RISK FACTORS FOR THE DEVELOPMENT OF PERSISTENT SHOULDER IMBALANCE AFTER SURGICAL CORRECTION OF IDIOPATHIC SCOLIOSIS

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Objective. To assess risk factors for the imbalance of the shoulder girdle and to identify reproducible X-ray criteria for persistent shoulder imbalance after correction of idiopathic scoliosis.

Material and Methods. A total of 94 patients with idiopathic scoliosis were included in the retrospective study. All patients underwent primary posterior correction of the deformity using pedicle screw instrumentation. Radiography of the spine throughout its length was performed before surgery, in the early postoperative and in the long-term (at least 12 months after surgery) periods. The shoulder imbalance was considered clinically significant with radiographic shoulder height difference more than 2 cm.

Results. A significant decrease in the magnitude of all curves after surgery and in the long-term period was noted. The magnitude of the proximal curve decreased from 25.38° ± 15.89° to 14.51° ± 8.17° ($p < 0.0001$) and to 14.29° ± 8.25° ($p = 0.24$); the main thoracic curve from 59.33° ± 20.76° to 20.096° ± 9.89° ($p < 0.0001$) and to 20.87° ± 9.48° ($p = 0.19$); and thoracolumbar curve from 47,20° ± 15,99° to 15.69° ± 8.66° ($p < 0.0001$) and to 16.98° ± 7.6° ($p = 0.01$), respectively. The shoulder imbalance was recorded in 27 patients (28.72 %) after surgery and in 13 (13.83 %) — in the long-term period. In these patients, various Lenke types of deformity were presented. A correlation of the distal adding-on phenomenon with self-correction of the shoulder balance is revealed ($r = 0.56$; $p < 0.005$). Persistent shoulder imbalance correlated with presence of a structural proximal thoracic curve ($p = 0.041642$), residual proximal curve magnitude after surgery ($r = 0.22$; $p = 0.03$), and presence of a symptom of double rib hump on radiographs after surgery ($r = 0.75$; $p \leq 0.005$).

Conclusion. The most characteristic pattern of persistent shoulder imbalance is the presence of asymmetry in the proximal and main regions of the chest. This sign can be detected by intraoperative lateral radiography of the spine, which will allow the surgeon to take measures to eliminate this phenomenon and reduce the probability of persistent shoulder imbalance development.

Key Words: idiopathic scoliosis, X-ray examination, shoulder imbalance, surgical correction, adding-on phenomenon.

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Modern surgical technologies allow achieving significant correction of the spinal deformity in the frontal and sagittal planes. However, patient satisfaction with the results of surgical treatment for idiopathic scoliosis is influenced, in addition to the correction degree, by such factors as the magnitude of the residual rib hump, the overall balance of the spinal column, and the balance of the shoulder girdle [1–3]. Correction of the rib hump can be ensured by thoracoplasty, the frontal balance of the spine is controlled by intraoperative radiography, while the prediction and intraoperative assessment of the balance of the shoulder girdle cause considerable difficulties [4, 5]. Shoulder girdle asymmetry occurs in 30 % of patients in the early postoperative period after correction of severe spinal deformity [6]. In most cases, the level of the shoulder girdle is restored over time. However, this does not happen in some patients, which leads to persistent shoulder imbalance (PSI). In this case, the asymmetry of the shoulder girdle negatively affects the patient's assessment of his/her appearance and may provoke chronic pain syndrome associated with overstrain of the back and neck muscles [1, 3].

There are a number of risk factors for the development of PSI which are based on the assessment of the parameters of the proximal thoracic spine segments in the frontal plane. Therefore, most studies devoted to this issue are focused on the choice of the proximal level for spinal fusion during surgery planning. Many authors [7–9] note that the inclusion of a structural proximal thoracic curve in the fusion area allows achieving a minimum incidence of shoulder imbalance. However, according to other studies [4, 10, 11], even fixation of the proximal thoracic curve with horizontal leveling of T1 does not allow reliable prediction of postoperative shoulder balance. Thus, to date, not a single reproducible perioperative criterion for predicting the development of shoulder imbalance has been proposed.

The aim of the study is to assess the risk factors for the imbalance of the shoulder girdle and to identify reproduc-

ible X-ray criteria for persistent shoulder imbalance after correction of idiopathic scoliosis.

Material and Methods

The retrospective study included 94 patients (13 males, 81 females; average age, 17.8 ± 6.3 years) with idiopathic scoliosis. All patients underwent primary posterior surgical correction of the deformity in 2013–2017. The average long-term follow-up period was 34.98 ± 14.96 months; the minimum follow-up period was 12 months.

The inclusion criteria were the following: the availability of spine radiographs before surgery, in the early postoperative (during the first week after surgery) and in the long-term (at least 12 months after surgery) periods for analysis. All surgeries were performed using pedicle screw instrumentation. The choice of fixation level was based on the Lenke classification [12], structural deformity curves were included in the fusion area, non-structural curves were excluded. The exception were type 1C and 2C deformities, when the lumbar non-structural curve was in some cases included in the fusion area. Patients with inverse curves (left-sided primary thoracic curve) and congenital abnormalities of the spine were excluded from the study.

X-ray examination. Patients underwent whole spine radiography in two projections in a standing position. The clavicle position of the hands was used for obtaining lateral radiographs (LR). A prerequisite was the inclusion of all spine departments, shoulder girdle to the level of the acromioclavicular joint, and hip joints in the study area. Measurements were performed using the Surgimap software (Spine Software, version 2.2.15.1).

The following parameters were evaluated on the anteroposterior radiographs (AR; Fig. 1): the inclination of the first thoracic vertebra relative to the horizontal line (T1 tilt), the clavicular angle (CA) (the angle between the line connecting the highest points of the clavicles at the acromioclavicular joint (ACJ) and the horizon line), the radiographic shoulder height difference (RSHD) (the height difference of the clavicle shadows at the ACJ level). Shoulder imbalance was considered clinically significant at RSHD ⩾ 20 mm [13, 14]. The persistence of significant shoulder imbalance one year after surgery was regarded as PSI. Angular parameters of the deformity were determined using the standard Cobb method: proximal thoracic curve (PT), main thoracic curve (MT), and thoracolumbar/lumbar curve (TL/L). Frontal balance of the spine was evaluated by translation of the C7 vertebra relative to the central sacral vertical line (CSL–C7).

The magnitude of thoracic kyphosis (TK) and lumbar lordosis (LL) was evaluated on lateral radiographs (Fig. 2a). The global sagittal balance of the spine was estimated by the magnitude of the translation of the vertical line drawn through the middle of the C7 vertebra relative to the posterior edge of the superior sacral endplate. After surgery, the rib cage symmetry was additionally studied on the LR. Radiological signs for the chest asymmetry are the presence of two overlying rib shadows; the first of them corresponds to PT, and the second one corresponds to MT. At the same time, a more than 1 cm difference in the contour of the ribs of the right and left chest is noted at the PT level. Other signs of asymmetry include the crossed rods at the level of MT to PT transition (usually T4–T6 vertebrae), a significant (more than 1 cm) difference in the screw location at the upper thoracic vertebrae (above the level of T4). The presence of pronounced asymmetry was interpreted as a double rib hump (DRH; Fig. 2b).

Statistical analysis was performed using StatSoft Inc. (2011) and Statistica v10 software. Demographic and radiological parameters were compared in patients with PSI and patients without imbalance using the Student'stest, Chi-square test or Fisher's exact test. The change in X-ray parameters during repeated measurements was evaluated using the Friedman's ANOVA test. In order to reveal the correlation between the shoulder balance and the measured X-ray parameters, the Spearman correlation analysis was performed. To assess the statistical significance of the influence of the factor, groups were compared using the Mann-Whitney test. The degree of influence of the most significant risk factors was evaluated using logistic regression analysis.

Results

According to the Lenke classification, the following deformity types were identified in patients before surgery: type 1 in 37 (39.36 %), type 2 in 9 (9.57 %), type 3 in 18 (19.15 %), type 4 in 8 (8.51 %), type 5 in 11 (11.7 %), and type 6 in 11 (11.7 %) cases, respectively. Lumbar C modifier was found in 55 (58.51 %), B modifier in 15 (15.96 %), and A modifier in 24 (25.53 %) patients. Most (89.36 %) patients had normal or decreased thoracic kyphosis, 10 (10.64 %) patients had increased thoracic kyphosis. Thus, the study included patients with all major types of idiopathic scoliosis. Changes in radiological parameters at different stages of the study are presented in Table 1.

Shoulder imbalance was recorded in 27 (28.72 %) cases in the early postoperative period. Spontaneous correction of the shoulder girdle level was noted in most patients during the first year after surgery (Fig. 3). However, shoulder imbalance was recorded in 13 (13.83 %) cases in the long-term period. These patients had different types of deformity: three patients had Lenke 1, three – Lenke 2, three – Lenke 3, two – Lenke 4, one – Lenke 5, and one – Lenke 6 curves, respectively. Thus, 5 (38.46 %) patients had a structural proximal thoracic curve before surgery, and 8 (61.54 %) patients did not have it. In 6 (46.15 %) patients with shoulder imbalance, the upper instrumented vertebra was higher than the T3 vertebra, and in 7 (53.84 %) patients, it was at T3 or below.

The magnitude of the proximal curve was an average of 25.38° ± 15.89° before surgery, 14.51° ± 8.17° after surgery ($p < 0.0001$) and 14.29° ± 8.25° in the long-term period ($p = 0.24$); no significant loss of correction was noted. The magnitude of the main thoracic curve was 59.33° ± 20.76° before surgery, 20.096° ± 9.89° after surgery ($p < 0.0001$)

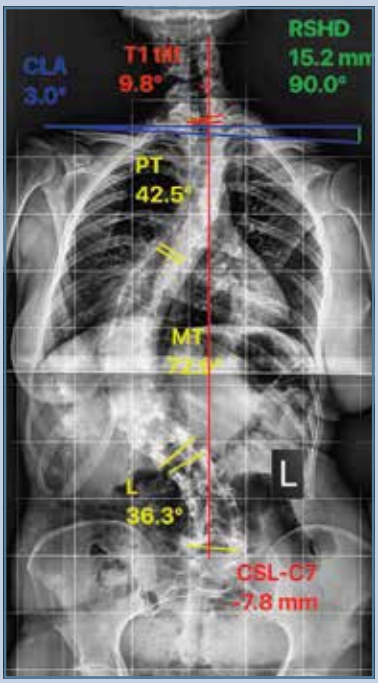

Fig. 1
Anteroposterior radiograph of the spine: T1 tilt –T1 slope relative to the horizontal line; CLA– clavicular angle; RSHD – radiographic shoulder height difference; PT – proximal thoracic curve; MT – main thoracic curve; L – lumbar curve; CSL–C7– C7 central sacral vertical line

Fig. 2
Lateral radiograph of the spine: **a** – whole spine (SVA – superior sacral end plate; TK – thoracic kyphosis; LL – lumbar lordosis); **b** – thoracic region (PT – proximal thoracic curve; MT – main thoracic curve), two overlying rib shadows at the level of MT and PT can be seen, more than 1 cm asymmetry in the contour of the ribs of the right and left chest at PT; the arrow indicates the crossing of the longitudinal rods

and 20.87° ± 9.48° in the long-term period (p = 0.19); no correction loss was noted. The magnitude of the thoracolumbar curve was 47.20° ± 15.99° before surgery, 15.69° ± 8.66° after surgery (p < 0.0001) and 16.98° ± 7.60° in the long-term period (p = 0.01); there was a slight loss of correction due to the distal adding-on phenomenon. The inclusion of the adjacent segments in a fixed curve was observed in 31 (32.98%) patients. There was no correlation between the shoulder imbalance and the development of the distal adding-on phenomenon. However, the relationship between the distal adding-on phenomenon and self-correction of the shoulder balance (r = 0.56; p < 0.005; Fig. 3) was noticed.

The proximal thoracic curve was not included in the fusion area in 60 patients, while the average PT in this group was 18.85° ± 9.98° before surgery, 13.38° ± 6.52° after surgery (p < 0.0001), and 12.78°± 5.87° 12 months after surgery (p = 0.236). Thus, spontaneous correction of the proximal curve was noted after fixation of the most pronounced curves. In addition, some spontaneous correction of the residual proximal curve is noted over time.

A comparison of the groups of patients with and without PSI was conducted, the results of the comparison are presented in Table 2.

According to the demographic parameters and the initial deformity parameters, no statistically significant differences were revealed between the patients with and without PSI. There were more patients with structural PT before surgery (p = 0.041642) in the PSI group; and this group is also characterized by a greater absolute value of the residual PT after correction (p = 0.03). There is a direct correlation between PSI and the presence of the DRH symptom on the radio-

graphs after surgery ($r = 0.75$; $p \leqslant 0.005$). According to the results of the logistic regression analysis, DRH is a significant prognostic factor for the development of PSI, the odds ratio is 76.364, 95 % CI [9.013; 646.965], Chi square = 33.197, $p < 0.0001$. The regression model correctly classified 87.23 % of cases with a specificity of 86.40% and a sensitivity of 92.31 %.

We did not find a dependence of PSI on the fixation level, the magnitude of the main thoracic and thoracolumbar curves, as well as on the initial parameters of the shoulder girdle.

Discussion

Shoulder balance is one of the most important criteria for evaluating the results of surgical correction of idiopathic scoliosis by the patient and the surgeon. The literature describes quite a large number of radiological and clinical parameters to evaluate the shoulder balance. The most reproducible of them are the T1 tilt, the clavicular angle and the radiographic clavicle height difference. The following division has been proposed for assessment of the imbalance severity: 0–1 cm is the absence of imbalance; 1–2 cm is considered as minimal imbalance; 2–3 cm is the pronounced imbalance; and more than 3 cm is considered as gross imbalance [3]. A study by Lee et al. [6] demonstrated that a more than 2 cm difference in shoulder height negatively affects patients' assessment of the surgery result. Taking into account the fact that minimal imbalance rarely worries patients, the level of RSHD ⩾ 2 cm was chosen as the criterion of the significant shoulder imbalance for this study.

According to the literature [14], a number of risk factors for the development of shoulder imbalance can be defined: a higher Risser grade, structural PT (Lenke curve types 2 and 4), T1 tilt > 5°, elevation of the left shoulder before surgery, and significant difference in the correction of the MT and TL curves. Most studies on shoulder balance are focused on assessing spinal deformity

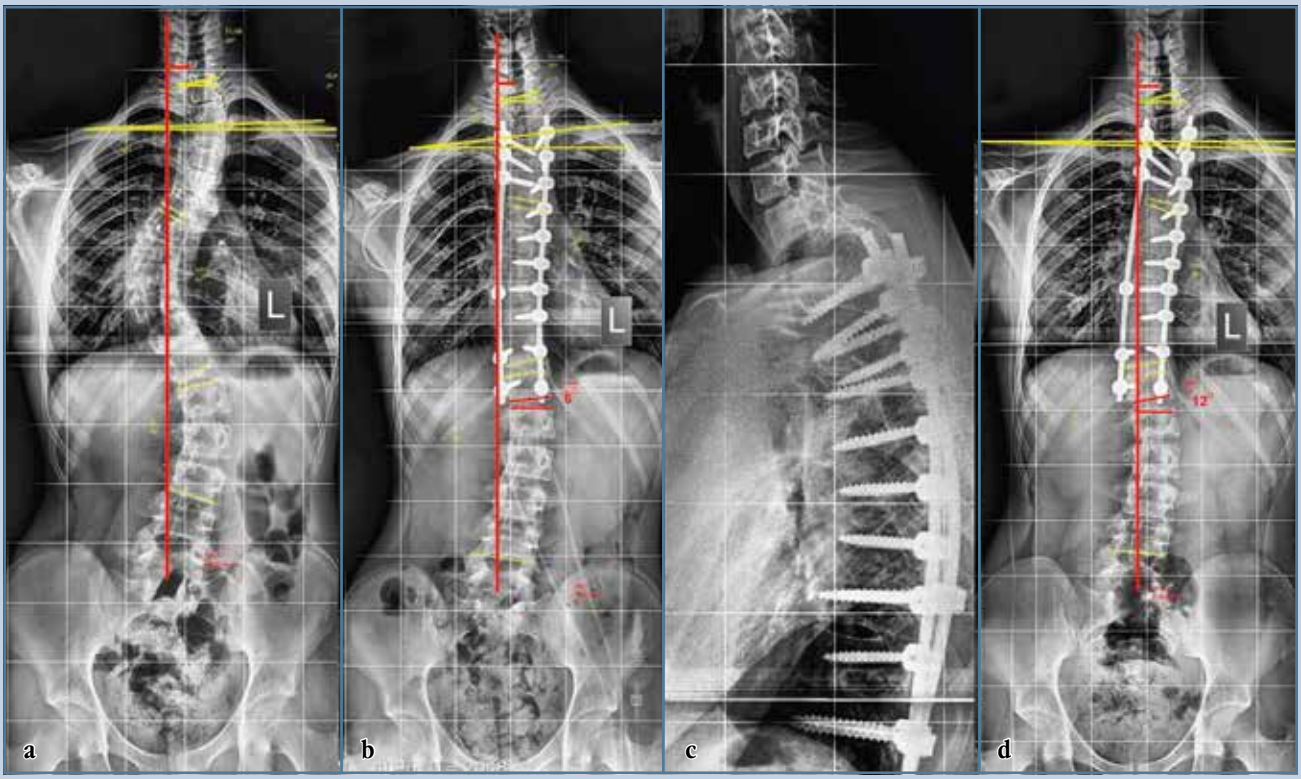

Fig. 3
Self-correction of the shoulder balance: **a** – anteroposterior radiograph before surgery, Lenke type 2C deformity (41/62/30), the T1 tilt relative to the horizontal line equals 10°, the clavicular angle is 2° (elevation of the left shoulder); **b** – anteroposterior radiograph after fixation and spinal fusion at T3–T1, the T1 tilt relative to the horizontal line equals 12°, the clavicular angle is 7° (elevation of the left shoulder); **c** – lateral radiograph after surgery, asymmetry of the proximal chest is not pronounced; **d** – one year after surgery, the T1 tilt relative to the horizontal line equals 16°, the clavicular angle is – -2° (normal shoulder balance), compensation due to the distal adding-on at T11–T12–L1

Table 1
Changes in the main radiological parameters at different stages of the study (Friedman's ANOVA)

Parameter	Before surgery	After surgery	12 months after surgery	p
Proximal thoracic curve, deg.	25.382980 ± 15.892180	14.510640 ± 8.169900	14.287230 ± 8.249630	<0.01
Main thoracic curve, deg.	59.329790 ± 20.762040	20.095740 ± 9.893050	20.872340 ± 9.481430	<0.01
Thoracolumbar/lumbar curve, deg.	47.202130 ± 15.989630	15.691490 ± 8.659670	16.978720 ± 7.601610	<0.01
Central sacral vertical vertebral line C7, mm	15.510640 ± 11.681940	20.319150 ± 17.530440	10.234040 ± 9.283380	<0.01
Radiographic shoulder height difference, mm	8.957450 ± 8.963380	12.553190 ± 10.868340	7.223400 ± 6.964050	0.004910
Clavicular angle, deg.	2.691489 ± 2.929371	3.085106 ± 2.593041	1.968085 ± 1.804726	0.018320
T1 tilt relative to the horizontal line, deg.	7.861702 ± 7.129525	7.159574 ± 4.693402	6.021277 ± 4.508007	0.005420

parameters in the frontal plane and fixing the proximal thoracic curve. The criteria of structural PT include the curve magnitude of more than 25° according to Cobb in a bending test, more than 20° kyphosis at the T2–T5 level, significant apical rotation (Nash-Moe grade II and higher), apical translation of more than 1 cm, a transitional vertebra between MT and PT are located at the T6 level and more caudally, a positive T1 tilt, and elevation of the left shoulder [7]. According to Li et al. [15], the inclusion of PT in the fusion area in Lenke type 2 deformities eliminates the development of shoulder imbalance. According to the results of our study, PSI can develop regardless of the Lenke type of deformity even in the absence of structural PT. In 8 (61.54 %) patients from the PSI group, PT was not structural before surgery. There is no doubt that the presence of structural PT is more typical for patients with PSI ($p = 0.041642$). Patients with a balanced level of shoulders are characterized by lower absolute PT magnitudes after surgery ($p = 0.030672$). However, no significant correlation between these signs and PSI was revealed. Thus, the magnitude and structurality of PT cannot determine the risk of shoulder imbalance with a high probability.

Ono et al. [4] proposed distinguishing the medial and lateral components of the shoulder imbalance, with the medial area of the shoulders having a high degree of dependence on the radiological parameters of the spine in the frontal plane (T1 tilt), and the lateral component of the imbalance not having a significant correlation with the estimated spinal parameters. Yang et al. [5] came to the same conclusions based on the analysis of treatment results for 79 patients with Lenke 2 scoliosis. The authors note that spine fixation up to the T2 level provides effective control of only the medial component of the shoulder balance, with the lateral component being mostly affected by the preoperative parameters of the shoulder girdle. Elevation of the left shoulder is not an indication for fixation up to the T2 level. The main reason for choosing a high level of fixation is a significant T1 tilt, and its aim is to compensate for the medial shoulder imbalance [5], while postoperative lateral shoulder balance cannot be predicted. In our study, spinal fusion was performed up to the level of T2 and higher in 6 (46.15 %) patients with PSI, which did not prevent the development of shoulder imbalance.

As it can be seen from the foregoing, most studies on shoulder balance are focused on the Lenke type 2 deformities, which are mostly treated by selective fixation of PT and MT, while TL/L curve is excluded. Compensation of the shoulder imbalance in this case is achieved by including the distal vertebrae in the fixed curve (Fig. 3). A number of publications established a correlation between the shoulder imbalance and distal adding-on [13], which explains the small number of patients with shoulder imbalance in these samples. However, according to our observations, distal adding-on not only can compensate for the shoulder imbalance but also cause its increase. In case of the left-sided frontal imbalance, elevation of the left shoulder occurs after surgery in a fixed PT with the self-correction of the frontal imbalance (Fig. 4).

In the literature, only a small number of studies describe the risk of shoulder imbalance after correction of various types of idiopathic scoliosis. Bjerke et al. [11] investigated the impact of various methods for selection of the upper instrumented vertebra (UIV) on the postoperative shoulder balance in 263 patients, analyzed the UIV choice methods described by Lenke [7], Ilharreborde [8] and Trobisch [9] and showed that, even if the choice of UIV is consistent with all the described algorithms, there is still a risk of shoulder imbalance. In addition, the proximal curve fixation significantly contributes to the injury rate of the surgery and increases the probability of complications associated with the damage to the adjacent segments. Taking into account the fact that spontaneous PT correction sometimes occurs after correction of more pronounced curves, it is advisable not to perform fixation of the proximal thoracic region in some cases [16]. Hong et al. [10] analyzed the effect of changes in the shoulder balance in 89 patients with all types of Lenke deformities but did not reveal any differences in the incidence of shoulder imbalance in patients with different curve types and different fixation levels. The authors note an increased risk of imbalance in case of large difference in the correction between MT and TL

Table 2

Comparison of the parameters characterizing patients with persistent shoulder imbalance and without it

Parameters	With persistent shoulder imbalance	Without persistent shoulder imbalance	p
Before surgery			
Gender (M/F), n (%)	3 (23.08)/10 (76.92)	10 (12.35)/71 (87.65)	0.38
Age, years	16.61540 ± 4.53759	18.00000 ± 6.54217	0.533741
Lenke type of spinal deformity, n (%)	1st – 3 (23.08); 2nd – 3 (23.08); 3rd – 3 (23.08); 4th – 2 (15.39); 5th – 1 (7.69); 6th – 1 (7.69)	1st – 34 (42.00); 2nd – 6 (7.40); 3rd – 15 (18.52); 4th – 6 (7.41); 5th – 10 (12.35); 6th – 10 (12.35)	–
Structural proximal thoracic curve, n (%)	5 (38.46)	12 (14.82)	0.041642
Proximal thoracic curve, deg.	30.53846 ± 14.79648	24.55560 ± 15.99219	0.150538
Main thoracic curve, deg.	63.07692 ± 21.32863	58.72840 ± 20.74187	0.514512
Thoracolumbar curve, deg.	46.92310 ± 16.89409	47.24690 ± 15.94955	0.956311
C7 central sacral vertical line, mm	15.23080 ± 11.93143	15.55560 ± 11.71644	0.899671
Risser test	3.84620 ± 0.98710	3.77780 ± 1.43178	0.674837
Left shoulder is higher, n (%)	3 (23.08)	13 (16.049)	0.4078
T1 tilt relative to the horizontal line, deg.	1.076923 ± 9.205628	-1.962960 ± 0.926400	0.131812
T1 tilt relative to the horizontal line ≥5°, n (%)	5 (38.46)	17 (20.99)	0.16
Radiographic shoulder height difference, mm	4.92310 ± 4.40571	9.60490 ± 9.34970	0.082222
Clavicular angle, deg.	1.38460 ± 1.12090	2.90120 ± 3.07654	0.073694
After surgery			
Proximal upper instrumented vertebra ≥T3, n (%)	6 (46.15)	29 (35.80)	0.54
Distal lower instrumented vertebra ≥L2, n (%)	9 (69.23)	38 (46.91)	0.2314
Proximal thoracic curve, deg.	19.23080 ± 9.33768	13.75310 ± 7.76616	0.030672
Main thoracic curve, deg.	21.23080 ± 11.86840	19.91360 ± 9.61275	0.720852
Thoracolumbar curve, deg.	14.07690 ± 6.14358	15.95060 ± 9.00125	0.543894
C7 central sacral vertical line, mm	13.69230 ± 11.35330	21.38270 ± 18.15597	0.105564
Clavicular angle, deg.	4.23080 ± 3.26991	2.90120 ± 2.44236	0.140576
Double rib hump, n (%)	12 (92.00)	11(13.58)	<0.0001
12 months after surgery			
Proximal thoracic curve, deg.	17.57 ± 9.30	13.79 ± 8.00	0.176468
Main thoracic curve, deg.	21.50 ± 11.32	20.76 ± 9.26	0.704688
Thoracolumbar curve, deg.	14.71 ± 7.26	17.24 ± 7.59	0.344726
C7 central sacral vertical line, mm	9.79 ± 9.01	10.11 ± 9.27	0.712754
Clavicular angle, deg.	4.57 ± 0.85	1.53 ± 1.52	<0.0001
Double rib hump, n (%)	12 (92.00)	9 (11.11)	<0.0001

curves [10]. It is difficult to predict and perform the intraoperative assessment of the required correction degree. Thus, according to the literature and our data, it is not possible to identify the radiological parameter from the AP X-ray images that would predict the imbalance of the shoulder girdle after correction of idiopathic scoliosis with high reliability.

At the same time, the most characteristic pattern in PSI is the presence of asymmetry of the proximal and main thoracic segments of the spine. DRH was detected after correction by X-ray imaging performed in the lateral projection ($r = 0.75$; $p \leqslant 0.005$), it did not significantly change during the entire follow-up period in 92 % of patients with PSI.

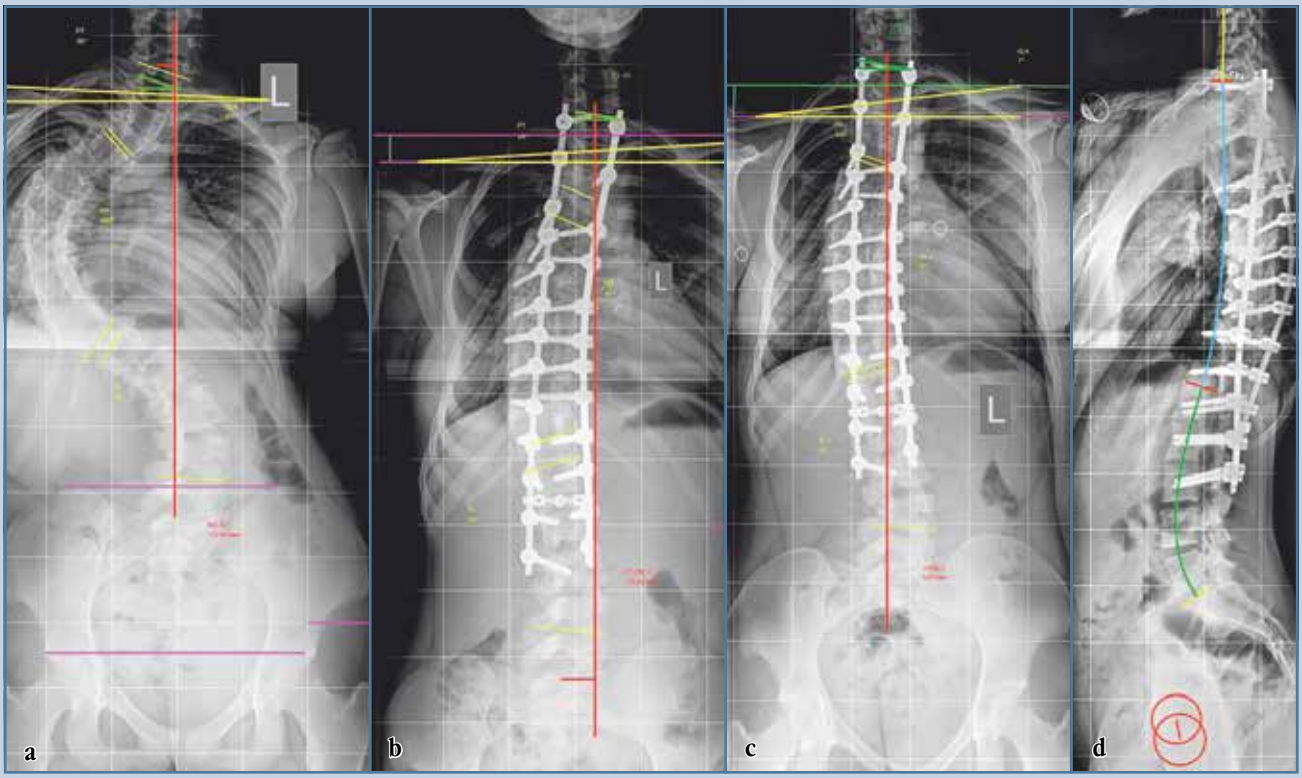

Fig. 4
Radiographs demonstrate increased shoulder imbalance in the long-term period: **a** – before surgery, the T1 tilt relative to the horizontal line equals -14°, left shoulder depression (shoulder height difference is -11 mm), the clavicular angle equals -3°; **b** – after surgery, fixation was performed at the level of T1–L3, the T1 tilt relative to the horizontal line equals -9°, elevation of the left shoulder (X-ray difference in shoulder height is 21 mm), clavicular angle equals – 4°; **c** – 24 months after surgery, the T1 tilt relative to the horizontal line equals -9°, elevation of the left shoulder (x-ray difference in shoulder height is 26 mm), clavicular angle equals 7°, progression of the shoulder imbalance, alignment of the C7 central sacral vertical line due to the distal adding-on; **d** – lateral radiograph demonstrates signs of thoracic asymmetry (double rib hump)

Conclusion

It is not only the changes in the frontal plane of the spine but also the asymmetry of the rib skeleton due by spinal deformity that affect the balance of the shoulder girdle. The inclusion of structural thoracic curve in the fusion area does not exclude the development of shoulder imbalance. Radiography performed in anteroposterior projection does not allow one to assess the possibilities to compensate for the shoulder balance after surgery. Radiographs in the lateral projection provide data on the chest deformity, which often underlies the development of PSI. The X-ray parameters we proposed can be reproduced in an operating room equipped with an C-arm, which will allow the surgeon to take measures to reduce the probability of PSI development after surgical correction of idiopathic scoliosis.

Limitations of the study. This study is retrospective and based on the data obtained from archival sources. Radiographs obtained in the upright position of the patient in the postoperative period were used for analysis. Therefore, the obtained data may differ from intraoperative ones, which were obtained in the prone position. In order to assess the effectiveness of the proposed criterion under intraoperative conditions, it is necessary to conduct a prospective study with the assessment of intraoperative radiographs and their comparison with the postoperative and long-term results. The minimum follow-up period is only 12 months, while a longer observation period is required to assess the significance of the evaluated parameters.

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