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Original Article

# An observational study of ultrasound to confirm cervical spine segmental positional rotation

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ABSTRACT

*Objectives:* Various studies demonstrate the significance of ultrasound use in undergraduate medical education. Palpatory assessment and diagnosis of the body is fundamental to osteopathic medical education and may be improved by ultrasonographic imaging. A previous study determined that ultrasound is a reliable instrument to assess lumbar spine somatic dysfunctions, yet the use of ultrasound to assess those of the cervical spine has not yet been established. This study investigated the use of ultrasound as an instrument to assess cervical spine vertebral rotation as a component of somatic dysfunctions and to establish the validity of cervical segmental rotatory motion testing.
*Methods:* In this observational study, two physicians independently confirmed the diagnosis of the most prominent cervical rotational asymmetry. Ultrasound measurements of the left and right articular pillars were obtained by a separate, blinded musculoskeletal radiologist and then compared to palpatory findings. Results: Nineteen of the 41 palpatory findings agreed with ultrasound findings. Results demonstrate no significant difference in rotation of the articular pillars in cases where ultrasound agreed with palpatory findings and in cases where ultrasound did not agree with palpatory findings ($p=.099$).
*Conclusions:* Our results demonstrate that ultrasound was not an appropriate tool to assess cervical spine segmental rotation compared to palpatory findings. Further studies need to be conducted to improve the assessment of the cervical spine utilizing ultrasound. Differences in cervical spine anatomy and biomechanics as compared to those of the lumbar spine may account for the discrepancy compared to prior studies.



## 1. Introduction

Ultrasound (US) is a noninvasive and radiation-free imaging modality that is used in patient diagnosis, clinical procedures, and medical student education [1–3]. Many medical schools are incorporating basic US training into core curricula [1,2,4]. While US is used most often to assist with teaching anatomy, physiology, pathology, and clinical diagnosis, osteopathic medical schools have extended US use to further explore osteopathic concepts of musculoskeletal biomechanics, somatic dysfunctions, and manipulative medicine techniques [1,5].

A somatic dysfunction (SD) is defined as an “impaired or altered function of related components of the somatic (body framework) system … ” or a change in the normal functioning of a joint [6]. Areas of impaired function are diagnosed using the criteria of detecting tissue texture changes, asymmetry, restriction of motion, and tenderness [7]. For example, a single vertebra in the cervical spine may be rotated and sidebent to one side relative to the adjacent vertebrae [8]. Static findings found by physicians are further evaluated through segmental rotatory motion testing, also known in osteopathic medicine as rotoscoliosis motion testing [8]. These findings are combined to allow differentiation between

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positional findings and morphological variation. Osteopathic medical student training emphasizes the use of palpation to identify the rotational component of SDs in the spine.

Previous studies have proposed the use of US to evaluate anatomical landmark asymmetry in order to objectively confirm medical students' palpatory assessment of SDs [9]. However, few studies have explored the content validity of cervical segmental rotatory motion testing, defined as the extent to which a procedure adequately and comprehensively measures what it claims to be evaluating [10,11]. Objective localization of SDs is necessary for standardization and reproducibility, which are crucial to osteopathic research, medical student training and patient treatment. Therefore, US's ability to confirm cervical spine segmental rotation would help to establish segmental rotatory motion testing as evidence-based medicine [12].

Our study propagates the idea put forward by Najm et al. that objective methods need to be established to determine the validity of spinal palpatory assessment [11]. A study by Shaw et al. used US to analyze the validity of palpation to locate a lumbar spine SD and to provide imaging of the effect of osteopathic treatment on that dysfunction [9]. In this study, US imaging of the lumbar spine provided reliable measurements that allowed objective identification of transverse process rotation [9]. Furthermore, physician and US findings demonstrated a concordance of 1.0 confirming palpatory assessment as a reliable method for diagnosis of the lumbar spine [9].

The use of US as a reliable instrument for objective confirmation of cervical spine findings remains elusive. Despite evidence that suggests US use in osteopathic medical education improved anatomical understanding of other body regions, such as the heart, abdomen, and upper and lower extremities, there has been limited educational gain after US examination of the neck [13]. This suggests a greater need for understanding cervical diagnosis and the role of US [13]. A study by van Eerd et al. recognized the difficulty of accurate identification of cervical spine landmarks and the current need for validated US images for all levels of the cervical spine [14]. In response, this study constructed an anatomical model of the cervical spine using cadaver vertebrae and beeswax [14]. US imaging of the model landmarks were verified using laser beams and applied to the development of an in vivo US protocol on 4 human subjects [14]. While this model and protocol may be used to detect and count cervical vertebrae, research remains lacking for accurate evaluation of cervical spine rotation [14].

With the increasing use of US in osteopathic medical education and the need to establish content validity and inter-examiner reliability, we sought to investigate the effectiveness of US as a standardization tool for confirming vertebral rotation of the cervical spine. We hypothesize that physician rotational findings will agree with US measurements.

## 2. Materials and methods

This study was developed as part of a larger randomized controlled trial that was approved by the Institutional Review Board (BHS-988) and registered with ClinicalTrails.gov (NCT02249858). The larger randomized controlled trial evaluated articular pillar depth of cervical spine SDs before and after performing a high-velocity, low-amplitude osteopathic technique to the dysfunctional segment. Osteopathic physicians diagnosed the cervical spine SDs and ultrasonographic imaging was obtained pre and post treatment for comparison. For the present study, STROBE statement for reporting observational studies was applied.

### 2.1. Subjects

Forty-one medical students were recruited through post-laboratory announcements and faculty emails. After physicians fully explained the study to each subject, written informed consent and demographic information of age, sex, race, height and weight were obtained. Inclusion criteria included asymptomatic, healthy subjects. Exclusion criteria included acute cervical pain, radiculopathy, ligamentous laxity, prior back surgery and history of seizure or stroke.

### 2.2. Clinicians

Licensed, board-certified osteopathic physicians performed the palpatory assessments. As full-time osteopathic manipulative medicine faculty, the physicians performing the assessments had a mean 18 years (range 13–24 years) of experience in clinical diagnosis and treatment. US imaging was completed by an osteopathic radiologist board certified in musculoskeletal radiology with 8 years of experience.

### 2.3. Procedure

#### 2.3.1. Cervical diagnosis

Two physicians independently assessed each subject for a single vertebral rotation between levels C2-C7 using segmental rotatory motion testing. Segmental rotatory motion testing is a standardized method for osteopathic evaluation of the cervical spine. It is performed with the subject lying supine and the physician cupping the subject's head posteriorly. Starting at the level C2, slight anterior pressure is alternatingly applied to the left and right articular pillars. This procedure is continued at each vertebral segment from C2 to C7 and the physician notes the relative restrictions and freedoms of rotational motion [8]. A consensus was reached between the physicians for each subject's key rotation by comparing C2 to C7 primary findings of motion restriction and asymmetry, along with secondary findings of tissue texture changes and tenderness. The agreed upon key cervical spine segmental positional rotation was recorded. The physician palpated the key segment and while maintaining contact with the posterior articular pillars, drew a 1-inch horizontal line at the level bilaterally. The subject then walked to a second room for imaging.

#### 2.3.2. Ultrasound imaging

Images and measurements were obtained using the SonoSite M-MSK Ultrasound System with a SonoSite M-Turbo HFL50x transducer (21919 30th Drive SE Bothell, WA 98021 USA). With the subject prone, the radiologist, blinded to the rotational diagnosis, obtained US imaging at the level of the marked segment. The radiologist obtained a single measurement of the tissue depths from the most superficial layer of the skin to the most posterior aspect of the articular pillar of the vertebral segment by uniformly floating the US probe over the marked segment (Fig. 1). This technique used sufficient US gel and avoided any downward force on the transducer.

### 2.4. Data analysis

Statistical analyses were performed using IBM SPSS software (version 22; IBM Corporation, Armonk, New York). US finding of a cervical spine rotation was defined as having one articular pillar more posterior than the other, indicating that it was rotated relative to midline. The posterior articular pillar was determined from the US image as the side with the shortest tissue depth measurement. An independent sample *t*-test was conducted to compare the

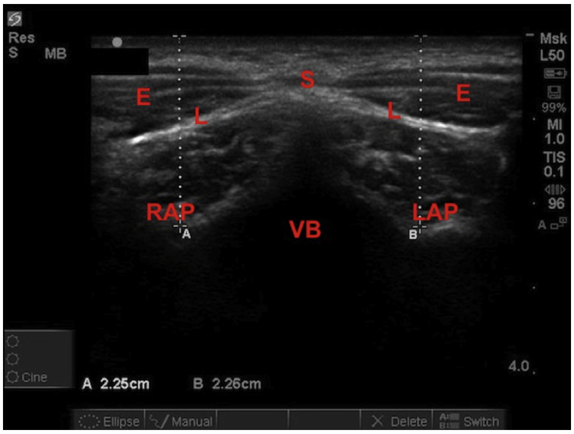


**Fig. 1.** Ultrasound image of cervical spine level C4. Image was obtained with the subject in the prone position. Measurements were recorded in centimeters from the most superficial layer of the skin to the most posterior aspect of the C4 articular pillars. Abbreviations: E, erector spinae muscles; L, lamina; S, spinous process; AP, articular pillar; VB, vertebral body.

average differences between articular pillars in cases where the US rotational findings agreed with palpatory rotational findings and in cases where the US did not agree with palpatory rotational findings. US rotational findings were compared to physician rotational findings to determine concordance. Independent sample t-tests were conducted to control for confounding variables among subject demographics (Table 1). $P < 0.5$ was used to establish statistical significance.

## 3. Results

Forty-one subjects were recruited and met the inclusion criteria: sex (23 F), age (range 22–40, mean 25.9, standard deviation 3.697), BMI (range 18.5–41.1 kg/m$^2$, mean 24.7 kg/m$^2$, standard deviation 4.622). Subjects participated from July 2014 to October 2014 and ranged in age from 22 to 40 years. Test measurements from the most superficial layer of skin to the articular pillar, collected by means of ultrasonography, are provided in Table 2. Physicians ascertained a rotational diagnosis in each of the 41 subjects. The findings of the segmental rotatory motion test were compared to the objectively determined side of rotation measurements as previously described. Of the 41 rotational diagnoses documented, 19 cases agreed with US, and the other 22 cases did not agree with US. The absolute values of the average difference between left articular pillar (LAP) and right articular pillar (RAP) were calculated (LAP-RAP). An independent sample *t*-test was conducted to compare the average differences between LAP-RAP in cases where the US rotational findings agreed with

**Table 1**
Subject descriptive statistics.

| Variable | US and Physician Findings Agreed | US and Physician Findings Disagreed | p-value |
|---|---|---|---|
| | Mean (SD) | | |
| Age (y) | 25.2 (4.0) | 26.5 (3.4) | 0.254 |
| Height (in) | 66.5 (4.8) | 66.7 (3.2) | 0.870 |
| Weight (lb) | 160.8 (53.9) | 155.2 (31.7) | 0.683 |
| BMI | 25.1 (5.5) | 24.4 (3.8) | 0.648 |
| | **N (%)** | | |
| Sex | | | 0.678 |
| Female | 10 (52.6%) | 13 (59.1%) | |
| Male | 9 (47.4%) | 9 (40.9%) | |

**Table 2**
Result data comparing palpatory findings to ultrasound measurements.

| Subject No. | Age, y | Sex | Palpatory Findings AP Rotation | US AP Rotation | US matches Palpation | US RAP Depth (cm) | US LAP Depth (cm) |
|---|---|---|---|---|---|---|---|
| 1 | 27 | F | R | L | N | 2.52 | 2.29 |
| 2 | 25 | M | L | L | Y | 3.47 | 3.32 |
| 3 | 22 | F | R | R | Y | 2.68 | 2.76 |
| 4 | 24 | F | R | L | N | 3.12 | 3.09 |
| 5 | 29 | M | R | R | Y | 3.15 | 3.21 |
| 6 | 26 | F | R | R | Y | 2.75 | 2.94 |
| 7 | 23 | F | R | R | Y | 2.57 | 2.60 |
| 8 | 29 | M | R | L | N | 3.92 | 3.01 |
| 9 | 23 | F | R | L | N | 3.08 | 2.88 |
| 10 | 24 | F | L | L | Y | 2.85 | 2.74 |
| 11 | 25 | F | R | L | N | 2.79 | 2.72 |
| 12 | 22 | M | R | R | Y | 2.93 | 2.97 |
| 13 | 22 | F | R | L | N | 2.90 | 2.88 |
| 14 | 28 | M | R | L | N | 3.35 | 3.33 |
| 15 | 29 | M | R | L | N | 3.72 | 3.24 |
| 16 | 23 | M | R | R | Y | 3.19 | 3.21 |
| 17 | 24 | F | R | R | Y | 2.47 | 2.49 |
| 18 | 26 | M | L | R | N | 3.30 | 3.44 |
| 19 | 26 | F | L | L | Y | 2.43 | 2.32 |
| 20 | 40 | M | L | L | Y | 3.52 | 3.19 |
| 21 | 23 | F | R | R | Y | 2.58 | 2.63 |
| 22 | 26 | F | R | L | N | 2.61 | 2.59 |
| 23 | 29 | F | R | L | N | 2.75 | 2.71 |
| 24 | 31 | F | R | L | N | 2.74 | 2.66 |
| 25 | 27 | F | R | L | N | 2.67 | 2.66 |
| 26 | 23 | F | R | R | Y | 2.62 | 2.76 |
| 27 | 25 | F | R | L | N | 2.54 | 2.43 |
| 28 | 38 | F | R | L | N | 2.59 | 2.53 |
| 29 | 24 | M | R | L | N | 2.90 | 2.89 |
| 30 | 24 | M | R | L | N | 3.39 | 3.24 |
| 31 | 27 | F | R | L | N | 2.51 | 2.51 |
| 32 | 24 | F | L | L | Y | 3.21 | 3.11 |
| 33 | 24 | M | R | L | N | 3.46 | 3.25 |
| 34 | 24 | F | R | R | Y | 2.29 | 2.48 |
| 35 | 25 | F | R | L | N | 2.58 | 2.55 |
| 36 | 25 | M | R | L | N | 3.51 | 3.44 |
| 37 | 24 | M | R | R | Y | 4.67 | 4.70 |
| 38 | 27 | F | R | R | Y | 2.84 | 3.00 |
| 39 | 26 | M | R | L | N | 3.32 | 3.19 |
| 40 | 24 | M | R | R | Y | 3.69 | 3.80 |
| 41 | 26 | M | R | R | Y | 3.74 | 3.79 |

Abbreviations: AP, articular pillar; US, ultrasound; RAP, right articular pillar; LAP, left articular pillar.

palpatory rotational findings and in cases where the US rotational findings did not agree with palpatory rotational findings. There was no significant difference between LAP-RAP in cases where the US did agree with the palpatory assessment ($M = 0.1036$, $SD = 0.07819$) and in cases where the US did not agree with the palpatory assessment ($M = 0.1373$, $SD = 0.2043$; $t(-0.674)$, $p = 0.099$).

## 4. Discussion

Our results demonstrated that US did not accurately correlate with rotational diagnoses of the cervical spine made by our physicians. This raised the question as to whether US would be a reliable instrument for confirming cervical rotation and whether it can be used to establish the content validity and inter-reliability of palpatory assessment. Results demonstrated no significant difference in articular pillar rotational measurements in cases where US both did and did not agree with palpatory rotational findings. In addition, US findings did not agree with physician findings in some cases with larger US measurements of articular pillar asymmetries (demonstrated in Fig. 2). These outliers are counterintuitive, as we

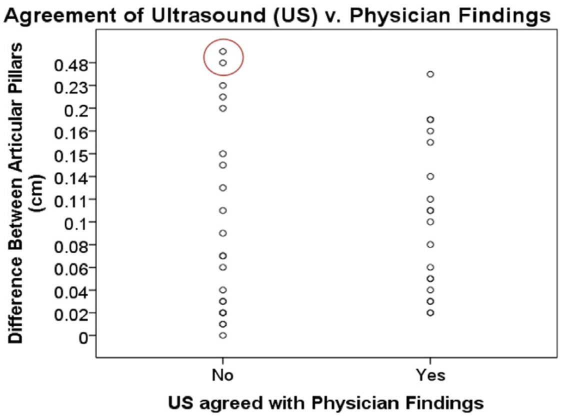


**Fig. 2.** Comparison of ultrasound measurements to physician findings.

expected US to more readily detect larger LAP-RAP differences.

The negative results found in this study may demonstrate an important and inevitable outcome regarding the lack of meaningful relationship between a palpatory clinical diagnosis of a rotated articular pillar and ultrasonographic evaluation. It is therefore hypothesized that the positional rotation indicated by ultrasound may in fact be independent of the wider finding of a physician-diagnosed SD. It is also possible that several study limitations prevented identification of such correlation, leading to the conclusion that US was ineffective in quantify cervical spine rotational findings. These limitations include increased cervical spine range of motion, the effect of subject positioning on coupled cervical intersegmental motion, the US technique, and the changes in cervical musculature.

### 4.1. Limitations

The unique structure of the C1 (atlas) through C7 cervical spine allows for its large range of motion. The occipito-atlantal (C0-C1) joint in isolation has 10-15° of flexion and extension. The atlanto-axial (C1-C2) joint is the most mobile joint of the spine with 47° of axial rotation [15]. As a result, normal cervical range of motion includes 45-90° of flexion, 45-90° of extension, 30-45° of sidebending, and 70-90° of rotation, making it the most mobile area of the human spine [15]. This amount of mobility may account for the inability of the US to properly diagnose the cervical spine. The effectiveness of ultrasonography to assess the SD in the lumbar spine (as seen in the Shaw et al. study) can be attributed to limited lumbar range of motion [9]. Normal lumbar range of motion is significantly smaller than cervical range of motion, as it includes 70-90° of flexion, 30-45° of extension, 25-30° of sidebending, and virtually no rotation due to 90° lumbar facet orientation [15,16]. According to Ehrenfeuchter's description of Fryette's third principle of physiologic laws of spinal motion, “initiating movement of a vertebral segment in any plane of motion will modify the movement of that segment in other planes of motion.” [17] Restricted rotation of the lumbar spine is therefore coupled with restricted lumbar flexion, extension and sidebending [17]. This limited range of motion may have allowed for statistically significant results with lumbar US findings while the large cervical range of motion made quantifiable evaluation by US unattainable [9].

Additionally, coupled motions exist in varying degrees within the spine and produce intrinsic instability [15]. As described by Punjabi and White, main and coupled motion is “a phenomenon where one motion component (translation or rotation) results in another motion component …” [18] Coupled intersegmental motion occurs to the largest degree within the cervical spine, causing this area to have a high range of mobility, yet a great amount of intrinsic instability [15]. This instability could have prevented stable and consistent placement of the US probe on the cervical spine. Furthermore, the prone position of the subject during imaging may not have permitted enough flattening of the cervical spine lordosis. This is in comparison to the Shaw et al. study in which the prone position allowed for proper flattening of the lumbar spine and therefore adequate imaging [9]. To overcome this instability, we suggest future studies attempt to flatten the cervical spine perhaps through use of a collar or fixture. Future studies may also attempt to image the subject from a supine position, which would be consistent with the subjects' position during cervical palpatory assessment. The Shaw et al. study did not have to account for this discrepancy because lumbar palpatory assessment and lumbar US imaging both occur in a prone position [9].

A change in the thickness as well as the level of contraction in spinal musculature can influence the distance from the posteriorly rotated articular pillar to the skin surface before and after treatment. A literature review analysis of the validity of real-time US imaging on the posterior cervical muscles from various studies reported variability in the measured thickness of cervical muscles depending on the positioning of the subject [19]. Therefore, changes in cervical muscle thickness can partially contribute to inconsistent measurements seen with US imaging from slight changes in the placement of the head and neck. As previously noted, this variability can be quite significant when a subject is placed in a supine position as compared to a prone position.

The degree of contraction can also influence the changes in muscle thickness during imaging of the cervical spine. A study by Koppenhaver et al. validates that US can detect changes in muscle activation but the images may not always be reproducible [20]. Such inconsistency may depend on the level of contraction as well as the contraction strategy being used. This may be due to competing forces of surrounding muscles suggesting that not only is it important to have consistent positioning of the head and neck but that the positioning of other aspects of the body influence cervical spine dynamics as well [20]. This explanation is supported by the principles of biotensegrity as applied to the small rotator and large erector spinae muscles of the spine [21]. Consequently, contraction or relaxation of cervical muscles due to the effect of surrounding muscles should be kept consistent in order to decrease the degree of variability seen during imaging of the cervical spine.

Further limitations to the study involve the US imaging process for the cervical spine. In comparison to lumbar imaging, cervical US imaging was limited by varying hairlines and a smaller surface area that made proper probe placement difficult with several subjects. US imaging of the lumbar spine, as conducted in the Shaw et al. study, calculated measurements from the “superficial layer of the skin to the most posterior aspect of the transverse process and spinous process of the dysfunctional lumbar vertebrae …” [9] Cervical US imaging, however, was measured to the most posterior aspect of the articular pillar as opposed to that of the transverse process. Our study also did not correct for spinous process depth as was done in the Shaw et al. study [9]. Moreover, our study did not evaluate for a possible correlation between additional physician findings, such as tissue texture changes and tenderness, and ultrasound rotational findings.

## 5. Conclusion

Our study demonstrated that US measurements did not correlate with physician rotational findings and cannot currently be used as a means of cervical spine diagnosis standardization. Our data, therefore, fails to establish the content validity of cervical segmental rotatory motion testing. These negative results may also indicate the lack of meaningful relationship between palpatory and ultrasound diagnosis of SDs. Given the significance and increasing use of US in medical education, as well as the importance of establishing a reference standard for cervical spine palpatory diagnosis, additional research is needed. We encourage future studies to further explore the unique structure of the cervical spine and to account for the differences in cervical spine anatomy and biomechanics as compared to those of the lumbar spine when using US. Possible measures, as discussed, include the use of a cervical collar and consistent patient positioning for assessment and imaging.

## Conflicts of interest

None.

## Author contribution statement

Please note all authors have approved the submitted version of the manuscript. Author contributions are as follows: Theodore Flaum and Sheldon Yao provided substantial contributions to study conception and design, subject diagnosis and treatment, acquisition of data, and manuscript editing. Aida Munarova made significant contributions to study conception and design as well as IRB approval. Frances Rusnack and Arfa Mirza aided in subject recruitment and management, data acquisition, and manuscript composition. Theresa Apoznanski contributed notably to data analysis and interpretation and manuscript review. Joseph Mazzie conducted ultrasound components of the study and assisted with discussion limitations. Michael Terzella made considerable contribution to manuscript editing and subject diagnosis and treatment.

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## References

[1] Baltarowich OH, Di Salvo DN, Scoutt LM, Brown DL, Cox CW, DiPietro MA, et al. National ultrasound curriculum for medical students. Ultrasound Q 2014 Mar;30(1):13–9. http://dx.doi.org/10.1097/ruq.0000000000000066.
[2] Benninger B, Corbett R, Delamarter T. Teaching a sonographically guided invasive procedure to first-year medical students using a novel finger transducer. J Ultrasound Med 2013 Apr;32(4):659–64.
[3] Sucher BM. Ultrasonography-guided osteopathic manipulative treatment for a patient with thoracic outlet syndrome. J Am Osteopath Assoc 2011 Sep;111(9):543–7.
[4] Syperda VA, Trivedi PN, Melo LC, Freeman ML, Ledermann EJ, Smith TM, et al. Ultrasonography in preclinical education: a pilot study. J Am Osteopath Assoc 2008 Oct;108(10):601–5.
[5] Lockwood MD, Kondrashova T, Johnson JC. Feasibility of using ultrasonography to establish relationships among sacral base position, sacral sulcus depth, body mass index, and sex. J Am Osteopath Assoc 2015 Nov;115(11):648–53. http://dx.doi.org/10.7556/jaoa.2015.135.
[6] Chila AG. Glossary. In: Chila AG, editor. Foundations of osteopathic medicine. third ed. Baltimore, MD: Lippincott Williams & Wilkins; 2011. p. 1106.
[7] DiGiovanna EL. Somatic dysfunction. In: DiGiovanna EL, Shiowitz S, Dowling DJ, editors. An osteopathic approach to diagnosis and treatment. third ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2005. p. 16–23.
[8] DiGiovanna EL. Evaluation of the cervical spine. In: DiGiovanna EL, Shiowitz S, Dowling DJ, editors. An osteopathic approach to diagnosis and treatment. third ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2005. p. 130–6.
[9] Shaw KA, Dougherty JJ, Treffer KD, Glaros AG. Establishing the content validity of palpatory examination for the assessment of the lumbar spine using ultrasonography: a pilot study. J Am Osteopath Assoc 2012 Dec;112(12):775–82.
[10] Kilby J, Heneghan NR, Maybury M. Manual palpation of lumbo-pelvic landmarks: a validity study. Man Ther 2012 Jun;17(3):259–62. http://dx.doi.org/10.1016/j.math.2011.08.008.
[11] Najm WI, Seffinger MA, Mishra SI, Dickerson VM, Adams A, Reinsch S, et al. Content validity of manual spinal palpatory exams - a systematic review. BMC Complement Altern Med 2003 May;3:1–14. http://dx.doi.org/10.1186/1472-6882-3-1.
[12] Degenhardt BF, Snider KT, Snider EJ, Johnson JC. Interobserver reliability of osteopathic palpatory diagnostic tests of the lumbar spine: improvements from consensus training. J Am Osteopath Assoc 2005 Oct;105(10):465–73.
[13] Kondrashov P, Johnson JC, Boehm K, Rice D, Kondrashova T. Impact of the clinical ultrasound elective course on retention of anatomical knowledge by second-year medical students in preparation for board exams. Clin Anat 2015 Mar;28(2):156–63. http://dx.doi.org/10.1002/ca.22494.
[14] van Eerd M, Patijn J, Sieben JM, Sommer M, Van Zundert J, van Kleef M, et al. Ultrasonography of the cervical spine. Anesthesiology 2014 Jan;120(1):86–96. http://dx.doi.org/10.1097/aln.0000000000000006.
[15] Wells MR. Biomechanics. In: Chila AG, editor. Foundations of osteopathic medicine. third ed. Baltimore, MD: Lippincott Williams & Wilkins; 2011. p. 93–117.
[16] Ehrenfeuchter WC. Screening osteopathic structural examination. In: Chila AG, editor. Foundations of osteopathic medicine. third ed. Baltimore, MD: Lippincott Williams & Wilkins; 2011. p. 410–30.
[17] Ehrenfeuchter WC. Segmental motion testing. In: Chila AG, editor. Foundations of osteopathic medicine. third ed. Baltimore, MD: Lippincott Williams & Wilkins; 2011. p. 431–6.
[18] Panjabi MM, White AA. Biomechanics in the musculoskeletal system. NY: Churchill Livingstone; 2001. p. 24–5.
[19] Javanshir K, Amiri M, Mohseni-Bandpei MA, Rezasoltani A, Fernández-de-las-Peñas C. Ultrasonography of the cervical muscles: a critical review of the literature. J Manip Physiol Ther 2010 Oct;33(8):630–7. http://dx.doi.org/10.1016/j.jmpt.2010.08.016.
[20] Koppenhaver SL, Hebert JJ, Parent EC, Fritz JM. Rehabilitative ultrasound imaging is a valid measure of trunk muscle size and activation during most isometric sub-maximal contractions: a systematic review. Aust J Physiother 2009;55(3):153–69. http://dx.doi.org/10.1016/s0004-9514(09)70076-5.
[21] Swanson RL. Biotensegrity: a unifying theory of biological architecture with applications to osteopathic practice, education, and research—a review and analysis. J Am Osteopath Assoc 2013 Jan;113(1):34–52.