SPINOPELVIC FIXATION IN NEUROGENIC SCOLIOSIS: VALIDITY OF INDICATIONS

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Objective. Analysis of the results of surgical correction of neuromuscular scoliosis in order to optimize indications for performing spinal and pelvic fixation.

Material and Methods. A total of 45 patients aged 10 to 17 years were operated on for neurogenic scoliosis in the period of 2012–2024. Thirty patients without pelvic fixation were divided into two groups: Group I included 15 patients with pelvic tilt of less than 15°, and Group II – 15 patients with pelvic tilt of more than 15°. Group III consisted of 15 patients with pelvic tilt of more than 15° who underwent pelvic fixation. All patients underwent postural radiographs before and after surgery. The treatment results were assessed according to the following criteria: the frontal pelvic tilt angle according to Maloney, the tilt of the L5 vertebra, and the magnitude of scoliotic curve angle according to Cobb. A search for possible relationships between various radiographic parameters was also performed.

Results. The average value of pelvic tilt before surgery in Group I was 7.9° ± 5.1°, in Group II – 36.3° ± 14.7°, and in Group III – 37.9° ± 14.2°; after surgery in Group I – 5.9° ± 4.5°, in Group II – 13.6° ± 10.4°, and in Group III – 12.8° ± 4.0°. The average degree of correction in groups was 36.8 ± 32.0 %, 61.2 ± 26.8 % and 62.9 ± 8.9 %, respectively. No significant loss of correction was found during long-term follow-up in all groups. The preoperative Cobb angle of the primary curve was 73.3° ± 20.2° in Group I, 99.9° ± 31.0° in Group II, and 96.7° ± 17.5° in Group III. In the postoperative period, the average Cobb angle was 29.4° ± 9.7° in Group I, 40.2° ± 24.9° in Group II, and 41.6° ± 19.5° in Group III. In Group II, a direct relationship was found between the correction of the primary curve and the correction of pelvic tilt. When assessing the relationship between the L5 inclination and the correction of pelvic tilt in Group II, an inverse relationship was found. No reliable relationship was found between the initial angle of pelvic tilt and the correction of pelvic tilt in Group II.

Conclusion. Correction of pronounced pelvic tilt in patients with neuromuscular scoliosis is possible without pelvic fixation and without significant loss of correction, provided that the degree of correction of the primary curve is satisfactory (more than 50 %). A possible parameter determining the need for spinopelvic fixation may be the angle of L5 inclination. Narrowing the indications for inclusion of the pelvis in the fusion zone during surgical correction of neurogenic spinal deformities helps to reduce the frequency of implant-associated complications that are typical for spinopelvic fixation, which in general will lead to a significant increase in the effectiveness of surgical treatment of this category of patients.

Key Words: neuromuscular scoliosis; spinopelvic fixation.

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One of the most challenging categories of patients with spinal deformities is those with neuromuscular scoliosis. The term "neuromuscular scoliosis" includes spinal deformities associated with a primary dysfunction of the nervous system or muscles, of which the most common are cerebral palsy (CP), spinal muscular atrophy (SMA), and other conditions. According to the SRS (Scoliosis Research Society), secondary neurogenic spinal deformity occurs in 20 % of patients with cerebral palsy, in 60 % of patients with myelodysplasia, in 25 % of patients with neurofibromatosis and polyneuropathy, and in 90 % of male patients with Duchenne muscular dystrophy [1]. The severity of spinal deformity correlates with the pronouncement of neurological disorders [2]. In cerebral palsy, the risk of neuromuscular scoliosis increases with the level of motor function decrease: the incidence of scoliosis is up to 25 % for GMFCS (gross motor function classification score) grades I–III, while for GMFCS grades IV–V it reaches 50 % [3]. In patients with GMFCS grade V at the age of 5 years, scoliosis was found in only 8 % of cases; by the age of 20 years, up to 75 % of patients had a deformity exceeding 40° [4]. Most spinal neuromuscular deformities continue to worsen in adulthood, promoting a reduced quality of life of patients [5].

The main targets of surgery for neurogenic scoliosis are to improve the upright stance by eliminating/reducing both sagittal and frontal imbalance and pelvic tilt, to simplify patient care, including by reducing the need for braces, to improve respiratory function or to prevent the worsening of respiratory and hemodynamic disorders, and, as a consequence, to increase the longevity of patients. In the case of severe pelvic tilt, spinopelvic fixation (SPF) may be required; however, there is no clear criteria for its appropriateness [6, 7]. Generally, SPF is recommended only for patients who are unable to move independently (GMFCS greater than III) in combination with severe frontal imbalance associated with pelvic tilt [8]. SRS and some authors consider pelvic tilt greater than 15° to be an indication for pelvic fixation [9–12].

The inclusion of the pelvis in the fusion area is known to have higher peri- and postoperative risks [7]. The incidence of implant-associated complications in SPF reaches 29 % [13], and the procedure itself is associated with greater blood loss volume, longer surgery time, higher costs, and limited possibility of graft harvesting from the iliac bone [14]. The implementation of the screw placement technique through the sacrum into the iliac wing (so-called Sacrum – Os Ilii instrumental fixation) has reduced the number of implant-associated, including infectious, complications due to the deeper point of screw placement [14, 15] and greater stability of fixation due to the overlap of the sacroiliac joint area. Nonetheless, the high incidence of pelvic fixation complications requiring revision surgeries has raised the question of clearer indications for the technique and the risks of including the pelvis in the fusion area.

The objective is to analyse the results of surgical correction of neuromuscular scoliosis in order to optimize indications for performing spinal and pelvic fixation.

Materials and Methods

The study was performed at the Neuro-Orthopaedic Department in cooperation with Orthopaedics of the National Medical Research Centre for Children's Health (Moscow). The inclusion criteria for the study were neurogenic scoliotic deformities that required surgical correction.

The study included 45 patients aged 10–17 years who were treated in 2012–2024. All patients underwent postural radiographs (in a sitting position). The magnitude of spinal deformity was evaluated according to the Cobb Angle Measurement before and after surgery. The parameters of sagittal and frontal balance were also evaluated, including in the frontal plane – Maloney method of pelvic tilt; the greatest reliability of this technique was shown by Shrader et al. [16]. We studied the index of L5 vertebral tilt, defined as the angle between lines drawn through the upper borders of the iliac crests and along the edge of the superior endplate of the L5 vertebra (Fig. 1).

All patients were divided into 3 groups with regard to the surgical technique:

Group I: 15 patients with pelvic tilt of less than 15°; pelvic fixation was not performed;

Group II: 15 patients with pelvic tilt of more than 15°; pelvic fixation was not performed;

Group III: 15 patients with pelvic tilt of more than 15° who underwent pelvic fixation, including 10 cases using the author's technique. Polyaxial screws were placed through the posterior superior iliac spine (PSIS) and fixed with additional rods to the main structure using open lateral connectors [17]. Also, for SPF, we used polyaxial screws inserted through the posterior superior iliac spine (PSIS) in two patients; screws in the S1 vertebra and the PSIS were placed in one patient; S1, S2-alar-iliac screw technique was used in one patient; and T-construction was used in one patient.

The general characteristics of the patients are given in Table 1.

Statistical analysis was performed using StatTech software version 4.6.1 (StatTech Ltd., Russia). Quantitative indicators were assessed for conformity to normal distribution using the Shapiro-Wilk test. Quantitative indicators having normal distribution were described using arithmetic mean (M) and standard deviations (SD) and 95 % confidence interval (95 % CI). If there was no normal distribution, quantitative data were described using the median (Me) and lower and upper quartiles (Q1–Q3). The Student's t-test was used to compare normally distributed quantitative indicators calculated for two linked samples. The direction and strength of the relationship between two quantitative indicators were evaluated using the Pearson correlation coefficient (with normal distribut ion of the compared indicators). Differences were considered statistically significant at $p < 0.05$.

Results

The mean postoperative follow-up was 24.8 ± 12.0 months (min 11; max 47) in Group I, 21.8 ± 10.2 (min 9; max 45) in Group II, and 20.5 ± 8.3 (min 8; max 38) in Group III, indicating that they were comparable. The main outcomes are summarized in Table 2.

The obtained data show that there were no significant differences in the degree of correction of anterior pelvic tilt in groups II and III, i.e., regardless of the inclusion/non-inclusion of the pelvis in the fusion area in patients with pelvic tilt more than 15° ($p > 0.01$).

There was no significant loss of pelvic tilt correction at follow-up in all groups ($p > 0.01$).

Frontal balance was also evaluated to compare groups II and III. In Group II, the mean value of frontal imbalance was 58.8 mm preoperatively and 25.5 mm postoperatively; the mean correction was 50.3 %. In Group III, it was 68.1 mm preoperatively and 22.2 mm postoperatively; the mean correction was 61.9 %. There were no statistical differences between the groups ($p > 0.05$). This demonstrates that inclusion of the pelvis in the fusion area does not increase the degree of correction of the primary scoliotic curve and, therefore, has no significant effect on the frontal balance of the trunk, since pelvic tilt in the absence of hip instability is secondary to structural scoliotic deformity of the thoracolumbar or lumbar spine.

We analysed the possible relationship of different radiological parameters in groups II and III in order to find a criterion to identify the need for pelvic fixation. In Group II, moderate direct relationship was found between correction of the primary deformity and correction of pelvic tilt (Fig. 2; $r = 0.568$; $p < 0.05$), while Group III showed no such correlation ($r = 0.078$; $p = 0.783$). This is explained by the fact that SPF with pelvic position correction was performed independently of the lumbar spine in the majority of Group III patients, which was assisted by the author's technique of pelvic fixation using polyaxial lateral connectors.

Evaluating the relationship between preoperative L5 angle and pelvic tilt correction in Group II, moderate negative correlation was found (Fig. 3; r = -0.594; $p < 0.05$), while no significant relationship was observed in Group III (r = -0.527; p = 0.145). This correlation increases to r = -0.662 ($p < 0.05$) when patients with low primary curve correction (less than 50%) are excluded. This indicates that the higher the L5 tilt, the lower the expected correction of pelvic tilt even with successful correction of the primary curve.

Moderate negative correlation (Fig. 4; r = -0.523; $p < 0.05$) was found between the initial Cobb angle and pelvic tilt correction in Group II. There was no significant correlation between these parameters in Group III (r = 0.345; p = 0.208). There was also no significant relationship between initial pelvic tilt angle and its correction in Group II (p = 0.623), while a strong direct relationship (r = 0.713; $p < 0.05$) was found in Group III.

Therefore, the data on the correlation between the studied parameters suggest the dominant role of correction of the primary curve and L5 vertebral tilt in the correction of pelvic tilt. This provides supporting evidence in favour of the need to reduce the indications for SPF in patients with neurogenic spinal deformities.

According to our data, implant-associated complications were observed in 3 out of 15 patients with pelvic fixation; all cases required revision surgery, and their incidence was 20.0%. The reasons for revision surgery were pronounced bone resorption around the screws in the iliac bone (1 case), screw malposition (1 case), and rod fracture (1 case).

Clinical case 1. Patient B., 16 years old, grade IV neurogenic left-sided lumbar scoliosis, cerebral palsy (spastic quadriparesis), GMFCS grade V (Figs. 5, 6). Before the surgery: pelvic tilt – 46°, primary deformity angle – 101°. Postoperative pelvic tilt – 6°, primary deformity angle – 30°, correction of pelvic tilt – 80.4%, primary curve – 70.3 %.

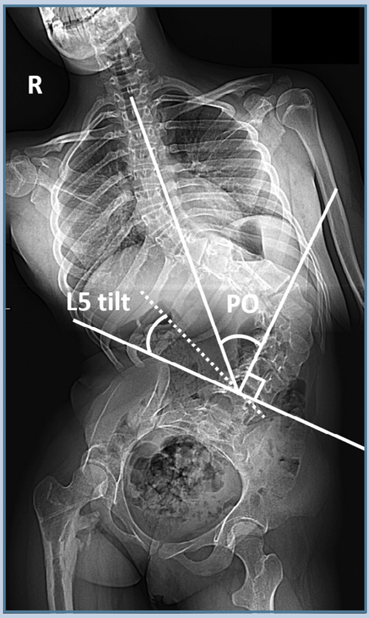

Fig. 1
Maloney pelvic tilt angle (PO): L5 tilt – tilt angle of the L5 vertebra

Because of the pronounced deficit of subcutaneous adipose tissue, the patient had a pressure ulcer at the site of the screw in the iliac bone 12 months after surgery, which required corrective surgery of the defect with local tissues (Fig. 7). A rod fracture was detected on the control radiograph after 25 months (Fig. 5); the revision surgery was performed, and the rod was replaced.

Clinical case 2. Patient D., 15 years old, grade IV neurogenic scoliosis, cerebral palsy, quadriparesis, GMFCS grade IV (Figs. 8, 9). The initial pelvic tilt was 52°, and the deformity angle by Cobb was 140°. The correction was performed at the T3–L5 level. The postoperative pelvic tilt was 4°, the primary deformity angle was 37°, the pelvic tilt correction without SPF was 92.3 %, and the primary curve correction was 73.6 %.

Clinical case 3. Patient S., 14 years old, grade IV neurogenic scoliosis, cerebral palsy, quadriparesis, GMFCS grade IV. Cobb angle of the primary curve before surgery – 114°, after surgery – 36°, correction – 68.4 %. Pelvic tilt before surgery – 44°, after surgery – 7°, correction – 84.1 % (Figs. 10, 11).

Discussion

The necessity of pelvic fixation in patients with neuromuscular deformities is still controversial. On the one hand, the relatively high rate of complications and revision surgeries in pelvic fixation necessitates reducing the indications for including the pelvis in the fusion area. Furthermore, the advantage of the L5-S1 mobile joint is that most of the angular and rotational movements of the trunk during movement in a wheelchair are attributed to it preserving the mobility of the L5–S1 segment and promoting greater mobility and motor

Table 1
Characteristics of patients in the study groups

Parameters	Group I	Group II	Group III
Number of patients, n	15	15	15
Mean age at the time of surgery, years	13.1 ± 1.9	13.2 ± 2.0	12.5 ± 2.5
Mean deformity angle according to Cobb, degrees	73.3 ± 20.2	99.9 ± 31.0	96.7 ± 17.5
Etiology, n			
Cerebral palsy	9	13	12
Spinal muscular atrophy	2	–	1
Duchenne muscular dystrophy	–	–	1
Consequence of spinal cord injury	2	1	–
Consequence of spinal cord tumour	1	1	1
Rigid spine syndrome	1	–	–

Table 2
Main outcomes

Indicator	Group I	Group II	Group III	p, I/II	p, I/III	p, II/III
Pelvic tilt, degrees						
Before surgery	7.9 ± 5.1	36.3 ± 14.7	37.9 ± 14.2	<0.001*	<0.001*	0.756
After surgery	5.9 ± 4.5	13.6 ± 10.4	12.8 ± 4.0	0.029*	<0.001*	0.797
Correction, %	36.8 ± 32.0	61.2 ± 26.8	62.9 ± 8.9	0.044*	0.013*	0.811
Final	6.5 ± 4.7	14.3 ± 10.0	13.0 ± 3.8	0.020*	<0.001*	0.662
Deformity magnitude, degrees						
Before surgery	73.3 ± 20.2	99.9 ± 31.0	96.7 ± 17.4	0.009*	0.001*	0.712
After surgery	29.4 ± 9.7	40. ± 24.91	41.6 ± 19.5	0.125	0.052	0.843
Correction, %	58.7 ± 15.2	61.9 ± 18.3	57.6 ± 16.2	0.664	0.857	0.443
L5 tilt angle, degrees						
Before surgery	10.4 ± 6.0	14.8 ± 10.2	20.3 ± 6.6	0.107	<0.001*	0.132
After surgery	6.3 ± 3.1	6.9 ± 4.4	7.0	0.673	0.307	0.271
Correction, %	40.0	47.8 ± 26.7	56.5 ± 23.9	0.221	0.003*	0.349

* Differences were considered statistically significant at $p < 0.05$.

activity of the patient, including in the sitting position [18, 19].

On the other hand, some authors believe it is imperative to include the pelvis in the fusion area because if SPF is abandoned, there is a significant loss of correction at long-term follow-up. Modi et al. [19] reported the outcomes of neuromuscular scoliosis correction in 55 patients, considering a preoperative pelvic tilt of more than 15° as an indication for pelvic fixation. In the group of patients with pelvic tilt more than 15° without SPF, they noted a significant loss of correction of 43.1% versus 3.4% in the group with pelvic fixation; they concluded that it was essential in this category of patients [11]. We did not find any significant loss of correction at a mean follow-up of 21.80 ± 10.21 months in the group without pelvic fixation. In our opinion, such differences are associated with the difference in the structure of the etiology of spinal deformities. In our study, patients with spastic forms of cerebral palsy predominated, while in the above study, more than 2/3 of patients suffered from SMA and Duchenne muscular dystrophy. We believe that patients with spastic cerebral palsy have an initially less mobile lumbopelvic segment, which is associated with a lower risk of subsequent relapse of pelvic tilt. Paralytic forms of scoliosis are characterized by a greater degree of pelvic mobility and possibly have a higher risk of relapse of pelvic tilt in the lack of SPF.

According to the results obtained, it is possible to achieve a satisfactory degree of correction of frontal pelvic tilt without its inclusion in the fusion area, which is confirmed by the absence of statistical differences in the magnitude of surgical correction of pelvic tilt in groups II and III.

The observed lack of correlation between the initial pelvic tilt angle and the degree of its correction may indicate that the previously proposed use of a pelvic tilt angle greater than 15° as an indication for SPF cannot be fully valid. This raises the question: why is there a highly significant correlation between preoperative pelvic tilt and its correction in patients with a pelvic tilt greater than 15° and SPF performed? This may be explained by the fact that the greater the initial tilt, the greater the correction required to bring the pelvis into the correct position. Moreover, there is no dependence on other parameters in the

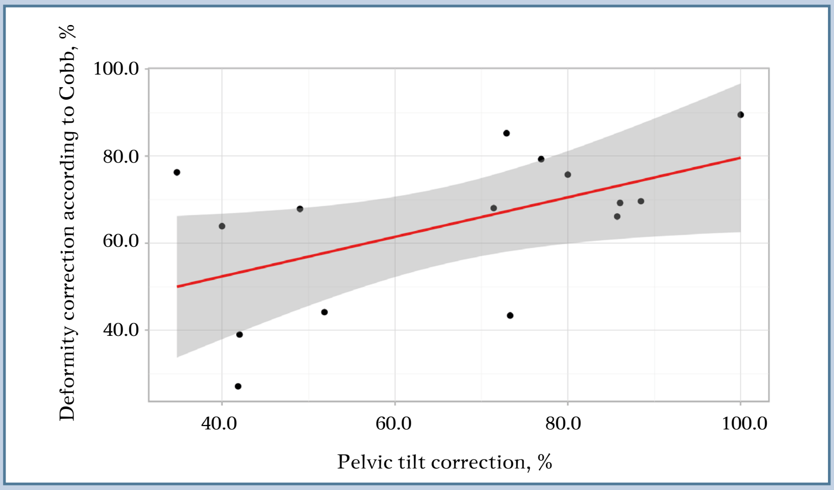

Fig. 2
Relationship between deformity correction according to Cobb and pelvic tilt correction

case of pelvic fixation and the correction is performed independently of the correction of the primary curve, as evidenced by the complete omission of the correlation between the correction of the primary deformity and the correction of pelvic tilt in Group III (r = 0.078; p = 0.783). Thus, it is possible to perform a greater correction of pelvic tilt even with a low correction of the primary deformity. This conclusion may be applicable when using pelvic fixation based on polyaxial screws, which allows adjustment of the pelvic position independent of the primary deformity, and is not fully applicable to the Luque-Galveston technique.

Moderate inverse relationship found in the study between preoperative L5 tilt and pelvic tilt correction in Group II suggests that the initial tilt of the L5 vertebra may be a parameter indicating the possibility of correcting the tilt by fixation only to the L5 vertebra. This is associated with the fact that the higher the initial L5 tilt, the less pelvic tilt correction we expect to obtain without pelvic fixation. A possible explanation for the reported correlation may be the fact that the lumbosacral joint is very stable in the normal condition due to the iliolumbar ligaments, the annulus fibrosus, and the anterior longitudinal ligament [18, 20]. Therefore, it has been suggested that a stable lumbosacral joint may provide correction of pelvic tilt by correcting the position of the L5 vertebra [18, 21]. This hypothesis is also confirmed by the direct relationship between correction of the primary deformity and correction of pelvic tilt found by us (Fig. 1), i.e., it is possible to achieve a reduction in tilt by correcting the primary deformity, which was also reported by Wild et al. [22] and Frischhut et al. [23]. A primary L5 vertebral tilt of more than 15° may indicate non-stability of the lumbosacral joint [10, 21], which does not allow correcting the pelvic position by changing the position of the vertebra, as evidenced by the lack of a significant correlation between L5 tilt and pelvic tilt correction in Group III. Presumably, using pelvic fixation, we can correct the pelvic position in space regardless of the primary L5 tilt. The revealed relationship of radiological parameters that influence the correction of pelvic tilt are presented in Fig. 12.

The incidence of implant malposition at SPF in studies by some authors reached 42 % when using the free-hand technique [24–26]. The free-hand technique for pelvic fixation was used in five patients in our study, which was combined with malposition of the pelvic screws in one case requiring revision surgery. The remaining 10 patients underwent SPF using O-arm navigation without malposition, indicating its effectiveness and safety.

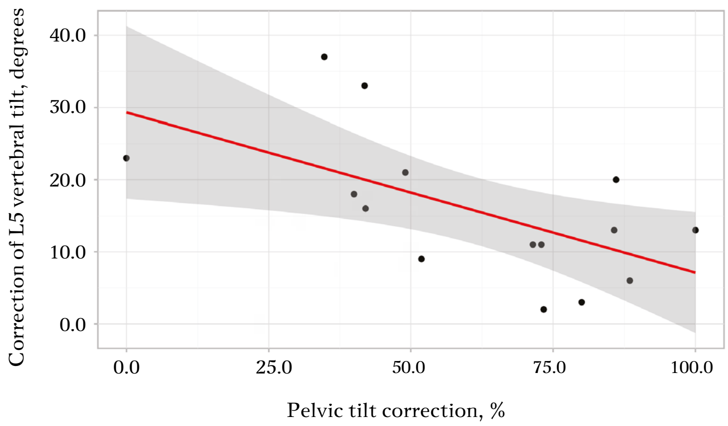

Fig. 3
Relationship between L5 vertebral tilt and pelvic tilt correction

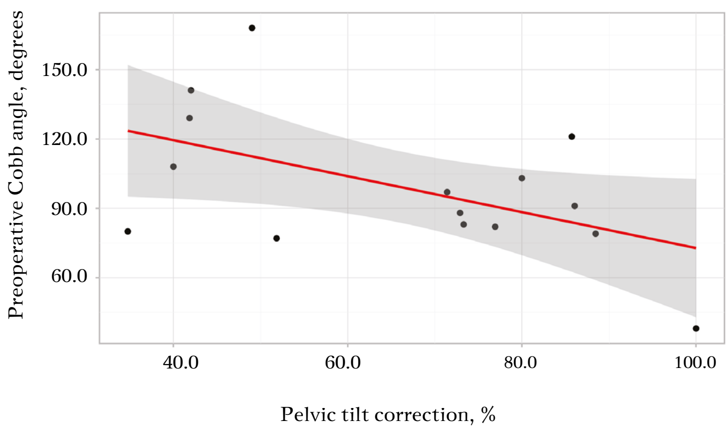

Fig. 4
Relationship between preoperative Cobb angle and pelvic tilt correction

Conclusion

According to the study findings, it is possible to correct pronounced pelvic tilt without including the pelvis in the fusion area.

The correction of pelvic tilt does not rely on its initial value, preventing the full use of an angle greater than 15° as an indication for pelvic fixation. The L5 tilt angle may reasonably fulfil this role, as

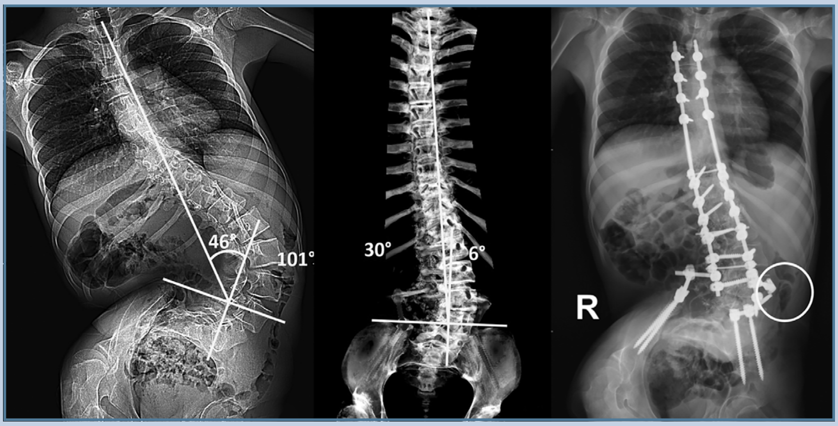

Fig. 5
Radiographs of male patient B., 16 years old, with grade IV neurogenic scoliosis, cerebral palsy, quadriparesis, GMFCS grade V before and after surgery

Fig. 6
Appearance of male patient B., 16 years old, before and after surgery

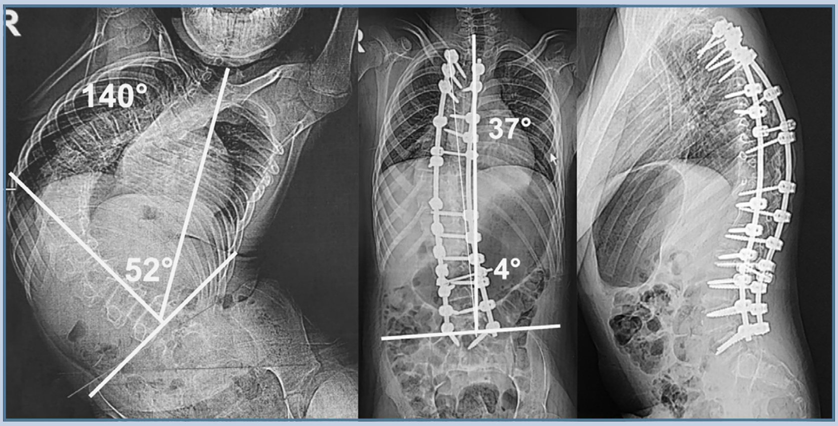

Fig. 8
Radiographs of male patient B., 16 years old, with grade IV neurogenic scoliosis, cerebral palsy, quadriparesis, GMFCS grade V before and after surgery

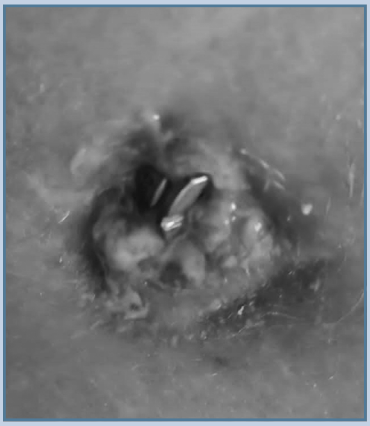

Fig. 7
Pressure ulcer in the area of the iliac wing of male patient B., 16 years old

its high initial value indicates instability of the lumbosacral segment and may prevent correction of tilt by fixation only to the L5 level, as evidenced by the inverse relationship between the L5 tilt angle and pelvic tilt correction in the group without pelvic fixation.

The high (20 %) incidence of complications and revision surgeries during surgical correction of neurogenic spinal deformities involving pelvic fixation may serve as a reason to narrow the indications for including the pelvis in the fusion area.

The study had no sponsors. The authors declare that they have no conflict of interest.
The study was approved by the local ethics committees of the institutions.
All authors contributed significantly to the research and preparation of the article, read and approved the final version before publication.

Fig. 9
Appearance of male patient D., 15 years old, before and after surgery

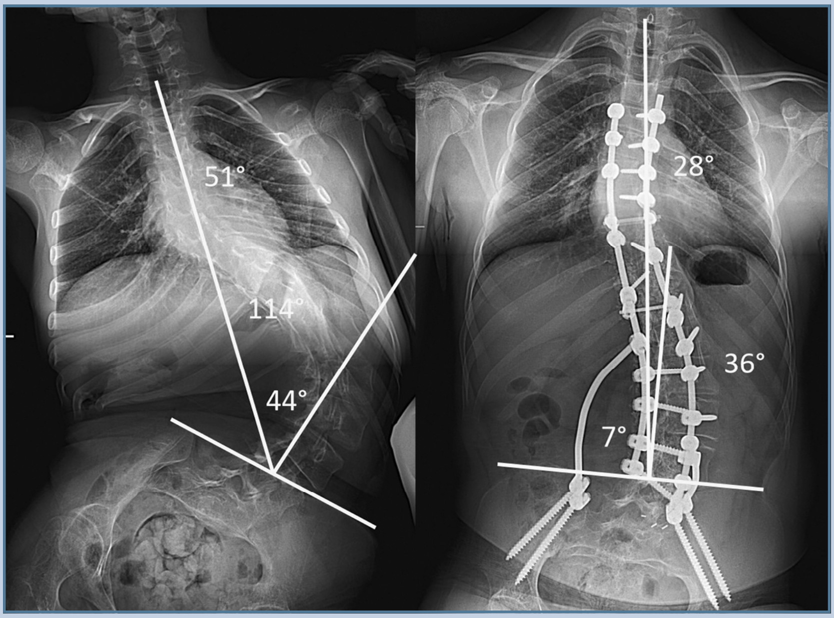

Fig. 10
Radiographs of male patient S., 14 years old, with grade IV neurogenic scoliosis, cerebral palsy, quadriparesis, GMFCS grade IV before and after surgery

Fig. 11
Appearance of male patient S., 14 years old, before and after surgery

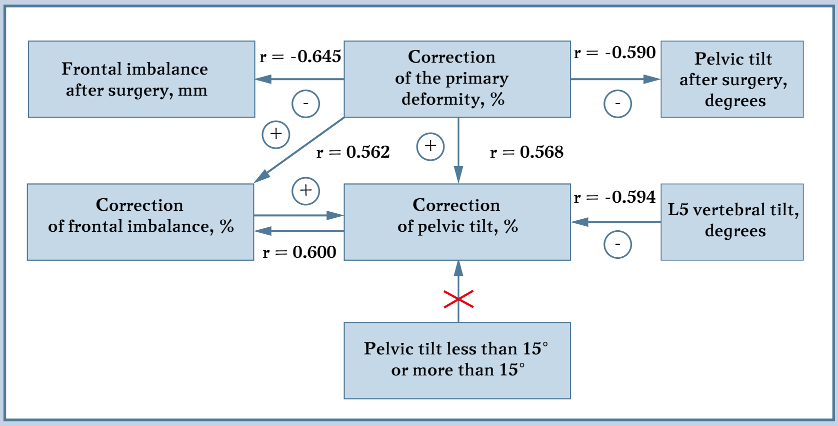

Fig. 12
Revealed relationship between radiological parameters

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