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Relationship between the spino-pelvic parameters and the slip grade in isthmic spondylolisthesis

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ABSTRACT

Purpose of the study: Analysis of changes in the spino-pelvic alignment, depending on the slip grade in patients with low and high-grade isthmic slip.

Materials and methods: A group of 60 patients who had lumbar spine radiograms adequate to measure the spino-pelvic parameters selected from a series of 195 cases of isthmic spondylolisthesis. We analyzed the following spino-pelvic parameters: pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), lumbosacral angle by Dubousset (LSA) and lumbar lordosis (LL). The ANOVA statistical test was used to examine whether there is a significant correlation between (1) the slip grade and the value of PI, PT, and LL, and the Pearson correlation was used to examine a correlation between (2) the size of PI and the value of other spino-pelvic parameters, (3) the value of LL and SS, (4) value of the LSA and LL, PI and PT.

Results: The greater the slip grade, the greater the value of PI, PT, and LL and lower LSA. Positive correlations have been found between PI and SS, PT and LL. There was also a positive correlation between LL and SS. Negative correlations were noted between LSA and LL, PI and PT.

Conclusion: The spino-pelvic alignment changes with the grade of isthmic spondylolisthesis, and the individual spino-pelvic parameters correlate together to form a causal chain in the development of isthmic spondylolisthesis.

1. Introduction

Over the past two decades, it has been proven that various spinal pathologies may affect normal anatomical relationships between the lumbar spine, sacrum, and pelvis. These normal spino-pelvic alignment is known as the spino-pelvic balance. It is well known that its disturbances may finally result in loss of a normal body posture and global sagittal balance. Isthmic spondylolisthesis is among these spinal pathologies and it may affect normal spatial relationships between the spine and pelvis to a greater extent than the others. This is because isthmic spondylolisthesis is not only about a local slip and neurological consequences of the latter, but also about misalignment of the spine and pelvis which may develop in response to the slip. Loss of the spino-pelvic

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balance may in turn affect a normal body posture and whole body sagittal balance in the upright standing position. Therefore, an isthmic slip being a very local pathology may produce more global disturbances in the spino-pelvic area with the latter affecting the whole body posture and sagittal balance.

A topic of the spino-pelvic balance has rapidly aroused much interest among practising spine surgeons within the last two decades. This spread of interest is called 'the French revolution in spinal surgery' because French-speaking authors were the ones who popularized the issue of the spino-pelvic balance in late 90s. In 1998, Duval-Beaupere defined and introduced an essential anatomical parameter called ''Pelvic Incidence'' that is the PI [1]. It specifically describes pelvic anatomy in an adult mature individual. The PI does not change throughout an adult life and is independent of a position of the pelvis. The PI is a basic anatomical characteristic of each individual [2,3]. It describes an angle which can be found on a lateral view standing radiogram of the lumbar spine by drawing a perpendicular line from the middle of the sacral endplate and a line from that point to the centre of the line connecting two femoral heads. The PI ratio depends entirely on the inclination of the L5/S1 in the sagittal plane. The PI can only be changed in the growth period in adolescence and the acquisition of an upright posture. Then, the PI remains constant and can be changed only during resection of the cranial endplate of the sacrum during a surgery [4–7]. Soon after the introduction of the PI two other positional parameters of the spine and pelvis known as the Sacral Slope (SS) and Pelvic Tilt (PT), were introduced into radiological measurements. A correlation between the above mentioned parameters was recognized and defined according to the equation: PI = SS + PT. The PI is always a sum of the SS and PT. Contrary to the PI the SS and PT vary with a position of a subject and their pelvis. However, their sum, SS + PT, does not change with a position of a subject or the pelvis. For example, when the SS decreases by a given value, the PT increases by the same value while the value of the PI stays unchanged according to the equation: PI = SS + PT [2].

The PI affects the magnitude of lumbar lordosis and indirectly the remained sagittal spinal curves. A low value of the PI correlates with flat lordosis while a high value of the PI correlates with hyperlordosis. The basic spino-pelvic parameters also include the lumbosacral angle (LSA) and lumbar lordosis (LL). The LSA defines a grade of lumbosacral kyphosis in spondylolisthesis. According to some authors [8,9] the LSA is a factor determining the size of most lumbar hyperlordosis in spondylolisthesis. If the kyphosis angle decreases, the lordosis increases to maintain a balance in the sagittal plane [10]. In isthmic spondylolisthesis increased lordosis of the lumbar spine allows to maintain the sagittal balance. In other words, lordotisation of the spine is a compensatory mechanism which develops in response to an anterior slip. Lordotisation is the first of three compensatory mechanisms which may be engaged in patients with isthmic spondylolisthesis. When with increasing slip the lordosis reaches its maximum than pelvis retroversion, the second compensatory mechanism goes into action. Pelvis retroversion is a result of hip extension that is by backward rotation around the axis of the femoral heads. The range of retroversion is only 10–15° [11]. High PI provides a greater reserve for hip extension (pelvis retroversion). Pelvis retroversion results in an increase in the PT and a decrease in the SS according to the equation: PI = SS + PT. In a healthy subject retroversion of the pelvis produces an increase in LL, while anteroversion of the pelvis results in a decrease of the LL. If it was not for this a subject would not be able to maintain the sagittal balance. This is not a case in isthmic spondylolisthesis where the LL is not reduced in response to pelvis retroversion, as it is in healthy subjects. This is because in isthmic spondylolisthesis a correct interaction between the spine and the pelvis is disturbed due to loosening of solid ''attachment'' of the spine and the pelvis produced by a defect in the L5 isthmus.

Fig. 1 – A female patient with grade IV spondylolisthesis. Note adaptations of her body posture to abnormal anatomical relations between the spine and pelvis which developed due to grade IV isthmic spondylolisthesis: pelvis retroversion and knee bending which are compensatory mechanism allowing the patient to maintain body balance in a vertical standing position.

When hip extension achieves its final range of motion, the third compensatory mechanism switches on. It is knee bending (Fig. 1). When all three compensatory mechanisms have been exhausted, a patient loses balance of the whole body in the sagittal plane.

2. Materials and methods

2.1. *Patient population*

A group of 60 patients whose lumbar spine radiograms were adequate for an analysis was selected from a series of 195

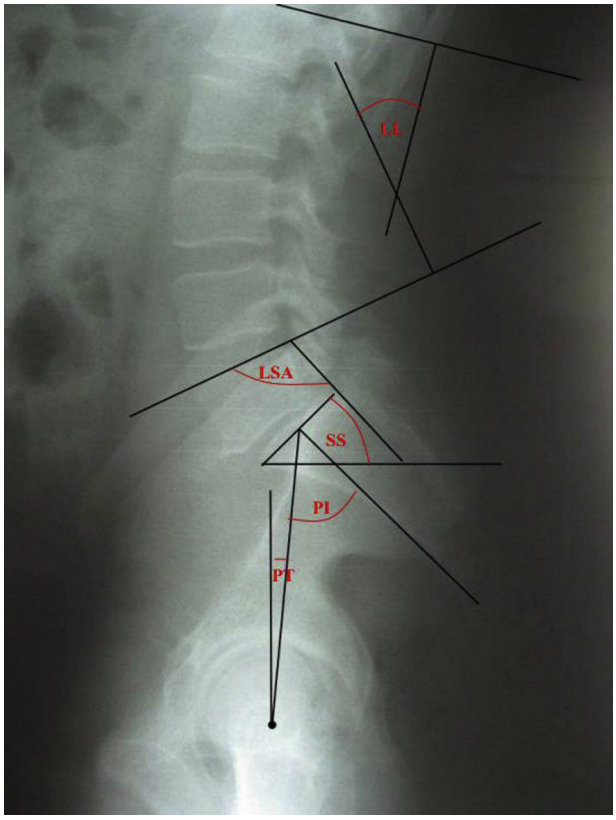

Fig. 2 – The exemplary radiogram with plotted spino-sacro-pelvic parameters.

cases of isthmic spondylolisthesis operated on in the Department of Neurosurgery in Tarnow. The mean age of patients was 54 years. Out of 60 patients, 19 had L4–L5 spondylolisthesis, and 41 had L5–S1. Grade I spondylolisthesis was found in 27 patients, grade II in 26 patients, grade III in 5 patients, and grade IV in 2 patients according to the Tailard's classification.

2.2. *Parameters assessed*

The following parameters were analyzed:

1. Pelvic Incidence (PI)
2. Sacral Slope (SS)
3. Pelvic Tilt (PT)
4. Dubousset's Lumbosacral Angle (LSA)
5. Lumbar Lordosis (LL)

Measurements were displayed on lumbar spine radiograms, preoperatively in a standing lateral view including both femoral heads. Linear parameters were plotted on radiographs by a surgeon (another author of this study), while measurements were performed by the first author who was blind to the patients' data. Examples of X-ray images of plotted parameters are shown in Fig. 2.

2.3. *Statistical analysis*

A statistical analysis included: (1) ANOVA to examine differences in parameter values between the stages, and (2) the Pearson correlation test to examine a correlation between indicators.

3. Results

An increase in the slip grade presented a statistically significant upward trend for the PI (Fig. 3) and PT (Fig. 4). This means that:

(1) Subjects with more obliquely set space at the L5/S1 (which is equivalent to a higher PI) have a higher slip or a greater predisposition to spondylolisthesis (Fig. 5).
(2) High PI coexisted in our patients with spondylolisthesis of the pelvic retroversion. The PT measures the pelvic rotation. The higher it is the more pelvic retroversion can be observed and vice versa (Fig. 6).

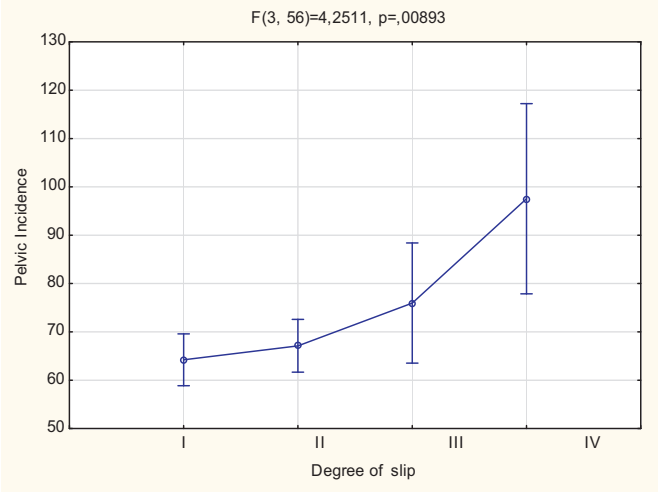

Fig. 3 – Graphic presentation of average values of the PI with regard to the slip grade. The higher the slip grade, the higher the PI.

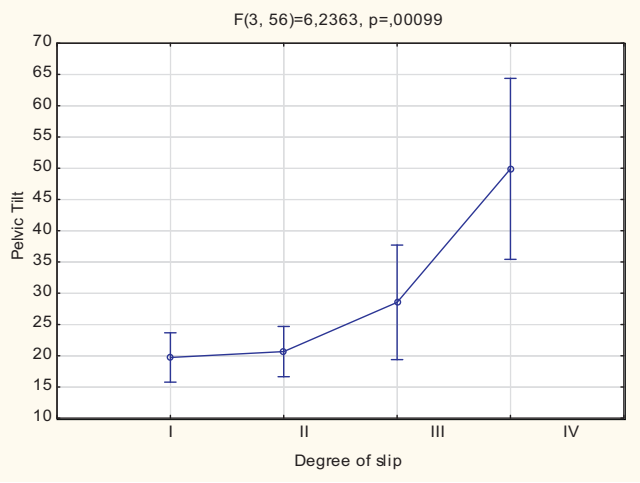

Fig. 4 – Graphic presentation of average values of the PT with regard to the slip grade. The higher the slip grade, the higher the PI.

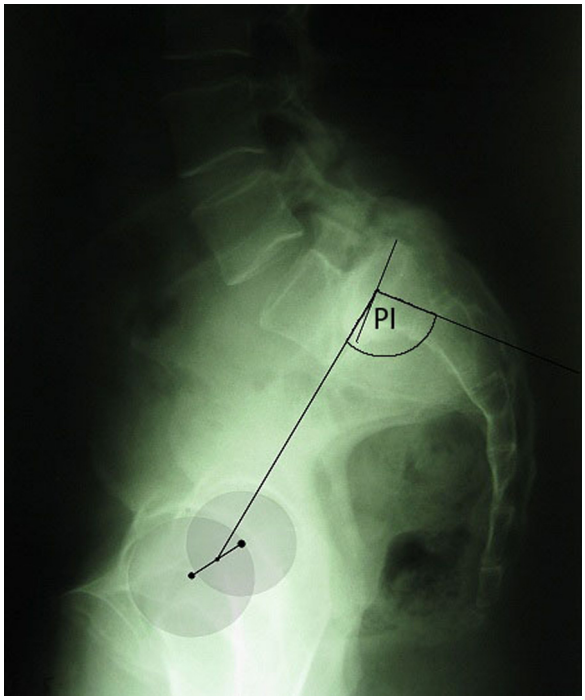

Fig. 5 – A radiogram of a female patient with a high-grade slip and high value of the PI.

We also observed a highly significant relationship between the slip grade and the LSA. The higher the slip, the smaller the LSA. The LSA determines the magnitude of lumbosacral kyphosis. Lower values of LSA mean greater lumbosacral kyphosis. The LSA angle decreases with increase of the slip (Figs. 6 and 7).

The LL increased with the slip grade, and this relationship was of borderline statistical significance ($p = 0.052$). There was a lack of correlation between the slip grade and the SS. Detailed results are presented in Table 1.

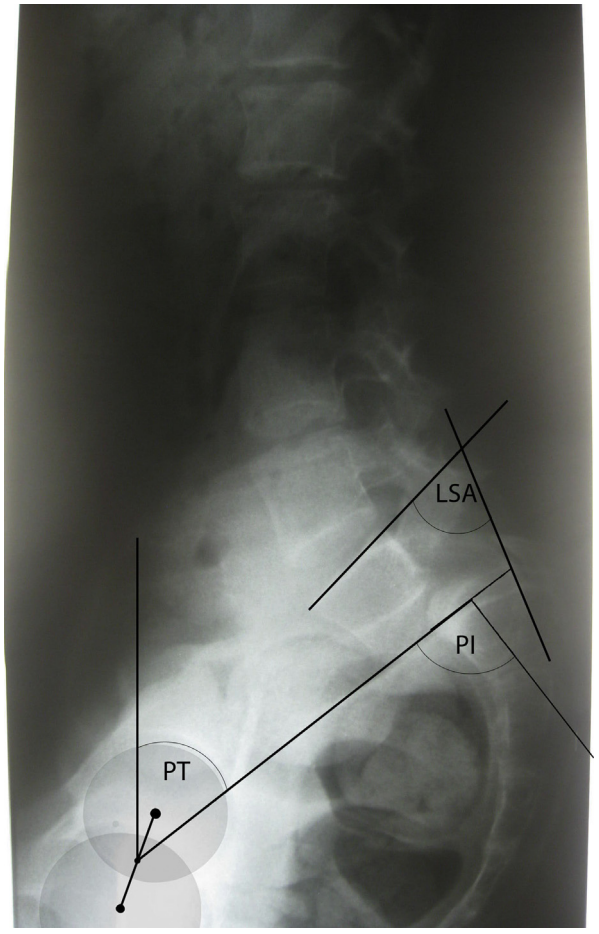

Fig. 6 – A radiogram of a female patient with a high-grade slip, high PI, high PT and small LSA.

A statistical analysis also included various parameters in order to test a correlation between them. Positive correlations were noted between the PI, and: SS – Fig. 8, PT – Fig. 9, LL – Fig. 10.

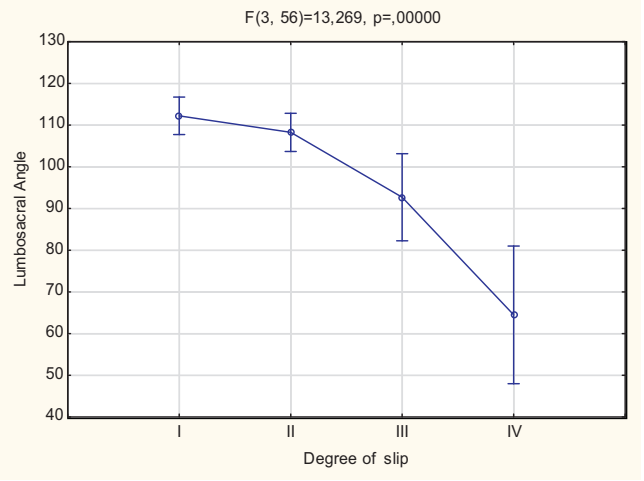

Fig. 7 – Graphic presentation of average values of the LSA value with regard to the slip grade. The higher the slip grade, the smaller the LSA.

Table 1 – Influence of slip grades on the changes in the spino-sacro-pelvic parameters.

Parameters	Slip grade	Mean (°)	Median	max	min	SD	ANOVA	
							F	*P*
PI	I	64.2	64	88.9	34.1	11.4	4.2511	0.008929
	II	67.1	64.2	111	48.5	15.9		
	III	76	72.8	96.8	56.5	15.9		
	IV	97.6	97.6	104	91.1	9.12		
SS	I	44.7	43	66.7	27.1	11.8	0.1661	0.918766
	II	46.3	43.2	68	19	11.4		
	III	47.8	46.3	66.5	25.7	14.9		
	IV	48.3	48.3	55	41.5	9.55		
PT	I	19.7	20.2	39	−2.6	10.4	6.2363	0.000993
	II	20.7	20.6	46	1.4	10.2		
	III	28.5	30.6	41.4	12.5	10.5		
	IV	49.9	49.9	50.8	49	1.27		
LSA	I	112.2	111	131.6	96	10.33	13.269	0.000000
	II	108.3	108	135	91	11		
	III	92.7	99.4	117	63.7	21.1		
	IV	64.5	64.5	68	61	4.95		
LL	I	40.4	41.2	62	12.3	12.8	2.7363	0.051997
	II	46.2	46.3	65.8	17.8	11.3		
	III	53	47.7	66.6	41.9	11.6		
	IV	57.4	57.4	69	45.5	16.5		

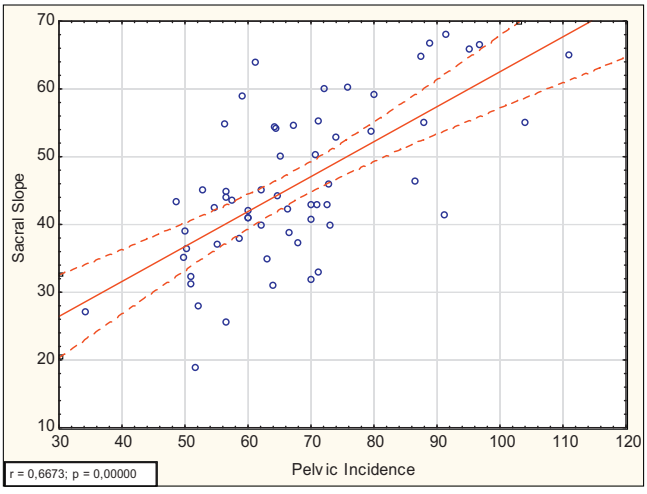

Fig. 8 – The higher the PI, the higher the SS.

There was also a positive correlation between the LL and SS – Fig. 11 which means that the higher value of LL the higher value of SS. Negative correlations were noted between the LSA and: LL – Fig. 12, PI – Fig. 13 and PT – Fig. 14.

This means that decrease in LSA correlates with increase in LL, PI and PT.

There was no significant correlation between the SS and LSA and between the LL and PT.

4. Discussion

It is assumed that the PI not only affects the attitude of the posture, but also certain values predisposing to a slip. The test results and data from the literature [12–16] showed that the PI correlated with a grade and progression of a slip in isthmic spondylolisthesis. This means that the greater the value of the PI, the greater the slip grade and the risk of progression. Many studies [3,17–21] confirmed that the PI was significantly higher in patients with isthmic spondylolisthesis than in healthy subjects. There is a directly proportional linear correlation between the PI and the slip grade.

This means that patients with spondyloptosis have higher PI than patients with incomplete slippage. On the other hand, patients with high grade slips (III, IV) have PI higher than patients with low grade slips (I and II°) [16]. In our study it was observed that the greater the PI, the greater the SS, and this correlation was very strong. High PI predisposes to a slip, as in

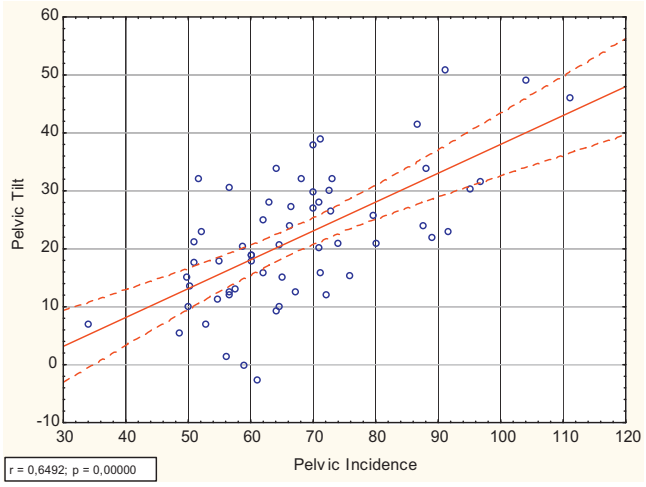

Fig. 9 – The higher the PI, the higher the PT.

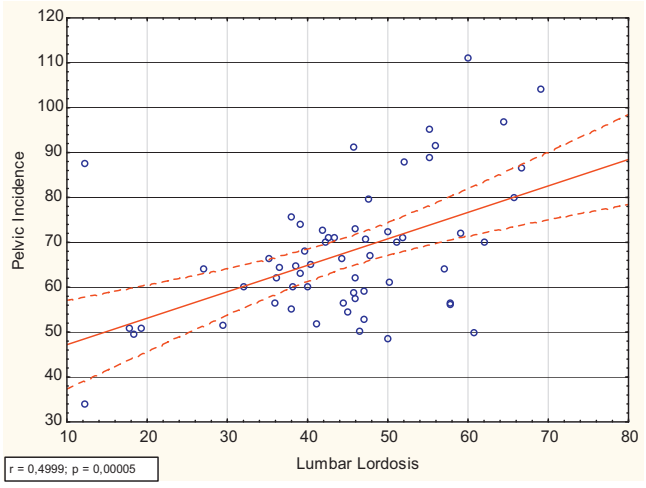

Fig. 10 – The higher the PI, the higher the LL.

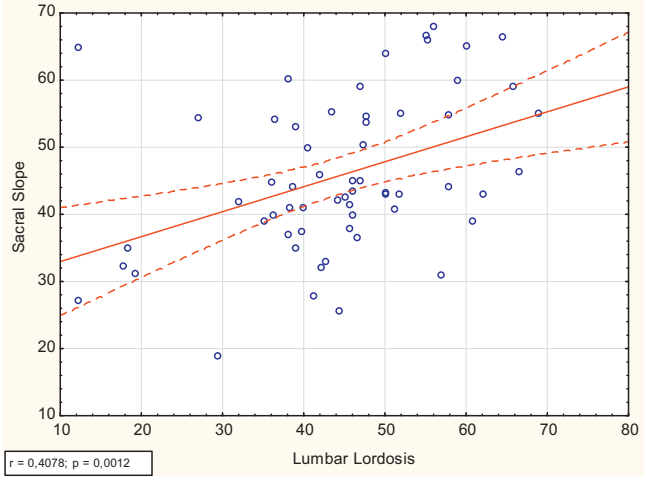

Fig. 11 – The higher the SS, the higher the LL.

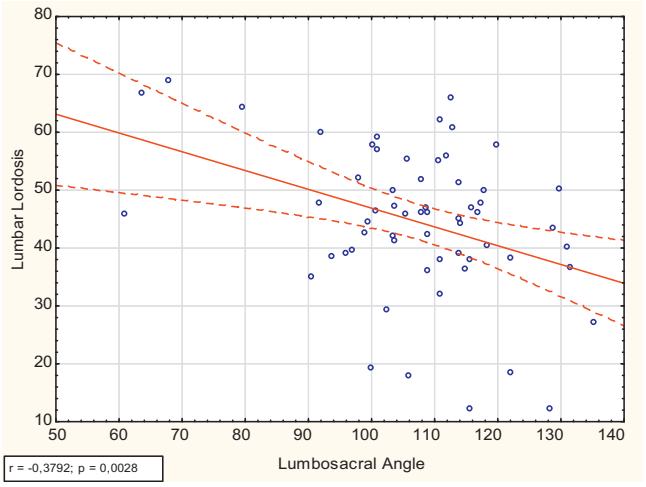

Fig. 12 – The higher the LL, the smaller the LSA.

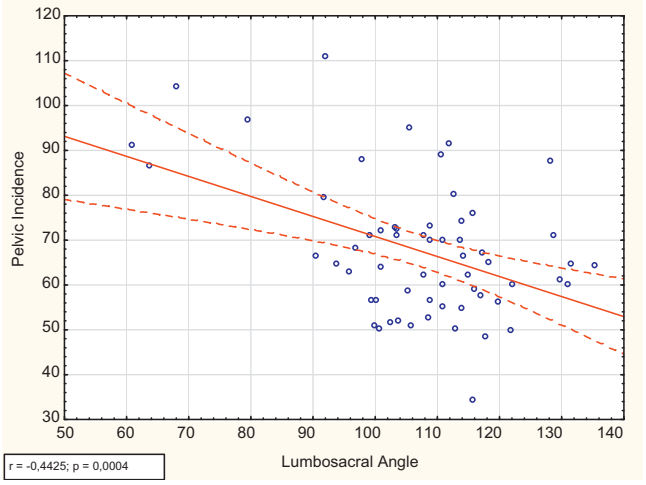

Fig. 13 – The higher the PI, the smaller the LSA.

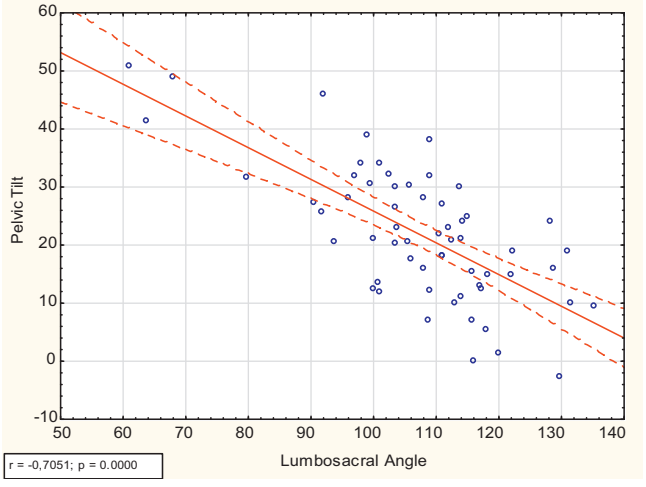

Fig. 14 – The higher the PT, the smaller the LSA.

such situations the disc at the L5/S1 is set more obliquely (high SS), and the shear forces on the lumbar spine are larger.

According to the research of Vialle's et al. [8] the value of the SS was higher in patients with isthmic spondylolisthesis than in healthy subjects and increased with the slip grade; but in the fourth and fifth grade this is reversed and the angle of the SS decreases to a value lower than the one observed in the group of healthy control subjects. This reversal in high grade slips is partially due to the pelvic retroversion which develops as a compensatory mechanism. Increase of pelvis retroversion reduces SS. In our study we observed a slight trend (not statistically significant): the SS increased with increase of slip grade. Inconsistent results may be associated with an insufficient number of subjects with grade IV spondylolisthesis in our research.

The PT increased in our study with a larger grade of a slip which was consistent with the results of other authors [8]. In our study, a very strong correlation was observed between the PI and the PT. The higher the value of the PI, the more the PT increased. An increase in the PT indicates the pelvic retroversion. The greater the retroversion, the greater the slip. It is a compensatory response aimed to maintain balance in the sagittal plane [10].

This study demonstrated a correlation when an increased slip grade also increased the LL. It is supported by the Vialle's research [8]. Vialle also demonstrated that the LL was greater in patients with spondylolisthesis (even I°) compared to the control group of healthy patients, and that this increases with a slip grade. Similar results were noticed by other authors [15–17]. It is believed that the level of lordosis depends directly on the value of the PI. According to our research, as well as studies of other authors [1,14,22], it is a directly proportional relationship: the higher the PI, the greater the LL, and this correlation is very strong. A similar correlation exists for the SS: the greater the SS, the higher the LL, because a more horizontal position of the sacrum forces an increase in the curvature of the lumbar spine. If it were not so, then an individual would lose balance in the sagittal plane. However, at very high grades of a slip (III, IV, V°) the setting of the sacrum no longer affects an increase in the LL. This is because the sacrum loses firm connection with L5 vertebra and cannot further transfer regulatory forces via lumbosacral junction to lumbar spine.

With regard to the next parameter, or the LSA, Vialle describes the lumbosacral kyphosis grade, that is, between the slipped L5 and the sacrum. According to our research the LSA value decreased (in other words, kyphosis increased) with a slip grade. According to some authors [9] lumbosacral kyphosis is the largest determinant of lumbar hyperlordosis in spondylolisthesis. In our study there was such a correlation, but much weaker than correlation between the LL and the PI.

In our study we observed a strong correlation between the PT and LSA. The smaller the angle of the LSA (or higher kyphosis), the greater the PT.

This means that when kyphosis is increased, the PT is increased. As already mentioned, this is a mechanism used to maintain body balance in the sagittal plane. When lumbar hyperlordosis reaches its maximum, increase in PT being the next compensatory mechanism switches on. In order to maintain balance of the body a patient engages their pelvis into retroversion. The pelvis becomes retroverted by rotating backwards through hip extension [10] and these are the biceps femoris muscle and gluteal muscles responsible for hip extension. As a result, there is constant tension and the hamstring of the above-mentioned muscles. As the scope of hip extension is small, it has a limited capacity as a compensatory mechanism. Upon exhaustion of this mechanism the last mechanism is switched on: flexion of the knees. Thus, when compensatory mechanisms are fully developed a patient has a characteristic abnormal posture (Fig. 1).

It can be speculated that the increase in lumbosacral kyphosis can produced by stenosis of the spinal canal at the segment adjacent to the slip. Patients with a lumbar stenosis do not tolerate extension of the lumbar spine equal to hyperlordosis and therefore automatically reduces their lumbar lordosis to decompress nerve roots.

5. Conclusion

We found statistically significant correlations between spinopelvic parameters and the grade of slip in patients with isthmic spondylolisthesis:

a. The greater the PI the higher the grade of slippage.
b. The greater the PT the higher the grade of slippage.
c. The smaller the LSA the higher the grade of slippage.
d. The greater the LL the higher the grade of slippage.

Conflict of interest

None declared.

Acknowledgement and financial support

None declared.

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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