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Anatomical and Anthropometric Features of Bone Bodies Structures in Children with Idiopathic Scoliosis of Lenke III Type

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Abstract

Introduction. Lenke III type spinal curvature occurs in 11% of all types of deformities in idiopathic scoliosis. Knowledge of the features of the structure of the bone structures throughout the main curve of the deformity allows to properly plan the installation of transpedicular supporting elements during the operation and carry out a specific sequence of correcting manipulations in order to achieve the optimal result. ***Purpose*** — to study the anatomical and anthropometric features of the bone structures of the vertebrae in children with Lenke III idiopathic scoliosis, using a navigation device. ***Materials and Methods.*** The study included 23 patients with S-type idiopathic scoliosis type III according to the classification of L. Lenke aged 14 to 18 years, of which 22 are female patients and 1 male. All children carried out spinal X-rays in standard projections (direct and lateral), multislice computed tomography, according to MSCT in the navigation unit measured anatomical and anthropometric indicators, certain parameters and coefficients were calculated mathematically. ***Results.*** The following patterns were determined: pronounced asymmetry of both the width and height of the bases of the arches of the vertebrae along the concave and convex sides of the deformity in the thoracic spine and moderately pronounced structural changes in the bone structures in the lumbar spine. Strong direct correlations between the asymmetry coefficient of the base areas of the arcs and the asymmetry coefficients of the width and height of the base of the arcs, as well as a direct correlation between the values of the rotational value of the apical vertebra and the asymmetry coefficient of the base areas of the arcs in the thoracic region were revealed. In the lumbar spine, only a directly proportional relationship was found between the asymmetry coefficient of the areas of the bases of the arches of the vertebrae and the coefficient of asymmetry of the heights of the bases of the arcs of the vertebrae. ***Conclusion.*** An analysis of the anatomical and anthropometric parameters of the bony structures of the vertebrae in children with idiopathic scoliosis of the Lenke III type has made it possible to identify certain features, to establish patterns and correlations that characterize this variant of deformity.

Keywords: idiopathic scoliosis, Lenke classification, anatomic and anthropometric parameters, transpedicular fixation.

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Introduction

Incidence of idiopathic scoliosis rate among all orthopaedic pathologies amounts to 1–1,5% [1]. The most widespread localization of deformity in such pathology is thoracic spine — Lenke I idiopathic scoliosis. Lenke III spine deformities in idiopathic scoliosis are observed in 11% of cases [2].

Many publications in national and world literature are dedicated to surgical treatment of children with idiopathic scoliosis. Such publications reflect in detail the correction techniques during surgery as well as late outcomes of surgery. At present spine systems with transpedicular support elements are used for spine curve correction in children with idiopathic scoliosis [3–6]. Assessment of anatomical and anthropometric values of pedicles area, their orientation in respect of vertebral body along the main deformity allows to perform a precise preoperative planning for placement of support elements and their accurate positioning during surgery [7–10]. Knowledge of bony structures features along the main deformity curve allows to correctly plan insertion of transpedicular support elements during surgery and to perform a certain sequence of correction procedures to achieve the optimal outcome [11–14].

Only sporadic research is dedicated to study and evaluation of anatomical and anthropometric parameters of vertebral body structures along the main deformity curve. Such papers are dedicated to evaluation of pedicles dimensions and their dimensional orientation in relation to vertebral body in patients with thoracic idiopathic scoliosis [15, 16]. Some researchers are analyzing there parameters basing on MRI examination and/or CT [15]. Other authors state that study of anatomical and anthropometric features of vertebral body structures in patients with idiopathic scoliosis based on above imaging examinations is accompanied by high inaccuracy percentage and measurement errors [17, 18]. Evaluation of parameters of vertebral bodies located along the main deformity curve basing on CT data processed by navigation device allows to visualize bony structures in children with more precision and more details [11, 19—21].

Purpose — to study the anatomical and anthropometric features of the bone structures of the vertebrae in children with idiopathic scoliosis, type Lenke III, using a navigation device.

Materials and Methods

The study included 23 patients with S-type idiopathic scoliosis of L. Lenke III aging from 14 to 18 years. Females prevailed — 22 patients. Thoracic deformity curve averaged 79° (from 35° to 124°), lumbar curve averaged 71° (from 32° to 108°).

X-rays in standard views were made in all patients. X-rays were used to evaluate the angle of the main deformity curve by Cobb in AP and lateral views, to identify deformity type by location of deformity curve apex and their structuring.

All patients underwent multi-layer spiral CT (MSCT) of deformed spine segment on computer tomograph „Brilliance CT64“ (Philips, USA) from Th1 level to S1.

CT scans were uploaded into the software of the optical navigation system SpineMap 3D to evaluate anatomical and anthropometric features of vertebras in the deformity curve. Basing on the large array of scans SpineMap 3D software built a three dimensional model of the spine. For each vertebra in the deformity curve an own spatial plane was selected to ensure equal positioning in relation to three mutually perpendicular planes. Upon achieving such conditions the authors measured height (lngd) and width (trd) of pedicles of each vertebra along the deformity curve on the right (R) and left (L) side (Fig. 1).

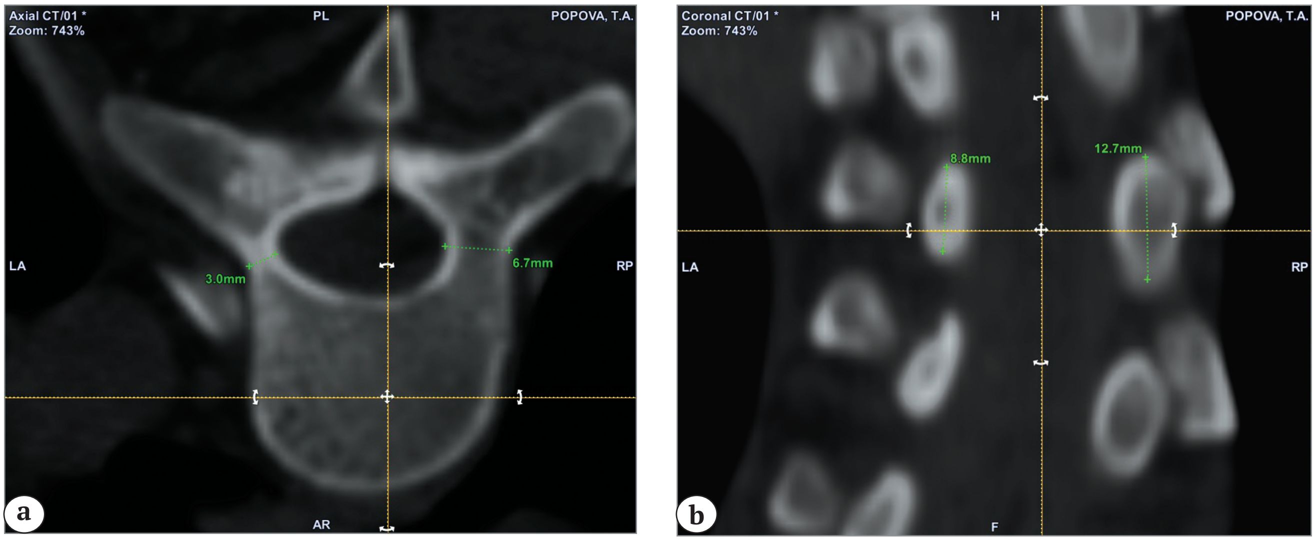

Fig. 1. Measurement of pedicle width (a) and height (b), green line marks the site of measurment

Apart from evaluation of the main deformity curve magnitude in thoracic and lumbar spine as well as measuring of height and width of pedicles along the deformity, the authors measured rotation of apical vertebras (RAV) in thoracic and in lumbar curves. Rotation was measured by a method developed by the authors (patent of Russian Federation 2587035) which was described in the previous publication [22].

Obtained measurements were recorded and tabulated individually for each patient. The pedicle square was calculated as the product of width value into height value and the resulting values were entered into aggregate table. Trd and lngd values and square values were arranged as mean and standard deviations.

The following coefficients were calculated to identify consistencies in scoliotic process:

– coefficient of pedicle width asymmetry (KAtrd) calculated as ratio of trdR к trdL;

– coefficient of pedicle height asymmetry (KAlng) equal to ratio of lngdR to lngdL;

– coefficient of asymmetry of pedicle square (KAS) as ratio of SR to SL.

Statistical analysis

Kolmogorov-Smirnov test and Lilliefors test were used to verify normalcy of distribution. Box plot of Tukey revealed interdependencies and correlations between the signs, and the correlation analysis (method of correlation constellations by V.P. Terentiev) was applied for the same purpose. Hotelling's T-squared distribution (T2) was used for multivariate dispersion analysis of trd and lngd values.

STATISTICA10 (StatSoft, Inc) software was used for statistical processing of the data.

Results

Pedicle width and height parameters, pedicle square values and asymmetry coefficients were obtained in result of the study (Table 1–3).

Table 1

Pedicle width and height parameters in patients with Lenke III idiopathic scoliosis (*n* = 23)

Vertebra	Left		Right	
	trdL, mm	lngdL, mm	trdR, mm	lngdR, mm
Th2	5.8±1.2	12.2±1.5	4.6±1.6	11.2±1.4
Th3	5.3±1.0	12.1±1.7	3.3±1.2	11.8±1.9
Th4	5.0±1.0	11.4±1.4	3.4±1.1	12.4±1.7
Th5	4.4±1.2	10.7±1.9	4.3±1.1	12.9±1.6
Th6	3.8±1.0	10.5±2.2	4.8±0.9	13.5±1,8
Th7	3.3±1.0	10.7±2.0	5.2±1.2	14.0±2.1
Th8	3.5±1.3	11.2±2,2	5.5±1.4	13.5±1.5
Th9	4.2±1.4	13,3±2.7	5.8±1.5	14.2±1.8
Th10	5.5±1.4	16.5±2.8	6.2±1.7	16.3±2.3
Th11	7.9±1.8	19.0±3.1	7.3±2.3	16.7±2.8
Th12	7.7±1.8	17.5±2.4	6.4±1.4	15.5±2.1
L1	6.2±1.6	15.6±2.4	6.1±2.0	14.5±2.5
L2	6.5±1.4	15.5±1.6	7.1±2.3	14.6±2.1
L3	8,4±1.7	15.0±1.8	8.4±2.1	14.8±1.7
L4	10.9±2.4	14.1±1.9	10.1±2.2	14.5±1.9
L5	14.9±3.3	13.0±1.5	13.4±2.5	14,6±1,4

Table 2

Left and right pedicles square in patients with Lenke III idiopathic scoliosis (*n* = 23)

Vertebra	Left curve	Right curve
	SL, mm²	SR, mm²
Th2	71.5±19.6	52.1±21.7
Th3	65.7±17.7	39.7±17.4
Th4	57.0±16.1	42.4±17.5
Th5	47.7±17.9	56.4±18.2
Th6	41.2±15.2	64.7±15.3
Th7	35.8±15.2	73.9±22.6
Th8	40.4±20.0	74.8±24.4
Th9	56.7±25.4	83.4±27.3
Th10	93.6±35.2	102.8±35.3
Th11	153.6±54.1	122.2±43.8
Th12	136.6±47.7	101.4±32.7
L1	97.0±33.4	90.4±40.4
L2	101.1±28.7	105.8±48.2
L3	125.6±31.3	125.1±40.3
L4	154.0±44.9	145.9±38.6
L5	193.0±46.5	195.8±45.4

Table 3

Hotelling's T-squared distribution (T2) test results for comparison of distribution of right and left pedicles' diameters

Spine segment	Trd	lngd
Th2-12 (thoracic)	T2 = 206.3 p<0.00017	T2 = 58.0 p = 0.041
L1-5 (lumbar)	T2 = 11.2 p = 0.16	T2 = 42.5 p<0.00089

The following consistencies were observed during analysis of pedicle width on concave and convex sides of deformity. The authors observed that width values on concave side trdL in thoracic spine are decreasing from Th2 level (5.8±1.2) to Th7 level. From level Th7 until Th11 the authors observed increasing width values (7.9±1.8). From Th11 to L1 level the width parameters are decreasing (6.2±1.6) with another increase in caudal direction. On the convex side of deformity the values of pedicle width in thoracic spine on level of Th2 equals to 4.6±1.6. Levels Th3 and Th4 feature insignificant decrease of value and then width value increases up to level Th11 (7.3±2.3) and then decreasing up to level L1 (6.1±2.0) followed by another gradual increase until level L5 (13.4±2.5).

Ingd values feature the following consistency: on concave side from Th2 to Th6 (10.5±2.2) the parameter demonstrates a gradual decrease, then from Th6 to Th11 (19.0±3.1) an increase is observed with a certain decrease by L5 level (13.0±1.5). On convex side the pedicle height increases from Th2 to Th11 (16.7±2.8) with insignificant decrease at level Th8 (13.5±1.5) and gradual decrease from Th11 until L5.

Table 2 contains values of left and right pedicles square measured as the product of width into height. The analysis of square variances demonstrated the following consistency. On concave side squares decrease almost twofold from Th2 to Th7 levels (35.8±15.2), followed by value increase from Th7 to Th11 with a maximum value on this level (153.6±54.1). In the area from Th11 to L1 square values decrease (97.0±33.4) with a gradual increase again in caudal direction. On the convex side of deformity the authors observed a contrary situation. Pedicles squares decrease from Th2 to Th3 level with following increase up to Th11 level (122.2±43.8). Parameter's value decreases until L1 level (90.4±40.4) with gradual increase by L5 level.

Thus, value of pedicles squares along the deformity curve in patients with Lenke III idiopathic scoliosis upon concave and convex sides demonstrated the similar variations consistency to their absolute values.

Multivariate dispersion analysis was applied to trd and lngd parameters to compare distribution of left and right pedicle diameters for thoracic and lumbar vertebras (Table 3). Outcomes of Hotelling's T-squared distribution (T2) test demonstrate an unambiguous and contrasting difference between aggregate of pedicle width in thoracic spine and length of pedicles in lumbar spine, at the same time there is an insignificant aggregate difference in width in lumbar spine and marginal aggregate difference in pedicle height in thoracic spine.

Kolmogorov-Smirnov test and Lilliefors test used for analysis of all four parameters of vertebras as well as for squares of right and left pedicles did not demonstrate significant variances from normal distribution for all vertebrae (p>0.05).

Tukey box plot was used to evaluate anatomical and anthropometric features of vertebrae in the deformity curve (Fig. 2). Visual diagrams analysis allowed to evaluate in detail and to verify differences in diameters of right and left pedicle identified earlier by Hotelling's T-squared distribution (T2) test. Figure 3 demonstrated significant differences in pedicle width in the area of apical thoracic vertebrae and insignificant differences for medians of lumbar apical vertebrae, as well as significant differences in height of right and left pedicles in the lumbar spine.

During the study the authors calculated asymmetry coefficients of transverse, longitudinal diameter and square of pedicles in children with idiopathic scoliosis along the deformity curve which allowed to make comparative evauation of such parameters with concave and convex sides of deformity (Table 4). Tukey box plots were used to visualize the difference in pedicle squares value (Fig. 4).

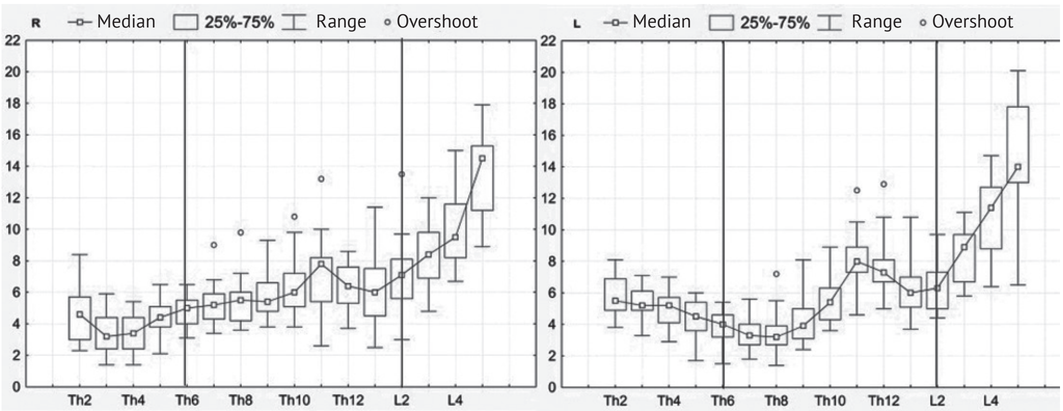

Fig. 2. Comparison of distribution for medians of pedicle width.
Vertical lines – medians of thoracic and lumbar apical vertebrae

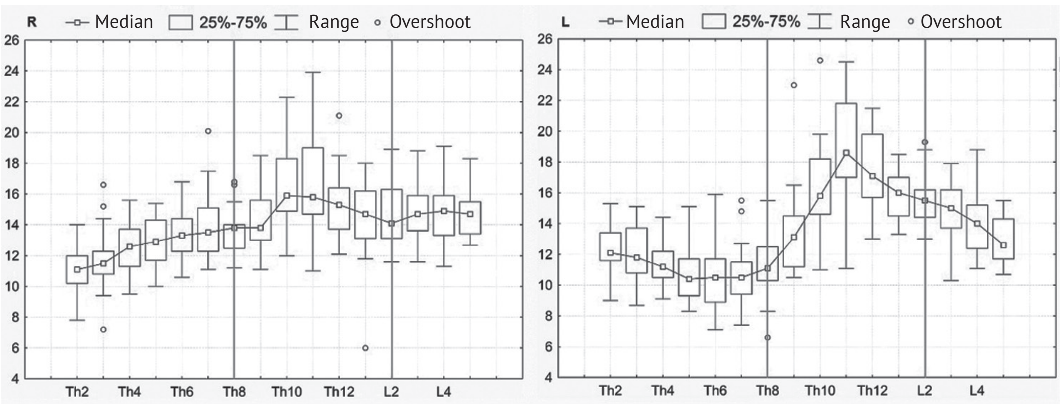

Fig. 3. Comparison of distribution for medians of pedicle height

Table 4

Asymmetry coefficients for width, height and square of pedicles in patients with Lenke III scoliosis (*n* = 23), values are presented in form of a median [minimum; maximum]

Vertebra	Transverse diameter	Longitudinal diameter	Square
	KAtrd	KAlngd	KAS
Th2	0.80 [0.45 ; 1.14]	0.90 [0,76 ; 1,18]	0.70 [0.36 ; 1.34]
Th3	0.63 [0.39 ; 0.87]	0.97 [0,67 ; 1,34]	0.52 [0.33 ; 0.92]
Th4	0.72 [0.40 ; 1.29]	1.07 [0,76 ; 1,43]	0.71 [0.35 ; 1.84]
Th5	0.94 [0.47 ; 2.74]	1.21 [0.95 ; 1,81]	1.28 [0.49 ; 4.25]
Th6	1.25 [0.91 ; 2.27]	1.30 [0.81 ; 2,24]	1.58 [0.88 ; 3.54]
Th7	1.70 [1.10 ; 2,86]	1.23 [0.89 ; 2.01]	2.12 [1.14 ; 5.45]
Th8	1.50 [1.02 ; 3.00]	1.14 [0.94 ; 2.09]	1.90 [1.14 ; 4.88]
Th9	1.53 [0.87 ; 2.31]	1.06 [0.72 ; 1.43]	1.63 [0.90 ; 2.70]
Th10	1.17 [0.67 ; 1.53]	0.98 [0.76 ; 1.26]	1.07 [0.68 ; 1.54]
Th11	0.94 [0.46 ; 1.69]	0.85 [0.71 ; 1.42]	0.82 [0.38 ; 1.38]
Th12	0.85 [0.51 ; 1.28]	0.89 [0.66 ; 1.23]	0.76 [0.44 ; 1.50]
L1	0.96 [0.60 ; 1.61]	0.92 [0.81 ; 1.18]	0.89 [0.55 ; 1.70]
L2	1.05 [0.67 ; 1.73]	0.92 [0.78 ; 1.20]	1.02 [0.57 ; 2.08]
L3	1.00 [0.56 ; 1.26]	0.97 [0.85 ; 1.36]	0.98 [0.48 ; 1.70]
L4	0.97 [0.65 ; 1,16]	1.07 [0.67 ; 1.19]	0.96 [0.43 ; 1.31]
L5	0.87 [0,67 ; 1,58]	1.12 [0.93 ; 1.33]	0.98 [0.86 ; 1.77]

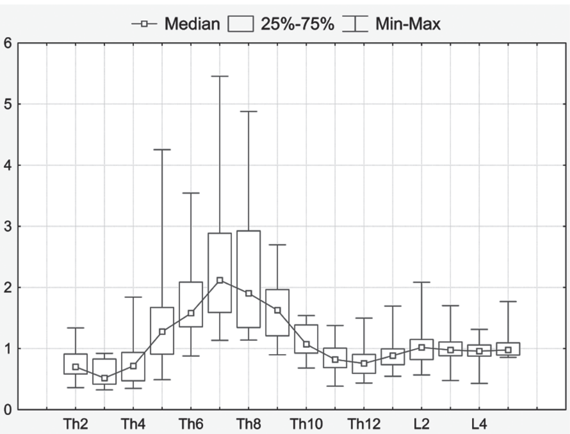

Fig. 4. Asymmetry coefficients of pedicle squares, presented in form of a median, minimum and maximum

Analysis of asymmetry coefficient of pedicle width revealed the following features. In lumbar spine asymmetry coefficient neared 1 with minimum value at level L5 (0.87), in thoracic spine KAtrd featured a bigger deviation from 1 of multidirectional pattern with maximum values at Th3 (0.63) and Th7 (1.70) levels. Analysis of asymmetry coefficient of pedicle height demonstrated that all KAlngd values approximated 1. The biggest deviation was observed at Th5-Th8 level, maximum — at Th6 (1.30), Th11 and Th12 (0.85; 0.89) levels.

Clear consistency was reported after analyzing the variation of asymmetry coefficient of pedicle square. KAS had a maximum deviation from 1 at Th3 level (0.52) demonstrating almost twofold prevalence of pedicle dimensions on concave side as compared to convex. Afterwards KAS values gradually increase achieving maximum at Th7 and Th8 levels (2.12; 1.90). Pedicles squares dimensions on convex side exceed squares value on concave side twofold. KAS values decrease at levels Th11 and Th12 to 0.82 and 0.76 respectively. Again it confirms the present severity of structural alterations in the bony structure of vertebrae in thoracic spine basing on KAS parameters in patients with Lenke III idiopathic scoliosis. At the same time it should be noted that in the lumbar spine asymmetry coefficient for pedicle width (0.87 at L5 level; 1.05 — at L2 level), pedicle height (0.92 at L1 and L2 levels; 1.12 — at L5 level) and pedicle square (0.89 at L1 level; 1.02 — at L2 level) are approximating 1. The minimal difference between coefficients of asymmetry for pedicle width and height in lumbar spine as well as between coefficients of asymmetry for pedicle square and their approximation to 1 in children with Lenke III idiopathic scoliosis confirms moderate structural alterations of bony structures in spine segment.

Method of correlation constellations of V.P. Terentiev was used for analysis of 10 anatomical and anthropometric parameters and their parameters of bony structure of vertebral bodies along deformity curves (Fig. 5).

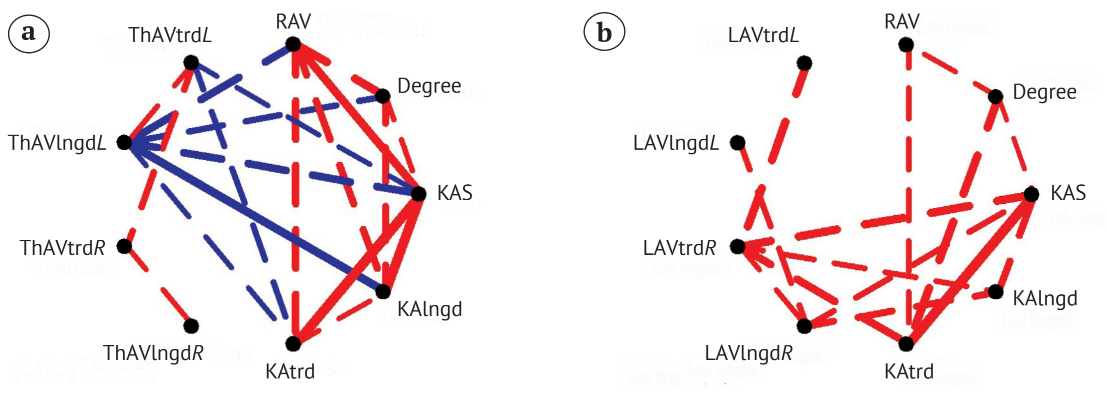

Fig. 5. Diagram of correlation constellations of V.P. Terentiev:
a — Thoracic spine; b — Lumbar spine.
Continuous line — Pearson correlation coefficient (*r*) above 0.8: $|r|>0.8$; dotted line: range $0.5<|r|<0.8$; line thickness are proportional to corresponding *r*-values.
Red lines — positive correlation ($r>0$), blue — negative ($r<0$).
AV — apical vertebra; trd — width of pedicle; lngd — height of pedicle;
L — left pedicle; *R* — right pedicle.
RAV — rotation of apical vertebra;
Degree — deformity angles according to Cobb in thoracic and lumbar spine respectively;
KAS — coefficient of asymmetry of pedicle squares;
KAlngd — coefficient of asymmetry for pedicle height;
KAtrd — coefficient of asymmetry for pedicle width

During analysis a constellation |*r*| = 0.7 (continuous line on Fig. 6a) was observed consisting of signs RAV, KAS KAtrd and KAlng. This data emphasizes a strong relation of RAV with asymmetry of laminas in thoracic spine and the latter is clearly marked by all three indices. Apart from relation of these indices at the level of constellation |*r*| = 0.5 (dotted line on Fig. 5a) a direct correlation with deformity angle by Cobb is added. Strong negative correlation is observed between AΠlngdL and KAlng for thoracic vertebrae. Strong negative correlation is observed for value of pedicle height on concave side and coefficient of asymmetry for pedicle heights for thoracic vertebrae. Diagram of thoracic spine (Fig. 5b) demonstrated absence of negative correlation between studied parameters of bony structure of vertebral bodies along the main deformity curve. However, a less strong direct correlation is observed between KAS, KAtrd. KAtrd, KAlngd and KAS indices being ratio of the product of right laminas' dimensions into left laminas' dimensions, are naturally directly proportional to „right" diameters and inversely proportional to „left" diameters. It should be noted that all three parameters of asymmetry demonstrate the strongest relation with dimensions of left laminas in thoracic spine, and with dimensions of right laminas — in lumbar spine.

Discussion

During procedures for correction of deformities in children using transpedicular support elements surgeons do not always manage to insert the screws into vertebral bodies along the whole deformity of the spine [23, 24] especially in upper and mid-thoracic spine. This is resulting due to small side of pedicles and severe spatial alterations of ratios between pedicles and vertebral body resulting from rotational deformity [10, 25]. Considering this fact research of bony structures of vertebral bodies and their spatial relations in children with various types of idiopathic scoliosis is an important and relevant topic for further studying. According to some authors the evaluation of anatomical and anthropometric features of bony structures along the main deformity curve allows to performe a rational preoperative planning of positioning for transpedicular support elements for each type of idiopathic scoliosis and to ensure their correct placement during the surgery [22, 26]. Most often radiological examinations are used to study bony structures parameters of vertebral bodies in patients with idiopathic scoliosis [12, 15, 27]. However, assessment of anatomical dimensions basing on above methods features rather significant errors in obtained results especially for rotation. In recent years some studies appeared where 3D-CT navigation [17, 18, 22, 28, 29] was used for visualization and evaluation of anatomical and anthropometric parameters of bony structure of vertebral bodies in patients with idiopathic scoliosis. Unified processes of spine growth are occurring in case of scoliotic diseases which according to some researchers [16, 30] is demonstrated by a certain similarity of gradient of pedicle diameters in craniocaudal direction. However, at the apex of the main deformity curve the pedicle diameter dimensions are varying in accordance with progressing scoliotic process which is demonstrated by asymmetry of bony structures.

Outcomes of the present study demonstrated that depending on deformity type, quantity and curves structure there are certain consistencies in deviations of anatomical and anthropomentric features of pedicles, in particular, their transverse and longitudinal diameters. Children with Lenke III idiopathic scoliosis feature similar deviations of parameters at Th3 and Th4 levels which were reported in children with Lenke I deformity [22].

Analysis of pedicles width and height parameters and coefficients of asymmetry for thoracic spine in Lenke III deformity demonstrated the presence of severe structural alterations in thoracic curve along convex and concave sides which is the principal deformity curve in patients with such scoliosis type [31].

Evaluation of the same parameters in the lumbar spine demonstrated a slight difference for values of parameters and coefficients of asymmetry on concave and convex sides. The authors explained this by the fact that lumbar curve is compensatory in children with such pathology and has no significant anatomical and anthropometric alterations of bony structures as compared to thoracic curve. Thus, evaluating the possibility for correction of Lenke III deformity by transpedicular implants, relying on correlation between Cobb angle and coefficients of asymmetry for pedicles width and height in thoracic spine the authors came to the following conclusions: transpedicular fixation is possible in lumbar spine and along the convex side of thoracic deformity, when implanting transpedicular elements along concave side of thoracic deformity we should be guided by the angle of the main deformity curve. Established that the bigger is the deformity angle of the main deformity the severity of rotational component at the apex of deformity is higher and alterations of spatial relations between pedicle and vertebral body are more pronounced, which means less chances to precise insertion of transpedicular implants at this level.

Conclusion

Analysis of anatomical and anthropometric parameters of bony structures of vertebrae in children with Lenke III idiopathic scoliosis allowed to identify certain features, establish consistencies and correlations specific for such type of deformity. The study revealed marked variances in absolute and relative parameters of bony structures of vertebral bodies and, as a consequence, importance of correlations in thoracic and lumbar spine. Thoracic spine features stronger direct proportional relations between asymmetry coefficients of pedicle squares, pedicle width and height as compared to lumbar spine. Besides, a direct correlation between asymmetry coefficient of pedicle square and apical vertebra rotation was observed. These consistencies support the processes of phylo- and ontogenesis which are formed and progress in deformed spine during child growth. Lumbar spine demonstrated direct proportional relation between asymmetry coefficient for pedicle square and asymmetry coefficient for pedicle width. Thus, in children with Lenke III idiopathic scoliosis we see severe anatomical and anthropometric alterations of bony structure of thoracic curve and moderate structural alterations in lumbar spine.

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References

1. Negrini S., De Mauroy J.C., Grivas T.B., Knott P., Kotwicki T., Maruyama T. et al. Actual evidence in the medical approach to adolescents with idiopathic scoliosis. *Eur J Phys Rehabil Med.* 2014;50(1):87-92.
2. Lenke L.G., Betz R.R., Clements D.. Merola A., Haher T., Lowe T. et al. Curve prevalence of a new classification of operative adolescent idiopathic scoliosis: does classification correlate with treatment? *Spine (Phila Pa 1976).* 2002;27(6):604-611.
3. Vissarionov S.V., Sobolev A.V., Efremov A.M. [Surgical correction of spinal deformity in idiopathic scoliosis: the history and current state (review)]. *Travmatologiya i ortopediya Rossii* [Traumatology and Orthopedics of Russia]. 2013;(1):138-145. (In Russ.). DOI: 10.21823/2311-2905-2013-0-1-4-18.
4. Vasyura A.S., Novikov V.V., Mikhailovsky M.V., Dolotin D.N., Suzdalov V.A., Sorokin A.N., Udalova I.G. [Surgical treatment of scoliosis using transpedicular fixation]. *Hirurgia pozvonocnika* [Journal of Spine Surgery]. 2011;(2):27-34. (In Russ.). DOI: 10.14531/ss2011.2.27-34.
5. Yilmaz G., Borkhuu B., Dhawale A.A., Oto M., Littleton A.G., Mason D.E. et al. Comparative analysis of hook, hybrid, and pedicle screw instrumentation in the posterior treatment of adolescent idiopathic scoliosis. *J Pediatr Orthop.* 2012;32(5):490-499. DOI: 10.1097/BPO.0b013e318250c629.
6. Vetrile S.T., Kuleshov A.A., Shvets V.V., Kisel A.A., Vetrile M.S., Guseinov V.G. [The concept of surgical treatment of various forms of scoliosis using modern technolo-

gies]. *Hirurgia pozvonocnika* [Journal of Spine Surgery]. 2009;(4):21-30. (In Russ.). DOI: 10.14531/ss2009.4.21-30.

7. Parent S., Labelle H., Skalli W., Latimer B., de Guise J. Morphometric analysis of anatomic scoliotic specimens. *Spine (Phila Pa 1976)*. 2002;27(21):2305-2311. DOI: 10.1097/01.BRS.0000030303.02003.2E.
8. Liljenqvist U.R., Link T.M., Halm H.F. Morphometric analysis of thoracic and lumbar vertebrae in idiopathic scoliosis. *Spine (Phila Pa 1976)*. 2000;25:1247-1253. DOI: 10.1097/00007632-200005150-00008.
9. Kokushin D.N., Vissarionov S.V., Bart V.A. [Evaluation of anatomical and anthropometric parameters of bone structures of the vertebrae in children with idiopathic scoliosis using navigation]. *Mezhdunarodnyi zhurnal prikladnykh i fundamental'nykh issledovanii* [International Journal of Applied and Fundamental Research]. 2015;11(2):207-211. (In Russ.). Available from: https://applied-research.ru/ru/article/view?id=7707.
10. Kuraishi S., Takahashi J., Hirabayashi H., Hashidate H., Ogihara N., Mukaiyama K., Kato H. Pedicle morphology using computed tomography-based navigation system in adolescent idiopathic scoliosis. *J Spinal Disord Tech*. 2013;26(1):22-28. DOI: 10.1097/BSD.0b013e31823162ef.
11. Vissarionov S.V., Kokushin D.N., Belyanchikov S.M., Murashko V.V., Kartavenko K.A., Nadirov N.N. [Surgical treatment of children with idiopathic scoliosis of Lenke type I with the use of total transpedicular fixation]. *Ortopediya, travmatologiya i vosstanovitel'naya khirurgiya detskogo vozrasta* [Pediatric Traumatology, Orthopaedics and Reconstructive Surgery]. 2014;2(2):3-8. (in Russ.) DOI: 10.17816/PTORS223-8.
12. Tian N.F., Huang Q.S., Zhou P., Zhou Y., Wu R.K., Lou Y., Xu H.Z. Pedicle screw insertion accuracy with different assisted methods: a systematic review and meta-analysis of comparative studies. *Eur Spine J*. 2011;20(6):846-859. DOI: 10.1007/s00586-010-1577-5.
13. Rafi S., Munshi N., Abbas A., Shaikh R.H., Hashmi I. Comparative analysis of pedicle screw versus hybrid instrumentation in adolescent idiopathic scoliosis surgery. *J Neurosci Rural Pract*. 2016;7(4):550-553. DOI: 10.4103/0976-3147.185510.
14. Vissarionov S.V. [Approaches to spinal deformity correction using transpedicular systems in children with idiopathic scoliosis]. *Hirurgia pozvonocnika* [Journal of Spine Surgery]. 2013;(1):21-27. (In Russ.). DOI:10.14531/ss2013.1.21-27.
15. Catan H., Buluc L., Anik Y., Ayyildiz E., Sarlak A.Y. Pedicle morphology of the thoracic spine in preadolescent idiopathic scoliosis: magnetic resonance supported analysis. *Eur Spine J*. 2007;16(8):1203-1208. DOI: 10.1007/s00586-006-0281-y.
16. Vaccaro A.R., Rizzolo S.J., Allardyce T.J., Ramsey M., Salvo J., Balderston R.A., Cotler J.M. Placement of pedicle screws in the thoracic spine. Part I: Morphometric analysis of the thoracic vertebrae. *J Bone Joint Surg Am*. 1995;77(8):1193-1199.
17. Gubin A.V., Ryabykh S.O., Burtsev A.V. [Retrospective analysis of screw malposition following instrumented correction of thoracic and lumbar spine deformities]. *Hirurgia pozvonocnika* [Journal of Spine Surgery]. 2015;12(1):8-13. (In Russ.). DOI: 10.14531/ss2015.1.8-13.
18. Shimizu M., Takahashi J., Ikegami S., Kuraishi S., Shimizu M., Futatsugi T., Oba H., Kato H. Are pedicle screw perforation rates influenced by registered or unregistered vertebrae in multilevel registration using a CT-based navigation system in the setting of scoliosis? *Eur Spine J*. 2014;23(10):2211-2217. DOI: 10.1007/s00586-014-3512-7.
19. Kuraishi S., Takahashi J., Hirabayashi H., Hashidate H., Ogihara N., Mukaiyama K., Kato H. Pedicle morphology using computed tomography-based navigation system in adolescent idiopathic scoliosis. *J Spinal Disord Tech*. 2013;26(1):22-8. DOI: 10.1097/BSD.0b013e31823162ef.
20. Ughwanogho E. Patel N.M., Baldwin K.D., Sampson N.R., Flynn J.M. Computed tomography-guided navigation of thoracic pedicle screws for adolescent idiopathic scoliosis results in more accurate placement and less screw removal. *Spine (Phila Pa 1976)*. 2012;37(8):E473-478. DOI: 10.1097/BRS.0b013e318238bbd9.
21. Macke J.J., Woo R., Varich L. Accuracy of robot-assisted pedicle screw placement for adolescent idiopathic scoliosis in the pediatric population. *J Robot Surg*. 2016;10(2):145-150. DOI: 10.1007/s11701-016-0587-7.
22. Kokushin D.N, Vissarionov S.V.,. Baindurashvili A.G, Bart V.A. [Analysis of anatomical and anthropometric parameters of vertebrae in children with thoracic idiopathic scoliosis using 3D-CT-navigation]. *Hirurgia pozvonocnika* [Journal of Spine Surgery]. 2016; 13(1):27-36 (In Russ.). DOI: 10.14531/ss2016.1.27-36.
23. Yilmaz G., Borkhuu B., Dhawale A.A., Oto M., Littleton A.G., Mason D.E., Gabos P.G., Shah S.A. Comparative analysis of hook, hybrid, and pedicle screw instrumentation in the posterior treatment of adolescent idiopathic scoliosis. *J Pediatr Orthop*. 2012;32(5):490-499. DOI: 10.1097/BPO.0b013e318250c629.
24. Modi H.N., Suh S.W., Hong J.Y., Yang J.H. Accuracy of thoracic screw using ideal pedicle entry point in severe scoliosis. *Clin Orthop Relat Res*. 2010;468(7):1830-1837. DOI: 10.1007/s11999-010-1280-1.
25. Karatoprak O., Unay K., Tezer M., Ozturk C., Aydogan M., Mirzanli1 C. Comparative analysis of pedicle screw versus hybrid instrumentation in adolescent idiopathic scoliosis surgery. *J Neurosci Rural Pract*. 2016;7(4):550-553. DOI: 10.4103/0976-3147.185510.
26. Meng X.T., Guan X.F., Zhang H.L., He S.S. Computer navigation versus fluoroscopy-guided navigation for thoracic pedicle screw placement: a meta-analysis. *Neurosurg Rev*. 2016;39(3):385-391. DOI: 10.1007/s10143-015-0679-2.
27. Bennett J.T., Hoashi J.S., Ames R.J., Kimball J.S., Pahys J.M., Samdani A.F. The posterior pedicle screw construct: 5-year results for thoracolumbar and lumbar curves. *J Neurosurg Spine*. 2013;19(6):658-663. DOI: 10.3171/2013.8.SPINE12816.
28. Mason A., Paulsen R., Babuska J.M., Rajpal S., Burneikiene S., Nelson E.L., Villavicencio A.T. The accuracy of pedicle screw placement using intraoperative image guidance systems. *J Neurosurg Spine*. 2014;20(2):196-203. DOI: 10.3171/2013.11.SPINE13413.
29. Du J.P., Fan Y., Wu Q.N., Wang D.H., Zhang J., Hao D.J. Accuracy of Pedicle Screw Insertion Among 3 Image-Guided Navigation Systems: Systematic Review and Meta-Analysis. *World Neurosurg*. 2018;109:24-30. DOI: 10.1016/j.wneu.2017.07.154.

30. Zindrick M.R., Wiltse L.L., Doornik A., Widell E.H., Knight G.W., Patwardhan A.G., Thomas J.C., Rothman S.L., Fields B.T. Analysis of the morphometric characteristics of the thoracic and lumbar pedicles. *Spine (Phila Pa 1976)*. 1987;12(2):160-166.

31. Lenke L.G., Betz R.R., Harms J., Bridwell K.H., Clements D.H., Lowe T.G., Blanke K. Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. *J Bone Joint Surg Am.* 2001;83-A(8): 1169-1181.

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