THE PROBLEM OF DOUBLE THORACIC IDIOPATHIC SCOLIOSIS: A NON-SYSTEMATIC LITERATURE REVIEW

D.N. Dolotin, V.L. Lukinov, M.V. Mikhaylovskiy
Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, Novosibirsk, Russia

Objective. To analyze the current situation in the community of spine surgeons regarding the determination of the zone of posterior spinal fusion for double thoracic idiopathic scoliosis.
Material and Methods. The content of 16 publications containing the results of surgical correction of double thoracic scoliotic deformities was analyzed. The number of studied clinical cohorts was 25, of which in 13 groups only the right-sided main thoracic (MT) curve (MT group) was blocked, and in 12 – both MT and left-sided proximal upper thoracic (PT) curve (MT + PT group). Four parameters were analyzed in both groups: preoperative Cobb angle, preoperative curve mobility, deformity correction, and postoperative deformity progression.
Results. Significant differences were found in the MT and MT + PT groups only in two cases: for the initial Cobb angle of the PT curve and the magnitude of its correction (Cobb angle before surgery minus Cobb angle immediately after the intervention). When choosing the extent of the instrumental fusion zone, the authors of the publications included in the review were guided, first of all, by the initial magnitude of the Cobb angle of the proximal thoracic curve. In the MT + PT group, it averaged 37–40° and was 11–13° more than in the MT group. At the same time, PT curve mobility in both groups is not statistically different. The achieved correction was statistically significantly greater in the MT + PT group, despite a more severe proximal curvature as compared to the MT group. Postoperative dynamics of kyphosis (both T2–T5 and T5–T12) is insignificant. The length of the instrumental spinal fusion zone has virtually no effect on the parameters of the sagittal contour of the thoracic spine. A fairly high frequency of the adding-on phenomenon development (20.6 %) indicates the presence of a connection between this complication and the dynamics of PT curve, but the available data are not enough to formulate a final conclusion. Literature data regarding patients' self-assessment of quality of life after surgical treatment of Lenke types 1 and 2 scoliosis are scarce, although the majority of those operated on assess the result of treatment as positive.
Conclusion. The problem of determining the extent of the instrumental fusion zone for double thoracic scoliosis remains unresolved. Most surgeons focus not so much on the mobility of the proximal curve, but on its magnitude. There is no consensus in predicting the development of the adding-on phenomenon; there is little information about changes in the quality of life of patients after surgery. New research is needed.
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It can be assumed that Ponseti et al. [1] were the first to focus on double thoracic deformities (usually the right-sided thoracic and the left-sided upper thoracic). They described the cranial curvature as cervicothoracic and noted the elevation of the scapula and shoulder on the side of its bulge. They also suggested that the upper thoracic curve is less prone to progression than the lower thoracic one. Cobb [2] found that if only the lower thoracic curve is blocked, the upper one usually does not progress, even if there are signs of the structurality of the deformity (wedging of the vertebral bodies, rotation). Moe and Kettleson [3] described double thoracic curves as an independent type of deformity, but they did not give clear criteria for recognizing this type, except for the extent (T1–T2 to T5–T6). In their view, the upper curve is rigid and poorly corrected by the Milwaukee brace. The authors recommended spinal fusion of the T1 vertebra to avoid imbalance of the shoulders. Ginsburg et al. [4] were the first to focus on the significance of T1 slope in the frontal plane. If its upper-left corner is above the right (positive slope), then, according to the authors, the upper curve is complete. If the body of the T1 vertebra is located horizontally or with a negative slope (the right angle is higher than the left one), the upper curve is defined as fractional. The authors pointed out that the position of the T1 vertebra correlates with imbalance of the shoulders. In prospect, a large number of articles described the issue of double thoracic scoliosis, since these deformities have considerable features and are rather common – up to 18 % [5].

Pooled experience has shown that double thoracic scoliosis, to a greater extent than other types of deformities, is associated with the risk of developing shoulder imbalance, which can result in dissatisfaction with the surgical outcome for both a patient and a surgeon. Postoperative imbalance of the shoulders causes a cosmetic defect associated with the asymmetry of the trapezius and possible degenerative cervical spine changes. The main issue is: in which cases should both curves be included in the block zone, and in which cases should they be limited only to the main curvature? We have not been able to find any reviews on this relevant issue.

The objective is to analyze the current situation in the community of spine surgeons regarding the determination of the zone of posterior spinal fusion for double thoracic idiopathic scoliosis.

Material and Methods

The content of the Scopus and Web of Science databases was studied using the following keywords: double thoracic scoliosis, Lenke 1, Lenke 2, the surgical treatment. After studying the full versions, 9 articles were excluded from the 25 publications since they did not contain data on the preoperative mobility of the left-sided upper thoracic curve. According to almost all authors, it is precisely this data that determines the criteria for the structurality degree of the secondary curve and thereby resolves the issue of its inclusion in the posterior spinal fusion zone.

In the proposed review we considered it necessary to answer the following questions:

1) main definitions;

2) criteria for the structurality of the proximal curve;

3) techniques of examination and objectification;

4) surgical outcomes;

5) changes in the sagittal contour of the upper thoracic spine;

6) development of the adding-on phenomenon;

7) the impact of surgical outcomes on the quality of life of patients;

8) shoulder imbalance in the pre- and postoperative periods.

Statistical analysis. Calculations were made in the RStudio IDE (version 2022.07.2 Build 576 © 2009-2022 RStudio, PBC, USA) in the R language (version 4.1.3, Austria) [6]; data conversions were prepared using the meta-analysis package (version 6.2-1) [7]. The creation of forest plots and the performance of corresponding calculations were made using the metaphor package (version 3.4-0) [8].

Results

Main definitions

In 1983, King et al. [9] proposed a classification of scoliosis based on the widely used Harrington technique in those years, i.e., one-plane correction. In 2001, Lenke et al. [5] proposed an innovative approach, wherein spinal deformity was studied and assessed in the frontal and sagittal planes. This was a significant advancement and the Lenke classification is still almost universally used, even though there are attempts to create a three-dimensional classification of scoliosis [10]. It is commonly known that the Lenke classification system determines six types of spinal deformity in the frontal plane; two of these types (types 1 and 2) are of special interest to surgeons because they need to be resolved in each individual case regarding whether the upper thoracic curve should be included in the area of instrumented spinal fusion or not. We consider it useful to refresh the definitions given in Lenke's study.

The thoracic curve is a curvature, the apex of which lies between the T2 vertebral body and the T11–T12 intervertebral disc. If there are two thoracic curves, the proximal thoracic curve (curvature, the apex of which lies at the levels of T3, T4 or T5 vertebrae) and the main thoracic curve (curvature, the apex of which lies between the T6 vertebral body and the T11–T12 intervertebral disc) are distinguished.

Criteria for the structurality of the thoracic curves

The proximal thoracic curve is regarded as structural, if the Cobb angle in the lateral flexion is at least 25° (with or without a positive tilt of the T1 vertebral body) and/or if kyphosis at the level of T2–T5 vertebrae is at least 20°.

The main thoracic curve is regarded as structural, if in the lateral flexion the Cobb angle is at least 25° and/or if thoracolumbar kyphosis at the level of T10–L2 vertebrae is at least 20°.

Techniques of examination and objectification of shoulder imbalance

According the literature data, the first techniques to objectify shoulder imbalance have been proposed by Bago et al. [11]:

• the slope of the T1 vertebra (T1 slope). A positive slope is to the right (towards the main curve) and a negative slope is to the left (towards the upper thoracic curve). It is defined by measuring the angle between the horizontal line and the cranial end plate of the T1 vertebra. It is considered significant if it exceeds 5° (Fig. 1a). Burton et al. [12] emphasized that the T1 vertebral body slope should be at least 5° to interpret the deformity as type V scoliosis, according to King;

• the first rib angle (FRA). The inclination of the line connecting the cranial borders of both first ribs is measured; a positive assessment is given when the line is inclined to the right (Fig. 1b);

• *processus coracoideus* height difference (coracoid height difference, coracoid process height – CPH). A horizontal line is drawn along the upper edge of each *processus coracoideus*. The vertical distance in mm between both lines is measured; this indicator is considered positive, if the left side lies above the right, otherwise it is negative (Fig. 1c);

• clavicle-rib cage intersection (CRCI). The clavicle shadow can intersect the outer contour of the rib cage at various levels. There is a reason to believe that this point is associated with the true height of the shoulder position. A horizontal line is drawn through this point; the difference in mm between the right and left sides is considered positive if the left half is located higher (Fig. 1d).

Suk et al. [13] proposed their own technique to objectify the imbalance of shoulders in terms of the height of their position. Horizontal lines are drawn along the cranial surface of both acromioclavicular joints on the same radiograph. The difference in the position of the shoulders can be positive (+) when the left shoulder is higher than the right one, and negative (-) when the right shoulder is higher. The shoulder height difference (SHD) is considered significant if it exceeds 5 mm (Fig. 2).

Kuklo et al. [14, 15] proposed two new techniques:

• radiographic shoulder height (RSH). It is determined on an anteroposterior radiograph performed in the patient's standing position by the shadow of soft tissues directly above the acromioclavicular joint. Imbalance is considered significant with a difference of more than 3 cm and minimal within 1–2 cm. If the difference in the height of the shoulders is less than 1 cm, it can be claimed that the shoulders are balanced (Fig. 3a).

• clavicle angle (CA) is defined at the point of intersection of the horizontal and the tangential line connecting the highest points of both clavicles. If the left clavicle is higher than the right one, the angle is considered positive (Fig. 3b).

Two more techniques have been developed by Qiu et al. [16]:

• the difference in the length of *m. trapezius* (TL) is the horizontal distance from the root of the T2 vertebral arch to the intersection of the second rib with the clavicle. The difference is considered positive when the specified distance is greater on the left (Fig. 4a);

• the vertical distance between the first rib-clavicle height (FRCH) is the height difference between the apex of the first rib and the upper border of the clavicle on the right and left. The indicator is considered positive when the vertical on the left is larger than one on the right.

Smyrnis et al. [17] proposed to measure the first rib index (FRI). A line is drawn from the geometric center C (the intersection of two diagonals at the level of the T1 vertebral body or the T1–T2 intervertebral disc) connecting the most distal points on the inner surfaces of the first ribs. The length of this line is 4.8–8.0 cm. The difference between the right and left segments of this line (CB - CA) is expressed by the ratio (CB - CA) / (CB + CA)   100%. A longer right curve means that shoulder imbalance to the right (Fig. 5).

Determination of shoulders imbalance is possible in clinical photographs [18]:

• the angle of the shoulder height (a) is between the line connecting the acromion processes and the horizontal;

• the angle of the height of the armpit (b) is between the line connecting the upper points of the axillary folds and the horizontal (Fig. 6).

The choice of the research method is the right of the author, especially since the above options range considerably in degree of complexity. It can be noted that among the most commonly used are the T1 slope, CA and RSH. Qiu et al. [16] studied in detail the possibilities of radiographic and clinical methods for evaluating imbalance of the shoulders in patients with double thoracic scoliosis. The authors concluded that the radiographic parameters only partially reflect a cosmetic defect with imbalance of the shoulders. None of the parameters in this regard has a decisive superiority over the others. Thus, a surgeon should pay more attention to the cosmetic aspect of the problem than to the radiographic measurements. Meanwhile, it is important to note that in healthy (without spinal pathology) adolescents the difference in shoulder height is around 0.9 cm [19].

Results of surgical correction of double thoracic scoliosis

The content of 16 publications [13, 14, 20–33] containing the results of surgical correction of double thoracic scoliotic deformities was analyzed. All the authors tried to find an answer to the main question in relation to the issue under discussion: should the proximal left-sided curve be included in the posterior spinal fusion zone? More than half of the articles contain the outcomes of both techniques. Therefore, the number of studied clinical cohorts increases to 25; 13 of them have only the main (right-sided thoracic) curve blocked; 12 have

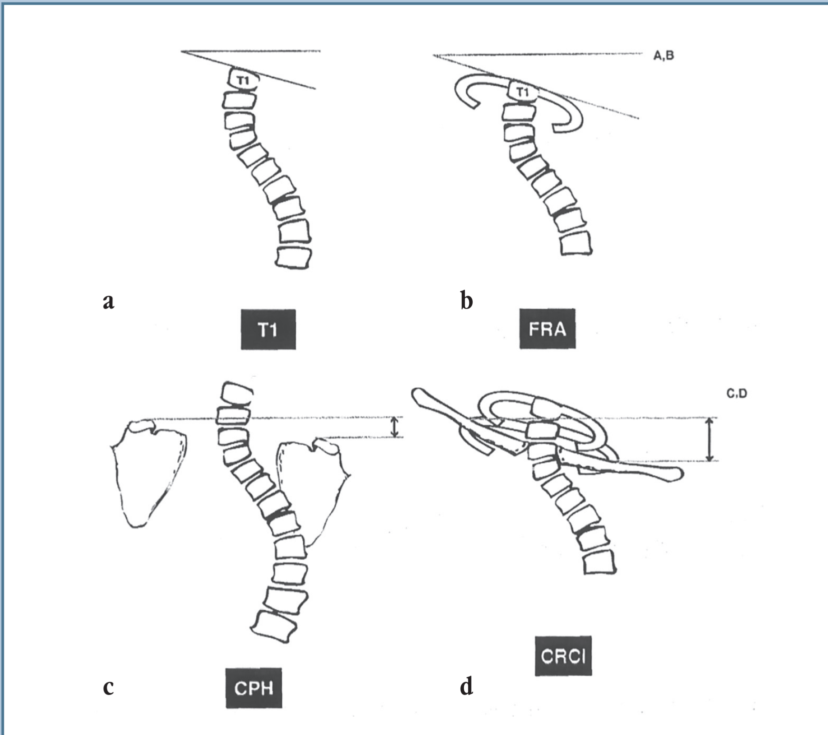

Fig. 1
Techniques that make it possible to objectify the asymmetry of the position of the shoulders, according to Bago et al. [11]: see explanations in the text

both curves (right-sided thoracic and left-sided upper thoracic).

The surgical outcomes of the correction of double thoracic scoliosis (Lenke types 1 and 2). The study of 16 publications dedicated to surgical correction of double thoracic scoliosis allows determining the parameters of 25 cohorts. In 13 of them only main right-sided thoracic curve (MT – main thoracic, the MT group) was included to the spinal fusion zone. The rest 12 cohorts include both curves: MT and left-sided upper thoracic (PT – proximal thoracic, the MT + PT group). All data concerning the changes in the Cobb angle of both curves before surgery, immediately after it and at the end of the follow-up were summarized in tables and subjected to statistical analysis. Table 1: Only MT is included in the fusion zone; Table 2: MT and PT are included in the fusion zone. 4 parameters were analyzed in connection with both groups:

- preoperative Cobb angle of MT and PT;
- preoperative curve mobility (the Cobb angle before surgery minus the Cobb angle in the lateral inclination position)
- deformity correction (the Cobb angle before surgery minus the Cobb angle immediately after surgery);
- postoperative deformity progression (the Cobb angle at the end of the follow-up minus the Cobb angle immediately after surgery).

The mean values of the Cobb angles of the PT curve before surgery in the MT + PT correction group are on average by 11.3° ± 3.4° more than in the group with one curve correction, this difference is statistically significant (RE-model, $p = 0.001$).

The Cobb angle of the PT curve when the patient is standing and tilted was 28.5° ± 10.7° and 19.4° ± 9.0°, respectively, in the MT correction group, and 37.7° ± 12.1° and 30.7° ± 14.8°, respectively, in the MT + PT correction group. The mean values of the PT curve mobility were 8.77° with a 95 % CI of 7.19–10.35° (the MT group) and 7.46° with a 95 % CI of 5.82–9.10° (the MT + PT group), respectively. There was no statistically significant difference in the PT curve mobility between the two analyzed groups ($p = 0.323$).

Fig. 2
Shoulder Height Difference (SHD) – the difference (in mm) in the height of the horizontal lines drawn through the top edge of each *proc. coracoideus*: if the difference is ⩽5 mm, the shoulders are considered balanced [35]

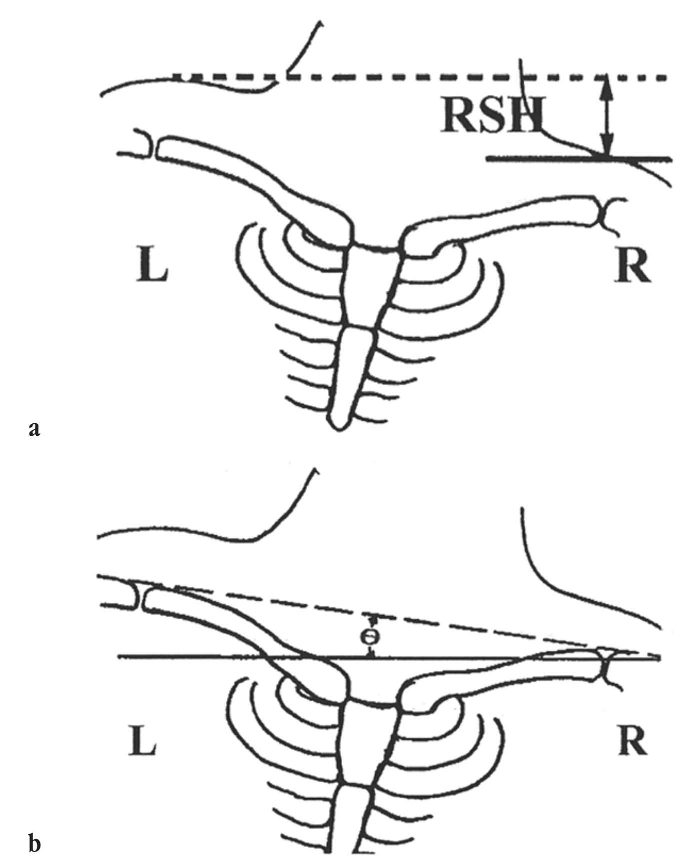

Fig. 3
Shoulder height difference according to Kuklo et al. [15]: **a** – radiographic height of the shoulders is determined by the difference in the location of soft tissue shadows at points located strictly above the acromial clavicular joints in a standing position; the difference is considered positive if the left shoulders is located higher than the right one; **b** – Clavicle angle is formed by the intersection of a horizontal line and a tangential line connecting the highest points of both clavicles

The mean values of the Cobb angles of the PT curve before and immediately after surgery in the MT group were 27.4° ± 9.1° and 17.2° ± 7.6°, respectively, and in the MT + PT group – 40.7° ± 9.5° and 21.6° ± 9.4°, respectively. The mean values of the PT curve correction were 10.94° with a 95 % CI of 9.08–12.80° (the MT group) and 19.99° with a 95 % CI of 15.50–24.47° (the MT + PT group), respectively. There was a statistically significant difference in the PT curve correction in the MT and MT + PT groups ($p < 0.001$; Fig. 7).

The mean values of the Cobb angles of the PT curve immediately after surgery and at the end of the follow-up in the MT group were 17.2° ± 7.6° and 17.9° ± 8.3°, respectively; in the MT + PT correction group they were 21.3° ± 9.3° and 23.5° ± 10.6°, respectively. The mean value of correction loss of PT curves in the two groups was -0.55° with a 95 % CI of 1.55–0.44° and -3.40° with a 95 % CI of -7.68–0.88°, respectively. There was no statistically significant difference in correction loss of PT curves in the MT and MT + PT groups ($p = 0.120$).

There was no statistically significant difference between the mean values of the Cobb angles of the MT curve before surgery in the MT + PT group and the group with correction on one curve (RE-model; $p = 0.359$).

The Cobb angle of the MT curve when the patient is standing and tilted was 52.2° ± 18.3° and 30.5° ± 21.9°, respectively, in the MT group; in the MT + PT group it was 59.5° ± 18.2° and 36.3° ± 20.5°, respectively. The mean values of MT curve mobility were 24.50° with a 95% CI of 21.65–27.35° (the MT group) and 23.71° with a 95% CI of 16.53–30.89° (the MT + PT group), respectively. There was no statistically significant difference in the MT curve mobility in the MT and MT + PT groups ($p = 0.350$).

The mean values of the Cobb angles of the MT curve before and immediately after surgery in the MT group were 52.2° ± 12.2° and 17.1° ± 8.1°, respectively, in the MT + PT group – 60.8° ± 15.3° and 19.7° ± 10.1°, respectively. The mean values of MT curve corrections were 37.05° with a 95 % CI of 31.09–43.01° (the MT group) and 40.44° with a 95 % CI of 36.21–44.67° (the MT + PT group), respectively. There was no statistically significant difference in the MT cor-

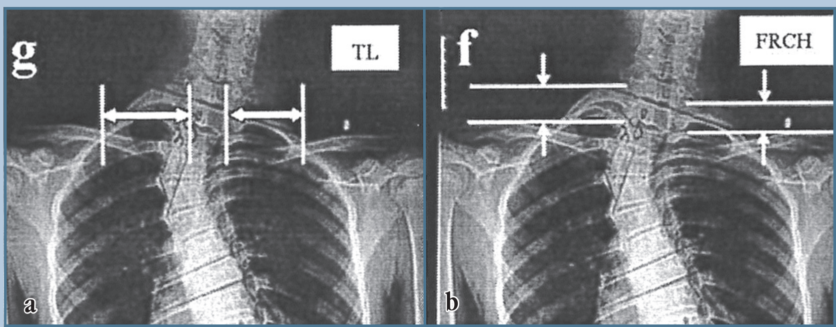

Fig. 4
Technique for objectifying shoulder asymmetry according to Qiu et al. [16]: **a** – difference in length *m. trapezius* (TL) – horizontal distance from the T2 pedicle to the intersection of the second rib with the clavicle; the difference is considered positive if the specified distance is greater on the left; **b** – height between the first rib and the clavicle (first rib-clavicle height – FRCH) – the difference in height between the top of the first rib and the upper border of the clavicle on the right and left; the indicator is considered positive if the vertical on the left is greater than the one on the right

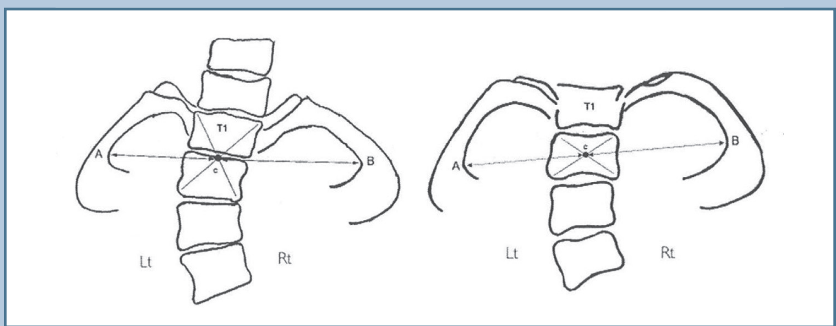

Fig. 5
First rib index according to Smyrnis et al. [17]: the diameter of the arch of the first rib is determined, a line is drawn from the geometric center C (the intersection of two diagonals at the level of the T1 body or the T1–T2 disc), connecting the most distal points on the internal surfaces of the first ribs; the difference between the right and left segments of this line (CB - CA) is expressed by the ratio (CB - CA) / (CB + CA) × 100 % and is defined as FRI; a longer right curve means imbalance of the shoulders to the right

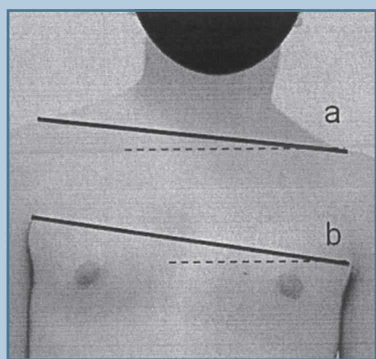

Fig. 6
Determination of shoulder asymmetry in clinical photographs

rection in the MT and MT + PT groups ($p = 0.359$).

The mean values of the Cobb angles of the MT curve immediately after surgery and at the end of the follow-up in the MT group were 17.7° ± 8.1° and 20.1° ± 8.8°, respectively, in the MT + PT group: 22.1° ± 9.8° and 24.4° ± 10.6°, respectively. The mean values of correction loss of the MT curve in the two groups was -2.76° with a 95 % CI of -5.06°–(-0.46°) and -1.83° with a 95 % CI of -3.53°–(-0.13°), respectively. There was no statistically significant difference in the loss of correction of the MT curve in the MT and MT + PT groups ($p = 0.825$).

Changes in the sagittal contour of the upper thoracic spine

Lenke et al. [5] consider the magnitude of kyphotic deformity in patients with double thoracic scoliosis to be one of the criteria for the structurality of both the proximal and main curves. In their opinion, the Cobb kyphotic angle at the PT level of more than 20° indicates that the deformity belongs to the category of structural and should be included in the zone of instrumented spinal fusion. Despite this recommendation, not all the authors of the articles included in this review considered it necessary to provide the results of measured kyphotic angle at the level of the proximal scoliotic curve of T2–T5 (Table 3). It is highly likely, that without seeing clinical signs of upper thoracic kyphosis, our colleagues just have not seen the indication to perform additional measurements. Nevertheless, the results of the study of the sagittal contour of the thoracic spine are given in 11 articles out of the considered ones. The mean value of proximal kyphosis slightly exceeded 20° only in one article [30] and was significantly less in all the rest.

The incidence rate of the adding-on phenomenon

There is no generally accepted definition of this phenomenon, though the majority of authors used criterion defined by Wang et al. [38]. According to this criterion the adding-on phenomenon is a progressive increase in the number of vertebrae included into the distal curve combined with either a deviation of the vertebra following the lowest instrumented vertebra (LIV) from the central sacral vertical line by more than 5 mm or more than 5° increase in wedging of the intervertebral disc located caudal to the lowest instrumented vertebra. Cao et al. [27] have specified this definition. They consider the deviation of LIV + 1 and the intervertebral disc wedging under LIV as two adding-on parameters. The intervertebral disc wedging open to the left is considered positive and open to the right is negative. In turn, the deviation of the LIV + 1 vertebra (the distance from its centroid to the central sacral line) to the right is defined as positive and to the left as negative.

Koller et al. [30] defined the adding-on as the wedging of intervertebral disc following LIV by more than 3°.

In 6 articles out of the reviewed literature the authors stated the development of the adding-on phenomenon.

Wang et al. [38] operated on 278 patients with Lenke type 1 deformities. The study group included 45 patients. The development of the adding-on phenomenon was reported in 23 cases. The mean postoperative follow-up was 3.6 years. The authors noted that the age of the patients, the difference in the localization of the stable and lowest instrumented vertebrae, the ratio of the central sacral line and the vertebra located distally to the lowest instrumented vertebra were significantly different in the groups with and without the adding-on. In turn, the initial magnitude of the deformity, the degree of its correction and the incongruity of the neutral and lowest instrumented vertebrae do not affect the risk of developing this complication. Its rate increases sharply if before surgery the dislocation of the vertebra located caudal to the lowest instrumented one from the central sacral line exceeds 10 mm.

Matsumoto et al. [26] operated on 106 patients; adding-on phenomenon was diagnosed in 20 patients. These patients had a lower clavicle angle and T1 slope in the presence of an adding-on than without it. Postoperative shoulder imbalance (PSI) may be followed by the development of adding-on. Nevertheless, it remains unclear whether it develops independently or as a consequence of PSI as a compensatory response. If there is such a connection, it is essential to prevent the development of PSI in every possible way, since adding-on can result in degenerative changes in the lumbar spine.

Cao et al. [27] consider adding-on to be one of the common complications developing distal to the fusion zone. It can result in loss of correction, deformation and degeneration of the intervertebral discs and a frontal imbalance of the trunk. The authors diagnosed adding-on in 20 patients; PSI was diagnosed in 23 out of 142 operated patients. Adding-on was revealed in 8 out of 20 patients immediately after surgery. Meanwhile, the development of adding-on was found to occur significantly less frequently in patients with imbalance of the shoulders. At the end of the follow-up, there were no signs of imbalance of the shoulders in patients with adding-on in any case. The radiological difference in the height of the shoulders clearly correlates with the parameters of adding-on.

Koller et al. [30] operated on 158 patients. In the general group, the rate of adding-on was 29.1 % (46 patients); it was 20.0 % (15 out of 60) if both curves were blocked; and it was 34.7 % (31 out of 98) if only the thoracic curve was blocked. An increase in PT and the formation of adding-on were noted in six cases after anterior thoracic fusion and an abnormal formation of the bone block.

Lee et al. [33] revealed adding-on in 6 out of 80 operated patients. There was no connection with the LIV level. The possibility of adding-on increases with the growth in PSI, although this correlation is not statistically significant.

Yang et al. [34] operated on 114 patients and noted the development of adding-on in 18 of them. PSI developed in 60 patients in the long term after surgery, 15 out of them showed adding-on. And only 3 of the remaining 54 patients also had adding-on. This difference is statistically significant. According to the authors, this indicates the significance

Table 1
Results of surgical correction of the right-sided thoracic curve in patients with Lenke types 1 and 2 deformities

Authors	Number of patients, n (m/f)	Age, years	Instrumentation	Follow-up, years	PT before surgery, degrees	PT in tilted position, degrees / mobility, %	PT after surgery, degrees	PT in the end of follow-up, degrees / correction, %	MT before surgery	MT in tilted position, degrees / mobility, %	MT after surgery, degrees	MT in the end of follow-up, degrees / correction, %
Li et al. [41] T1 slope (+)	108 –	15.9	Harrington	4.8	27.1 ± 5.7	17.9 ± 9.1	–	19.4 ± 6.8	56.8 ± 11.6	32.0 ± 13.5	–	31.4 ± 10.2
Li et al. [41] T1 slope (- or 0)	–	–	–	–	31.1 ± 6.6	19.2 ± 8.4	–	23.6/24.1	55.5 ± 11.6	29.5 ± 14.7	–	33.0 ± 12.3
Lenke et al. [22]	27 –	14.9	CDI	3.2	24.0 (16–60)	10.0 (0–24)	–	16.0 (0–30)	51.0 (44–78)	22.0 (5–50)	–	25.0 (12–45)
Suk et al. [13]	22 –	15.9	TPF	–	32.0 ± 5.0	14.1/55.9	18.0 ± 6.0	–	58.0 ± 10.0	22.7/60.9	18.0/68.9	–
Kuklo et al. [14]	44	14.7	PSF	3.6	28.8 ± 6.9	19.8 ± 7.5	19.7 ± 7.8	20.8 ± 8.2	63.0 (46–95)	35.0 (14–79)	32.0/49.2	–
Kuklo et al. [15]	41 –	15.4	ASF	2.8	28.2 ± 6.8	15.8 ± 8.4	15.6 ± 8.1	16.3 ± 7.5	58.0 (42–90)	31.0 (15–71)	28.0/51.7	–
Cil et al. [23]	14 (6/31)*	14.0	–	4.1	23.5 ± 5.2	14.6 ± 7.6	13.9 ± 5.5	14.4 ± 7.8	51.1	28.7/43.8	17.4/65.9	23.0/55.0
Ilharborde et al. [24]	71 –	15.2	Hooks, Universal Clamps	2.5	25.0 ± 11.4	15.6/37.8	19.6 ± 10.0	20.8 ± 11.0	57.5 ± 15.0	32.0/43.9	26.4 ± 11.0	30.0 ± 12.0
Elfiky et al. [25]	15 (1/14)	16.4	–	–	41.0 ± 2.3	–	30.6 ± 6.5	30.6 ± 5.1	58.7 ± 10.4	–	20.8 ± 7.4	26.2 ± 7.8
Matsumoto et al. [26]	106 (8/98)	16.2	TPF, Hybrid	2.0	26.7 ± 7.9	17.9 ± 6.7	14.9 ± 6.4	14.9 ± 7.1	54.6 ± 9.5	28.8 ± 11.6	13.4 ± 7.0	14.5 ± 7.5
Koller et al. [30]	49 (28/130)*	14.9	–	2.3	38.3 ± 6.1	30.3 ± 6.4	27.7 ± 7.8	26.8 ± 8.2	62.9 ± 10.7	34.6/45.9	25.9 ± 10.4	32.6 ± 11.0
Gotfrid et al. [31]	52 –	14.8	–	2.0	25.7 ± 8.4	12.9 ± 8.0	–	13.4 ± 7.4	59.7 ± 10.1	31.3 ± 12.8	–	19.5 ± 7.5
Yang et al. [32]	30 –	15.0	TPF	2.6	35.0 (29–37)	30.0 (25–33)	17.0 ± 6.2	–	58.0 (52–64)	38 % (34–52)	8.5 (5–16)	–
Lee et al. [33]	59 (20/39)	14.9	TPF	2.5	40.1 ± 8.0	32.3 ± 7.3	–	21.5 ± 7.6	61.3 ± 10.6	33.7 ± 12.3	–	13.9 ± 5.5
Yang et al. [34]	114	16.6	TPF	>2.0	20.40 ± 12.35	15.10 ± 10.94	11.60 ± 7.59	13.1 ± 8.0	39.7 ± 13.81	18.6 ± 7.87	12.3 ± 5.34	12.9 ± 6.19

MT (main thoracic) – right-sided thoracic curve; PT (proximal thoracic) – left-sided upper thoracic curve; PSF – posterior spinal fusion; ASF – anterior spinal fusion; TPF – transpedicular fixation;
* data refer to the general group of patients presented by these authors.

of the PT correction during surgery. The development of adding-on is an essential compensatory mechanism. Regression analysis showed that the adding-on angle can serve as a predictor of PT development in patients with idiopathic scoliosis. The authors defined the adding-on angle between the plane of the upper endplate of the LIV and the lower endplate of the vertebra that is two levels more caudal.

In the six mentioned studies, the total incidence of adding-on was 20.6 % (133 cases per 645 operated patients).

Health-Related Quality of Life (HRQoL) according to the questionnaire survey

Information on this section of the study is available in four of the reviewed articles.

Kuklo et al. [15] operated on 94 patients and, when analyzing the treatment outcomes, assessed the subjective data of patients regarding the position of the shoulders and the degree of satisfaction with the current situation. Before surgery 35 people believed that the left shoulder was higher than the right one, 35 patients believed that the right shoulder was higher than the left one and 24 believed that the shoulders were balanced. 66 patients were dissatisfied with the current situation, 12 patients were satisfied and the rest had no opinion. After surgery the vast majority of patients (72) stated balance of the shoulders; 14 patients stated imbalance to the right and 8 patients stated imbalance to the left. As a result, 74 people were satisfied with their appearance, 5 were dissatisfied and 15 had no opinion.

Smyrnis et al. [17] examined the degree of satisfaction with surgical outcomes in 56 patients. 42 (7 5%) of these patients rated the result as good or excellent, 11 (20 %) as acceptable and 3 (5 %) as bad. The surgeons gave a similar assessment.

The SRS-22 questionnaire was offered to 106 patients operated on by Matsumoto et al. [26]. They did not find out significant correlation

Table 2
Results of surgical correction of the right-sided thoracic and left-sided upper thoracic curves in patients with Lenke types 1 and 2 deformities

Authors	Number of patients, n (m/f)	Age, years	Instrumentation	Follow-up, years	PT before surgery, degrees	PT in tilted position, degrees / mobility, %	PT after surgery, degrees	PT in the end of follow-up, degrees / correction, %	MT before surgery	MT in tilted position, degrees / mobility, %	MT after surgery, degrees	MT in the end of follow-up, degrees / correction, %
Li et al. [41]	138	15.9	Harrington	4.8	36.9	24.5/33.6	–	26.9/27.1	51.0	25.8/49.4	–	31.0/39.2
Lenke et al. [22]	27	15.3	CDI	3.0	38.0 (25–50)	27.0 (13–45)	–	23.0 (7–45)	56.0 (43–88)	27.0 (6–65)	–	27.0 (15–57)
Suk et al. [13]	18	15.9	TPF	Min 2.0	45.0 ± 9.0	27.6/38.7	21.0 ± 11.0	–	55.0 ± 16.0	23.5/57.3	20.0 ± 10.0	–
Cil et al. [23]	23	15.0	–	4.9	25.9 ± 6.4	17.5 ± 6.0	13.6 ± 6.7	12.9 ± 8.3	55.5 ± 9.8	30.7 ± 16.3	19.7 ± 9.3	23.5 ± 11.0
Ilharreborde et al. [24]	61	15.2	Hybrid	4.3	36.1 ± 14.8	30.7 ± 19.9	27.4 ± 12.0	29.4 ± 14.7	58.3 ± 22.0	50.0 ± 14.8	23.8 ± 12.7	28.2 ± 13.0
Elfiky et al. [25]	15 (7/8)	16.2	Hybrid	3.1	51.8 ± 5.2	–	28.3 ± 7.1	33.0 ± 7.5	63.6 ± 13.9	–	25.0 ± 9.9	29.3 ± 8.9
Cao et al. [27]	142 (21/121)	16.1	TPF, Hybrid	2.4	43.0 ± 9.5	–	22.3 ± 9.3	22.3/48.4	63.7 ± 15.3	–	18.9 ± 10.3	18.9/70.3
Chang et al. [28]	57 (13/44)	15.2	TPF	7.2	40.2 ± 7.0	25.8 (35.9 ± 15.1)	17.9 ± 7.3	19.9 ± 7.4	56.6 ± 11.4	21.8 ± 16.4	16.1 ± 7.1	16.7 ± 6.9
Koller et al. [30]	49	14.9	Different types	2.1	39.9 ± 6.2	31.5 ± 6.4	20.5 ± 10.5	23.9 ± 11.1	63.9 ± 11.1	34.6 ± 13.7	30.3 ± 9.3	31.0 ± 11.5
Sudo et al. [29]	21 (2/19)	15.8	TPF	2.7	47.0 ± 7.2	36.3 (22.8)	18.0 ± 5.1	19.7 ± 5.6	65.6 ± 11.7	23.5/64.2	14.5 ± 8.0	16.8 ± 9.0/4.0
Yang et al. [32]	49 (16/33)	15.0	TPF	2.8	40.0 (35–46)	34.0 (30–41)	15.0/62.5	–	58.0 (49–70)	41.0 (31–52)	10.0 (4–18)	–
Lee et al. [33]	15 (4/11)	15.5	TPF	2.6	46.7 ± 13.7	38.1 ± 11.9	–	18.5 ± 5.4	63.3 ± 12.9	39.3 ± 18.0	–	13.0 ± 5.1

MT (main thoracic) – right-sided thoracic curve; PT (proximal thoracic) – left-sided upper thoracic curve; TPF – transpedicular fixation.

between questionnaire results and such indicator as clavicle angle and T1 slope. Moreover, this applied to both the total indicator and all its component results for individual domains.

Sudo et al. [29] set out the surgical outcomes of 21 patients with mean postoperative follow-up of 2.7 years. According to the SRS-22 questionnaire data, the quality of life of patients improved significantly: mean total indicator was 3.7 before surgery and 4.4 at the end of the follow-up, positive changes were noted in all domains.

Shoulder imbalance in the pre- and postoperative periods

The analysis of the pre- and postoperative balance of the shoulders is very important for the group of patients under discussion. However, it is turn to be proved to be very complicated to bring together the numerous literature data and obtain any convincing result for the following reasons: the authors use a different grouping of patients depending on the extent of the fusion zone; they use various treatment techniques (instrumentation); the changes in the position of the shoulders are correlated with various radiographic parameters; initial mobility of scoliotic curves; various approaches to quantifying imbalance of the shoulders. Moreover, the changes in the position of the shoulders themselves are extremely variable: stabilization, decrease or increase in inclination, transformation of the left into the right and vice versa. Such a variety of interdependent parameters makes analysis extremely complicated, if not possible at all.

Discussion

The literature contains a significant number of studies on the issue of double thoracic scoliosis. Apart from the surgical correction outcomes, they include plenty of considerations and recommendations mainly based on the authors' own experience. It was impossible to find any reviews, but we made an attempt to generalize by analyzing the quantitative information contained in a number of articles. Review of these studies shows

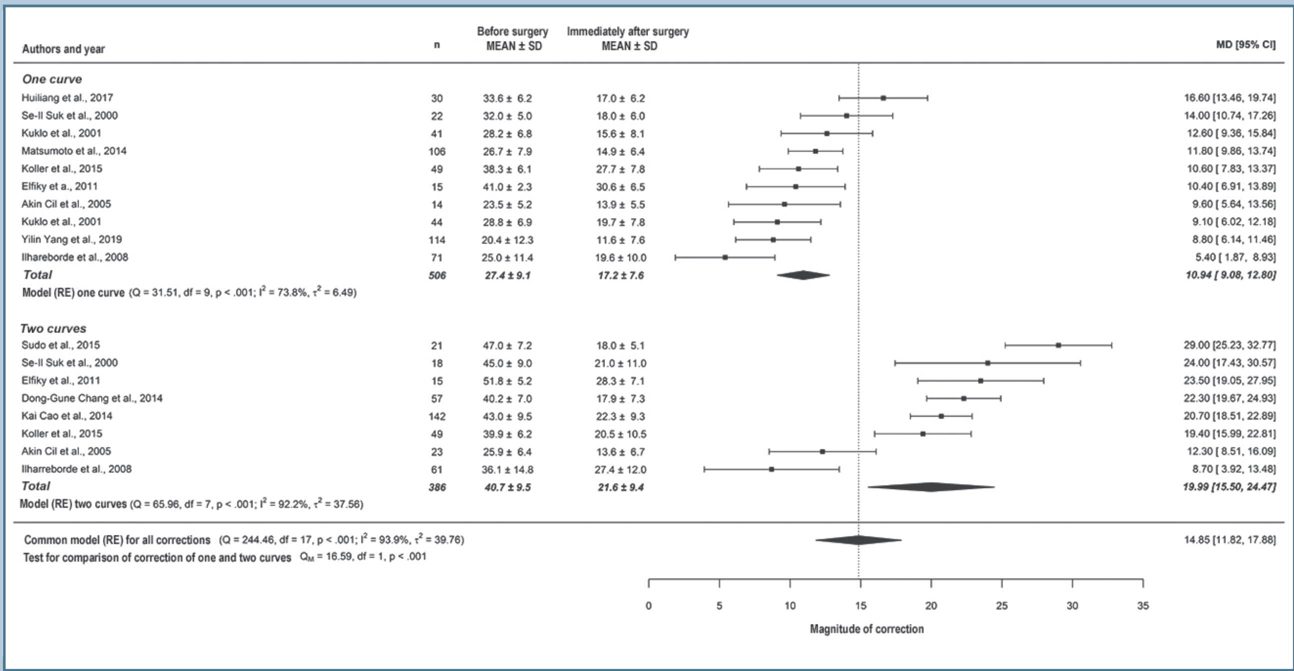

Fig. 7
Forest plot comparing PT correction during surgery involving one and two curves

a variety of opinions concerning the choice of the zone of instrumented spinal fusion and the assessment of the achieved outcome.

In the classification of scoliosis by King et al. [9], they defined double thoracic curves as type V identified by the rigidity of the upper curve and the positive slope of the T1 vertebra. Fusion should extend to both curves if the upper one is bigger than the correction of the lower one in the lateral flexion.

Winter [39] highlighted fullness of the trapezius muscle, protrusion of the left ribs and elevation of the shoulder, while characterizing the clinical pattern. Using CDI can give more correction to the main curve than the PT mobility can compensate for. Alternately, if you do not previously identify the rigidity of PT, you can get imbalanced spine with an elevation of the ribs on the left and imbalance of the shoulders. Using CDI and a 90° rotational maneuver to correct MT allow achieving elevation of the left shoulder, even if the right shoulder was elevated before surgery or there was no imbalance at all. Thus, the structural PT should be included in the block. Lee et al. [20] pointed out that it is easy to achieve adverse MT hypercorrection using CDI since the instrumentation is strong and can correct both curves separately, and the mobility of the lower curve is higher than that of the upper one. The loss of PT correction exceeds that of MT. Both curves must be corrected in a balanced manner to achieve postoperative balance of the shoulders (more PT or less MT). Postoperative imbalance causes a cosmetic defect due to the asymmetry of the area of trapezius muscle and possible degenerative changes in the cervical spine. Bago et al. [40] used CDI just at the MT level and noted that this surgery always induces or aggravates the left shoulder elevation that cannot be balanced by the internal mobility of MT. The same authors [11] studied the validity of four radiological indicators of shoulder balance: CPH, CRCI, T1 slope and FRA. According to their data, the T1 slope does not always correspond to shoulder imbalance. The authors believe that the most reliable technique is to determine the intersection points of the rib and the clavicle.

Li et al. [41] examined 246 patients with PT greater than 20° and distinguished 3 groups: I – positive slope of T1, both thoracic curves are blocked; II – positive T1 slope, only the lower curve is blocked; III – negative or neutral T1 slope, only the lower curve is blocked. The positive T1 slope is not correlated with shoulder imbalance. PT is more rigid than MT. In patients in groups II and III, the progression of the upper curve did not exceed 5° with a mean follow-up of 4.8 years. Self-correction of PT was noted in most cases. In groups II and III, shoulder imbalance increased. The diagnosis of a double thoracic curve is applicable only to cases where both curvatures should be blocked. The mechanism of spontaneous correction of the PT curve may include a regulating reflex that controls the position of the head and prevents further progression and includes a corrective effect of the musculature

Table 3

Dynamics of the sagittal contour of the thoracic spine in the pre- and postoperative periods in patients with Lenke types 1 and 2 scoliosis

Authors	Number of patients, n	Follow-up	T2–T5 Cobb angle, degrees			T5–T12 Cobb angle, degrees		
			before surgery	immediately after surgery	long-term period	before surgery	immediately after surgery	long-term period
Lenke et al. [22]	54	3 years	–	–	–	–	–	–
Block up to T2	27	–	15.0	–	13.0	19.0	–	18.0
Block up to T5	27	–	19.0	–	18.0	14.0	–	22.0
Cil et al. [23]	37	4.5 years	–	–	–	–	–	–
Block up to T2	–	–	8.1	13.6	16.6	–	–	–
Block up to T5	–	–	10.5	10.5	17.2	–	–	–
Elfiky et al. [25]	30	2 years	–	–	–	–	–	–
Chang et al. [28]	57	5 years	–	–	–	–	–	–
Rod derotation with direct vertebral derotation	–	–	–	–	–	18.9	23.7	26.5
Rod derotation	–	–	–	–	–	20.6	26.2	25.5
Block up to T2	–	–	9.2	8.5	8.9	–	–	–
Block up to T5	–	–	10.6	10.5	9.9	–	–	–
Sudo et al. [29]	21	2 years	–	–	–	–	–	–
Block up to T2–T3	–	–	8.3	7.1	7.1	9.3	17.4	19.0
Koller et al. [30]	138	2 years	22.0	21.0	25.0*	–	–	–
Gotfrid et al. [31]	52	2 years	–	–	–	–	–	–
Block up to T5	–	–	–	–	–	22.2	–	26.8
Yang et al. [32]	79	2.5 years	–	–	–	–	–	–
Block up to T2	49	–	16.0	–	13.0	17.0	–	14.0
Block up to T2–T3	30	–	11.0	–	15.0	16.0	–	16.0
Ketenci et al. [35]	63	2 years	–	–	–	–	–	–
Block up to T2	–	–	9.6	–	5.8	22.5	–	23.0
Block up to T3	–	–	10.1	–	6.4	24.2	–	21.8
Block up to T4	–	–	11.3	–	9.1	25.1	–	23.2
Lee et al. [33]	74	–	16.7**	–	–	–	–	–
Machida et al. [37]	66	2 years	–	–	–	–	–	–
Block up to T4	–	–	–	–	–	20.0	17.0	20.0

* The authors did not find a significant connection with the extend of the spinal fusion zone; they did not provide specific data;
** postoperative data are not provided by the authors.

of the neck. Inclusion of PT in the block is indicated by the presence of shoulder imbalance. The extend of the block with balanced shoulders depends on the mobility of both thoracic curves. There will be no spontaneous correction if PT is more rigid and it is necessary to block both curves. If the mobility of PT is higher, it is possible to limit the block to MT only, but hypercorrection should be avoided. There are two principles stated by the authors: the more rigid PT, the less MT should be corrected. The more the right shoulder is lifted, the greater the MT correction is necessary to achieve shoulder balance.

Lenke et al. [22] clarified the previously formulated criteria for the structurality of PT: a value of more than 30°, at least 20° remains in the lateral flexion, rotation of the apical vertebra of more than Grade I, translation of the apex by more than 1 cm, elevation of the left shoulder of any degree of severity, positive T1 slope, transitional vertebra between two curves – at the level of T6 or below. If these criteria are present, the use of CDI involves the extension of the block to T2. Suk et al. [13] argued that inclusion of PT in the block normalizes the difference in the position of the shoulders, if initially the left shoulder was higher or on the same level with the right one. Therefore, the indications for the block of both curvatures are: PT is greater than 25°, balanced shoulders or the left shoulder is higher than the right one (double thoracic scoliosis). It is necessary to block both curves with segmental instrumentation. The shift of T1 by 20 mm to the side from the middle of the sacrum is an indicator of imbalance. According to the authors' results, if the left shoulder is lower before surgery, then it is not necessary to block it, provided that the difference is more than 12 mm.

Kuklo et al. [14] emphasize that the correction of MT always results in the self-correction of PT. Postoperative correction of PT favorably correlates with its preoperative value and initial mobility and remains in the long-term postoperative period. The same authors [15] analyzed the surgical outcomes depending on the level of the upper instrumented vertebra: posterior spinal fusion up to T2 (I), up to T3 (II), up to T4 or T5 (III) and anterior spinal fusion up to T4 (IV). The best correction of PT was registered in groups I and IV. Imbalance of the shoulders decreased in all groups without significant differences. The assessment of the surgical outcome was positive in all groups. The clavicular angle, rather than the T1 slope, and overall and functional images of the proximal curve are the best radiographic predictors of the postoperative balance of the shoulders. In all groups, the postoperative balance of the shoulders and the clinical pattern improve and correlate with self-appraisal.

Cil et al. [23] stated a lack of consensus regarding the criteria for the structurality of PT in double thoracic scoliosis. Since there were no differences found between the inclusion or non-inclusion of non-structural PT in the block, fusion to T2–T3 is optional.

Ilhareborde et al. [24] proposed a technique of preoperative planning based on the expected effect of deformity correction. The aim of the strategy is to balance T1 and the shoulders and restore balance in the frontal plane. The T1 slope, shoulder imbalance (along the clavicles), the Cobb angle while standing and tilted, and the T1 shift (mm between the center of T1 and the center of S1) were measured. A combined analysis of the PT rigidity, the slope of T1 and the shoulders, and the expected correction of MT. In case of type 1, only MT was blocked. In type 2 and two rigid curves, both curves were blocked; in case of the PT mobility, the level of the block was determined by the slope of T1 and the shoulders. If they are tilted to one side and their position deteriorates during the MT correction, both curves are blocked. If they are tilted in different directions, only part of PT is blocked. The sagittal plane was not considered. This is how 132 patients were operated on. The surgical outcomes have met the authors' expectations. T1 and shoulder imbalance should be treated separately because shoulder correction meets the patient's aesthetic expectations and T1 slope correction prevents the development of a proximal deformity near the block zone that can cause cervical spine pain. The balance of the trunk and the shoulders is restored in 89 % of cases; it is not always necessary to block both curves.

Li et al. [41] noted that both thoracic curves were well corrected with transpedicular fixation. Despite the Lenke classification system developed for CDI, it is also suitable for the planning of spinal fusion using transpedicular fixation.

Smyrnis et al. [17] described the FRI (first rib index; see above) and considered it a good predictive factor in combination with the previously described tests. Postoperative elevation of the left shoulder by 2 cm or more is unsatisfactory and can be prevented by using all tests. Postoperative elevation of the left shoulder may be a consequence of selective the MT correction. Asymmetry of more than 2 cm causes dissatisfaction, especially among teenage girls. This effect is combined with the presence of structural PT. To reduce it, the MT correction should be moderate. One more solution is to block both curves. In cases of poor prognosis (especially for skinny teenage girls), the surgeon can rely on radiography data after rod placement on the concave side of MT. If the T1 slope remains or increases, it is possible to reduce the MT correction or include it in the PT block.

Qiu et al. [16] pointed out that excellent radiological findings are often followed by complaints from the patient regarding a cosmetic defect. The authors studied the correlations between clinical and radiographic findings in double thoracic scoliosis using six cosmetic and seven radiographic parameters. It turned out that none of the radiographic parameters reflected the position and shape of the shoulders. The surgeon should pay more attention to the cosmetic aspect of shoulder balance than to the radiographic parameters when making a final decision about surgery.

Elfiky et al. [25] argue that spontaneous correction of PT is possible in structural curves from 35 to 45°, and this correction is stable. Thus, the block of PT is optional at such values. Preoperative radiographic parameters of the position of the shoulders are unreliable in predicting their postoperative balance. Ono et al. [42] paid attention to the discrepancies between the radiographic and clinical manifestations of shoulder imbalance. They studied the correlation between the results of examining clinical photographs of patients (CA, TL, the ratio of the right and left zones of the *m. trapezius*) and radiographic examination data (T1 slope, FRA, Cobb angles of all curves and frontal imbalance). There were two components of shoulder imbalance: lateral and medial. The medial one reflects the asymmetric contour of the *m. trapezius*, formed by the slope of the proximal ribs and T1 vertebra. The lateral component, which is based on the slope of the clavicle, slightly correlates with radiographic parameters. Consequently, the asymmetry correction of the contour of the *m. trapezius* may be more predictable compared to the change in the slope of the clavicle after surgical correction of scoliotic deformity.

Hong et al. [43] emphasized that satisfaction with the surgical outcomes is largely determined by the visual appearance (scars appearance, the shape of the back) and the reduction of pain syndrome. Shoulder imbalance after surgery is one of the frequent complaints. The authors concluded that development of shoulder imbalance is possible with any type of deformity (middle thoracic or lumbar localization). In this respect, the extent of correction and the preoperative position of the shoulders really matter. The authors found that CA and CHD are the most valid among the techniques of studying shoulder imbalance.

Matsumoto et al. [26] concluded that imbalance is more often associated with a greater correction of MT with transpedicular fixation, with a larger preoperative clavicular angle and with a larger and more rigid PT. Imbalance can be compensated by the development of distal adding-on. In order to prevent imbalance in such patients, it is required either to completely correct the proximal curve to at least T2 vertebra or higher or to correct the main thoracic curve in a limited way.

Chang et al. [28] were the first to assess the effect of direct rotation when using transpedicular fixation in patients with double curves. The derotation of the rod is effective in the immediate postoperative period, but the effect is not preserved. Imbalance of the shoulders is slightly corrected even with the use of direct vertebral derotation with transpedicular fixation in double thoracic curves. PT is rigid and corrects worse. Consequently, a smaller correction of MT gives smaller shoulder imbalance.

Koller et al. [30] emphasize that the success of surgery is defined by the initial position of the left shoulder, the Cobb angle of PT greater than 40° and the extent of correction of the main curve. The inclusion of PT in the block is not important. However, the compensatory mechanisms necessary for shoulder balance can cause changes in the alignment of the whole trunk with the formation of the lumbar curve.

Sudo et al. [29] described the technique of simultaneous double-rod rotation. The indications are a rigid PT of more than 30° with a mobility of less than 30 %. A temporary rod is implanted on the concavity of PT, followed by correction of PT by distraction. As a result, the sigmoid double curve is reformed into a single thoracic curve. A rod is placed into the heads of all screws on the concave side of MT (including PT) and a short temporary rod is removed. Then a rod is placed along the convex side of MT. After that, the simultaneous rotation of both rods is performed. This technique is very similar to the one described by the authors of CDI [44]. At the end of the follow-up, the authors observed balance or slight imbalance of the shoulders in all patients.

Elsebaie et al. [45] proposed a scoliotic deformity classification that includes the definition of shoulder balance. There are 3 types of deformities consisting of 2 subtypes depending on the initial position of the shoulders.

Matamalas et al. [18] found that in non-operated patients with moderate deformities (less than 80°), the shoulder imbalance and complaints on this issue have no valid correlation with the radiographic picture. Shoulder imbalance is not a key point in the self-appraisal of the patients examined by them. Apparently, there are other factors to be assessed.

Sharma et al. [46] suggested that the radiographic parameters slightly reflect the cosmetic defect in Lenke 1C, and this, in their opinion, emphasizes not only the vulnerability of the most reliable indices, but also the critical importance of a clinical examination of a cosmetic defect.

Amir et al. [47] argue that the correction of PT is not a guarantee of clinical balance of the shoulders and the clavicles. The asymmetry of the trapezius muscle is corrected by aligning the position of the T1 vertebra and the first ribs, as well as by reducing PT. It remains unclear how to achieve balance in the lateral sections of the shoulders after surgery.

Lee et al. [33] believe that shoulder imbalance after surgery for Lenke type 2 scoliosis is common and correlates with the Risser sign, with a large postoperative PWA (proximal wedge angle – wedging of the intervertebral disc located under the upper instrumented vertebra) and the ratio of Cobb angles of both curves. Radiographic imbalance of the shoulders does not correlate with clinical one. The preoperative examination failed to identify risk factors for the development of imbalance, except for the Risser sign. Reliable techniques are CA and RSH.

Yang et al. [32] found that preoperative lateral imbalance of the shoulders defines postoperative imbalance to a greater extent than the level of the upper instrumented vertebra. The inclusion of T2 in the block area improves medial balance but not lateral one (CHD, CRID, CA). The positive T1 slope is an indicator of the inclusion of T2 in the block to improve the medial balance.

Gotfrid et al. [31] noted spontaneous correction of PT after correction of MT in 52 % of cases. Imbalance of the shoulders before surgery was noted in 51 % and after surgery in 30 %. In 17 % of cases, so-called reversible imbalance developed from left to right. This complication was more common in those who had minimal or no imbalance at all before surgery. In case of Lenke type 1 deformities with an elevated right shoulder and in the absence of problems in the sagittal plane, the correction of the main curve is sufficient to balance the shoulders. There is no connection between balance of the shoulders and the extent of correction of the main and proximal curves.

Lee et al. [33] believe that the block up to T2 is significant in case of sufficient maturation of the skeleton and a more mobile PT to prevent shoulder imbalance. If T3 or T4 is selected as the UIV, the decrease in the right shoulder may become a challenge after surgery. A high degree of skeletal maturation and greater MT mobility may be preoperative risk factors for the development of imbalance after surgery.

According to Brooks et al. [48], choosing T4 as the UIV gives better balance after surgery than T2 or T3, regardless of which shoulder was more elevated before surgery. The choice of T2 does not guarantee postoperative balance of the shoulders after blocking the main thoracic curve. Nevertheless, when compared with a more caudal UIV (T4), an improved correction of PT can be expected.

Ketenci et al. [35] examined the cervical spine and noted that in Lenke type 1 deformities, after transpedicular fixation with pre-bending and rotation of the rod, postoperative smoosing of cervical lordosis is more frequent if the UIV is placed at the T2 or T3 level. Smoosing of lordosis is due to a decrease in kyphosis at the level of T1–T5 and the T1 slope. There are no clinical manifestations of a decrease in lordosis. Therefore, the block should be extended for optimal balance of the shoulders.

According to Sielatycki et al. [49], significant correction of the main curve (> 54 %) combined with insufficient correction (< 52 %) of the proximal curve results in shoulder imbalance in 59 % of cases of Lenke types 1 and 2 deformities, regardless of UIV position. It is essential to carefully examine the proximal curve to achieve balance, especially if there is a significant correction of MT.

Yang et al. [34] argue that postoperative balance of the shoulders is defined by the apical translation of the proximal curve (AVT – apical vertebral translation) and the angle of adding-on. These are two cross-compensating mechanisms. Imbalance prevention is the correction of the AVT of the proximal curve and adding-on.

Bram et al. [50] believe that patients with a left elevated shoulder before surgery are less likely to achieve balance after surgery. The choice of a more proximal UIV also does not affect postoperative imbalance. The proximal curve of more than 34.5° in preoperative imbalance can result in aggravation of the asymmetry of the shoulders.

It is easy to verify that the considerations expressed by the authors often contradict each other. This relates to the examination techniques, the concept of rigidity of PT and the extend of the instrumented fusion zone. The attempted analysis of the data submitted in the literature was based on a comparison of a number of indicators: preoperative Cobb angle, preoperative mobility of the curvature, deformity correction and postoperative progression of deformity. All these parameters were calculated for both PT and MT.

In the variety of figures obtained, it is remarkable that significant differences were found in the MT and the MT + PT subgroups only in two cases: for the initial Cobb angle of PT and the magnitude of its correction (the Cobb angle before surgery minus the Cobb angle immediately after surgery).

This circumstance suggests that the authors of the articles included in the review, when choosing the extend of the instrumented spinal fusion zone, were guided primarily by the initial value of the Cobb angle of the proximal thoracic curve. In the MT + PT group, it is mean 37–40° and by 11–13° higher than in the MT group. Moreover, the mobility of PT in both groups does not differ statistically. Perhaps it is this circumstance that makes surgeons focus, first of all, on the initial value of PT. Despite a more severe proximal curvature than in the MT group, the correction obtained is statistically significantly greater in the MT + PT group. This difference can be explained by the high efficiency of modern instrumentation and the extensive application of transpedicular fixation.

The postoperative changes in kyphosis (both T2–T5 and T5–T12) are quite insignificant. According to these data, the extent of the instrumented spinal fusion zone has practically no effect on the parameters of the sagittal contour of the thoracic spine.

A sufficiently high incidence rate of the adding-on phenomenon indicates the presence of a relationship between this complication and the dynamics of PT. But probably the available data are insufficient to formulate the final conclusion.

The literature data on patients' self-appraisal of the quality of life after surgical treatment of Lenke types 1 and 2 scoliosis is quite scarce, while most of the operated patients rate the surgical outcome as positive.

Conclusion

Determining the extent of the instrumented spinal fusion zone in cases of double thoracic scoliosis is still an open issue. Most surgeons focus more on the magnitude of the proximal curve than on its mobility. There is no agreement in the choice of methods for assessing shoulder imbalance, in predicting the development of the adding-on phenomenon, and there is little data on changes in the quality of life of patients after surgery. It is necessary to conduct more research.

The study had no sponsors. The authors declare that they have no conflict of interest.

The study was approved by the local ethics committee of the institution. All authors contributed significantly to the research and preparation of the article, read and approved the final version before publication.

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Address correspondence to:
Mikhaylovskiy Mikhail Vitalyevich
Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan,
17 Frunze str., Novosibirsk, 630091, Russia,
MMihailovsky@niito.ru

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Denis Nikolayevich Dolotin, trauma orthopaedist, Department of Pediatric Orthopedics, Novisibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, 17 Frunze str., Novosibirsk, 630091, Russia, ORCID: 0000-0003-0430-6595, d.dolotin@mail.ru;
Vitaliy Leonidovich Lukinov, PhD in Physics and Mathematics, senior researcher, Department of organization of scientific research, Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, 17 Frunze str., Novosibirsk, 630091, Russia, ORCID: 0000-0002-3411-508X, vitaliy.lukinov@gmail.com;
Mikhail Vitalyevich Mikhaylovskiy, DMSc, Prof., chief researcher, Department of Pediatric Vertebrology, Novosibirsk Research Institute of Traumatology and Orthopaedics n.a. Ya.L. Tsivyan, 17 Frunze str., Novosibirsk, 630091, Russia, ORCID: 0000-0002-4847-100X, MMihailovsky@niito.ru.