Original

# Elastic Modulus of Suboccipital Muscles, Cervical Range of Motion, and Forward Head Posture in Cervicogenic Headache

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## ABSTRACT

**Background:** Although stiffness of neck muscles, the limitation of cervical range of motion (ROM), and forward head posture (FHP) are proposed as clinical characteristics of cervicogenic headache (CGH), adequate consistent data failed to support these characteristics.

**Objective:** This study aims to compare the elastic modulus of suboccipital muscles, cervical ROM, and FHP between individuals suffering from CGH and healthy controls.

**Material and Methods:** In this cross-sectional study, 20 individuals with a history of CGH and 20 normal individuals participated. Sonography images and a universal goniometer (UG) were used to assess elastic modulus and cervical ROM, respectively. In addition, FHP was assessed based on measuring craniovertebral angle (CVA) using a digital imaging technique and also the distance of anterior tragus of the ear with the vertical line passed from anterior of lateral malleolus according to the Kendall and McCreary method.

**Results:** Elastic modulus of suboccipital muscles in the CGH group was significantly higher than that of the normal group (*P*=0.008). The two groups were not significantly different in terms of FHP. Moreover, ROM of cervical extension (*P*=0.035), right rotation (*P*=0.046), and left rotation (*P*=0.018) showed a significant reduction in the CGH group compared to the control group.

**Conclusion:** Suboccipital muscles are stiffer and ROM of cervical rotation and extension is smaller in CGH patients than the healthy controls, but FHP is not different between the groups, leading to diagnosing CGH and treatment.

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## Keywords

Headache; Elastic Modulus; Motion; Posture

## Introduction

Cervicogenic headache (CGH) is one of the most common types of headache affecting about 2.5% of the general population and also observed more frequently among middle-aged patients especially in women; in addition, 17.8% of people complain about frequent headaches [1].

The cervical spine is considered a referral site for the pain experienced by CGH patients, considered chronic and manifested as unilateral cephalgia that may be developed due to musculoskeletal problems in the neck. Pain is transferred from the cervical spine to the face and then to the head by sensory fibers in the upper three cervical spinal nerves when

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converged with the trigeminal nerve located at the trigeminocervical nucleus. The spinal accessory nerve is assumed to affect by this pain referral mechanism. Accordingly, before reaching the descending tract of the trigeminal nerve, spinal accessory nerve fibers are connected to the nerve roots of the upper cervical spine [1-3].

Elastic modulus is an indicator of the stiffness of the tissue, used as an index for showing the number of attached cross-bridges [4]. Cervical pain in CGH can lead to increased neutrally mediated reflex stiffness in cervical muscles by influencing alpha-motor neurons. Enhanced stimulation of these neurons can increase the frequency of attached cross-bridges in the actin and myosin filaments of these muscles [5].

According to the muscle mechanics theory, the intensity of stiffness in a joint partly depends on the internal spring-like stiffness of the muscles attached to that joint [6], i.e. increased stiffness of cervical muscle can reduce the range of motion (ROM) in the cervical region in CGH patients [7].

Thus, based on the mechanism of CGH, some authors have proposed increased stiffness of neck muscles and restricted cervical ROM as clinical characteristics of CGH [1, 8, 9].

Forward head posture (FHP) is excessive anterior positioning of the head compared to a vertical reference line [10]. Quek et al. showed that higher FHP correlated with more deficits in cervical ROM and confirmed that treating FHP can lead to improving cervical impairments [11]. Cervical impairment and ROM limitation are proposed as characteristics of CGH. Therefore, FHP may be a prevalent abnormal posture among CGH patients, causing or aggravating CGH [12]. Watson et al. found that FHP is more common in CGH patients than normal subjects [13]. However, Zito et al. showed that FHP is not a prevalent abnormal posture among CGH patients [14].

Although stiffness of neck muscles, limited cervical ROM, and FHP are proposed as clinical characteristics of CGH [1, 8, 9, 12], only one study (Park et al.) addressed the elastic modulus of neck muscles in CGH patients [15]. Moreover, previous studies on cervical ROM [16-19] and FHP in CGH patients have reported controversial results. Thus, this study aimed to compare the elastic modulus of suboccipital muscles, cervical ROM, and FHP in CGH and normal subjects.

## Material and Methods

In this cross-sectional study, data were collected from 20 CGH patients (15 females and 5 males) and the same number of healthy individuals (14 females, 6 males). The two groups were matched in terms of age, height, weight, and body mass index (BMI). The participant's basic characteristics are shown in the results. CGH patients were selected according to ICHD-2018 criteria for diagnosis of CGH (e.g., Spurling's test in the cervical region leading to headache in these patients). All participants received some information about the objectives, the procedures, and the data collection process was ensured that their identity and information would remain anonymous and signed informed consent to enter the study. This study was conducted based on a research protocol confirmed by the Ethical Committee of Tarbiat Modares University.

### Basic evaluation

Elastic modulus of suboccipital muscles was measured based on elastic modulus equals stress/strain (Hooke's law of elasticity) [20, 21].

Based on the studies, applying compressive force and detecting changes in ultrasound images can be effective for evaluating biomechanical properties of the tissues such as stiffness [22, 23]. Accordingly, in the present study, the following method was used for measuring elastic modulus:

The subject lay prone and a transducer of sonography apparatus (Siemens Medical

Solutions, USA) was placed in the first segment of cervical vertebrae next to the spinous process. To gain elastic modulus, compressive force (F) was applied to the transducer and the images were recorded in two force levels (F1=0N and F2=2N). The strain was determined by measuring the diameter of suboccipital muscles at two force levels (L1 and L2) using image J software according to the equation Strain = (L2-L1)/L1. Stress was determined based on the applied force (F) measured with a force gauge connected to the transducer via a retaining ring made of polylactic acid, according to the equation Stress = F2-F1/S (the area of the transducer) [22, 23].

Previous studies have confirmed the reliability of assessment of mechanical properties of muscles using ultrasonography [24, 25] that is the basis of elastography (ultrasonography signals before and after a distorting force to form an image of the tissue's response by comparing the two signals [26]), whose reliability and validity have been approved by previous studies [27-30]. Moreover, the method used in the present study is widely applied to diagnose malignancies in the liver, prostate, breast, cervix, thyroid, pancreas, and lymph nodes based on the elastic modulus in the tissue. Considering biomechanical variations in neuromuscular and musculoskeletal problems, the technique used in the present study can have clinical applications in musculoskeletal problems [22].

Neck ROM was measured by the universal goniometer (UG), whose reliability has been confirmed by previous studies [31-33]. The cervical ROM measurement was done in a standardized sitting position to eliminate errors and prevent improper movements. The participants were required to sit with their back straightly closed to the back of the chair. The reference points for the placement of UG were determined according to the method proposed by Youdas et al., [33]. To measure flexion and extension, the UG axis was held on the tragus of the ear so that the movable arm was parallel with the base of the nares and the fixed arm was vertical. For side flexion, the UG axis was held on a sternal notch, the stationary arm tracked an imaginary line running from the participant's acromion processes and the movable arm was along the center of the person's nose. For rotation, the axis of UG was placed above the midpoint of the participant's head. The fixed arm of UG followed an imaginary line between the person's acromion processes, while the movable arm was placed along the tip of the person's nose.

FHP was assessed using two methods as follows:

1) Measuring craniovertebral angle (CVA) using a digital imaging technique. The markers used for specifying the landmarks were fixed to C7 (detected by palpation and after excluding C6) and the easily identified tragus of the ear. Lateral photographs were taken from the subjects in the standing posture. The CVA was identified using the image taken from a digital camera at the meeting point of a horizontal line crossing the C7 spinous process and another line connecting the midpoint of the tragus to the skin on the top of the C7 spinous process. In addition, CVA was measured by Image J software whose reliability and validity were confirmed [34]. Measurement of CVA for FHP assessment has been validated in the literature [35, 36].

2) Measuring the distance between the anterior tragus of the ear and the vertical line passed from the anterior lateral malleolus in the sagittal plane according to the Kendall and Mccreary method [37].

### Statistical analysis

The data in this study were processed with SPSS-26 software and the CGH and control groups were statistically compared using the Mann–Whitney U test. Statistical significant level was considered at $P<0.05$.

## Results

Independent T-Test showed that there is no significant differences between the participant's basic characteristics (Table 1).

The elastic modulus of suboccipital muscles in the members of the CGH group was greater than that in the individuals in the normal group, showing a significant difference (*P*=0.008) (Table 2). FHP showed no significant intergroup difference, but ROM of cervical extension (*P*=0.035), right rotation (*P*=0.046), and left rotation (*P*=0.018) were significantly reduced in the CGH group compared to the normal group (Table 2).

## Discussion

In this study, the elastic modulus was used as an indicator of the stiffness of suboccipital muscles that stiffness in muscles was used as an index showing the number of attached cross-bridges [4]. According to previous studies, cervical pain in CGH can increase the number of attached cross-bridges of the actin and myosin filaments and cause spasm and increased stiffness in cervical muscles [5]. Thus, some authors have proposed increased stiffness of neck muscles as a clinical characteristic of CGH [1, 8, 9].

In this study, measuring the elastic modulus of suboccipital muscles showed that they were significantly stiffer in the CGH patients than in normal healthy subjects. In the literature, only one study assessed the elastic modulus of these muscles [15], which its findings supported the results obtained from the present study.

Different methods were used to measure the elastic modulus of tissues: the measuring procedure used by Park et al. involved pressing an oscillatory device against the skin with a force of 0.18 N and an instant impulse of 0.4 N for 15 milliseconds. The skin surface oscillation induced by this device was estimated to verify the value of the mechanical variability [15]. Other devices used to measure the elastic modulus were durometer [38] and shear wave elastography [39]. Although all of these systems were reliable for qualitative assessment and diagnosis of diseases, various quantitative analysis methods are utilized for computing

**Table 1:** The participants' basic characteristics

| | Group | Mean | Std. Deviation | *P*-Value |
|---|---|---|---|---|
| Age | Normal | 30.05 | 7.78 | 0.583 |
| | CGH | 32.00 | 9.31 | |
| Height | Normal | 1.67 | 0.089 | 0.593 |
| | CGH | 1.65 | 0.094 | |
| Weight | Normal | 68.51 | 10.99 | 0.784 |
| | CGH | 70.33 | 16.59 | |
| BMI | Normal | 24.98 | 5.42 | 0.740 |
| | CGH | 30.05 | 7.78 | |

BMI: Body Mass Index, CGH: Cervicogenic Headache

**Table 2:** A comparison between CGH (Cervicogenic Headache) and normal groups

| | Headache | Mean | SD | *P*-Value |
|---|---|---|---|---|
| FHP (CVA) | Normal | 54.60 | 7.34 | 0.738 |
| | CGH | 54.60 | 8.43 | |
| FHP (Ken) | Normal | 4.32 | 1.66 | 0.121 |
| | CGH | 5.09 | 1.11 | |
| Stiffness | Normal | 112.82 | 69.46 | *0.008 |
| | CGH | 269.20 | 270.96 | |
| Flx | Normal | 55.95 | 10 | 0.355 |
| | CGH | 53.40 | 10 | |
| Ext | Normal | 63.05 | 9.20 | *0.035 |
| | CGH | 54.80 | 11.97 | |
| Rsideflx | Normal | 40.25 | 13.17 | 0.738 |
| | CGH | 36.50 | 10.73 | |
| Lsideflx | Normal | 38.40 | 10.75 | 0.862 |
| | CGH | 38.15 | 8.30 | |
| Rrot | Normal | 78.35 | 9.64 | *0.046 |
| | CGH | 72.55 | 9.46 | |
| Lrot | Normal | 76.65 | 8.93 | *0.018 |
| | CGH | 69.65 | 9.82 | |

CGH: Cervicogenic Headache, SD: Standard Deviation, FHP: Forward Head Posture, CVA: Craniovertebral Angle, Ken: Kendall and Mccreary method, Flx: Flexion, Ext: Extension, Rsideflx: Right side flexion, Lsideflx: Left side flexion, Rrot: Right rotation, Lrot: Left rotation

*$P<0.05$

stiffness in these devices. For example, however, shear wave elastography measures the propagation speed of the shear wave, the durometer uses resistance to indentation for stiffness analysis. On the other hand, the resolution is different in these elastography devices. Therefore, the method and device used for measuring the elastic modulus can affect the results, and thus methodological differences should be noticed when comparing the results of different studies [40].

Suboccipital muscles in CGH patients seem stiffer than those in healthy subjects. However, this conclusion needs attesting by more studies with consistent methods of measuring elastic modulus and larger samples.

This study showed that cervical pain increases the stiffness of suboccipital muscles, leading to dysfunction in CGH patients. In this study, therefore, cervical ROM in these patients was assumed to be limited in comparison with normal subjects. Generally, it is proposed that, in chronic pain syndromes, the pain reduces the ROM of painful parts [41]. The findings of this study confirmed this result and showed that ROM of cervical extension ($P$=0.035), right rotation ($P$=0.046), and left rotation ($P$=0.018) in CGH patients were significantly smaller than that in normal subjects. Based on the results of Zwart's study, the patients with CGH were significantly different from healthy normal subjects in terms of rotation ($P$<0.001) and flexion/extension ($P$<0.001), but not in terms of lateral neck movement [17]. Zito et al. showed that CGH patients had a lower cervical range of flexion/extension in comparison with the normal group [18]. Further, Jull et al. reported that active cervical ROM (extension and bilateral rotation) in patients with CGH was significantly different from that of the patients suffering from migraine and tension-type headache and asymptomatic controls [1]. Huber et al. reported that all cervical movements (especially flexion) decreased in CGH patients [1]. However, Hall et al. found no difference between patients with CGH and the normal group in terms of active cervical ROM [19] that their results may have been affected by compensatory movements of other spinal levels. It was presumed that the most limited cervical movements in CGH patients are rotation and extension, but further researches are needed to confirm this conclusion.

Both the Kendall and McCreary method and CVA measurement in this study showed that the FHP variable was not significantly different between CGH patients and normal subjects.

Watson and Trott concluded that FHP was more common in CGH patients compared to other patients [14]. More recently, however, Zito et al. found no significant differences in the prevalence of FHP in CGH or migraine patients in comparison with normal ones [14]. Farmer et al. reported no significant difference in posture between the CGH patients and normal subjects [12].

Different factors can be considered for neck pain in CGH patients and FHP is considered age-related, leading to CGH in older subjects, and the other factors are more common in younger patients [18]. Further researches are needed to compare the FHP of CGH patients in different age groups. However, based on two methods in this study, assessing FHP and confirming the results of this study by most recent studies, FHP cannot be used as a diagnostic criterion for CGH. Thus, although FHP may be related to a decrease in cervical ROM, it is not the prevalent posture in CGH patients and its modification should not be considered as a major and general treatment for CGH.

## Conclusion

According to the data in this study, suboccipital muscles in CGH patients were stiffer and ROM of cervical rotation and extension were smaller in these patients than in the normal group, resulting in diagnosing the CGH and treatment. However, FHP is not the most common posture in CGH patients, this posture cannot be used as a diagnostic criterion for CGH and its modification should not be considered as a major and general treatment for CGH. Further studies should be conducted on larger samples to measure stiffness in CGH patients and compare the results with the data obtained in the present study.

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## Authors' Contribution

F. Bahrpeyma was the supervisor of the project and conceived the original idea. M. Tavakkoli carried out the study and wrote the manuscript. Both of authors read, modified, and approved the final version of the manuscript.

## Ethical Approval

This study was conducted based on a research protocol confirmed by the Ethical Committee of Tarbiat Modares University with the code IR.modares.REC.1397.238.

## Informed Consent

All participants received some information about the objectives, the procedures, and the data collection process was ensured that their identity and information would remain anonymous and signed informed consent to enter the study.

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## Conflict of Interest

None

## References


1. Howard PD, Behrns W, Martino MD, DiMambro A, McIntyre K, Shurer C. Manual examination in the diagnosis of cervicogenic headache: a systematic literature review. *J Man Manip Ther*. 2015;**23**(4): 210-8. doi: 10.1179/2042618614Y.0000000097. PubMed PMID: 26917939. PubMed PMCID: PMC4727734.
2. Martelletti P, Van Suijlekom H. Cervicogenic headache: practical approaches to therapy. *CNS Drugs.* 2004;**18**(12):793-805. doi: 10.2165/00023210-200418120-00004. PubMed PMID:15377169.
3. Biondi DM. Cervicogenic headache: mechanisms, evaluation, and treatment strategies. *J Am Osteopath Assoc.* 2000;**100**(9 Suppl):S7-14. PubMed PMID: 11070659.
4. Ford L, Huxley A, Simmons R. The relation between stiffness and filament overlap in stimulated frog muscle fibres. *J Physiol.* 1981;**311**(1):219-49. doi: 10.1113/jphysiol.1981.sp013582. PubMed PMID: 6973625. PubMed PMCID: PMC1275407.
5. Lieber RL, Roberts TJ, Blemker SS, Lee SS, Herzog W. Skeletal muscle mechanics, energetics and plasticity. *J Neuroeng Rehabilitation*. 2017;**14**(1):1-16. doi: 10.1186/s12984-017-0318-y. PubMed PMID: 29058612. PubMed PMCID: PMC5651624.
6. Brown SH, McGill SM. How the inherent stiffness of the in vivo human trunk varies with changing magnitudes of muscular activation. *Clin Biomech (Bristol, Avon)*. 2008;**23**(1):15-22. doi: 10.1016/j.clinbiomech.2007.08.011. PubMed PMID: 17910898.
7. Dieterich AV, Andrade RJ, Le Sant G, Falla D, Petzke F, Hug F, et al. Shear wave elastography reveals different degrees of passive and active stiffness of the neck extensor muscles. *Eur J Appl Physiol.* 2017;**117**(1):171-8. doi: 10.1007/s00421-016-3509-5. PubMed PMID: 27913924.
8. Biondi DM. Cervicogenic headache: a review of diagnostic and treatment strategies. *J Am Osteopath Assoc*. 2005;**105**(4 Suppl 2):16S-22S.
9. Sjaastad O, Saunte C, Hovdahl H, Breivik H, Grønbâk E. "Cervicogenic" headache A hypothesis. *Cephalalgia.* 1983;**3**(4):249-56. doi: 10.1046/j.1468-2982.1983.0304249.x. PubMed PMID: 6640659.
10. Do YL, Nam CW, Sung YB, Kim K, Lee HY. Changes in rounded shoulder posture and forward head posture according to exercise methods. *J Phys Ther Sci.* 2017;**29**(10):1824-7. doi: 10.1589/jpts.29.1824. PubMed PMID: 29184298. PubMed PMCID: PMC5684019.
11. Quek J, Pua Y-H, Clark RA, Bryant AL. Effects of thoracic kyphosis and forward head posture on cervical range of motion in older adults. *Man Ther.* 2013;**18**(1):65-71. doi: 10.1016/j.math.2012.07.005. PubMed PMID: 22959228.
12. Farmer PK, Snodgrass SJ, Buxton AJ, Rivett DA. An investigation of cervical spinal posture in cervicogenic headache. *Phys Ther.* 2015;**95**(2):

212-22. doi: 10.2522/ptj.20140073. PubMed PMID: 25301967.

13. Watson DH, Trott PH. Cervical headache: an investigation of natural head posture and upper cervical flexor muscle performance. *Cephalalgia.* 1993;**13**(4):272-84. doi: 10.1046/j.1468-2982.1993.1304272.x. PubMed PMID: 8374943.
14. Page P. Cervicogenic headaches: an evidence-led approach to clinical management. *Int J Sports PhysTher*. 2011;**6**(3):254. PubMed PMID: 22034615. PubMed PMCID: PMC3201065.
15. Park SK, Yang DJ, Kim JH, Heo JW, Uhm YH, Yoon JH. Analysis of mechanical properties of cervical muscles in patients with cervicogenic headache. *J Phys Ther Sci.* 2017;**29**(2):332-5. doi: 10.1589/jpts.29.332. PubMed PMID: 28265168. PubMed PMCID: PMC5332999.
16. Hall T, Briffa K, Hopper D. Clinical evaluation of cervicogenic headache: a clinical perspective. *J Man Manip Ther.* 2008;**16**(2):73-80. doi: 10.1179/106698108790818422. PubMed PMID: 19119390. PubMed PMCID: PMC2565113.
17. Zwart JA. Neck mobility in different headache disorders. *Headache.* 1997;**37**(1):6-11. doi: 10.1046/j.1526-4610.1997.3701006.x. PubMed PMID: 9046716.
18. Zito G, Jull G, Story I. Clinical tests of musculoskeletal dysfunction in the diagnosis of cervicogenic headache. *Man Ther.* 2006;**11**(2):118-29. doi: 10.1016/j.math.2005.04.007. PubMed PMID: 16027027.
19. Hall T, Robinson K. The flexion-rotation test and active cervical mobility-a comparative measurement study in cervicogenic headache. *Man Ther*. 2004;**9**(4):197-202. doi: 10.1016/j.math.2004.04.004. PubMed PMID: 15522644.
20. Sokolnikoff IS, Specht RD. A mathematical theory of elasticity: McGraw-Hill: New York; 1956.
21. Rychlewski J. On Hooke's law. *Journal of Applied Mathematics and Mechanics*. 1984;**48**(3):303-14. doi: 10.1016/0021-8928(84)90137-0.
22. Jafari M, Bahrpeyma F, Mokhtari-Dizaji M, Nasiri A. Novel method to measure active myofascial trigger point stiffness using ultrasound imaging. *J Bodyw Mov Ther.* 2018;**22**(2):374-8. doi: 10.1016/j.jbmt.2017.06.019. PubMed PMID: 29861237.
23. Estaji M, Mokhtari-Dizaji M, Movahedin M, Ghaffari Khaligh S. Non-invasive evaluation of elasticity of skin with the processing of ultrasound images during ultraviolet radiation: An animal photoaging model. *Photodermatol Photoimmunol Photomed.* 2021;**37**(2):131-9. doi: 10.1111/phpp.12622. PubMed PMID: 33098351.
24. Adigozali H, Shadmehr A, Ebrahimi E, Rezasoltani A, Naderi F. Reliability of assessment of upper trapezius morphology, its mechanical properties and blood flow in female patients with myofascial pain syndrome using ultrasonography. *J Bodyw Mov Ther*. 2017;**21**(1):35-40. doi: 10.1016/j.jbmt.2016.04.010. PubMed PMID: 28167187.
25. Nagai T, Schilaty ND, Krause DA, Crowley EM, Hewett TE. Sex differences in ultrasound-based muscle size and mechanical properties of the cervical-flexor and-extensor muscles. *J Athl Train.* 2020;**55**(3):282-8. doi: 10.4085/1062-6050-482-18. PubMed PMID: 31967864. PubMed PMCID: PMC7093927.
26. Thomas K, Shankar H. Targeting myofascial taut bands by ultrasound. *Curr Pain Headache Rep.* 2013;**17**(7):349. doi: 10.1007/s11916-013-0349-4. PubMed PMID: 23793988.
27. Chino K, Akagi R, Dohi M, Fukashiro S, Takahashi H. Reliability and validity of quantifying absolute muscle hardness using ultrasound elastography. *PLoS One.* 2012;**7**(9):e45764. doi: 10.1371/journal.pone.0045764. PubMed PMID: 23029231. PubMed PMCID: PMC3448710.
28. Miller T, Ying M, Sau Lan Tsang C, Huang M, Pang MY. Reliability and validity of ultrasound elastography for evaluating muscle stiffness in neurological populations: a systematic review and meta-analysis. *Phys Ther.* 2021;**101**(1):pzaa188. doi: 10.1093/ptj/pzaa188. PubMed PMID: 33508855.
29. Xiang X, Yan F, Yang Y, Tang Y, Wang L, Zeng J, et al. Quantitative assessment of healthy skin elasticity: reliability and feasibility of shear wave elastography. *Ultrasound in Medicine & Biology.* 2017;**43**(2):445-52. doi: 10.1016/j.ultrasmedbio.2016.10.002. PubMed PMID: 27919522
30. Fruscalzo A, Schmitz R, Klockenbusch W, Steinhard J. Reliability of cervix elastography in the late first and second trimester of pregnancy. *Ultraschall Med*. 2012;**33**(07):E101-7. doi: 10.1055/s-0031-1299330. PubMed PMID:22623133
31. Farooq MN, Bandpei MAM, Ali M, Khan GA. Reliability of the universal goniometer for assessing active cervical range of motion in asymptomatic healthy persons. *Pak J Med Sci Q*. 2016;**32**(2):457. doi: 10.12669/pjms.322.8747. PubMed PMID: 27182261. PubMed PMCID: PMC4859044.
32. Whitcroft KL, Massouh L, Amirfeyz R, Bannister G. Comparison of methods of measuring active cervical range of motion. *Spine (Phila Pa 1976).* 2010;**35**(19):E976-80. doi: 10.1097/BRS.0b013e3181cd6176. PubMed PMID:

20700085.

33. Youdas JW, Carey JR, Garrett TR. Reliability of measurements of cervical spine range of motion-comparison of three methods. *Phys Ther.* 1991;**71**(2):98-104. doi: 10.1093/ptj/71.2.98. PubMed PMID: 1989013.
34. Tran AM, Rugh JD, Chacon JA, Hatch JP. Reliability and validity of a computer-based Little irregularity index. *Am J Orthod Dentofacial Orthop*. 2003;**123**(3):349-51. doi: 10.1067/mod.2003.76. PubMed PMID: 12637908.
35. Salahzadeh Z, Maroufi N, Ahmadi A, Behtash H, Razmjoo A, Gohari M, et al. Assessment of forward head posture in females: observational and photogrammetry methods. *J Back Musculoskelet Rehabil.* 2014;**27**(2):131-9. doi: 10.3233/BMR-130426. PubMed PMID: 23963268.
36. Kerry C. Reliability of measuring natural head posture using the craniovertebral angle. *Irish Ergonomics Review.* 2003;**2003**:37.
37. Kendall FP, McCreary EK, Provance PG, Rodgers M, Romani WA. Muscles, testing, and function: with posture and pain. Williams & Wilkins Baltimore; 1993.
38. Kuruma H, Takei H, Nitta O, Furukawa Y, Shida N, Kamio H, et al. Effects of myofascial release and stretching technique on a range of motion and reaction time. *J Phys Ther Sci.* 2013;**25**(2):169-71. doi: 10.1589/jpts.25.169.
39. Herman J, Sedlackova Z, Vachutka J, Furst T, Salzman R, Vomacka J. Shear wave elastography parameters of normal soft tissues of the neck. *Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub.* 2017;**161**(3):320-5. doi: 10.5507/bp.2017.024. PubMed PMID: 28546639.
40. Franchi-Abella S, Elie C, Correas J-M. Ultrasound elastography: advantages, limitations, and artefacts of the different techniques from a study on a phantom. *Diagn Interv Imaging.* 2013;**94**(5):497-501. doi: 10.1016/j.diii.2013.01.024. PubMed PMID: 23567179.
41. Farooq MN, Bandpei MAM, Ali M, Khan GA. Reliability of the universal goniometer for assessing active cervical range of motion in asymptomatic healthy persons. *Pak J Med Sci Q*. 2016;**32**(2):457. doi: 10.12669/pjms.322.8747. PubMed PMID: 27182261. PubMed PMCID: PMC4859044.