under altered neuromuscular conditions caused by CNP due to hypolordosis. These results underline the importance of trunk stabilization assessment and training in individuals with neck pain associated with altered cervical alignment.

Our findings highlight the complex neuromuscular interactions and synergistic patterns between cervical and core musculature in individuals with CNP. The observed adaptations may represent protective mechanisms; however, they may also predispose patients to maladaptive loading and altered motor control strategies over time. Longitudinal studies are needed to determine whether these compensatory changes are beneficial adaptations or indicators of dysfunctional motor control that could perpetuate chronic symptoms. Future studies should also aim to evaluate the effects of targeted interventions, such as core stabilization or motor control training, on the structural and mechanical properties of the TrA and SCM muscles in patients with CNP. Additionally, longitudinal designs are warranted to investigate the temporal relationship between changes in cervical posture, muscle adaptations, and clinical outcomes. Understanding these interactions may contribute to the development of individualized rehabilitation strategies that aim to optimize neuromuscular control, reduce pain, and enhance functional recovery in individuals with chronic neck pain.

A notable strength of this study is the use of SWE, which enables quantitative evaluation of muscle mechanical properties. However, the absence of intra-rater reliability analysis and ICC calculation represents an important methodological limitation that should be addressed in future research. In addition, it has several limitations that should be acknowledged. First, the cross-sectional design restricts the ability to establish causal relationships between the observed changes in muscle characteristics and clinical symptoms such as pain intensity, disability, and physical activity levels. Second, cervical hypolordosis was identified based on X-ray findings, which may not reflect the dynamic nature of cervical curvature. Moreover, ultrasound elastography is operator-dependent and can be affected by technical factors such as probe pressure and participant positioning. Intra-rater reliability of the SWE measurements, including the calculation of intraclass correlation coefficients (ICCs), was not assessed, which should be considered an important methodological limitation. Third, functional assessments of the muscles, such as electromyographic activity during dynamic tasks or endurance testing, were not performed, limiting the interpretation of whether the increased TrA thickness and elasticity in the CNP group represent functional adaptations or passive stiffness due to hypertonicity. Fourth, the sample consisted mainly of young adults, which limits generalizability to older populations. Finally, the proposed adaptive mechanism suggesting that altered SCM and TrA properties may contribute to maintaining cervical and trunk stability under neuromuscular conditions associated with CNP due to hypolordosis remains speculative and was not directly tested in this study. Future research with larger, more diverse cohorts, longitudinal designs, and the inclusion of functional and kinematic analyses is recommended to provide deeper insights into the neuromuscular adaptations and their clinical relevance in individuals with CNP.

## Conclusion

This study found no significant differences in SCM elasticity between individuals with CNP and controls; however, the CNP group showed greater TrA thickness and elasticity compared to the control group. These findings may indicate that reduced SCM efficiency and increased TrA activity could reflect a possible compensatory strategy aimed at supporting postural stability and core control in individuals with altered cervical alignment. Furthermore, the significant correlations observed between TrA properties, pain intensity, disability, and physical activity highlight the multifactorial interactions between muscle morphology, function, and clinical symptoms in CNP. Effect sizes indicated that the differences in TrA thickness and elasticity were of medium to large magnitude, highlighting their clinical relevance.

**Author contributions** Ömer Faruk Özçelep: Conceptualization, Methodology, Data Collection, Formal Analysis, Writing—Original Draft, Visualization. Mustafa Gülcan: Supervision, Methodology, Validation, Writing—Review & Editing. Mustafa Şahin: Resources, Clinical Evaluation, Data Verification, Writing—Review & Editing. All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

**Data availability** No datasets were generated or analysed during the current study.

## Declarations

**Competing interests** The authors declare no competing interests.

## References


1. Cerezo-Téllez E, Torres-Lacomba M, Mayoral-del-Moral O, Pacheco-da-Costa S, Prieto-Merino D, Sánchez-Sánchez B (2018) Health related quality of life improvement in chronic non-specific neck pain: secondary analysis from a single blinded, randomized clinical trial. Health Qual Life Outcomes 16(1):207. https://doi.org/10.1186/s12955-018-1032-6
2. Teo C, Giffard P, Johnston V, Treleaven J (2019) Computer vision symptoms in people with and without neck pain. Appl Ergon 80:50–56. https://doi.org/10.1016/j.apergo.2019.04.010
3. Kazeminasab S, Nejadghaderi SA, Amiri P, Pourfathi H, Araj-Khodaei M, Sullman MJ et al (2022) Neck pain: global epidemiology, trends and risk factors. BMC Musculoskelet Disord 23(1):26
4. Fernández-Gualda MÁ, Postigo-Martin P, Fernandez-Gonzalez M, Martin-Martin L, Vargas-Arrabal P, Lozano-Lozano M et al (2025) Prevalence and characteristics of persistent pain among head and neck cancer survivors: a systematic review and meta-analysis. Pain Med pnaf051. https://doi.org/10.1093/pm/pnaf051
5. Weerakoon TCS, Dissanayake PH, Weerasekera MM, Jayakody S, Abeywickrama BN, Yasawardene SG (2022) Chronic neck pain and its association with the angle of the cervical curve. Sri Lanka Anat J. https://doi.org/10.4038/slaj.v6i2.163

6. O'Leary S, Falla D, Elliott JM, Jull G (2009) Muscle dysfunction in cervical spine pain: implications for assessment and management. J Orthop Sports Phys Ther 39(5):324–333
7. Yalcinkaya G, Ozyurek S, Kalemci O, Sengul YS (2022) Comparison of ultrasonographic characteristics of deep abdominal muscles in women with and without chronic neck pain: a case-control study. J Musculoskelet Neuronal Interact 22(1):52–58
8. Bogduk N (2016) Functional anatomy of the spine. Handb Clin Neurol 136:675–688. https://doi.org/10.1016/B978-0-444-53486-6.00032-6
9. Myers TW, Hillman SK (2004) Anatomy Trains. Primal Pictures Ltd.
10. Joshi S, Balthillaya G, Neelapala YR (2019) Thoracic posture and mobility in mechanical neck pain population: a review of the literature. Asian Spine J 13(5):849–857. https://doi.org/10.31616/asj.2018.0302
11. Treleaven J, Takasaki H, Grip H (2019) Altered trunk–head coordination in those with persistent neck pain. Musculoskelet Sci Pract 39:45–50. https://doi.org/10.1016/j.msksp.2018.11.010
12. Kang KW, Kwon YH, Son SM (2021) Ultrasound measurement of the transverse abdominis, internal oblique, and external oblique muscles associated with forward head posture and reduced cranio-vertebral angle. Med Sci Monit 27:e928987. https://doi.org/10.12659/MSM.928987
13. Colak GY, Kirmizi M, Sengul YS, Kalemci O, Angin S (2025) Comparison of trunk muscle endurance between women with and without chronic neck pain. Pain Manag Nurs 26(1):e82–e87. https://doi.org/10.1016/j.pmn.2024.08.002
14. Yalcinkaya G, Sengul YS, Ozyurek S, Kirmizi M, Kalemci O (2021) Is the pain pressure threshold linked to the transversus abdominis in women with chronic neck pain? A preliminary report. Somatosens Mot Res 38(2):133–139. https://doi.org/10.1080/08990220.2021.1879776
15. Oglat AA, Abukhalil T (2024) Ultrasound elastography: methods, clinical applications, and limitations: a review article. Appl Sci 14(10):4308. https://doi.org/10.3390/app14104308
16. Blank J, Blomquist M, Arant L, Cone S, Roth J (2022) Characterizing musculoskeletal tissue mechanics based on shear wave propagation: a systematic review of current methods and reported measurements. Ann Biomed Eng 50(7):751–768. https://doi.org/10.1007/s10439-022-02935-y
17. Alfuraih AM, Tan AL, O'Connor P, Emery P, Wakefield RJ (2019) The effect of ageing on shear wave elastography muscle stiffness in adults. Aging Clin Exp Res 31(12):1755–1763. https://doi.org/10.1007/s40520-019-01139-0
18. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP, STROBE Initiative (2008) The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. J Clin Epidemiol 61(4):344–349. https://doi.org/10.1016/j.jclinepi.2007.11.008
19. Dieterich AV et al (2020) Neck muscle stiffness measured with shear wave elastography in women with chronic nonspecific neck pain. J Orthop Sports Phys Ther 50(4):179–188. https://doi.org/10.2519/jospt.2020.8821
20. Boonstra AM, Preuper HRS, Balk GA, Stewart RE (2014) Cut-off points for mild, moderate, and severe pain on the visual analogue scale for pain in patients with chronic musculoskeletal pain. Pain 155(12):2545–2550. https://doi.org/10.1016/j.pain.2014.09.014
21. Goolkasian P, Wheeler AH, Gretz SS (2002) The neck pain and disability scale: test–retest reliability and construct validity. Clin J Pain 18(4):245–250. https://doi.org/10.1097/00002508-200207000-00005
22. Bicer A, Yazici A, Camdeviren H, Erdogan C (2004) Assessment of pain and disability in patients with chronic neck pain: reliability and construct validity of the Turkish version of the neck pain and disability scale. Disabil Rehabil 26(16):959–962. https://doi.org/10.1080/09638280410001696755
23. Hallal PC, Victora CG (2004) Reliability and validity of the international physical activity questionnaire (IPAQ). Med Sci Sports Exerc 36(3):556–562. https://doi.org/10.1249/01.mss.0000117161.66394.07
24. Teyhen DS, Gill NW, Whittaker JL, Henry SM, Hides JA, Hodges P (2007) Rehabilitative ultrasound imaging of the abdominal muscles. J Orthop Sports Phys Ther 37(8):450–466. https://doi.org/10.2519/jospt.2007.2558
25. Gnat R, Saulicz E, Miądowicz B (2012) Reliability of real-time ultrasound measurement of transversus abdominis thickness in healthy trained subjects. Eur Spine J 21(8):1508–1515. https://doi.org/10.1007/s00586-012-2184-4
26. Aktar B, Ozyurek S, Goz E, Colakoglu BD, Balci B (2023) The relationship between transversus abdominis and internal oblique thickness and disease-related characteristics in Parkinson's disease: an ultrasound-based study. Neurol Sci 40(1):9–14. https://doi.org/10.4103/nsn.nsn_97_22
27. Cortez CD, Hermitte L, Ramain A, Mesmann C, Lefort T, Pialat J (2016) Ultrasound shear wave velocity in skeletal muscle: a reproducibility study. Diagn Interv Imaging 97(1):71–79. https://doi.org/10.1016/j.diii.2015.05.010
28. Schober P, Boer C, Schwarte LA (2018) Correlation coefficients: appropriate use and interpretation. Anesth Analg 126(5):1763–1768. https://doi.org/10.1213/ANE.0000000000002864
29. Park JH, Lim OB (2022) Relationship between the craniovertebral angle, cervical lordosis, and cervical muscles. Korean Soc Phys Med 17(1):40–48. https://doi.org/10.13066/kspm.2022.17.1.41
30. Berberoğlu U, Fanuscu A, Öz M, Aslıyüce YÖ, Onan D (2023) Association between forward head posture, sternocleidomastoid muscle thickness, and body composition in individuals with forward head posture. Gait Posture 106:S26–S27. https://doi.org/10.1016/j.gaitpost.2023.07.035
31. Loturco I, Pereira LA, Kobal R, Kitamura K, Ramírez-Campillo R, Zanetti V et al (2016) Muscle contraction velocity: a suitable approach to analyze the functional adaptations in elite soccer players. J Sports Sci Med 15(3):483–490 PMID: 27803627
32. Iliopoulos F, Dimitriadis Z, Koumantakis GA (2022) Electromyographic activity of sternocleidomastoid muscle in individuals with neck pain and healthy volunteers: a reliability and between-group differences examination. J Manipulative Physiol Ther 45(6):459–468. https://doi.org/10.1016/j.jmpt.2022.09.001
33. Strasser EM, Draskovits T, Praschak M, Quittan M, Graf A (2013) Association between ultrasound measurements of muscle thickness, pennation angle, echogenicity and skeletal muscle strength in the elderly. Age 35(6):2377–2388. https://doi.org/10.1007/s11357-013-9517-z
34. Yoon SY, Moon HI, Lee SC, Eun NL, Kim YW (2018) Association between cervical lordotic curvature and cervical muscle cross-sectional area in patients with loss of cervical lordosis. Clin Anat 31(5):710–715. https://doi.org/10.1002/ca.23074
35. El Bojairami I, Driscoll M (2022) Coordination between trunk muscles, thoracolumbar fascia, and intra-abdominal pressure toward static spine stability. Spine 47(9):E423–E431. https://doi.org/10.1097/BRS.0000000000004223
36. Mendes-Fernandes T, Puente-González AS, Márquez-Vera MA, Vila-Chã C, Méndez-Sánchez R (2021) Effects of global postural reeducation versus specific therapeutic neck exercises on pain, disability, postural control, and neuromuscular efficiency in women with chronic nonspecific neck pain: study protocol for a randomized, parallel, clinical trial. Int J Environ Res Public Health 18(20):10704. https://doi.org/10.3390/ijerph182010704
37. Knox MF, Chipchase LS, Schabrun SM, Romero RJ, Marshall PW (2018) Anticipatory and compensatory postural adjustments

in people with low back pain: a systematic review and meta-analysis. Spine J 18(10):1934–1949. https://doi.org/10.1016/j.spinee.2018.06.008

38. Guduru RKR, Domeika A, Obcarskas L, Ylaite B (2022) The ergonomic association between shoulder, neck/head disorders and sedentary activity: a systematic review. J Healthc Eng 2022:5178333. https://doi.org/10.1155/2022/5178333