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ORIGINAL ARTICLE

Relation between the sagittal pelvic and lumbar spine geometries following surgical correction of adolescent idiopathic scoliosis

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Abstract Sagittal spinopelvic relations have been reported in adolescent idiopathic scoliosis (AIS), but there is little information on their effect following surgery. The objective of this study is to evaluate the relation between the pelvic and lumbar spine geometries following posterior spinal instrumentation and fusion (PSIF). Sixty patients with AIS undergoing PSIF were studied retrospectively. Thoracic kyphosis (TK), lumbar lordosis (LL), LL within and below fusion, pelvic incidence (PI), sacral slope (SS) and pelvic tilt (PT) were measured on preoperative and postoperative standing lateral radiographs. Significant postoperative correlations were found between PI and LL ($r = 0.67$), SS and LL ($r = 0.90$), PI and LL below fusion ($r = 0.40$), SS and LL below fusion ($r = 0.48$). Pelvic parameters did not influence LL within fusion. A strong correlation was found between LL below and within fusion ($r = -0.76$). The close interdependence between lumbar lordosis and pelvic geometry preoperatively is maintained postoperatively following PSIF. In the planning of surgery for AIS, it may be helpful to evaluate the sagittal pelvic morphology (PI) in addition to the spinal curves. Preoperative evaluation of the pelvic morphology could be used to optimize intraoperative positioning of the patient and to determine the optimal amount of LL that needs to be restored or preserved by the instrumentation, so that LL remains congruent with the pelvic morphology.

Keywords Adolescent idiopathic scoliosis · Lumbar lordosis · Pelvic morphology · Sagittal alignment · Spinal instrumentation

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Introduction

Many studies have reported a correlation between pelvic and spinal geometric measurements of sagittal alignment in healthy subjects [14–16, 21]. A positive correlation of lumbar lordosis with sacral slope and pelvic incidence has also been described in subjects with spinal disorders such as adolescent idiopathic scoliosis (AIS) [11, 13, 14, 17]. However, the relationship between pelvic parameters and lumbar lordosis before and after posterior spinal instrumentation and fusion (PSIF) has never been studied in detail in patients with AIS. In particular, the amount of lumbar lordosis created by the instrumentation has never been correlated with the lumbar lordosis below the instrumentation and with the pelvic geometry. The purpose of this study was therefore to investigate the influence of pelvic geometry on lumbar lordosis in patients with AIS treated by PSIF, with the hypothesis that the underlying sagittal pelvic morphology has a significant influence on the postoperative sagittal spinopelvic alignment and could be an important parameter to evaluate preoperatively.

Materials and methods

Patients

A cohort of 60 patients (57 females and 3 males) diagnosed with AIS who have undergone PSIF were recruited from the clientele of three spinal deformity surgeons at a single pediatric hospital. The criteria for inclusion in this study were (1) a diagnosis of AIS, (2) a surgical correction by PSIF using segmental instrumentation system, (3) a lowest instrumented vertebra located between L1 and L5, (4) a minimum follow-up of 6 months, and (5) the availability of preoperative and postoperative standing lateral and frontal radiographs of the spine and pelvis with the two femoral heads visible on the lateral radiographs. Exclusion criteria were (1) any previous spine surgery, (2) a revision surgery, (3) history or clinical signs of hip, pelvic or lower limb disorder, (4) the presence of a spondylolysis or spondylolisthesis, and (5) any clinical or radiological evidence of pseudarthrosis at last follow-up. All patients were positioned intraoperatively on a Relton-Hall frame.

Radiographic measurements

Digital standing lateral radiographs of the spine and pelvis using a Fuji FCR machine (Fuji, Tokyo, Japan) were taken preoperatively and at last available postoperative follow-up. All radiographs were taken in the fist-on-clavicle position [5, 9]. All radiographs were evaluated using the SpineView software (SurgiView, Paris, France). Once the upper and lower endplate of each vertebra from T4 to S1 and the two femoral heads are identified, this software allows the calculation of every parameter used in this study. All measurements were performed by a single observer. Validity and reproducibility of the measuring technique has already been assessed in previous studies [18]. Four spinal and three pelvic parameters were measured on each preoperative and postoperative lateral standing radiographs (Fig. 1):

(1) *Thoracic kyphosis* (*TK*): angle between the upper endplate of T4 and the lower endplate of T12.
(2) *Lumbar lordosis* (*LL*): angle between the upper endplate of L1 and the upper endplate of S1.
(3) *Lumbar lordosis within fusion* (*LL within fusion*): angle between the upper endplate of L1 and the lower endplate of the lowest instrumented vertebra.
(4) *Lumbar lordosis below fusion* (*LL below fusion*): angle between the lower endplate of the lowest instrumented vertebra and the upper endplate of S1.
(5) *Pelvic incidence* (*PI*): angle between the perpendicular of the upper endplate of S1 and the line joining the middle of the upper endplate of S1 and the hip axis (midway between the centers of the two femoral heads).
(6) *Sacral slope* (*SS*): angle between the upper endplate of S1 and the horizontal line.
(7) *Pelvic tilt* (*PT*): angle between the vertical line and the line joining the middle of the upper endplate of S1 and the hip axis (positive when the hip axis lies in front of the middle of the upper endplate of S1).

Statistical analysis

A sample size study was done at the beginning of this study. After reviewing the correlations between pelvic geometry and sagittal spine parameters in the literature [11, 13–17, 21], correlations between 0.50 and 0.70 were expected. With $\alpha = 0.01$ and $\beta = 0.1$, a sample size of at least 52 patients was necessary to detect

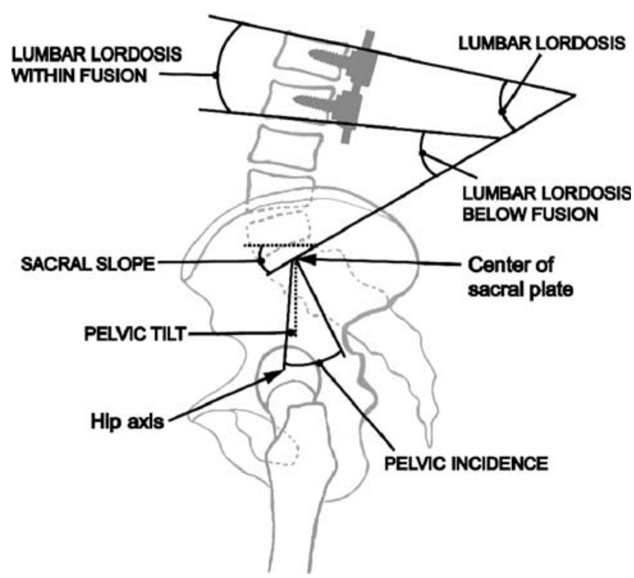

Fig. 1 Sagittal lumbar and pelvic parameters from the standing lateral radiograph. The hip axis is located midway between the center of the two femoral heads. Sacral slope and pelvic tilt are positional parameters. Pelvic incidence is a constant morphological parameter, unaffected by the orientation of the pelvis

statistically significant relationships [10]. Accordingly, 60 patients were recruited for this study.

Patients were classified in two groups for statistical analysis according to the lowest instrumented vertebra: group I if the lowest instrumented vertebra was between L1 and L3 (40 patients), and group II if the lowest instrumented vertebra was L4 or L5 (20 patients). Patients with the lowest instrumented vertebra at L1 were not included in group I when studying LL within fusion. Similarly, patients with lowest instrumented vertebra at L5 were not included in group II when studying LL below fusion. The data was analyzed using the InStat Software (GraphPad Software, San Diego, USA). Statistical analysis was initially done for all patients as one group and was repeated separately for each group of patients. Pearson coefficients were used for the correlation analysis. The level of significance was set at 0.01 due to the multiple statistical tests performed in this study.

Results

The average age at the time of surgery was 14.7 ± 1.7 years. The average follow-up time was 14.4 ± 8.5 months (range: 6–52 months). The lowest instrumented vertebra was L1 for 11 patients, L2 for 11 patients, L3 for 18 patients, L4 for 16 patients and L5 for four patients. The average Cobb angle of the major coronal curve was 66.2 ± 14.6° (range 31–104) preoperatively and 32.1 ± 12.6° (range 12–76) postoperatively, for an average correction of 51.6 ± 14.8% (range 10–77).

Table 1 presents the results from the correlation study for the entire cohort. PI was strongly related to SS and PT preoperatively and postoperatively. However, the correlation between PT and SS was not significant. PI and SS were strongly correlated with LL preoperatively and postoperatively. On the opposite, none of the lumbar parameters was significantly influenced by PT. Strong correlation coefficients are found for postoperative LL below fusion with PI and SS. However, none of the pelvic parameters seem to influence the LL within fusion. TK has a significant influence on the preoperative LL but postoperatively, this relationship is lost. A strong negative correlation is found between LL below fusion and within fusion postoperatively. Figure 2 presents a global overview of the postoperative sagittal balance based on the significant correlations between pelvic and lumbar parameters.

Statistical tests were also done for each group of patients (groups I and II) taken separately (Table 2).

Table 1 Correlations between pelvic and sagittal spine parameters for all patients

Parameters	Preoperative		Postoperative	
	r	*P* value	*r*	*P* value
PI–SS	0.80	$<10^{-4}$	0.78	$<10^{-4}$
PI–PT	0.75	$<10^{-4}$	0.75	$<10^{-4}$
SS–PT	0.20	0.12	0.16	0.22
LL–PI	0.53	$<10^{-4}$	0.67	$<10^{-4}$
LL–SS	0.76	$<10^{-4}$	0.90	$<10^{-4}$
LL–PT	0.02	0.91	0.10	0.46
LL–TK	–0.57	$<10^{-4}$	–0.12	0.35
LL within fusion–PI			0.04	0.77
LL within fusion–SS			0.09	0.55
LL within fusion–PT			–0.04	0.81
LL within fusion–TK			0.13	0.37
LL below fusion–PI			0.40	$<10^{-2}$
LL below fusion–SS			0.48	$<10^{-3}$
LL below fusion–PT			0.18	0.19
LL below fusion–TK			–0.05	0.69
LL within fusion–LL below fusion			–0.76	$<10^{-4}$

LL lumbar lordosis, *PI* pelvic incidence, *SS* sacral slope, *PT* pelvic tilt, *TK* thoracic kyphosis

Correlations between the sagittal parameters are similar in both groups. However, the correlation between LL below fusion and LL within fusion is significant in group I while in group II, a strong, but non significant, negative correlation coefficient of –0.62 is found. The main difference between the two groups is for the relationship between lumbar parameters and TK. The preoperative relation between LL and TK is significant in group I but the postoperative relation is not significant. For group II, neither the preoperative or postoperative relations between these parameters are significant.

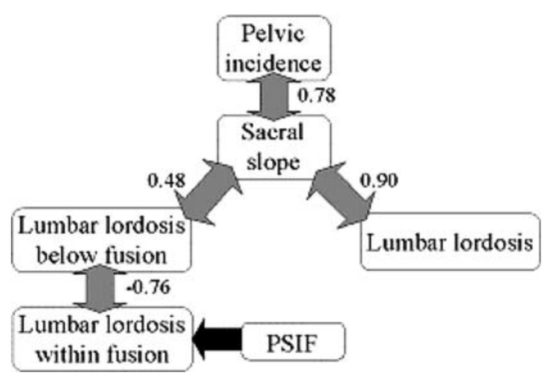

Fig. 2 Postoperative significant correlations between pelvic and lumbar parameters for the entire cohort. Posterior spinal instrumentation and fusion (*PSIF*) imposes a lumbar lordosis (*LL*) within fusion and lumbar lordosis below fusion must compensate to maintain a good correlation between lumbar lordosis and pelvic geometry (sacral slope and pelvic incidence)

Table 2 Correlations between pelvic and sagittal spine parameters for groups I and II

Parameters	Group I (n = 40)				Group II (n = 20)			
	Preoperative		Postoperative		Preoperative		Postoperative	
	r	P value	r	P value	r	P value	r	P value
LL–PI	0.54	$<10^{-3}$	0.69	$<10^{-4}$	0.60	$<10^{-2}$	0.59	$<10^{-2}$
LL–SS	0.76	$<10^{-4}$	0.88	$<10^{-4}$	0.85	$<10^{-4}$	0.92	$<10^{-4}$
LL–PT	0.002	0.99	0.22	0.18	0.06	0.79	–0.10	0.66
LL–TK	–0.67	$<10^{-4}$	–0.30	0.06	–0.15	0.52	0.15	0.54
LL within fusion–PI			0.35	0.06			0.37	0.11
LL within fusion–SS			0.47	0.01			0.33	0.15
LL within fusion–PT			0.07	0.72			0.15	0.52
LL within fusion–TK			0.27	0.16			–0.02	0.93
LL below fusion–PI			0.31	0.05			0.41	0.11
LL below fusion–SS			0.45	$<10^{-2}$			0.71	$<10^{-2}$
LL below fusion–PT			0.046	0.78			0.02	0.94
LL below fusion–TK			–0.37	0.02			0.19	0.49
LL within fusion–LL below fusion			–0.52	$<10^{-2}$			–0.62	0.01

LL lumbar lordosis, *PI* pelvic incidence, *SS* sacral slope, *PT* pelvic tilt, *TK* thoracic kyphosis

Discussion

In normal adolescents [16], the pelvic morphology (PI) controls the sacro-pelvic orientation (SS), which in turn determines the LL. The role of PI in controlling directly the SS and indirectly the LL (through its influence on SS) is of paramount importance. This is the first study that specifically investigates the influence of pelvic geometry on the sagittal spinal geometry in patients with AIS after PSIF. The results support our hypothesis that assessment of the sagittal pelvic morphology (PI) could be important in the planning of the surgical treatment of AIS. In fact, this study suggests that pelvic morphology (PI) has a predominant role in the determination of the magnitude of LL after surgery. Since PI is a true morphological parameter that should not be significantly modified by PSIF, its preoperative evaluation could become very helpful in the determination of an adequate postoperative LL.

As shown in the postural model in Fig. 2, PI controls SS, which is strongly correlated to LL. More specifically, SS is significantly related to LL below fusion. In addition, LL below fusion is also inversely correlated with LL within fusion that is mostly determined by PSIF. In other terms, PSIF imposes LL within fusion and LL below fusion must compensate to maintain a good congruency between overall LL and pelvic geometry (sacral slope and pelvic incidence), as reflected by the strong relation between pelvic geometry and LL postoperatively. This concept is in agreement with the frequent clinical observation of an increased angular LL below fusion with the Harrington system as a compensation mechanism when the LL within fusion imposed by the instrumentation is insufficient [23].

Based on the results of this study, a more systematic approach to determine the optimal amount of LL to be set during surgical correction within the instrumented segment is suggested. Preoperatively, the pelvic (PI, SS and PT) and spinal (TK and LL) geometries should be assessed from the lateral standing radiographs in order to evaluate the global spinopelvic alignment. The PI should be used to predict the optimal LL because PI remains similar pre- and postoperatively since it is a true morphologic parameter. Figure 3 is a graph illustrating the relationship between PI and LL in normal adolescents, based on a previous study [16]. The regression line on this graph can be used as a guide to estimate the amount of LL which should be expected with respect to a specific PI value. Alternatively, the logistic regression equation provided can also be used (Fig. 3). This technique is in accordance with studies reporting that the shape and orientation of adjacent anatomical regions of the spine and pelvis are interdependent and their relationships result in a stable and compensated posture [2, 4, 16]. The proposed technique integrates this concept and could be more appropriate than determining the geometry of each segment separately using standard values, although a range of target values would probably be adequate for most of the patients. With the proposed technique, the value of LL is personalized for each patient, and would be particularly useful for those scoliotic patients with extreme values of PI for which the optimal LL is not similar to that found in normal subjects. For example, since many patients with AIS have a high PI [17], planning to achieve a normal LL of 60° [22] after surgery may be adequate for a patient with a PI of 50° but inadequate for another subject with a PI of 80° in

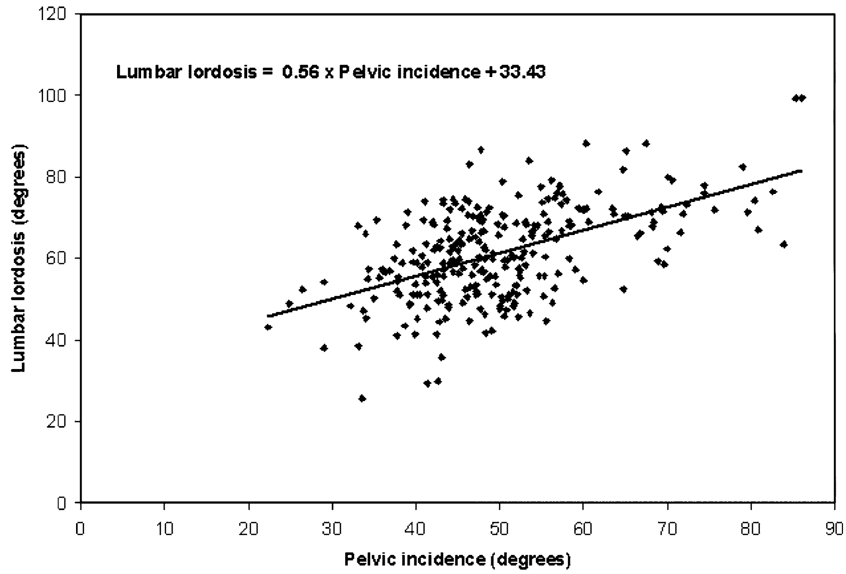

Fig. 3 Linear regression between the lumbar lordosis and the pelvic incidence in 272 normal subjects aged 10–18 years old

order to maintain a congruent spinopelvic alignment. This concept is particularly important when the fusion level and the instrumentation extend distally to L4 or L5, since many authors [3, 8] have suggested that patients fused down to L4 or L5 may have a poorer long-term outcome. In that case, the surgeon should strive to provide enough LL within fusion to allow a LL that is congruent with the pelvic morphology, and therefore avoid hypolordosis within fusion. This will prevent overcompensation below fusion, and should decrease the risk of a transition syndrome [6, 12, 19] and of potential instability below the fused segments at the L5–S1 (and perhaps L4–L5) disc. Whether providing a LL congruent with the sagittal pelvic morphology will effectively decrease the risk of long-term disc degeneration remains unknown and will need to be addressed in future long term outcome studies.

In addition, a more individualized determination of LL based on these concepts can also guide the surgeon in the proper intraoperative positioning of the lower limbs of patients in the operating room: a more extended position of the hips and pelvis [1, 7, 20] should be used to recreate LL for subjects requiring higher amounts of LL, and vice versa. Intraoperative radiographs routinely used as localization films after surgical exposure could be used to evaluate the congruency between the lumbar lordosis and the pelvic incidence.

Conclusion

In summary, a close interdependence between pelvic morphology (PI) and LL (total and below fusion) is maintained postoperatively following PSIF. LL within fusion also has a significant effect on LL below fusion. Evaluation of the sagittal pelvic morphology (PI) in addition to the spinal curves in the planning of surgery for AIS could therefore be an important guidance to maintain this equilibrium postoperatively. Future studies should include C7–S1 plumbline to measure the global spinopelvic balance. Furthermore, a prospective study would allow to study properly the effect of age and degenerative changes on the spinopelvic relations and if postoperative lumbar lordosis congruent with pelvic incidence is associated with lower occurrence of transition syndrome.

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