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Quantitative Indicator for Vertebra Position of the Cervical-Thoracic Junction on the Base of Spine Radiographs

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ABSTRACT: *In the paper we discuss a new method for assessing the spatial position of the cervical-thoracic junction vertebrae.*
Objective: *to develop an indicator for assessing the vertebra positions of the cervical-thoracic junction from spine radiographs.*
Materials and methods: *Digital radiographs of all spine parts in the sagittal projection were obtained for 141 patients aged 21 to 88 years, 57 males and 84 females. The images were combined with each other so that a single digital image of the entire spine in the sagittal projection was obtained. In the image of the spine on a PC screen the occipital vertical is drawn from the external occipital protuberance down along the entire spine. The anteroposterior axes of vertebrae from CV to TV were drawn. At the point of each axis intersection with the occipital vertical a normal to the axis was raised. The angle between the normal and the occipital vertical (r angle) was measured. It was shown that r angle values of CVII…TIII vertebrae correlated most with the shape of the spine cervical-thoracic junction. It is shown that the value of r angles of the CVII…TIII vertebrae correlates most with the shape of the spine cervical-thoracic junction.*
Results*: The indicator $ar_{CVII-TIII}$ was constructed as an average for r angles of CVII…TIII vertebrae. On the base of the indicator value it was possible to distinguish four shape types of the cervical-thoracic junction: type I – the straightened type ("Giraffe Neck") with the CVII…TIII vertebrae aligning one above the other and abs($ar_{CVII-TIII}$) less than 15.5°; type II – the physiological type ("Harmonious Kyphosis") with CVII…TIII vertebrae keeping the middle position and abs($ar_{CVII-TIII}$) = 15.6-24.5°; type III – the increased kyphosis of the CVII…TIII vertebrae ("Bear Withers") with abs($ar_{CVII-TIII}$) =24.6-34.0°; and type IV – hyperkyphosis of the cervical-thoracic junction ("Buffalo Hump") was diagnosed when abs($ar_{CVII-TIII}$) was more than 34.1°.*
Conclusion*: The developed indicator $ar_{CVII-TIII}$ and shape typology of the cervical-thoracic junction are useful for the diagnosis of the cervical-thoracic disorders.*
Keyword: *Spine; Radiography of the Spine; Straightened Kyphosis; Harmonious Kyphosis; Hyperkyphosis; Forward Head Posture; Diagnostic Indicator of the Cervical-Thoracic Junction Vertebra Position; Cervical-Thoracic Junction Types.*

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I. INTRODUCTION

Hyperkyphosis of the cervical-thoracic junction and Forward Head Posture are associated with a decrease in physical performance, lower quality of life, and an increase in the mortality rate among the elderly people [1, 2]. Hyperkyphosis of the cervical-thoracic junction can cause dentoalveolar system diseases [3]. With hyperkyphosis, the risk of falling increases as a result of poor postural control, due to dysfunction of the vestibular apparatus [4], the functioning of the respiratory organs is often disrupted, including obstructive sleep apnea [5].

Today, the problem of the forward head posture (FHP) is widely discussed. It occurs when a person is in a stable position, with prolonged flexion in the area of the cervical-thoracic junction, for example, when working on a personal computer.

The forward head posture (FHP) and accompanying hyperkyphosis today is often found among young people. The prevalence of the forward head posture among students of the physiotherapy college aged 20 to 25 years was 70% [6], and among students and teachers of the dental college – 85.5% [7].

X-ray studies demonstrate that thoracic kyphosis increases with age with cervical lordosis flattens and average location of the cervical-thoracic arch transition shifts from TIII to CVII-TI vertebrae [8].

The spine is a whole system, one of its functions is to maintain the correct posture and keep a stable head position during standing and moving. Constructing an objective indicator of the vertebra positions in this area should be the first step for developing criteria which might describe all types of neck and head positions.

On a digital radiograph, an image of the cervical-thoracic junction vertebrae is well differentiated, and subsequent digital processing on a personal computer screen makes it possible to perform a quantitative analysis of the vertebra positions.

II. GOAL OF RESEARCH:

Using digital radiographs to develop a method for quantifying the position of the vertebrae of the cervical-thoracic junction; to determine the indicators that reliably characterize positions of the vertebrae in cervical-thoracic junction; on the base of obtained indicators to develop a typology of the vertebra positions for the cervical-thoracic junction area.

III. MATERIALS AND METHODS

In order to select the parameters for quantifying the spatial position of the vertebrae of the cervical-thoracic junction, radiographs for four groups were examined: 32 patients aged 21-45 years, 38 patients aged 46-59 years, 50 patients aged 60-74 years and 21 patients aged 75-88 years, total 141 patients, 57 males and 84 females. The selection of patients was random.

The criteria for inclusion in the study were the availability of digital radiographs of all spine parts made simultaneously in accordance with the required standards of radiography. Exclusion criteria: the presence of scoliosis of the III–IV degree and/or spondylolisthesis with spondylolysis of the vertebral arch LV.

The study was conducted on a personal computer screen and did not require additional radiation or any patient participation once a single digital X-ray image of all parts of the spine in the sagittal projection was obtained. The occipital vertical was drawn down along all spine structures starting from the well-defined on radiographs external occipital protuberance. The vertical was used as a base of the single coordinate system for all measurements [9].

The anteroposterior vertebral axes (r-axes) were drawn on the shadow X-ray images of the CV…TV vertebrae in the sagittal projection. To do this, the median points on the anterior and then on the posterior contour of the vertebral body were determined and straight lines were drawn through these two points until they intersected with the occipital vertical. At the intersection points, the perpendiculars to the r axes were restored, and the angles between the perpendiculars and the occipital vertical (r angles) were measured. Orel's universal ruler was used as a measuring device [9, 10].

IV. RESULTS

Reviewing the array of r angles for 141 patients detected that the maximum absolute values of r angles were observed for the vertebrae CVII, TI, TII and TIII. The minimum absolute value of the angle r for these vertebrae was not less than 1-4° and they were always tilted forward saving kyphosis shape even for patients with straightened cervical-thoracic junction type.

In this paper the emphasis was on measuring angles rather than linear head extension. This approach was chosen for two reasons. First, information about the array of angles does not impose strict requirements for scale correspondence and perfect match of different radiographs of a patient spine parts. And secondly, for angular analysis random individual characteristics of each patient such as height variability or disproportion in different spine parts and individual vertebrae are not so influencing. Based on the measured angle arrays, a schematic model for the studied spine part was constructed with the origin in the middle of the lower plane of the vertebra TV. The sum of the sines of the r angles (SumSin r) for the eight vertebrae (CV…TV) was considered a measure of horizontal forward extension for this part of the spine (that is, the model did not take into account the linear dimensions of all individual vertebrae for any person). A comparison for two small groups of patients with different ages through the prism of this model is shown in Figure 1.

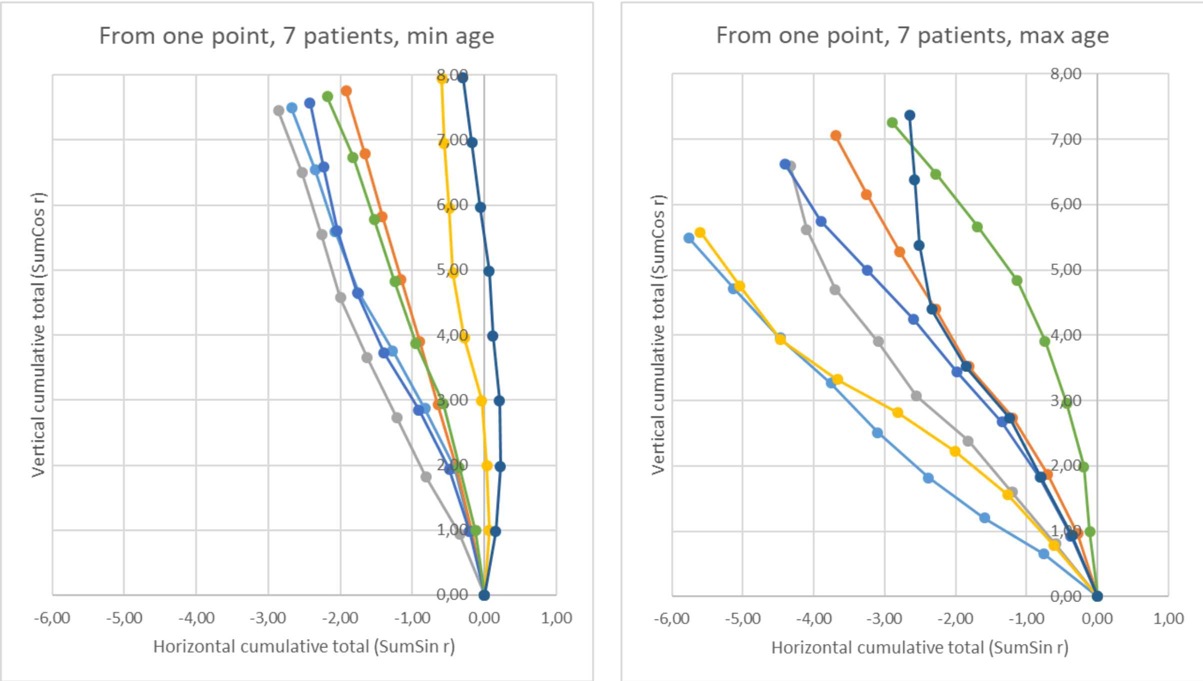


Figure 1: Modeling of the spatial position for vertebrae (CV…TV) of the cervical-thoracic junction.

Despite the simplifications, the proposed schematization illustrates quite clearly the key features of age-related changes. In this case, a comparison of two small groups of patients, which differ as much as possible in age, allows to note that the oldest patients not only have the extension of the cervical-thoracic junction vertebrae increased on average in the group, but the range of their spatial position options itself becomes wider. Deviations from the group average pattern increase.

The study found that the SumSin r array of eight vertebrae (CV…TV) for 141 patients showed a pronounced trend in age (Figure 2):

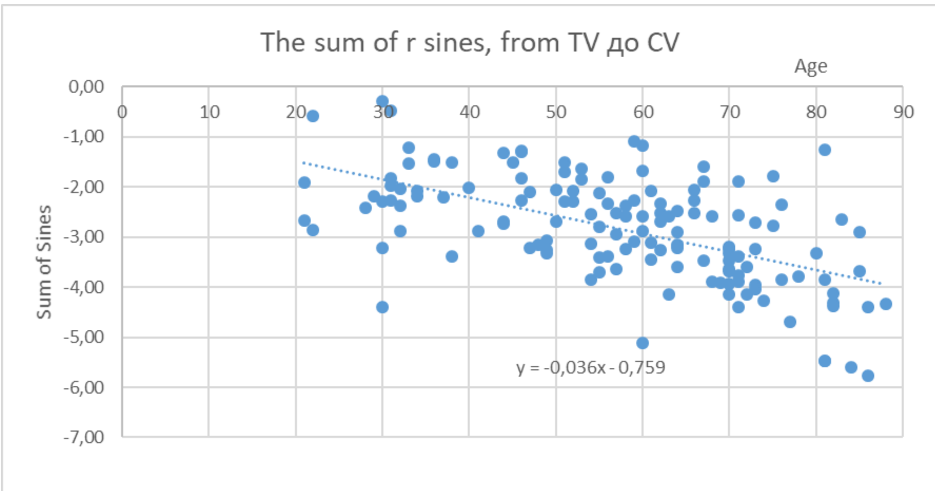


Figure 2: Scatter plot for the sum of the sines of the r angles for eight vertebrae of the cervical-thoracic region (CV…TV) with age.

A similar trend of age-related changes is demonstrated by each individual vertebrae of the area under consideration. Strong correlation with the sum array of eight r sines for vertebra (CV…TV) was shown by r angles of four vertebrae: CVII, TI, TII and TIII (Figure 3). In addition, the correlation is increased by taking into account the r angles of all four vertebrae at the same time. To quantify the age-related changes in relative values, instead of the eight sine sum, we use the usual arithmetic mean of the four angles r (in degrees) (Figure 4).

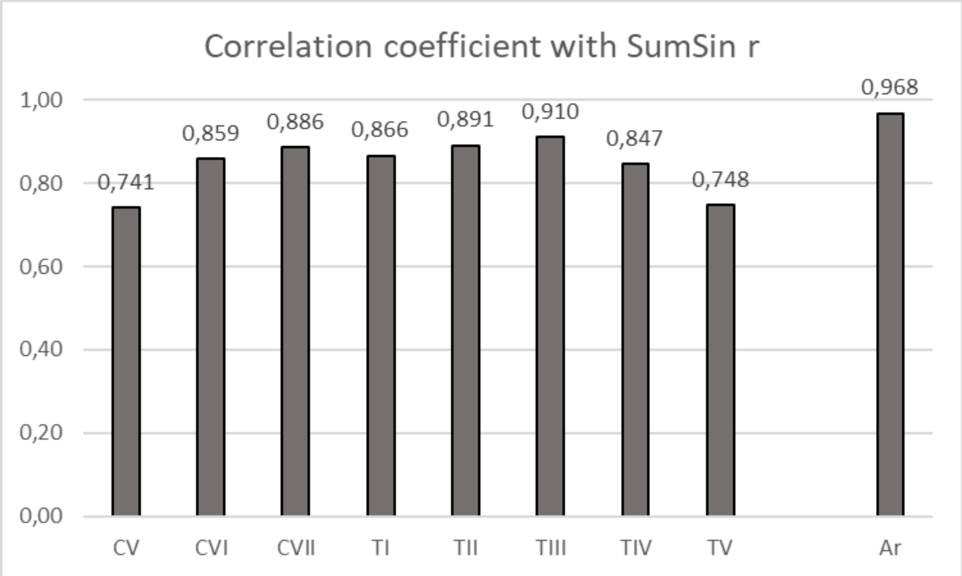


Figure 3: Correlation coefficients for sum array of r angle sines for eight vertebrae of the cervical-thoracic region (CV…TV) with each array of individual r angles and with mean value array for four vertebrae r angles (CVII…TIII).

Thus for diagnosing the vertebra positions of the cervical-thoracic junction, we have proposed an indicator $ar_{CVII\text{-}TIII}$, which is calculated as the mean value of the angles r for vertebrae of the cervical-thoracic junction CVII…TIII by the formula:

$$ar_{CVII\text{-}TIII} = (r_{CVII}+r_{TI}+r_{TII}+r_{TIII})/4 \qquad (1)$$

The physical meaning of the indicator is that it can be used to give a generalized characteristic of the forward angle of the CVII…TIII vertebral group relative to the occipital vertical.

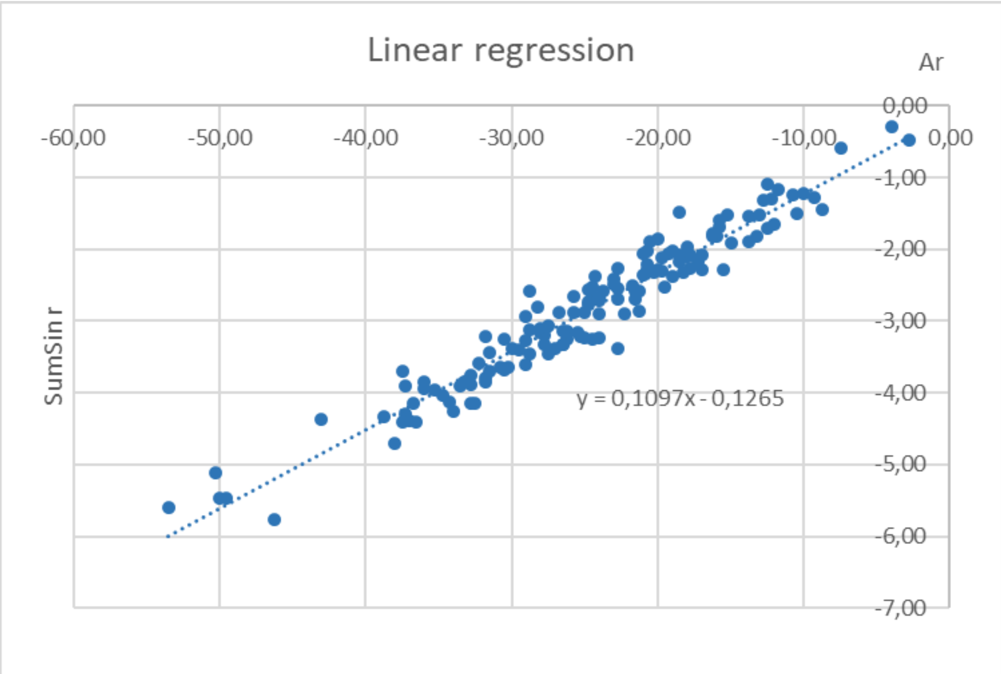


Figure 4: Linear regression for sum array of r angle sines for eight vertebrae of the cervical-thoracic region (CV…TV) with mean value array $ar_{CVII\text{-}TIII}$ for four vertebrae r angles (CVII…TIII).

Figure 5 shows the age-related changes in indicator arCVII-TIII for 141 patients aged 21 to 88.

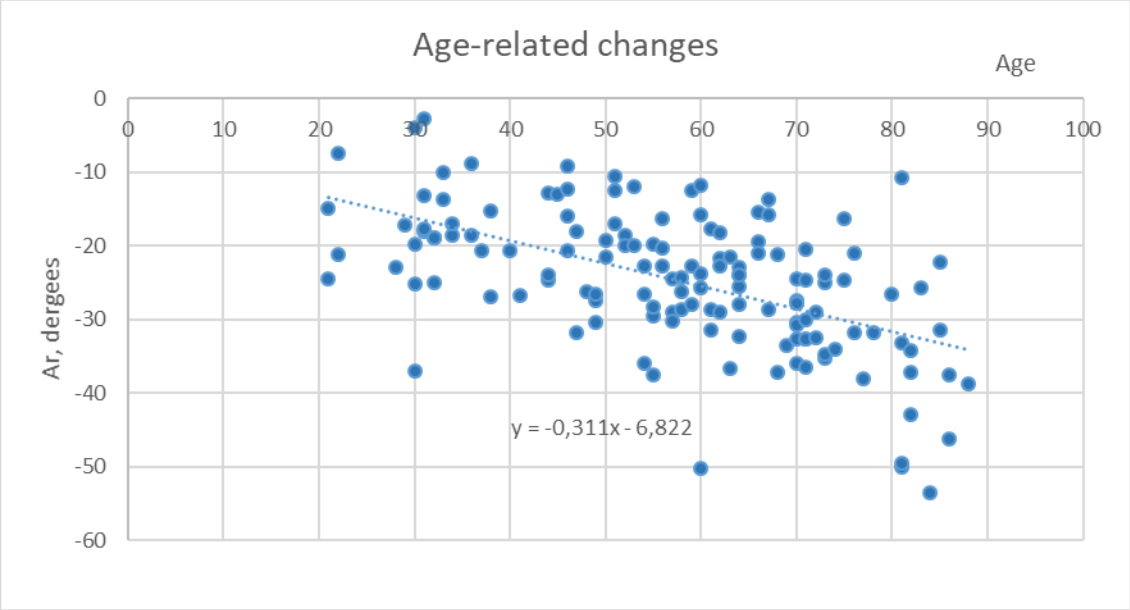


Figure 5: Scatter plot for the value $ar_{CVII-TIII}$ with age.

For the selected $ar_{CVII-TIII}$ indicator the linear age regression (trend) was estimated in MS Excel using the least squares method:

$$\text{trend}\ (ar_{CVII-TIII}) = -0{,}311 \times \text{age} - 6{,}821 \qquad (2)$$

After subtracting the age-related trend described by equation (2) from $ar_{CVII-TIII}$ indicator, the array of values [$ar_{CVII-TIII}$ - trend ($ar_{CVII-TIII}$)] remains randomly distributed in the group of 141 patients. The hypothesis of the distribution normality checking and corresponding diagrams were performed with STATISTICA 12 software package (Figure 6).

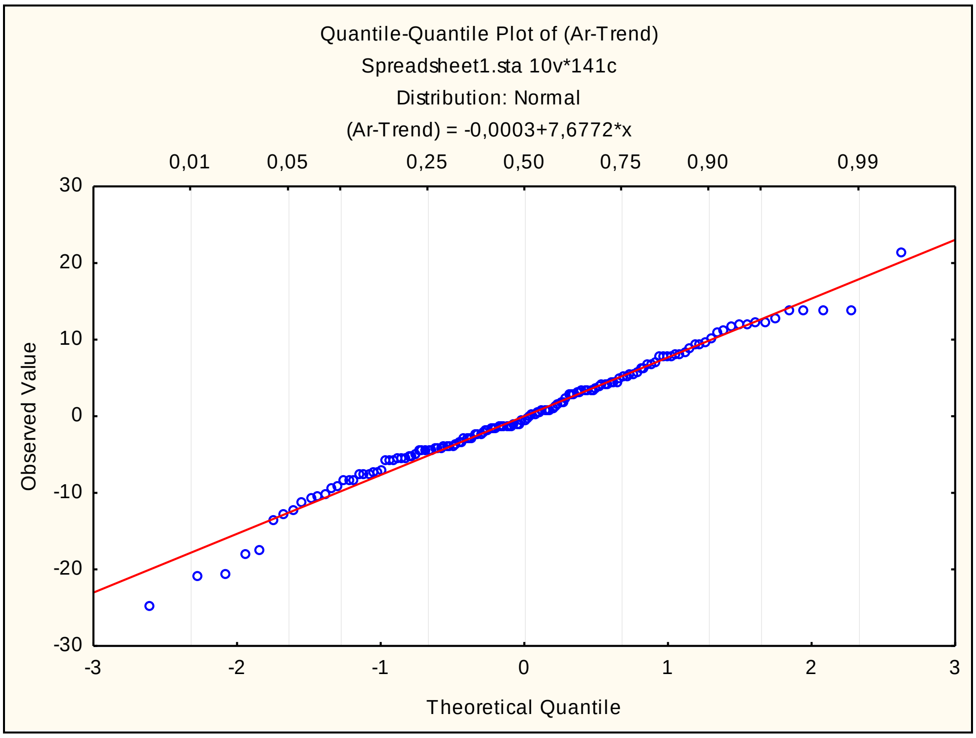


Figure 6: Comparison of standardized normal distribution quantiles with quantiles of $ar_{CVII-TIII}$ minus the age-related trend data distribution.

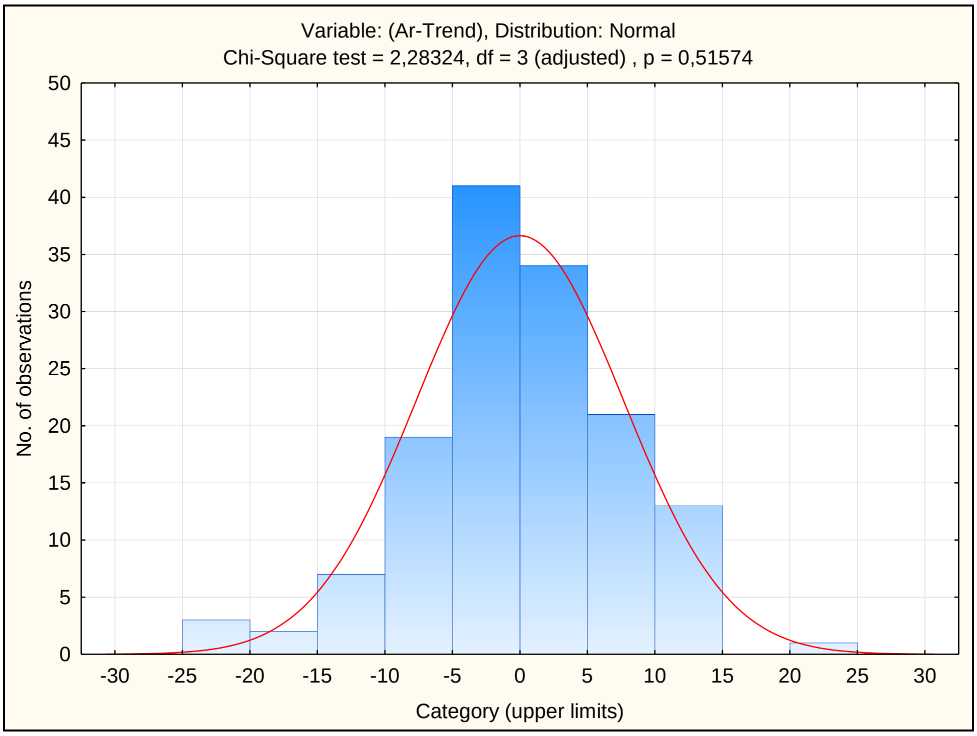


Figure 7: Frequency histogram of the data distribution for $ar_{CVII-TIII}$ minus the age-related trend in comparison with the normal distribution as well as χ^2 test.

As a result of testing the array [$ar_{CVII-TIII}$ - trend ($ar_{CVII-TIII}$)] by Shapiro-Wilk and χ^2 criteria the hypothesis about the normality of the data distribution was not rejected (Figure 7). Later on, the results make it possible to combine our data with databases of other researchers or to conduct evidence-based comparisons of various factors, preventive measures and therapeutic actions.

Thresholds values for different types of vertebrae spatial positions in the cervical-thoracic junction were determined on the base of indicator $ar_{CVII-TIII}$ (Table 1).

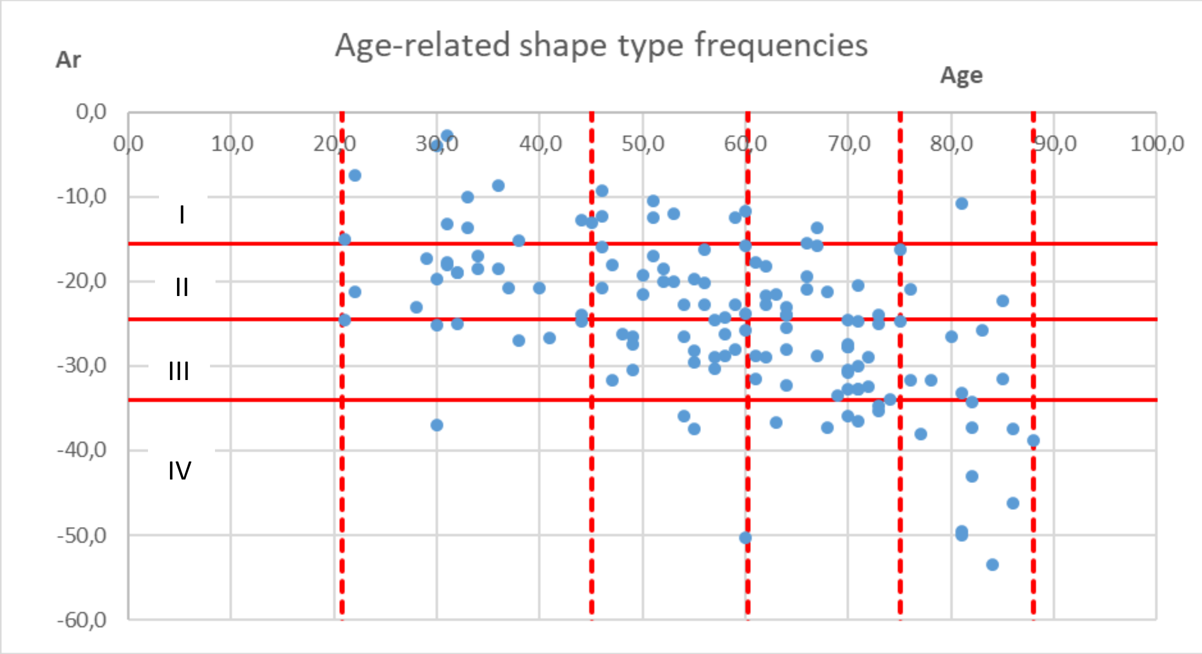
Table 1

Shape types of the cervical-thoracic junction according to the $ar_{CVII-TIII}$ indicator

Shape type of the cervical-thoracic junction	Absolute $ar_{CVII-TIII}$ value limits, degr.	
	min	max
I - Straightened (“Giraffe Neck”)	1	15,5
II - Physiological (“Harmonious Kyphosis”)	15,6	24,5
III - Increased Kyphosis (“Bear Withers”)	24,6	34,0
IV - Hyperkyphosis (“Buffalo Hump”)	34,1	and over

In accordance with the indicator $ar_{CVII-TIII}$, straightened kyphosis of the cervical-thoracic junction (type I) was diagnosed in 21 cases (15%), 52 patients (37%) were classified as type II, 48 patients (34%) had type III, and 20 patients (14%) had type IV kyphosis.

The frequencies of the cervical-thoracic junction four types were age-related (Figure 8). Both the young group (21-45 years) and the middle age group (46-59 years) were demonstrated mostly types I and II. In the elderly group (60-74 years) types I and II became less popular but still occurred in two thirds of cases. In the oldest group (75-88 years) types I and II were diagnosed in less than a fifth of cases.



(Figure 8) Four types of the cervical-thoracic junction shape in four age groups.

The type III of cervical-thoracic junction occurred relatively rare in the young group, and its frequency raised almost twice for middle age group patients. For elderly group the type III became the most popular. In the oldest group the type III of cervical-thoracic junction became less frequent than the IV type – the leader of the group.

The type IV of cervical-thoracic junction occurred only once in the young group (21-45 years) and only twice for middle age group patients (46-59 years). For elderly group (60-74 years) the type IV became more frequent (14%). In the oldest group (75-88 years) the type IV of cervical-thoracic junction was diagnosed in approximately 50% of cases. More than 80% patients of the oldest group demonstrated type III or type IV of the cervical-thoracic junction shape.

Thus people from the young group and the middle age group demonstrated mostly I and II shape types. In the elderly group the III kyphosis type of the cervical-thoracic junction was the most frequent, in the oldest group the IV and III types were more frequent.

V. DISCUSSION

Taking into account individual patient spine features makes it possible to differentiate surgery and rehabilitation programs. An indicator $ar_{CVII\text{-}TIII}$ can serve as a criterion that reflects the spatial position features of the cervical-thoracic junction vertebrae of a patient. The indicator is effective for determining shape type of the cervical-thoracic junction for patients of any age regardless of degenerative-dystrophic changes.

The main application sense for the developed indicator is that it clearly distinguishes all shapes of the cervical-thoracic junction. The straightened position of the vertebrae of the cervical-thoracic junction (type I) often accompanies the straightening of all the physiological arches throughout the spine and, as a result, an increased frequency and amplitude of the anteroposterior displacements of the vertebrae of the cervical and lumbar spines. The harmonious position of the vertebrae of the cervical-thoracic junction (type II) is the most physiological. Even a small or moderate increase in CVII…TIII vertebral kyphosis (type III) is accompanied by a forward movement of the head with all consequences and syndromes described as FHP. This type can be considered as a compensation phase. Finally, a pronounced increase in the kyphosis of the cervical-thoracic junction (type IV) indicates far-reaching changes. It can be considered as a phase of subcompensation due to a pronounced limitation of a person's physiological capabilities.

Such type division will be useful for implementation of surgery and/or therapeutic measures. The presence of a harmonious type of the cervical-thoracic junction allows to offer the patient entire complex of preventive measures. If the cervical-thoracic junction is straightened the patient can be offered therapeutic procedures to prevent excessive displacement of the cervical spine vertebrae and assign gymnastic exercises that promote the kyphosis harmonization throughout the entire spine. The increased kyphosis of the cervical-thoracic junction vertebrae deserves special attention. In the case it is important to clearly understand whether the physiological potential of the patient is kept and $ar_{CVII\text{-}TIII}$ indicator gives the necessary information. A moderate increase in the CVII…TIII vertebral kyphosis of type III allows to apply confidently therapeutic measures and offer wide range of restorative medicine possibilities. Type IV of the cervical-thoracic junction indicates the phase of subcompensation and imposes restrictions on the of therapeutic measure implementation.

The frequencies of the cervical-thoracic junction types were age-related. In the young group (21-45 years) type II (harmonious) was the most frequent, type I (straightened) was less popular and types III (increased kyphosis) and IV (hyperkyphosis) were rare. In the middle age group (46-59 years) type II was the most frequent as well, but number of cases with type III raised. In addition, type IV frequency went up and type I became less popular. For the elderly group patients (60-74 years) the most frequent was type III with type II slightly less frequent. In the oldest group (75-88 years) type IV of the cervical-thoracic junction prevailed followed by type III.

VI. CONCLUSION

Modern technologies of digital radiography make it possible to examine the spine image on the PC screen without additional radiation of the patient. A single digital image of all spine parts in the sagittal projection allows to explore it as a whole. A single coordinate system based on occipital vertical is a key element in assessing the position of the cervical-thoracic junction vertebrae. It was drawn from external occipital protuberance well-defined both on radiographs and clinically along all the structures of the spine. The next step was to take into account the individual characteristics of the patient's spine such as a position of each vertebra. To do this, the anteroposterior axes of the CV…TV vertebrae were drawn and from the point of their intersection with the occipital vertical a perpendicular to each axis was raised. The angles between the perpendiculars and the occipital vertical (r angles) were measured. It was shown that the value of the r angles of the CVII…TIII vertebrae correlated most with the shape of the cervical-thoracic junction.

During the study it was possible to determine a reliable indicator $ar_{CVII-TIII}$ for diagnosing the positions of the cervical-thoracic junction vertebrae.

Four shape types of the cervical-thoracic junction were distinguished: type I – the straightened type ("Giraffe Neck") with the CVII…TIII vertebrae aligning one above the other and abs($ar_{CVII-TIII}$) less than 15.5°; type II – the physiological type ("Harmonious Kyphosis") with CVII…TIII vertebrae keeping the middle position and abs($ar_{CVII-TIII}$) = 15.6-24.5°; type III – the increased kyphosis of the CVII…TIII vertebrae ("Bear Withers") with abs($ar_{CVII-TIII}$) =24.6-34.0°; and type IV – hyperkyphosis of the cervical-thoracic junction ("Buffalo Hump") is diagnosed when abs($ar_{CVII-TIII}$) is more than 34.1°.

The frequencies of the cervical-thoracic junction types are age-related. People from the young group and the middle age group demonstrate mostly I and II shape types. In the elderly group the III kyphosis type of the cervical-thoracic junction is the most frequent. In the oldest group the IV and III types are more frequent and are followed by forward head posture.

Thus both increased kyphosis and hyperkyphosis of the cervical-thoracic junction and accompanying the forward head posture (FHP) are age-related features more frequent in the oldest group.

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