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Changes in spino-pelvic alignment after surgical treatment of isthmic spondylolisthesis

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ABSTRACT

Background and purpose: To analyze the changes in spino-pelvic parameters after surgical treatment of lumbar isthmic spondylolisthesis.

Materials and methods: Sixty patients recruited from a group of consecutive series of 128 cases with isthmic spondylolisthesis operated on between 2002 and 2012 in the Department of Neurosurgery, Tarnow, Poland. All patients were operated on by the same surgeon (the first author). Spino-pelvic parameters: PI, SS, PT, LSA, and LL were measured manually on standing lateral view radiograms. Patients were divided according to Spinal Deformity Study Group classification which we modified for means of analysis: (A) low-grade group: subgroups with balanced pelvis and unbalanced pelvis (instead of normal and high PI subgroups), (B) high-grade group: subgroups with balanced and unbalanced pelvis.

Results: Twenty-nine patients had unbalanced pelvis before the operation. In 10 of them (34%), the procedure resulted in full correction of pelvis position meaning that they achieved balanced pelvis after the surgery. There were 6 patients with low-grade slip who had balanced pelvis preoperatively but showed unbalanced pelvis after the surgery but this loss of balanced pelvis did not affect the clinical outcome which overall was good among them. Patients with unbalanced pelvis presented changes towards restoration of spino-sacro-pelvic anatomy postoperatively: PT decreased while SS increased, although these changes were not statistically significant.

Conclusion: Further studies are needed to confirm whether surgical correction of spino-pelvic parameters results in better clinical outcome in patients with isthmic spondylolisthesis.

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1. Introduction

Over the last two decades the analysis of spino-sacro-pelvic parameters became a hot topic in spine surgery. The analysis of these parameters allows thorough assessment of the results of different spinal pathologies and spondylolisthesis in particular. Thanks to that we know that in spondylolisthesis the symptoms go beyond the typical clinical picture of foraminal stenosis at the level of the slip and lumbar stenosis and the upper adjacent segment. They also include disturbance in anatomic relationship between pelvis, sacrum and spine. These can finally affect posture and even sagittal balance of the whole body. The analysis of spino-sacro-pelvic parameters allows for qualitative and quantitative assessment of these changes. In literature there are more and more reports assessing the efficacy of spondylolisthesis surgery in terms of correction of disturbed spino-sacro-pelvic relationships. This is a relatively new approach and philosophy in operative treatment of isthmic slip. Thanks to this, the method of assessment and the final objective of spondylolisthesis surgery are changing. Instead of asking whether the correction of slip or lumbo-sacral kyphosis influences the clinical effect of surgery, we are thinking of posing this question in a different way: 'Does surgical correction of sacro-spino-pelvic anatomy have a direct influence on the outcome of surgery?' Thus, the ''eternal'' question about the necessity of slip reduction and of the other aspects of operative technique is put in a new context: do the reduction of slip and other aspects of operative techniques have an influence on the correction of the parameters of spino-sacro-pelvic equilibrium.

Apart from fusion and decompression of compromised neural structures, the correction of spino-sacro-pelvic parameters becomes an equally important goal of surgery in spondylolisthesis. So far, it is not known whether the correction of spino-sacro-pelvic parameters affects clinical outcomes. The authors of this paper present how surgical correction and fusion changed the parameters of spino-sacro-pelvic balance in their series of consecutive patients with isthmic spondylolisthesis. This is the first stage of the studies the purpose of which is to examine: (a) if there is a relationship between the clinical effect of treatment and the correction of sacro-spino-pelvic parameters and (b) which aspects of surgical technique (e.g. slip reduction) influence the correction of spino-pelvic anatomy

2. Materials and methods

The studied group consisted of 60 cases from the series of 128 consecutive patients with isthmic spondylolisthesis operated on between 2002 and 2012 in the Department of Neurosurgery at St. Luke Hospital, Tarnów, Poland. These were the patients whose pre- and postoperative standing radiograms of lumbar spine with both femoral heads were available for analysis. The study group consisted of 30 women and 30 men. The mean age of patients was 54 years. Twenty-seven cases presented with grade I, 26 patients with grade II, five patients with grade III, one patient with grade IV slip, and one patient with spondyloptosis (Table 1).

Table 1 – Grade of slip.

Grade of slip	Number (%)	Total
Group I (low-grade)		
I°	27 (45%)	53 (89%)
II°	26 (44%)	
Group II (high-grade)		
III°	5 (8%)	7 (11%)
IV°	2 (3%)	

2.1. Surgical technique

All patients were operated by the same surgeon, the first author of the paper. Whenever feasible, the surgical protocol included: (a) complete reduction of slip and correction of kyphosis (Fig. 1a and b); (b) monosegmental stabilization limited to the level of slip (Fig. 1a and b); (c) 360° fusion: posterolateral with PLIF (posterior lumbar interbody fusion) or ALIF (anterior lumbar interbody fusion) (Fig. 1a–c); (d) foraminotomy at the level of slip; (e) laminectomy of the upper adjacent segment (for decompression of stenosis produced at the segment above the slip).

It is obvious that this protocol was impossible to implement among all the patients. Either it was unfeasible at some point (s) (e.g. failure to mobilize the affected segment which appeared extremely stiff) or some of its elements were abandoned on purpose (e.g. reduction of slip in obese or heavy patients requiring significant destabilization of the offending segment and therefore exposure of transpedicular construct to extreme loads and risk of failure).

2.2. Slip reduction

Complete or almost complete reduction of slip (at least by 80%) was achieved in 60% patients. The reduction was always performed through the posterior approach. In very stiff slips, surgical mobilization was always attempted in order to perform reduction. Slip reduction failed only in a few cases in which the course of L5 nerve root did not allow exposure and therefore entrance to L5/S1 interspace, thus not allowing for mobilization of the slip. In some cases the slip reduction was rejected upfront because of obesity or high body mass of patients. The rationale behind this is that surgical mobilization of the slipped segment produces complete transverse destabilization of the spine and weakens its load bearing capabilities. Therefore any construct in the extremely destabilized spine in heavy patients will be exposed to extreme loads and therefore to higher risk of failure than in individuals of normal body weight. Thus, in obese patients, it is better to leave the slipped segment unreduced in a stable position than to destabilize it in order to reduce the slip. Such cases where a decision was made not to make any reduction reached 20% in our series.

2.3. Monosegmental stabilization

In many cases one or more segments adjacent to the slip had to be stabilized. Usually this took place in two situations: (a) adjacent segments were unstable preoperatively (e.g. spondylolysis in the neighbouring segment) – Fig. 2a and b; (b)

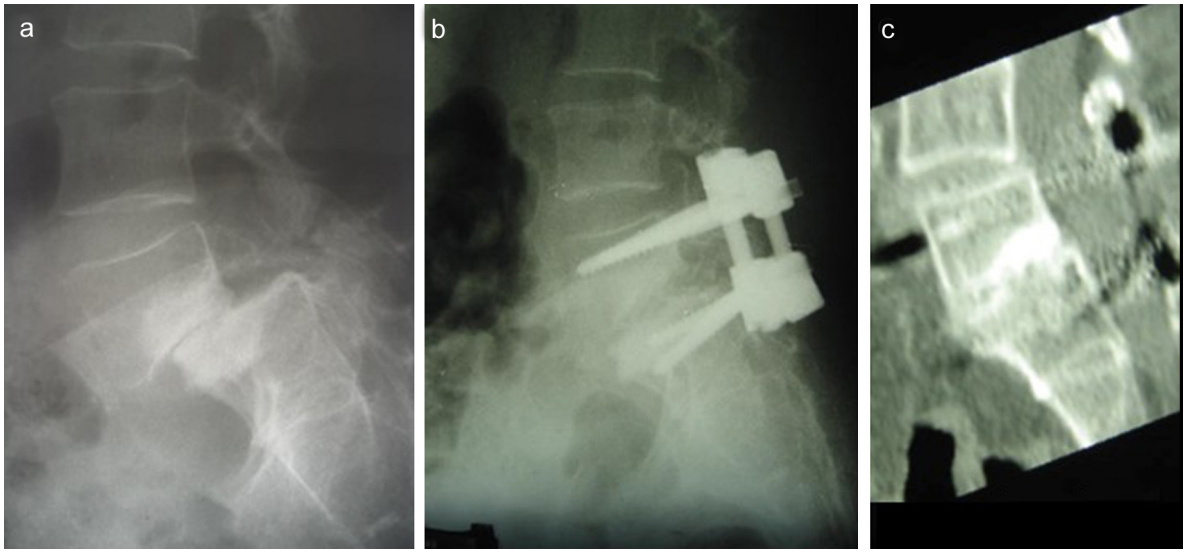

Fig. 1 – (a) High grade isthmic spondylolisthesis; (b) complete slip reduction with monosegmental stabilization; and (c) healed posterior interbody fusion PLIF.

adjacent segments were destabilized intraoperatively, e.g. as a result of decompression of stenosis or correction of degenerative deformation coexistent with spondylolisthesis.

Monosegmental stabilization was carried out in 77% of patients, two-level in 20%, and three-level in 3%.

2.4. *Fusion*

In all patients, fusion (bone graft) was made with pedicle screw fixation. Interbody fusion, either ALIF or PLIF, was performed in 69% of patients. It was combined with posterolateral fusion (360° fusion) in 47% of patients. Posterolateral fusion was made in 31% of operated patients. The latter subgroup included mostly unreduced cases of slip.

2.5. *Decompression (foraminotomy at the slip level and laminectomy in the segment adjacent to the slip)*

Decompression was not employed in the patients without or with mild symptoms of nerve root compression. Such patients were treated with pedicle screw stabilization and reduction performed as the first stage and anterior interbody fusion (ALIF) performed as the second stage. The majority of patients from this subgroup underwent minimally invasive percutaneous pedicle screw fixation and reduction with mini-ALIF.

The patients who received decompression of the spinal canal had either PLIF or ALIF with the latter performed in the second stage. A few patients had PLIF performed with minimally invasive technique that is via keyhole interlaminar

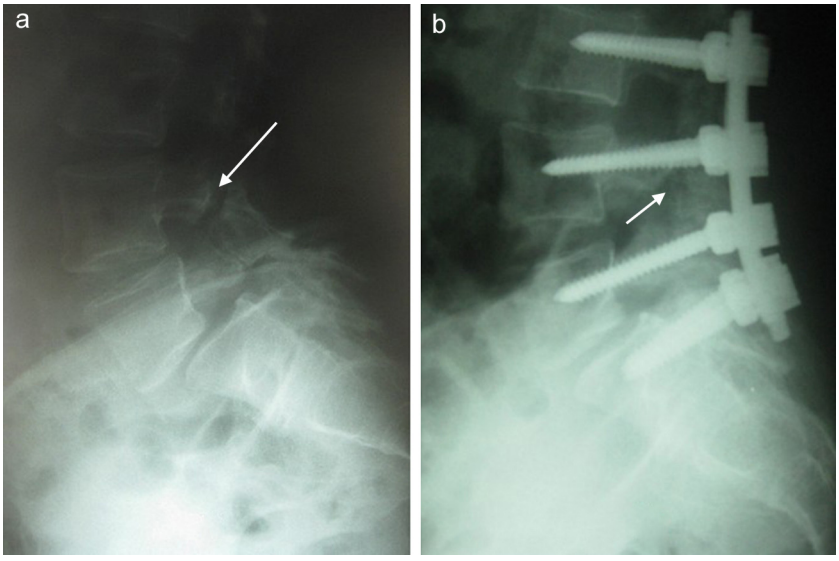

Fig. 2 – (a and b) L5/S1 spondylolisthesis accompanied by L4/L5 spondylolysis. Nearly total slip reduction with multilevel stabilization including the level of the slip, spondylolysis and decompressed L3/4 segment.

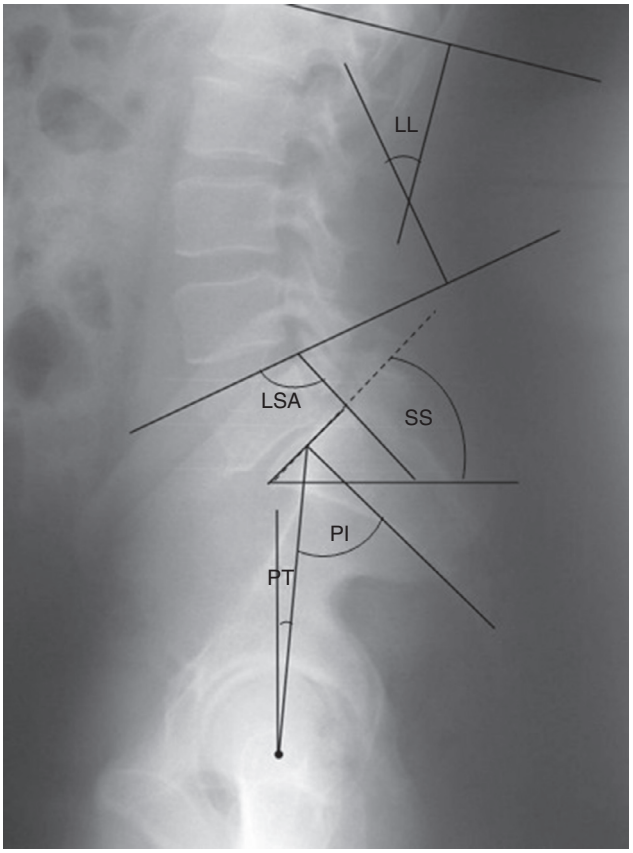

Fig. 3 – A radiogram of the lumbar spine in standing neutral position including both femoral heads. Lines drawn for measurements of spino-sacro-pelvic parameters.

approach combined with percutaneous pedicle screw fixation. Decompression always included laminectomy at the upper adjacent segment and foraminotomy at the level of slip. The latter was always extended as far laterally as the external outlet of the foramen.

2.6. *Measurements of spino-sacro-pelvic parameters*

Anatomic relationships between spine, sacrum and pelvis were defined by spino-sacro-pelvic parameters. They were measured before and after the operation on lateral view radiograms of the lumbar spine in standing neutral position, showing both heads of femur (Fig. 3). The lines of parameters were drawn on radiograms by the operating surgeon (the first author of the paper), and to provide objectivity of the study, the same measurements and data processing were carried out by the second author who was involved neither in treatment nor in the diagnosis.

The following parameters were analyzed:

1. Pelvic incidence (PI) – pelvic incidence is defined as the angle between the perpendicular of the upper sacral plate and the line joining the middle of the upper sacral plate and the hip axis. One should emphasize that PI parameter is not the same as the inclination of pelvis in classical anatomy, which is recognized as the angle between the plane of the entrance of the pelvis and the horizontal plane in a standing position.
2. Sacral slope (SS) – the sacral slope represents the angle between the sacral plate and the horizontal line.
3. Pelvic tilt (PT) – pelvic tilt is measured from the angle between the vertical line and the line joining the middle of the upper sacral plate and the hip axis. It is positive when the hip axis lies in front of the middle of the upper sacral plate. Geometrically, pelvic incidence equals the sum of the sacral slope and the pelvic tilt.
4. Lumbosacral angle Doubosset (LSA) – according to the Doubosset method the angle between the line running alongside the upper border endplate of L5 and the line running alongside the long axis of the sacrum.
5. Lumbar lordosis (LL) – the angle measured with the Cobb method, between the upper endplate of vertebra L5 and the upper endplate of vertebra L1.

For the purpose of the analysis, spondylolisthesis was divided according to Spinal Deformity Study Group (SDSG) classification into two large groups, and in each of them two subgroups were differentiated [1]:

(I) Low-degree slips (I°, II° according to Tailard)
- with high PI (above 60°) – 19 patients (36%)
- with normal PI (below 60°) – 34 patients (64%)

(II) High-degree slips (III°, IV° according to Tailard)
- with unbalanced pelvis – 5 patients (71%)
- with balanced pelvis – 2 patients (29%).

In the second stage of the studies, it was decided to divide group I (low-degree slips) in the same way as it was done in group II (high-degree slips). That means that we modified the original SDSG classification but thanks to this we obtained interesting results. After this modification the low-grade group with balanced pelvis consisted of 29 patients (55%), while low-grade with unbalanced pelvis included 24 patients (45%). Authors' modification allowed for achieving crucial results. We allocated patients to balanced or unbalanced pelvis group according to criteria by Hresko et al. [2] (Fig. 4). Each subject is

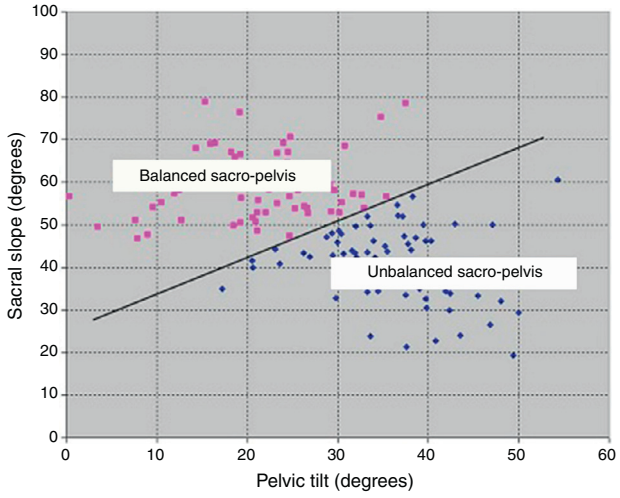

Fig. 4 – Criteria of balanced and unbalanced pelvis according to Hresko.

classified as high SS/low PT (balanced sacro-pelvis) or low SS/high PT (unbalanced sacro-pelvis). If the values of both angles crossed above the line on the graph – the pelvis was regarded as balanced, if the values of angles were below this line, the pelvis was qualified as unbalanced. Finally, global spino-pelvic balance is determined using the C7 plumbline. If this line falls over or behind the femoral heads, the spine is balanced, while if it lies in front of both femoral heads, the spine is unbalanced. According to Mac-Thiong et al. [1] the spine is almost always balanced in low-grade and in high-grade spondylolisthesis with a balanced sacro-pelvis and therefore, spinal balance needs to be measured mainly in high-grade deformities with an unbalanced pelvis.

For the statistical analysis of the differences between the groups, Student's *t*-test and Statistica 7.0 software were used.

3. Results

3.1. *High grade slips*

In the subgroup of patients with unbalanced pelvis (i.e. pelvis in pathological retroversion), surgery resulted in the correction spino-pelvic parameters, that is anatomic relationships between the spine and pelvis. The correction referred to all the parameters (Table 2): The PT angle was reduced, i.e. pathological retroversion of pelvis diminished, SS angle increased, LL increased, and LSA increased, i.e. kyphosis of slip was reduced (the lower the LSA, the higher the kyphosis of slip and vice versa). However, the statistical significance of this correction only referred to two parameters, but the ones crucial in the high-grade spondylolisthesis: PT and SS. The changes in lordosis (LL) and the angle of lumbo-sacral kyphosis (LSA) were not statistically significant.

In the subgroup with the balanced pelvis, all spino-pelvic parameters except of lumbar lordosis (LL) changed the other way round. All these changes were, however, not significant statistically (Table 2): PT increased, i.e. the pelvis rotated backwards; SS angle decreased and LSA angle decreased.

It is difficult to conclude whether such changes should be recognized as a correction of spino-sacro-pelvic relationships. We believe that at least changes in lumbar lordosis (LL) which increased similarly to patients with pelvic retroversion can be qualified as correction.

3.2. *Low-grade slips*

In this group neither trend of changes nor statistical significance was observed in any of the subgroups (the patients with PI $< 60^{\circ}$ and patients with PI $> 60^{\circ}$). The trend and statistical significance of the changes appeared only when the low-grade group was divided according to pelvic balance, i.e. in the same way as the high-grade group. Thus, like in high-grade slips, the subgroups of patients with balanced and unbalanced pelvis were differentiated.

3.3. *Patients with low grade slip and unbalanced pelvis*

Changes after the surgery were noted in all the parameters, and like in high grade slips, characterized with the correction of the

Table 2 – Comparison of pre- and postoperative values[a] of spinopelvic parameters in studied subgroup of patients.

Parameter/subgroup of patients	Before surgery	After surgery	P-value
High-grade slip and unbalanced pelvis (n = 5)			
Lumbosacral angle Doubosset	79.1 (20.6)	85.2 (18.2)	0.234
Lumbar lordosis	53.5 (13.1)	56.6 (9.1)	0.59
Pelvic incidence	82.2 (18.2)	82.1 (18.2)	0.714
Sacral slope	42.9 (10.8)	50.7 (14.1)	0.017
Pelvic tilt	39.7 (10.8)	31.7 (11.9)	0.014
High-grade slip and balanced pelvis (n = 2)			
Lumbosacral angle Doubosset	98.5	93.7	
Lumbar lordosis	56.1	58.8	
Pelvic incidence	81.9	81.7	
Sacral slope	60.6	57.9	
Pelvic tilt	22.1	24.2	
Low-grade slip and unbalanced pelvis (n = 24)			
Lumbosacral angle Doubosset	107.4 (9.8)	109.2 (8.6)	0.169
Lumbar lordosis	39.9 (13.1)	40.1 (12.9)	0.913
Pelvic incidence	63.4 (13.9)	63.4 (13.8)	0.974
Sacral slope	37.2 (8.4)	39.5 (9.6)	0.045
Pelvic tilt	26.4 (8.6)	23.9 (8.3)	0.031
Low-grade slip and balanced pelvis (n = 29)			
Lumbosacral angle Doubosset	112.6 (11.1)	110.6 (8.6)	0.078
Lumbar lordosis	46.0 (11.2)	46.8 (11.1)	0.709
Pelvic incidence	67.5 (13.5)	67.5 (13.5)	0.799
Sacral slope	52.4 (9.0)	48.2 (9.7)	0.0002
Pelvic tilt	15.1 (8.5)	19.3 (8.6)	0.0005

[a] Data are reported as means (standard deviations) except for the subgroup of patients with high-grade slip and balanced pelvis in which only means were reported due to the low absolute number of subjects.

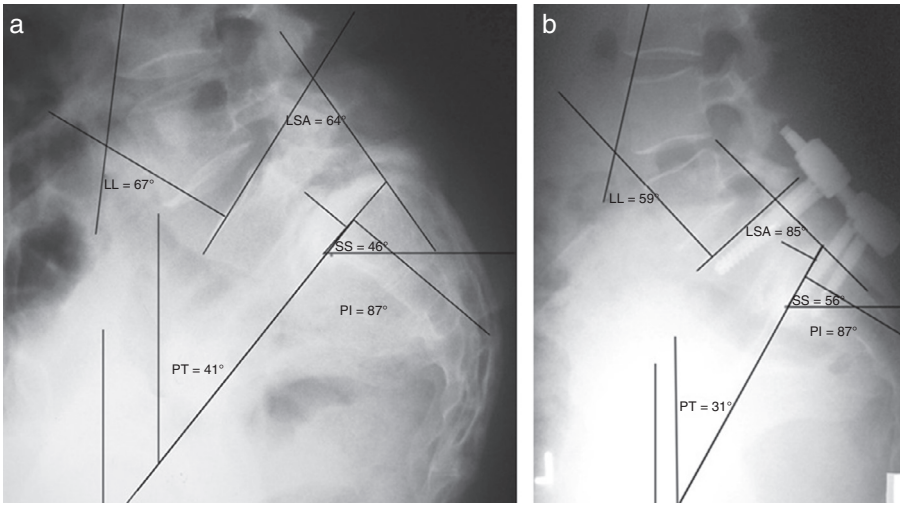

Fig. 5 – (a) High grade spondylolisthesis with unbalanced pelvis; (b) postoperatively, the patient presents with balanced pelvis.

anatomic relationships between the spine and pelvis (Table 2): PT was reduced, i.e. the retroversion of pelvis was reduced; SS increased; lordosis (LL) increased; and kyphosis (LSA) increased, i.e. slip kyphosis was reduced. Two of these parameters were statistically significant: the reduction of pelvic retroversion, i.e. PT angle and the angle of sacral inclination (SS). Thus, the correction was similar as in high degree slips.

3.4. *Patients with low-grade slip and balanced pelvis*

Changes in anatomic relationships (their direction) were very similar as in high-grade slips (Table 2). First of all, it referred to PT, which increased (pelvis retroversion increased) and SS, which was reduced. Such a trend was observed in nearly 80% of patients (in the group of high-degree slips – 100% of patients). In the group with low-grade slips, the increase of PT and reduction of SS were statistically significant (in high grade slips there was no such significance).

3.5. *Postsurgical changes of pelvis balance*

In the whole group of 60 patients, the initial position of pelvis (balanced or unbalanced) changed in 16 patients (26%) after the surgery. In 10 patients, surgery reversed unbalanced position of pelvis into balanced one. Among them, 3 patients had high-grade and 7 low-grade slip. There were also 6 patients; in whom surgery resulted in unbalanced position of preoperatively balanced pelvis.

Table 3 – Postoperative pelvic balance in subgroups of patients with preoperatively unbalanced or balanced pelvis. Changes according to preoperative slip grade – data shown as *n* (%).

Slip grade	Before surgery	After surgery	
		Balanced	Unbalanced
Patients with preoperatively unbalanced pelvis			
Low-grade	24 (100%)	7 (29%)	17 (71%)
High-grade	5 (100%)	3 (60%)	2 (40%)
Total	29 (100%)	10 (34%)	19 (66%)
Patients with preoperatively balanced pelvis			
Low-grade	29 (100%)	23 (79%)	6 (21%)
High-grade	2 (100%)	2 (100%)	0
Total	31 (100%)	25 (81%)	6 (19%)

3.6. *Patients with unbalanced pelvis before the operation*

There were 29 such patients. In 10 patients (34%), the procedure resulted in full correction of pelvic position meaning they achieved balanced pelvis after the surgery (Table 3): three out of five patients (i.e. 60%) with high-grade slip preoperatively and seven out of 24 patients (i.e. 29%) with low-grade slip before surgery (Fig. 5). There were as many as 6 patients who had balanced pelvis preoperatively but showed unbalanced pelvis after the surgery (Table 3). All these patients had low grade slips before the operation. Loss of balanced pelvis in this group did not affect the clinical outcome which in overall was good among many of them.

4. Discussion

Legaye et al. [5] defined the PI as a basic and unchangeable parameter describing anatomic relationships between pelvis and sacrum, which determines the position of the spine in the sagittal plane. The PI is the key pelvic parameter. It remains unchanged throughout the whole adult life, and does not change after the surgery, because in healthy mature individuals the sacrum is stiffly joined to pelvis with sacroiliac joints. The latter show no motions except of some micromotions which are not detectable on standard radiograms. Also in our studies, no changes were noted in the values of this parameter. To describe the anatomic relationships between spine, sacrum and pelvis, apart from the PI parameter, two other parameters are used: the angle of the inclination of sacrum referred to as sacral slope (SS) and pelvic tilt (PT) [3,4,6]. These three parameters are mutually linked by the equation: PI = PT + SS (Fig. 6). The PI reflects the anatomy of the pelvis and does not change with pelvic or spine positioning, whereas the SS and PT

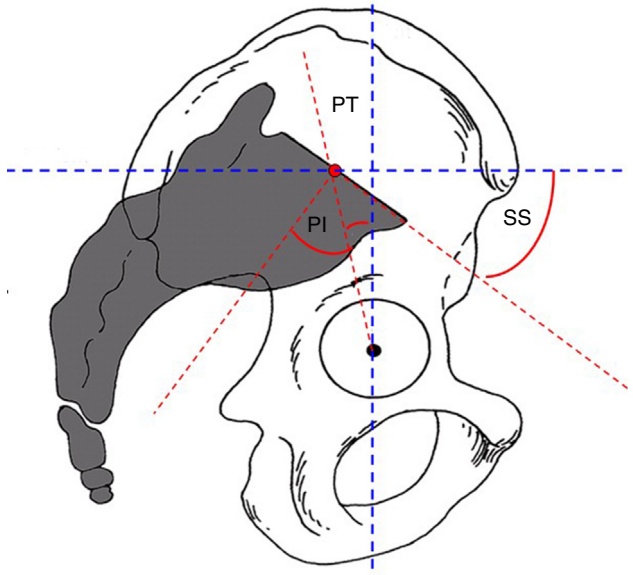

Fig. 6 – Sacro-spino-pelvic parameters. Pelvic incidence (PI) = pelvic tilt (PT) + sacral slope (SS).

are directly related to pelvic position. Thus, if one of the two remaining parameters PT or SS changes, the value of the second parameter must change, respectively (the equation PI = PT + SS must work). This refers to every change in the position of the body. This means that if e.g. PT increases when an individual rotates his/her pelvis backward by straightening the hip, at the same time SS (inclination of the sacrum) will decrease and vice versa. PT and SS are also indirectly influenced by other spinal parameters. The key role is played by lumbar lordosis and kyphosis angle between the spine and sacrum. For example, an increase in LL must be accompanied by increase in SS; otherwise an individual would lose her/his balance in the sagittal plane due to uncompensated shift of the centre of gravity and the plumb line. At the same time the increase of SS will cause automatic decrease of pelvic tilt PT according to the equation PI = PT + SS. Therefore any change in LL will produce change in both SS and PT.

This correlated 'game' of parameters is disturbed in spondylolisthesis. The cause is the 'separation' of the spine and sacrum as a result of spondylolysis. The separation is both anatomic and functional. The greater the slip, the greater the 'functional' separation between the spine, pelvis and sacrum. The greater the slip, the less efficient is the role of spine in preserving dynamic spino-sacro-pelvic balance. Let us take, as an example, the lordosis and its changes in the slip. The lordosis changes in the slip are nothing more than a compensation reaction in the pelvis-sacrum-spine, being a response to the slip. The compensation is to preserve balance in the sagittal plane. Thus if the slip appears, lordosis must deepen, otherwise, the gravity centre and the plumb line will move forwards. Deepening the lordosis in the slip prevents translation of the gravity centre and plumb line. The compensation mechanism of hyperlordosis does not work in high-grade slips. The cause is the loss of 'stiff' connection between spine and sacrum and thus the loss of 'transmission chain' by which lordosis affects the position of sacrum and pelvis. Hyperlordosis can be inefficient as a compensation mechanism also due to great lumbo-sacral kyphosis, which may be present in higher-grade slips. Kyphosis of the slip is the effect of the 'separation' of spine from sacrum. This kyphosis per se moves the gravity centre and the plumb line anteriorly, distorting the balance of the body in sagittal plane. This effect of kyphosis is also compensated by hyperlordosis. But in high-grade spondylolistheses, hyperlordosis may become inefficient in compensating effects of both slip itself, and kyphosis at the same time. When this takes place, another compensation mechanism appears – retroversion of pelvis. In high-grade slips (III and IV) pelvic retroversion does not influence changes in lordosis, because the spine has already lost its stiff connection with pelvis that would be able to transfer the effects of the position of pelvis into the spine and vice versa. Some authors consider that the main generator of hyperlordosis in spondylolisthesis is the degree of kyphosis, rather than the degree of slip [7].

In specialist literature, there are more and more opinions that the surgery of spondylolisthesis should be aimed rather at the correction of spino-pelvic anatomy than reduction of slip itself. Slip reduction should be at least the measure of achieving correction of disturbed spino-pelvic anatomy. Whether the slip reduction results in such correction remains a matter of discussion except for high-grade slips. Many authors proved that reduction of high-grade slip provides correction of spino-pelvic parameters. The philosophy of spino-pelvic correction was a base for several novel classifications of spondylolistheses, based on the parameters of spino-sacro-pelvic balance [1,8,9]. These classifications are aimed at providing the surgeon with recommendations for the best surgical strategy [1]. Contemporary literature on spondylolisthesis surgery more and more often considers the parameters of spino-sacro-pelvic balance in the assessment of the degree of clinical effects of the slip and efficacy of the treatment. The contributions to this topic are more and more numerous, but the question remains: which aspects of surgery are most important for the reconstruction of the proper spino-pelvic anatomy? Still, there is no agreement if this is the reduction of slip, correction of lumbo-sacral kyphosis, decompression in the segment neighbouring with the slip (in this segment there is stenosis caused by the slip), including the neighbouring segments into stabilization. Moreover, there are no studies of a high degree of scientific credibility, which confirm that the correction of distorted spino-sacro-pelvic balance is related to better clinical outcome as measured by both the improvement in the quality of life and the reduction of pain. In this paper we, however, do not answer the question if such a correction means better clinical result but we hope to answer it soon. Here we present preliminary results from our study in progress designed to answer three crucial questions: (1) Is there any correlation between correction of spino-pelvic parameters and the clinical outcome? (2) Which aspect of surgical technique i.e. slip reduction, has the greatest influence on the correction of the spino-sacro-pelvic anatomy distorted by spondylolisthesis? (3) In which type and grade of spondylolisthesis does the correction of spino-pelvic parameters affect the clinical outcome (i.e. goes with better clinical result)?

Data we present here show that in patients with retroversion of pelvis (unbalanced pelvis), the surgery of spondylolisthesis resulted in partial or total correction of the position of pelvis. This effect was achieved in all patients with a high-grade slip

and in 60% of those with low-grade slip. This correction appeared statistically significant for PT and SS. We believe such changes in PT and SS can be recognized as a correction of the distorted spino-pelvic anatomy, because of shift towards normal positioning of pelvis. Some of these patients showed a complete correction achieving balanced pelvis postoperatively. In the group of high-grade slips (III and IV°), none of the patients with a balanced pelvis lost this balance after the surgery. Similar results of the studies were obtained by other authors [10]. In our group of low-grade slips, when divided into subgroups according to the standard SDSG classification, no significant changes were observed. Thus, we decided to check the results, when the group of patients with low-grade slips is divided in the same way as the high-grade group. i.e. according to a non-standard scheme not described in the literature. After such division of patients with low-grade slips (into patients with balanced and unbalanced pelvis), we achieved trend of changes similar to that obtained in high-grade slips. This trend was statistically significant. This means that also in low-grade slips, the operation resulted in correction of pelvis positioning. Because of the fact that low-grade slips were divided according to the authors' own experimental scheme and no similar studies were found in literature, they should be treated with caution.

As far as the other parameter is concerned, i.e. kyphosis of the slip, its reduction was observed postsurgically in patients with unbalanced pelvis. Such a change in this group of patients bears characteristics of correction. In the group with balanced pelvis, the change of the kyphosis angle had an opposite direction and the lumbo-sacral angle decreased, changing the position of the segment towards kyphosis. The term kyphosis in this group of patients can wrongly suggest pathology. *De facto* in this group of patients there was no real kyphosis, because the lumbo-sacral angle was higher than 90°, which means lordosis. We do not interpret this change as negative.

According to our studies, lumbar lordosis increased after the surgery both in the group of low- and high-grade slips. In a similar way, LL changed after the surgery, according to other authors [11,12]. However, there are studies where LL decreased after the surgery [10]. It is assumed that the discrepancy of results referring to the change of lordosis after the surgery can depend on the applied operational strategy.

The patients included into our studies had standard decompression in the cephalad adjacent level. We believe that such decompression allows for postoperative increase of lumbar lordosis in our series independently of other aspects of surgical technique i.e. reduction of slip or lumbosacral kyphosis, the shape of a construct. The mechanism can be similar to that one observed after decompression of the lumbar degenerative stenosis. Based on this observation, we propose our original hypothesis. This assumes that one of the factors that can modify lordosis in the surgery of spondylolisthesis and can do it solely is the decompression of the spinal canal in the cephalad segment adjacent to the slip. In one of the cases, with L5/S1 grade IV slip presenting typical changes in body posture including retroversion of pelvis, bended knees, hamstring, and characteristic spastic-hip gait due excessive tightness of hamstring muscles, we achieved significant improvement of body stature and gait despite the fact that postoperative retroversion of pelvis and inclination of sacrum remained virtually the same as before the surgery. The only parameter which changed postoperatively was LL which increased from 45° to 56°. The patient was operated with L4/L5 decompression and L5/S1 foraminotomy without reduction of slip combined with instrumented L5/S1 360° fusion via posterior approach. We believe the direct cause of striking improvement in the body posture and gait which were reversed in this patient postoperatively was decompression of L4/L5 segment alone. Instrumented L5/S1 fusion itself could not be the reason for this improvement because it fixed spine and pelvic exactly in the same position as before surgery leaving PT and SS unchanged. Therefore one needs to assume that this was the L4/L5 decompression that allowed the patient to 'switch on' lordosis as a compensation mechanism after surgery instead of bending knees. Before the surgery, the mechanism of lordosis could not be 'turned on' because of stenosis in L4/L5 segment, which did not allow the patient to extend the trunk and deepen lordosis. Because of the fact that the operation did not cause changes in spino-sacro-pelvic parameters in this patient, the reason for the increase of lordosis could only be decompression of the segment neighbouring with the slip. In this patient, the degree of slip and lumbo-sacral kyphosis stayed unchanged after surgery. We consider that decompression of the cephalad adjacent segment is one of the most important factors influencing the clinical outcome in the surgery of high-grade spondylolisthesis. Such decompression allows lordosis to be back in the game as a compensation mechanism in high grade spondylolisthesis.

Lumbar lordosis itself is believed as one of the crucial and independent factors affecting outcome (quality of life and decrease of pain) in spondylolisthesis surgery and spine surgery in general [12,13].

The subject of spino-sacro-pelvic balance is fresh enough, that the practical clinical application of this knowledge is now in its initial phase. Owing to the above, the surgical treatment of spondylolisthesis still remains a hot topic in spine surgery. Due to the implementation of the knowledge on the parameters of spino-sacro-pelvic balance, the approach of the surgery of spondylolisthesis is changing. The aim equivalent to the reduction of spondylolisthesis and decompression of nerve structures in the surgical treatment is the attempt to correct the distorted parameters of spino-pelvic balance and the body stature in the sagittal plane. It is assumed that restoration of the normal configuration of the spine, and in particular, its lordosis and normalization of remaining spino-sacro-pelvic parameters, can improve the clinical effect and in particular sacral pain. Despite this, establishing the algorithm of strategy for the surgical treatment of spondylolisthesis remains to be uncovered.

5. Conclusions

Among the patients with spondylolisthesis and unbalanced pelvis, surgery resulted in the correction of anatomic spino-sacro-pelvic parameters, i.e. the reduction of retroversion and the increase of the SS.

Surgery of spondylolisthesis resulted in total or partial correction of the positioning of pelvis in all the patients with high-grade slips and 60% patients with low-degree slips.

Patients with spondylolisthesis and balanced pelvis showed an increase of PT and decrease of SS after the surgery.

We consider these changes as improvement, although their decompensative character cannot be excluded.

Studies are needed to verify whether the correction of spino-sacro-pelvic parameters is parallel with clinical improvement. The authors' research is in progress.

Conflict of interest

None declared.

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Ethics

The work described in this article has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans; Uniform Requirements for manuscripts submitted to Biomedical journals.

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