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ORIGINAL ARTICLE

Sagittal spino-pelvic alignment in chronic low back pain

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Abstract
Introduction The differences in sagittal spino-pelvic alignment between adults with chronic low back pain (LBP) and the normal population are still poorly understood. In particular, it is still unknown if particular patterns of sagittal spino-pelvic alignment are more prevalent in chronic LBP. The current study helps to better understand the relationship between sagittal alignment and low back pain.
Materials and methods To compare the sagittal spino-pelvic alignment of patients with chronic LBP with a cohort of asymptomatic adults. Sagittal spino-pelvic alignment was evaluated in prospective cohorts of 198 patients with chronic LBP and 709 normal subjects. The two cohorts were compared with respect to the sacral slope (SS), pelvic tilt (PT), pelvic incidence (PI), lumbar lordosis (LL), lumbar tilt (LT), lordotic levels, thoracic kyphosis (TK), thoracic tilt (TT), kyphotic levels, and lumbosacral joint angle (LSA). Correlations between parameters were also assessed.
Results Sagittal spino-pelvic alignment is significantly different in chronic LBP with respect to SS, PI, LT, lordotic levels, TK, TT and LSA, but not PT, LL, and kyphotic levels. Correlations between parameters were similar for the two cohorts. As compared to normal adults, a greater proportion of patients with LBP presented low SS and LL associated with a small PI, while a greater proportion of normal subjects presented normal or high SS associated with normal or high PI.
Conclusion Sagittal spino-pelvic alignment was different between patients with chronic LBP and controls. In particular, there was a greater proportion of chronic LBP patients with low SS, low LL and small PI, suggesting the relationship between this specific pattern and the presence of chronic LBP.

Keywords Low back pain · Pelvic morphology · Sagittal balance · Spino-pelvic alignment

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Introduction

The etiology of low back pain (LBP) is usually multifactorial. Based on a previous literature review [1], it was found that there are three main risk factors for recurrent and chronic LBP: (1) history of LBP with associated limitations and treatments, (2) dissatisfaction at work, and (3) poor general medical condition. Other risk factors such as socioeconomic and employment status, psychological status, and physically demanding work are also suggested.

Although psychosocial and environmental factors seem important in predicting recurrence and chronicity in LBP, morphological and postural factors can also potentially influence the occurrence of LBP.

Several studies have shown the importance of sagittal spino-pelvic alignment for maintaining a balanced posture in the normal population [2–6]. However, the influence of sagittal spino-pelvic alignment on LBP is still poorly understood. During et al. [7] evaluated sagittal lumbopelvic alignment in 20 patients with L5-S1 disk degeneration and 24 patients without specific radiographic abnormality presenting for LBP. They observed abnormal lumbosacral angle (LSA) only in patients with L5-S1 disk degeneration, but they did not find any difference in lumbar or pelvic parameters—including pelvic morphology—when compared to normal individuals. Similarly, Gautier et al. [8] did not find any difference in segmental and total lumbar lordosis (LL) nor pelvic incidence (PI) when comparing 74 subjects with a history of LBP to 152 asymptomatic subjects. On the opposite, Jackson and McManus [9] observed decreased total LL associated with decreased distal and increased proximal LL as well as a more vertical sacrum in 100 patients with LBP compared to 100 matched controls. Similarly, Barrey et al. [10] showed similar PI, but decreased sacral slope (SS), LL, and thoracic kyphosis (TK), as well as increased pelvic tilt (PT) in 57 patients with disk degeneration or herniation prior to lumbosacral arthrodesis, compared with 154 controls. Rajnics et al. [11] also observed significant differences for SS, PT, and LL—but not PI nor TK—in 50 patients presenting with low back pain and disk herniation compared to 30 healthy subjects. Other studies also reported conflicting results suggesting either decreased [12], increased [13], or normal [14–17] LL in patients with LBP.

Whether specific patterns of sagittal spino-pelvic alignment are more prevalent in patients with LBP is also unclear. Roussouly et al. [5] proposed a classification in which they defined four types of LL based on SS and on the number of vertebral levels included in the lordotic segment. Type 1 LL is observed when SS is smaller than 35° and is typically associated with a short LL, with lordotic levels including three vertebrae or less. Type 2 LL also involves an SS smaller than 35° but LL is longer, with lordotic levels including more than three vertebrae. Type 1 and especially Type 2 LL are presumed to be the least common patterns seen in normal adults. Type 3 LL is the pattern most commonly seen in normal adults and is associated with SS greater than 35° but smaller than 45°. In type 4 LL, SS is greater than 45° and subjects tend to hyperextend their lumbar spine. The authors suggested that patients with symptomatic disk disease are most commonly classified as Type 1 or 2, while spinal stenosis is usually associated with Type 4 LL. On the contrary, Type 3 LL is rarely seen in patients with spinal disorders. However, these clinical observations have never been confirmed in a study.

In an attempt to better understand the characteristic features of sagittal spino-pelvic alignment in adult with chronic LBP, this paper reports the largest database in the literature on the evaluation of sagittal spino-pelvic alignment in chronic LBP in comparison with the asymptomatic adult population.

Materials and methods

Prospective adult cohorts of 198 subjects with chronic LBP (LBP cohort) and 709 controls without spinal disorder (control cohort) are compared. Subjects in the LBP cohort were involved in a multidisciplinary rehabilitation program at a single institution. Inclusion criteria for the LBP cohort were the following: (1) age between 18 and 60 years and (2) predominant LBP for a minimum of three consecutive months. Subjects were excluded if they had (1) spinal deformity such as scoliosis or spondylolisthesis, (2) spinal fracture, (3) spinal tumor, (4) previous spinal fusion, (5) previous discectomy involving more than one level, (6) history of hip or pelvic disorder, (7) contraindication for radiographic exposure (e.g., pregnancy, tumor), (8) predominant leg pain, and (9) presence of motor deficit. In particular, patients with radiculopathy presenting predominant leg symptoms were excluded from the study, whereas patients with previous single level discectomy were included. Mean age is 39.4 ± 11.5 years in the LBP cohort; there are 111 men and 87 women aged 40.2 ± 11.4 and 38.4 ± 11.6 years, respectively.

A prospective cohort of 709 controls without spinal disorder (control cohort) is used as a basis for comparison. Controls were recruited based on the following inclusion criteria: (1) age of 18 years or older, (2) absence of spinal pathology confirmed after evaluation by an orthopedic surgeon, (3) no history of spine, hip, or pelvic disorder, and (4) no contraindication for radiographic exposure (e.g., pregnancy, tumor). All controls are white Caucasians with a mean age of 36.8 ± 14.3 years; there are 354 men and 355 women aged 37.9 ± 14.7 and 35.7 ± 13.9 years, respectively.

All subjects had a standing left lateral radiograph including the spine and pelvis from which sagittal spino-pelvic alignment (Table 1) was assessed using the Optispine software (SMAIO, Lyon, France) [2, 4, 5]. The software generates a geometric model of the spine composed of a thoracic kyphotic segment, a straight thoracolumbar junction, and a lumbar lordotic segment (Fig. 1a) that allows measurement of TK and LL. Segmental alignment of thoracic and lumbar segments is assessed from the

Table 1 Parameters of sagittal spino-pelvic alignment

Parameter	Abbreviation	Description
Pelvic incidence (°)	PI	Angle between superior endplate of S1 and line joining hip axis[a] to center of superior endplate of S1
Pelvic tilt (°)	PT	Angle between vertical line and line joining hip axis[a] to center of superior endplate of S1[b]
Sacral slope (°)	SS	Angle between superior endplate of S1 and horizontal line
Lumbosacral angle (°)	LSA	Angle between inferior endplate of L5 and superior endplate of S1. Positive when in kyphosis
Lumbar lordosis (°)	LL	Segmental angle of spinal segment in lordosis (down to L5)
Lumbar tilt (°)	LT	Orientation of lordotic segment with respect to vertical line. Positive when tilted forward
Lordotic levels (vertebrae)	–	Number of vertebrae included in the lordotic segment
Thoracic kyphosis (°)	TK	Segmental angle of spinal segment in kyphosis
Thoracic tilt (°)	TT	Orientation of kyphotic segment with respect to vertical line. Positive when tilted forward
Kyphotic levels (vertebrae)	–	Number of vertebrae included in the kyphotic segment

[a] Hip axis: midpoint of line joining center of both femoral heads

[b] Positive when tilted forward with respect to vertical line

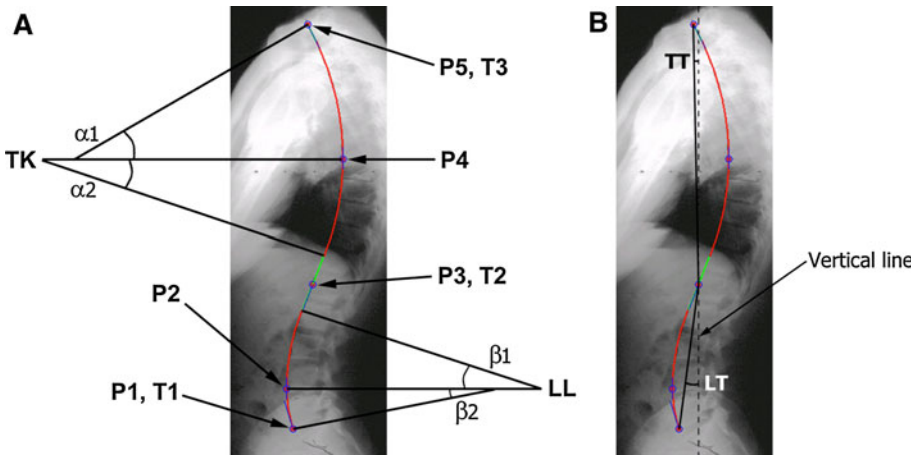

Fig. 1 **a** A geometric model of the spine is generated by the software after identification of five anatomical landmarks (*P1–P5*) and three tangential lines (*T1–T3*). Thoracic kyphosis (*TK*) and lumbar lordosis (*LL*) are represented by the angles subtended by the arcs of circle used to model the thoracic ($\alpha 1 + \alpha 2$) and lumbar ($\beta 1 + \beta 2$) segments, respectively. **b** Segmental alignment of thoracic (*TT*) and lumbar (*TL*) segments is measured with respect to the *vertical line*

TT and LT (Fig. 1b). PI, PT, and SS describe pelvic morphology and balance, while LSA characterizes the relation between L5 and S1. Lordotic and kyphotic levels represent the number of vertebrae contained, respectively, in the lumbar lordotic and thoracic kyphotic segments, as the length of these segments varies from one subject to the other. The type of LL is determined for each subject with respect to the classification of Roussouly et al. [5] based primarily on SS and lordotic levels.

Results

Sagittal spino-pelvic alignment in low back pain and controls[1] was analyzed.

[1] Bilateral independent Student *t* tests and chi-square tests were performed to compare means and proportions, respectively. Relationships between parameters were assessed using Pearson's coefficients. A level of significance of 0.05 was used for all statistical analyses.

Parameters are similar between men and women in the LBP cohort (Table 2), except for LSA and kyphotic levels for which the mean difference is 2.2° and 0.5° vertebra, respectively. When comparing LBP and control cohorts (Table 3), all parameters are significantly different with the exception of PT, LL, and kyphotic levels. The smallest and largest mean significant differences in angular parameters are observed for PI (2.0°) and LSA (3.7°), respectively. Mean TK, LSA, PI, and SS are significantly smaller in the LBP cohort. PT and LL are, respectively, larger and smaller in the LBP cohort, but the differences are not statistically significant. When adding LSA to LL for each subject, the mean value is significantly smaller in LBP cohort (50.2 ± 13.5 vs. 54.8 ± 10.5, $P < 10^{-6}$). LT is tilted more backward in controls on average (−6.7° in LBP cohort vs. −4.4° in control cohort). While mean TT is tilted backward in the control group (−1.4°), it is reversed and tilted forward in the LBP cohort (1.4°). Significantly, more lordotic levels are included in the LBP cohort, but the mean difference is only 0.2 vertebra. Kyphotic levels are similar

Table 2 Mean (standard deviation) for parameters of sagittal spino-pelvic alignment in women and men with chronic low back pain

Parameter	Women ($n = 87$)	Men ($n = 111$)	P value
Age	38.4 (11.6)	40.2 (11.4)	0.3
Pelvic incidence (°)	51.2 (12.9)	50.1 (11.3)	0.5
Pelvic tilt (°)	14.3 (7.5)	13.6 (7.1)	0.5
Sacral slope (°)	36.9 (9.7)	36.5 (8.6)	0.8
Lumbosacral angle (°)	−8.0 (5.9)	−10.2 (5.2)	0.008†
Lumbar lordosis (°)	42.6 (13.0)	39.7 (12.7)	0.1
Lumbar tilt (°)	−3.8 (5.9)	−4.9 (4.1)	0.1
Lordotic levels (vertebrae)	4.9 (1.3)	5.0 (1.1)	0.4
Thoracic kyphosis (°)	47.2 (24.1)	46.4 (12.1)	0.8
Thoracic tilt (°)	0.8 (5.3)	1.9 (4.0)	0.09
Kyphotic levels (vertebrae)	11.0 (2.1)	11.5 (1.5)	0.049†

P values from mean comparisons are also reported

† Statistically significant correlation coefficient ($P < 0.05$)

Table 3 Mean (standard deviation) for parameters of sagittal spino-pelvic alignment in patients with chronic low back pain (LBP) and controls

Parameter	LBP ($n = 198$)	Controls ($n = 709$)	P value
Age	39.4 (11.5)	36.8 (14.3)	0.02†
Pelvic incidence (°)	50.6 (12.0)	52.6 (10.4)	0.02†
Pelvic tilt (°)	13.9 (7.3)	13.0 (6.8)	0.1
Sacral slope (°)	36.7 (9.0)	39.6 (7.9)	$<10^{-4}$†
Lumbosacral angle (°)	−9.2 (5.6)	−12.9 (4.7)	$<10^{-18}$†
Lumbar lordosis (°)	41.0 (12.8)	42.0 (11.2)	0.3
Lumbar tilt (°)	−4.4 (5.0)	−6.7 (4.9)	$<10^{-8}$†
Lordotic levels (vertebrae)	4.9 (1.2)	4.7 (1.0)	0.03†
Thoracic kyphosis (°)	46.7 (18.3)	50.1 (10.4)	0.001†
Thoracic tilt (°)	1.4 (4.6)	−1.4 (4.0)	$<10^{-15}$†
Kyphotic levels (vertebrae)	11.3 (1.8)	11.1 (1.6)	0.1

P values from mean comparisons are also reported

† Statistically significant correlation coefficient ($P < 0.05$)

Table 4 Number of subjects with each type of lumbar lordosis in low back pain (LBP) and control cohorts

Type of lumbar lordosis	LBP ($n = 198$)	Controls ($n = 709$)	P value
Type 1	10 (5.1%)	32 (4.5%)	0.8
Type 2	74 (37.4%)	165 (23.3%)	$<10^{-4}$†
Type 3	77 (38.9%)	338 (47.7%)	0.03†
Type 4	37 (18.7%)	174 (24.5%)	0.08

P values from the comparison of the proportions for each type of lumbar lordosis are also reported

† Statistically significant correlation coefficient ($P < 0.05$)

between the two cohorts although the mean difference is also 0.2 vertebra.

The number of subjects with each type of LL for both cohorts is presented in Table 4. The proportion of subjects with Type 2 LL is significantly greater in the LBP cohort, while the proportion with Type 3 LL is significantly smaller in the LBP cohort. PI is similar between LBP and control cohorts in Types 1, 2, and 3 LL; it is significantly increased in the LBP cohort for Type 4 LL (Table 5).

Correlations between parameters are similar in LBP and control cohorts (Table 6). Strong correlations greater than 0.5 are found in both cohorts between PI–PT, PI–SS, PI–LL, SS–LL, and kyphotic–lordotic levels.

Discussion

Several authors have investigated sagittal spino-pelvic alignment in spinal disorders such as developmental spondylolisthesis [18–21], degenerative spondylolisthesis [22, 23], adolescent idiopathic scoliosis [24, 25], and adult spinal deformity [26, 27]. Previous studies have also assessed spino-pelvic alignment in LBP and lumbar disk disease [7–17], but the relationship between sagittal alignment and LBP is still poorly understood. The current paper helps to better understand the relationship between sagittal alignment and LBP because it involves the largest database published so far in the literature on the evaluation of sagittal spino-pelvic alignment in chronic LBP. Accordingly, the findings could potentially help in identifying subjects prone to develop LBP in the future based on their sagittal spino-pelvic alignment. Whether specific

Table 5 Main pelvic incidence (standard deviation) associated with each type of lumbar lordosis in low back pain (LBP) and control cohorts

Type of lumbar lordosis	LBP cohort	Control cohort	*P* value
Type 1	42.4 (10.9)	41.0 (6.4)	0.6
Type 2	42.1 (7.3)	43.8 (7.7)	0.1
Type 3	52.4 (8.0)	52.7 (7.4)	0.7
Type 4	66.0 (9.8)	62.8 (8.6)	0.04†

P values from the mean comparison in pelvic incidence are also reported

† Statistically significant correlation coefficient ($P < 0.05$)

preventive modalities could be instituted to prevent the occurrence of LBP in subjects with particular sagittal alignment (especially those with Type 2 LL) remains unclear and should be addressed in future studies. Similarly, the clinical relevance of specific rehabilitation protocols aiming at modifying the sagittal spino-pelvic alignment in patients with LBP needs to be investigated.

The relationships between parameters are similar between LBP and control cohorts (Table 6). In particular, strong correlations usually found in normal individuals between pelvic morphology (PI) and pelvic orientation (PT and SS), as well as between pelvic parameters (PI and SS) and LL are preserved in LBP, confirming the strong interdependence between the pelvis and the lumbar spine in order to maintain a balanced posture.

Significant differences are found for various parameters of pelvic, lumbar, and thoracic segments in subjects with chronic LBP (Table 3). Three previous studies have specifically shown decreased SS, increased PT, and decreased LL in patients with LBP [9–11]. Barrey et al. [10] argued that loss of LL was not only structural secondary to disk degeneration but also postural in order to decrease pain related to posterior disk loading. Rajnics et al. [11] suggest that smaller SS and increased PT along with smaller LL lead to greater compressive forces contributing to disk degeneration. In the cohorts presented herein, mean SS is significantly decreased, but the increase in PT and decrease in LL do not reach significance. Lordosis down to S1 (LL + LSA) is significantly decreased in subjects with LBP. Interestingly, mean differences for all parameters are only small between subjects with LBP and controls (largest mean difference of 3.7°), which could explain why conclusions from studies on LBP can be conflicting and significantly influenced by patient selection. Even in asymptomatic individuals composing the control cohort, sagittal spino-pelvic alignment is highly variable and associated with large standard deviations. Therefore, although statistically significant differences are found, it is assumed that the differences in sagittal spino-pelvic alignment in chronic LBP are only small and that clinically, multiple factors other than spino-pelvic alignment will contribute to LBP and/or lumbar disk degeneration.

As for pelvic morphology, mean PI found in LBP cohort is $50.6 \pm 12.0°$, which is similar to values reported by

Table 6 Pearson's correlation coefficients between all parameters for low back pain (LBP) and control cohorts (See Table 1 for abbreviations)

Parameter		PT	SS	LSA	LL	LT	Lordotic levels	TK	TT	Kyphotic levels
PI	Controls	0.65†	0.76†	0.21†	0.63†	0.53†	0.36†	−0.01	0.02	−0.18†
	LBP	0.66†	0.79†	−0.06	0.62†	0.44†	0.16†	0.18†	0.06	−0.12
PT	Controls		−0.002	0.36†	0.13†	0.26†	0.12†	−0.03	0.11†	−0.07
	LBP		0.07	0.23†	0.15†	0.27†	0.02	0.02	0.09	0.06
SS	Controls			−0.03	0.71†	0.48†	0.37†	0.01	−0.07	−0.17†
	LBP			−0.26†	0.71†	0.37†	0.19†	0.22†	0.10	−0.21†
LSA	Controls				0.36†	0.44†	0.28†	−0.15†	0.03	−0.10†
	LBP				0.09	0.32†	0.25†	−0.28†	−0.06	−0.17†
LL	Controls					0.26†	0.40†	0.25†	−0.26†	−0.22†
	LBP					0.23†	0.24†	0.22†	−0.12	−0.14
LT	Controls						0.25†	−0.41†	0.31†	−0.03
	LBP						0.29†	−0.26†	0.25†	−0.21†
Lordotic levels	Controls							−0.07	−0.05	−0.62†
	LBP							−0.12	0.07	−0.52†
TK	Controls								0.17†	−0.06
	LBP								0.42†	0.02
TT	Controls									0.17†
	LBP									0.17†

† Statistically significant correlation coefficient ($P < 0.05$)

other studies on patients with LBP [7, 10, 11]. In contrast to these three previous studies, PI is significantly different between LBP subjects and controls, although the mean difference is only 2°. The presence of a statistically significant difference might be related to the greater number of subjects included in the present cohorts.

Some authors already suggested that the type of LL was different between patients with LBP and the normal population. More specifically, Jackson and McManus [9] observed that patients with LBP stand with less distal segmental LL and more proximal segmental LL. On the opposite, Gautier et al. [8] reported no correlation between the type of LL (assessed by proximal vs. distal LL) and the occurrence of LBP. In fact, describing the type of LL by differentiating only between proximal and distal LL may be too simplistic to fully represent the types of LL that are typically seen, especially since the contribution from the pelvic geometry is not taken into account. In that sense, the classification proposed by Roussouly et al. [5] yields a better potential to encompass all the types of LL seen in humans. In a smaller study, Roussouly et al. [5] suggested that Type 1 LL was the least common type of LL found in normal adults. The current paper also shows that Type 1 LL is by far the least common type of LL seen in both normal adults and subjects with LBP. Based on this classification, there are a significantly greater proportion of subjects with LBP presenting Type 2 LL (37.4%), as compared to controls (23.3%). Conversely, the proportion with Type 3 LL is significantly decreased in the LBP cohort when compared to controls (38.9% vs. 47.7%). The proportion of subjects with either Type 1 or Type 4 LL is similar between the two cohorts. Therefore, the distribution of the types of LL is shifted from Type 3 LL (and to a lesser extent Type 4 LL) toward Type 2 LL in subjects with LBP. This finding confirms that a greater proportion of subjects with chronic LBP tend to present a small SS (<35°) associated with a long but small LL (flatback). As presented in Table 5, mean PI is similar between LBP and control cohorts within each specific type of LL, again confirming the strong interdependence between PI and the lumbar spine, as already demonstrated by the significant relationships found between PI–LL, PI–LT, and PI–lordotic levels (Table 6). Consequently in the LBP cohort, there is also a shift toward a greater proportion of subjects with abnormally small PI (usually associated with Type 1 or Type 2 LL). Because PI is a morphological parameter (independent of positioning) and is linked to the type of LL, it is possible that individuals with an abnormally small PI are at increased risk of LBP because of increased disk pressure/degeneration secondary to decreased LL and/or of suboptimal muscular/postural biomechanics needed to maintain adequate balance. As suggested by Barrey et al. [10], it is also possible that the greater proportion of subjects with Type 2 LL in the LBP cohort is secondary to preexistent disk degeneration or to postural adaptations to decrease pain from posterior disk loading. However, when compared specifically to the study of Barrey et al. [10] who used the same measurement technique on preoperative patients with disk degeneration, it is important to notice that overall, preservation of LL and PT in the present report suggests that disk degeneration is not as advanced in the current nonsurgical LBP cohort and that there is no evidence of pelvic retroversion, which represents a compensatory mechanism from the pelvis when LL decreases in order to preserve normal sagittal balance. Indeed, this suggests that the increased prevalence of Type 2 LL in LBP cohort is mainly due to a constitutionally small PI rather than a compensation or consequence of disk degeneration only. In case of a shift from an original Type 3 to a Type 2 LL, an increase in PT would have been expected in LBP subjects in order to compensate for a loss of LL, and that was not observed. Similarly, the findings do not suggest a shift from an original Type 4 to a Type 3 LL, again due to the absence of PT increase and LL decrease in LBP cohort. However, these assumptions cannot be confirmed, and a comparative study with pediatric subjects or a longitudinal study of LBP with respect to the type of LL should be performed in the future.

Conclusion

The normal relationships between parameters of spino-pelvic alignment are preserved in subjects with LBP. Significant but small differences are found for various parameters of pelvic, lumbar, and thoracic segments in subjects with LBP. The type of lumbar lordosis is also distributed differently among subjects with LBP. A significantly increased proportion of subjects with LBP stand with abnormally small sacral slope (<35°) and PI associated with a long but small LL, when compared to controls. Future studies should attempt to prospectively evaluate young asymptomatic subjects in order to identify whether specific parameters of sagittal spino-pelvic alignment are predictive for the development of chronic LBP.

Conflict of interest None.

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