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MSCT-semiotics of vertebrae in patients with cervical spine stenosis

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Abstract

Introduction The number of surgical interventions on the cervical spine for stenosis has been constantly increasing. This fact proves that there is a need for careful preoperative preparation that would consider the complexity of the intervention and the age of the patients.

Purpose To substantiate the need to include the MSCT data processing algorithm of bone tissue density of vertebral bodies and arches to assess their quality for planning osteoplastic decompressive laminoplasty in patients with cervical spine stenosis due to degenerative changes.

Material and methods This single-center retrospective study investigated qualitative and quantitative characteristics of the spine with radiography and multislice computed tomography (MSCT) in 82 patients with degenerative diseases of the cervical spine and associated spinal canal stenosis (CSS).

Results and discussion The data obtained indicate a tendency for the total density of the cervical vertebrae to increase from C3 to C5 and to decrease caudally, with minimal density in C7 without signs of osteoporosis. A similar trend is characteristic of trabecular bone. The density of the osteon layer of the vertebral arch cortex differs significantly from the density of the outer and inner plates. The total density of the compact layer of the vertebral arch cortex exceeds 785.15 ± 38.4 HU.

Conclusion The data obtained justify the need to include the study of the density of vertebral bodies, vertebral arches, and its thickness in the MSCT data processing algorithm to develop a plan for surgical intervention in patients with cervical spine stenosis in order to obtain objective data on the quality of the bone.

Keywords: spine, cervical spine, stenosis, semiotics, MSCT

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INTRODUCTION

Current imaging techniques provide excellent anatomical images of the cervical spine. The choice among them depends on the clinical scenario and therapeutic alternatives. Polypositional radiography remains a fundamental method, as it allows assessment of the spinal axis, the size and changes of the vertebrae and the subsequent follow-up after treatment, being an economically available and imaging-based examination [1, 2, 3]. The role of MRI has increased significantly and allows visualization of soft tissue formations of the spine, including intervertebral discs, ligaments, the spinal cord, in particular, its mobility, which is extremely important for patients with cervical spinal stenosis (CSS), complicated by myelopathy [2, 4, 5, 6, 7, 8]. Of no less importance is multislice computed tomography (MSCT) in the study of dystrophic changes in the spine due to its high spatial resolution and unique ability to qualitatively and quantitatively assess the condition of the vertebrae, both before treatment and at its various stages [2, 9, 10]. A complex of radiological diagnostic methods is often used in CSS patients to assess the results of treatment [2, 11].

Examination of the anatomy of vertebrae, their architectonics, and density parameters is extremely important for deciding the choice of treatment method for any type of surgical intervention on the spine, including the management of cervical spinal stenosis. Evaluation of bone quality is critical to treatment success in many cases, but it is also part of optimal surgical preparation for spine surgery [12, 13].

First of all, the issue is about assessing the condition of the bone for introduction of implants in different types of transpedicular fixation and other methods of metal osteosynthesis in order to prevent various complications associated with malposition of screws or other structures, failure of metal structures. Much consideration should be paid to patients with pronounced degenerative alterations in density indicators (HU) [14, 15, 16].

Bone density, as an important factor of strength, is determined by various methods, but the most common and universal is MSCT using standardized Hounsfield units (HU), providing a reliable assessment of bone density, improving diagnostic performance [10, 18, 19]. The study of anatomy, architectonics, and vertebral density is carried out using separate methods or in a complex manner, as in the study of Schröder et al., who used micro-CT and MSCT [12]. A histomorphometric study ("gold standard" for studying bone quality) was applied in the work of Grote et al. to assess trabecular bone density [20]. In MSCT studies, cancellous bone density in HU is determined for vertebrae C2–C7 on each sagittal, coronal and axial CT image, the results of computed tomography of the cervical spine (CS) provide reliable information regardless of the measurement plane, age or gender, and degeneration severity [21].

According to Q. Zaidi et al. and Leonova et al., the greatest importance should be given to assessing the density of various structural formations of the vertebrae according to MSCT data in patients with degenerative changes of the spine [15, 22].

The literature sources mentioned above that determined vertebral bone quality based on bone density according to MSCT data studies only some indicators and parameters of the vertebral body and mainly the local density of cancellous bone was measured. However, it is important to know the condition of all structural formations of the vertebra, especially if the laminoplasty method is applied, where the most important anatomical zones for the surgeon are the vertebral arches and facet joints, being the main objects to which the plates are fixed.

Purpose To substantiate the need to include the MSCT data processing algorithm of bone tissue density of vertebral bodies and arches to assess their quality for planning osteoplastic decompressive laminoplasty in patients with cervical spine stenosis due to degenerative changes

MATERIAL AND METHODS

A single-center retrospective study was carried out at the neurosurgical department No. 3 of the Federal Center for Neurosurgery (Tyumen). Qualitative and quantitative characteristics of the spine were studied using radiography and MSCT in 82 patients with degenerative diseases of the cervical spine with spinal canal stenosis.

Level of evidence: IV.

Clinical and statistical characteristics of patients

In the sample there was prevalence of males (86.6 %) aged from 56 to 75 years (70.7 %). The majority of patients (89.0 %) had multilevel spinal canal stenosis (Table 1).

Cervical laminoplasty was performed at levels C3–C6 and C3–C7 in 68.3 % of patients (Table 2).

Table 1

Distribution of patients by age, gender and number of levels of stenosis in the cervical spine

Age	Gender		Number of stenosis levels				
	Males	Females	2	3	4	5	Total
36–40	1	–	–	1	–	–	1
41–45	2	1	–	3	–	–	3
46–50	8	1	1	8	–	–	9
51–55	9	2	2	5	4	–	11
56–60	19	3	8	8	7	–	23
61–65	16	–	2	5	8	1	16
66–70	12	3	2	7	6	–	15
71–75	4	–	1	2	1	–	4
Total	71	11	16	39	26	1	82

Table 2

Distribution of patients by the level of cervical spine laminoplasty

Extension of fixation	Number of patients		Total	
	Males	Females	abs.	%
C2–C4	1	–	1	1.2
C2–C5	1	–	1	1.2
C2–C6	1	–	1	1.2
C2–C7	1	–	1	1.2
C3–C5	5	–	5	6.1
C3–C6	26	5	31	37.8
C3–C7	22	3	25	30.5
C4–C6	7	1	8	9.8
C6–C7I	4	2	6	7.3
C5–C7	2	–	2	2.4
C5–Th1	1	–	1	1.2
Total	71	11	82	100

Methods

1. Polypositional and functional radiography was performed in all 82 patients.
2. Multislice spiral computed tomography (MSCT) was performed in all 82 patients using an Aquilion One X-ray computed tomography system (1385 Shmoishigami, Otawara-shi, Tochigi 324-8550, Japan, 320 detector lines; maximum number of slices was 640).

MSCT was used to assess bone quality (density, structure, dimensions of the vertebral body, arches). Vertebral density measurements were carried out on axial and sagittal sections (total density, density of cancellous bone, compact layer). The density of the cortex of the vertebral arch in different layers was studied. If necessary, 3D reconstructions were made (Fig. 1).

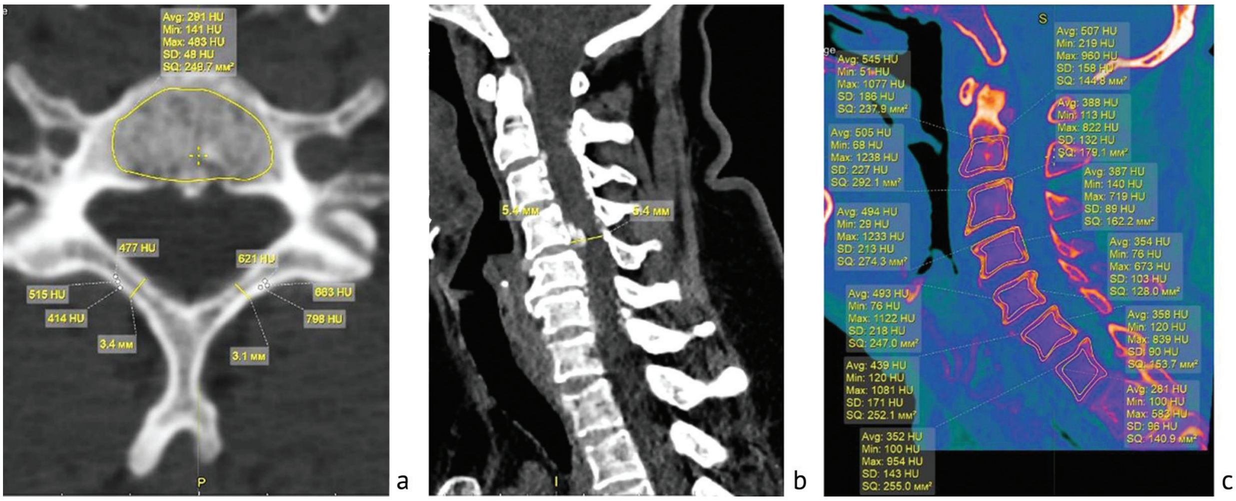

Fig. 1 MSCT of the cervical spine in patients with degenerative disease of the spine and spinal canal stenosis; axial plane, measurement of trabecular (spongy) bone density of the vertebral body, density of the compact layer and thickness of the vertebral arch C5 (*a*), sagittal plane (*b*), sagittal plane, measurement of the total density of vertebrae C3–C7 and trabecular bone density (*c*)

Inclusion criteria:

1) Stenosis of the cervical spine according to MSCT and MRI, complete radiological archive;

2) No history of surgery on the cervical spine;

3) Available patient's consent to the publication of data obtained during the study, without personal identification.

The study was carried out in accordance with the ethical standards of the Declaration of Helsinki of the World Medical Association with amendments by the Ministry of Health of the Russian Federation. All patients signed informed consent for publication of data without personal identification.

Statistical processing of density parameters was carried out using the Attestat program for Microsoft Excel. To confirm the conclusions about the differences between the results obtained in the two groups, given the small samples, the Mann – Whitney U test was used. The sample parameters given below in the tables had the following designations: M — mean, σ — standard standard deviation, n — number of patients, p — achieved level of significance. The critical level of significance when testing statistical hypotheses in this study was taken equal to 0.05.

RESULTS

A study of the total density of vertebrae from C3 to C7 in the sagittal plane showed its increase from level C3 to C4, and from level C5 and caudally there was a decrease in the indicators in descending order, reaching a minimum at C7 level (Table 3).

Table 3

Total vertebral density in patients with cervical spinal stenosis depending on the level, HU

Parameter	Density, HU					
	C2	C3	C4	C5	C6	C7
Mean value, M	394.4	445.3	452.2	439.8	411.9	337.1[1]
Standard deviation, σ	51.7	57.4	65.7	74.8	66.4	38.9

[1] — $p < 0.044$

The results of studying the total and local density of cancellous bone of the cervical vertebral bodies are presented in Figure 2.

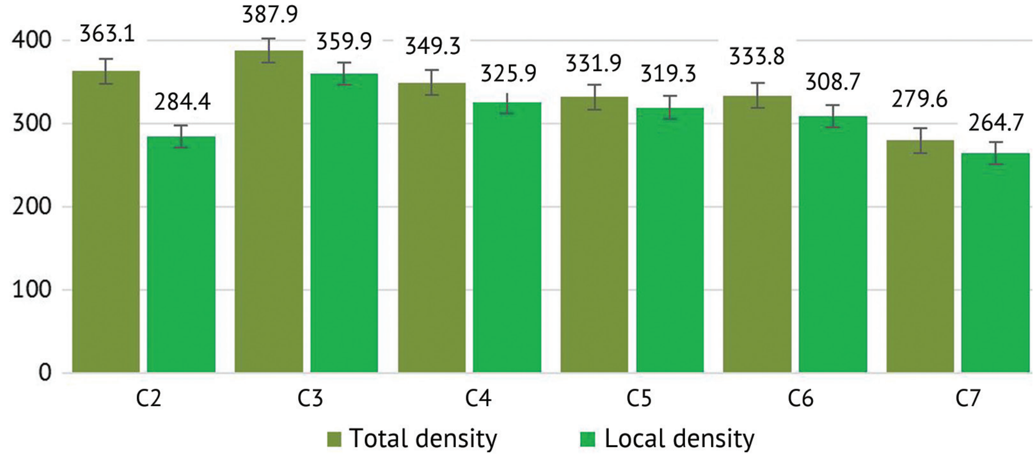

Fig. 2 Diagram of the total and local cancellous bone density of cervical vertebral bodies

Measurement of the density of the vertebral body compact layer in the sagittal plane along the anterior and posterior surfaces showed that the density of the compact layer of bone tissue was higher in the posterior parts of the vertebral bodies compared to the anterior ones, but without significant differences. This is due to the fact that the boundaries of the compact layer and trabecular bone on axial sections are clearly visualized, while in the sagittal plane the boundaries are determined conditionally. The study of the density of the compact layer of the cervical vertebrae along the anterior and posterior surfaces showed that the differences in axial density are significant, except for C7. As for C7 vertebra, it had minimal density with resorption zones and minimal differences along the anterior and posterior surfaces, and therefore the density indicators did not differ (Table 4).

Table 4

Density of the compact layer of vertebrae along the anterior and posterior surfaces in the axial plane, HU

Zone of interest	Density of the compact layer of vertebrae in the axial plane, HU				
	C3	C4	C5	C6	C7
Anterior vertebral surface	449.1 ± 60.8	547.2 ± 21.8	628.5 ± 53.9	436.1 ± 63.1	312.0 ± 45.6
Posterior vertebral surface	516.6 ± 51.6	821.3 ± 48.9[1]	972.4 ± 61.6[2]	599.7 ± 75.7[3]	309.25 ± 42.8

[1] — $p \leqslant 0{,}041$; [2] — $p \leqslant 0{,}034$; 3 — $p \leqslant 0{,}05$

The local total and pointed density of the three layers of the cortex was also studied, since the density of the osteon (central) layer was much higher than the density of the outer and inner plates, which must be considered in preoperative measuring of the density of the vertebral arch to which the plates are fixed during laminoplasty (Fig. 3).

Statistical data on the density of various layers of the vertebral arch cortex are presented in Figure 4.

The density of the osteon layer is 33.3 % greater than the density of the inner plates and 10.4 % greater than the density of the outer plates. This should be taken into account when measuring cortical density of the arch. Measuring in the area of the inner plates, the layer of which is thinner than the osteon layer, very low density values can be obtained. It is necessary to measure the density of all layers not only pointwise, but also by determining the local total density of all layers of the cortex, which was measured in the area of interest in the form of a circle covering the entire thickness of the cortex (ROI = 1.5–2.2 cm2). The local density of all layers of the vertebral arch cortex ranged from 700 to 1150 HU, averaging (785.15 ± 38.4) HU, and in the area adjacent to the facet joints, the density was slightly higher in 75.6 % of patients.

Measuring the thickness of the vertebral arches in the axial plane at an equal distance from the central axis of the vertebra revealed that in 83 % of patients this indicator differed on the right and left sides. On the right the thickness was lower in 45 % of patients (Fig. 5).

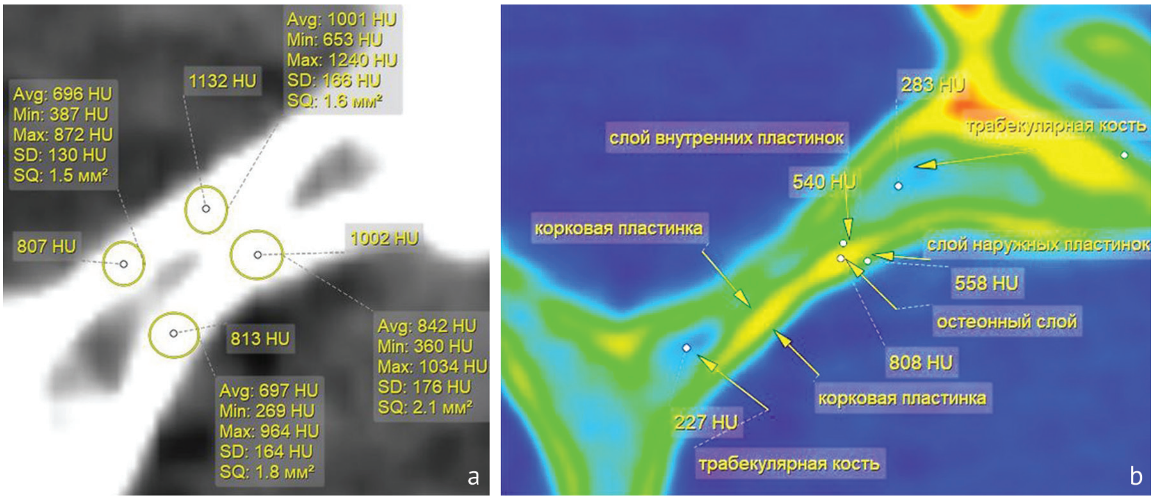

Fig. 3 MSCT of the cervical spine. Axial section of C5; scheme for measuring the total local density of the vertebral arch cortex (*a*); enlarged fragment of the vertebral arch cortex. Determination of the density of the cortex layers. Filter (palette) perfusion (*b*)

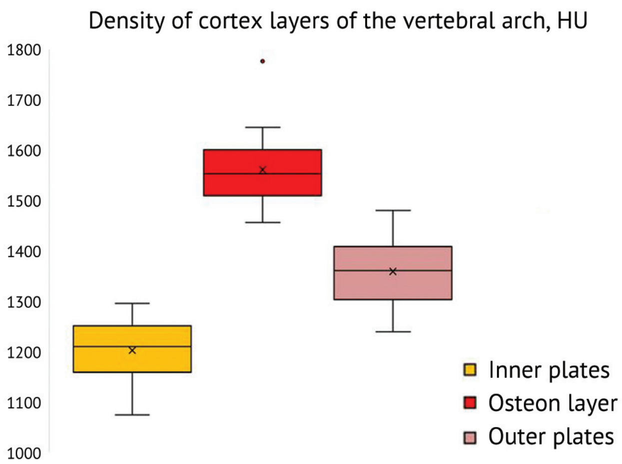

Fig. 4 Diagram of the pointed density of the cortex layers of the vertebral arch. Note In the diagram, the color represents the mean, the horizontal line represents the median, the box represents the interquartile range, and the vertical lines represent error bars

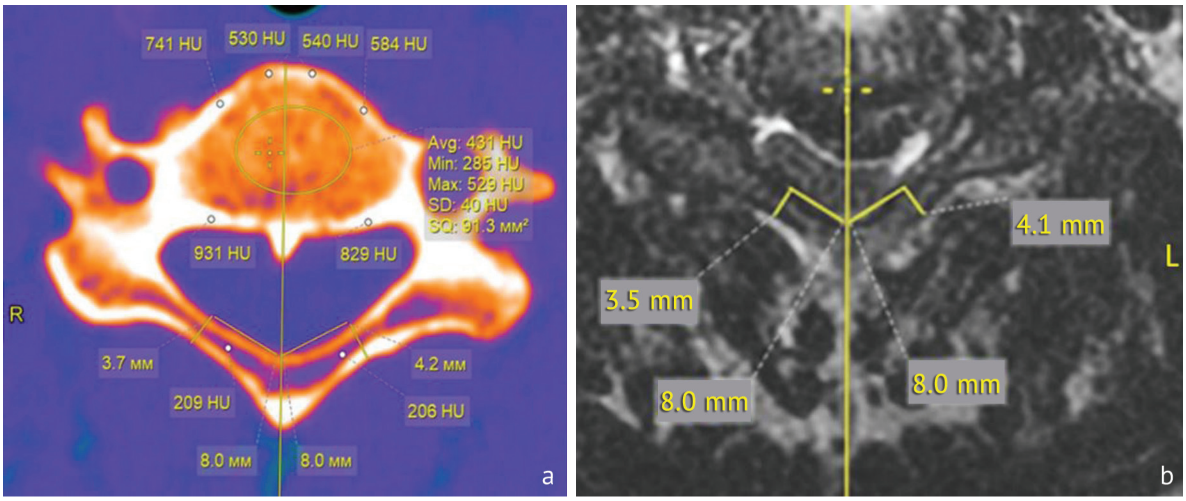

Fig. 5 MSCT of the cervical spine of patient Yu., 65 years old. Axial plane, measurement of the thickness of the C5 vertebral arches at two levels (*a*), MRI of the cervical spine of the same patient, axial plane, Ax T2FRFSE. Measuring the thickness of the arches of the C4 vertebra (*b*)

Table 5 presents data on the thickness of the vertebral arches at levels C3 and C5 on the right and left; measurements were made in all cases at a distance of 8 mm from the central axis of the vertebra.

Table 5

Thickness of vertebral arches at levels C3 and C5 in patients with their different thicknesses

Arch thickness, mm	Zone of interest	
	C3	C5
Right	3.8 ± 0.5	4.1 ± 0.6
Left	4.0 ± 0.3	4.3 ± 0.8

Measuring the thickness of the vertebral arch closer to the facet joint showed that it was by 1.2–1.5 mm greater.

DISCUSSION

MSCT is able to determine not only the nature and extent of changes in the spine but also to study the quantitative density characteristics of the vertebrae in CSS. It enabled to objectively evaluate the state of trabecular and compact bone tissue assessed in Hounsfield units (HU). This conclusion is confirmed by the research of Mikhailova et Lukyanenko [23]. The work of Schröder et al. used micro-CT and MSCT in all examined patients and found that the density of cancellous bone was significantly higher in the cervical vertebrae (average 177.6 HU) than in the thoracic (average 94.4 HU) or lumbar vertebrae (average 62.8 HU, $p < 0.001$). In our study, the density of cervical vertebrae was significantly higher than those data. This is due to the fact that patients with one or two vertebral fractures were examined at the age of (84.3 ± 8.4) years in the mentioned above work, while in our sample the mean age did not exceed (58.9 ± 7.9) years, and there were no patients with vertebral fractures. Moreover, we studied trabecular bone density over the entire vertebral area in the axial plane, whereas the authors mentioned examined a small area in the center of the vertebra. It did not always reflect the overall density [24]. Histomorphometric study (a "gold standard" for studying bone quality) of Grote et al. found that trabecular bone density in the cervical spine was markedly higher than in the thoracic or lumbar spine [20]. Bone loss in the cervical spine was shown to be less with age than in other parts of the spine. There was no significant age-related loss of trabecular density in the C3 and C4 vertebrae, which is consistent with the data of Schröder et al. [24, 25]. In the studies that used MSCT, cancellous bone density in HU was determined for vertebrae C2–C6 on each sagittal, coronal and axial CT images [21]. According to the authors, the mean values of density in Hounsfield units (HU) that can be attributed to osteopenia and osteoporosis were (284.0 ± 63.3) and (231.5 ± 52.8), respectively. The density indicators of the two upper cervical vertebrae (C2 and C3) had a higher density than other segments [21]. According to our data, the trabecular density of the vertebrae was much higher, averaging (387.89 ± 49.14) — (333.81 ± 46.09) for C3–C6. We also studied the density of various layers of the vertebral arch cortex, which is an important object in the surgical scenario. The highest density corresponded to the osteonic layer, which coincides with the data of Dyachkova et al. [26]. The local density of all layers of the vertebral arch cortex ranged from 700 to 1150 HU, averaging (785.15 ± 38.4) HU.

According to Zaidi et al., MSCT assessment of the density of various structural formations of the vertebrae in patients with degenerative changes in the spine should be given the greatest importance [15]. First of all, assessing bone density becomes increasingly important as patient's age grow. Determination of bone quality is critical to treatment success, especially for the prevention of osteoporotic fractures, but is also part of optimal surgical preparation for spine surgery and screw position monitoring [24, 27]. The data obtained indicate a tendency for the total density of the cervical vertebrae to increase from C3 to C5 and to decrease caudally, with minimal density in C7 without signs of osteoporosis. A similar trend is characteristic of trabecular bone. According to Liang et al., it is necessary to determine not only the general and local density of the vertebrae, but also to study it at three levels in the sagittal plane (upper third, central part, lower third) to clarify the effect of disc degeneration on vertebral density [28]. Significant differences in compact bone density along the posterior surface of vertebrae C3–C5 were revealed on axial sections. There is a moderate asymmetry in the thickness of the vertebral arch on axial sections. The density of the osteon layer of the vertebral arch cortex differs significantly from the density of the outer and inner plates. The total density of the compact layer of the vertebral arch cortex exceeds 785.15 ± 38.4 HU, which is sufficient density for the vertebral arch with regard to all its layers for safe insertion of fixation screws.

CONCLUSION

The data obtained substantiate the need to include the study of the density of the vertebral bodies, of the vertebral arch and its thickness in the MSCT data processing algorithm to develop a plan for surgical intervention in patients with cervical spine stenosis in order to obtain objective data on the quality of the bone.

Conflict of interest *The authors declare that this work, its topic, subject and content do not involve competing interests. The opinions expressed in this article are those of the authors of the manuscript.*

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