Sagittal balance in adolescent idiopathic scoliosis: radiographic study of spino-pelvic compensation after surgery

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Abstract

Study design Radiographic retrospective study of a consecutive series of 76 patients with adolescent idiopathic scoliosis (AIS) undergoing posterior only surgical correction and fusion.

Objective To evaluate the sagittal profile changes in a population of adolescent idiopathic scoliosis after posterior only surgical correction.

Summary of background data Although the relationship between pelvic indexes and sagittal profile is well known, little has been published about the sagittal profile changes after posterior surgery in adolescent idiopathic scoliosis.

Methods Radiological data of 76 AIS patients were analyzed by an independent observer to compare pelvic indexes and spino-pelvic parameters before and at the last follow-up after surgical posterior correction. All patients underwent a posterior only surgical correction by using different anchor techniques (all screws or hybrid construct), but the same derotation correction maneuver (C-D technique). The collected data were analyzed, on AP and LL radiographic views of the entire spine in the upright position, from the same independent observer and using the same Impax software analysis. We collected for each patient on latero-lateral X-rays the following data: pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), lumbar lordosis (LL), thoracic kyphosis (TK), C7 plumb line (C7PL) and spino-sacral angle (SSA). All data were

analyzed using a D'Agostino–Pearson normality test and the comparison between the groups was performed with a student's *t* test.

Results The mean pelvic incidence (PI) of the cohort was $48.89^\circ (\pm 11.24)$, with a mean Cobb angle for the main curve of $60.13^\circ (\pm 13.6)$. The mean value of residual scoliosis after surgery was $28.18^\circ (\pm 13.22)$ with an average improvement of the curve in the frontal plane of 53.2 %. The amount of curve correction of the primary scoliosis curve was statistically significant ($p < 0.0001$). In the evaluation of the whole group after surgery, we observed an increasing amount of PT (average delta value 2.38°) with a statistical significance ($p = 0.0034$). If we compare the mean ideal PT value (11.09°) with the pre- and post-operative mean true PT values, we found statistical significance only for the post-operative difference ($p = 0.0014$). In the general assessment, C7PL seems to remain stable after surgery, and in particular it remains negative. In Lenke 1 group, there was a mean PI value of $50.54^\circ (\pm 11.45)$ which is higher than the one reported in the global assessment. Also in this subgroup, we observed a reduction in the mean SS values, with consequent increase in the PT values, as in the general assessment. The C7PL tends to move posteriorly after surgery and this difference is statistically significant. In Lenke 1 group we found a strong statistical significance between pre- and post-surgery data for the Cobb primary curve and for the C7PL, which continues to remain negative. The C7PL remains relatively stable only in the normokyphotic group, while it tends to move behind in the other three groups (Lenke 3, hyperkyphosis and hypokyphosis).

Conclusions In our series of 76 adolescent affected by AIS, we reported mean PI values of 48.9° with a mean pre-operative PT of 11.51° . After surgery we observed an increase in the PT mean value, about three degrees higher

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than the ideal value, meaning that there was some compensatory mechanism. Patients affected by AIS showed a slight posterior imbalance and the intervention of scoliosis correction seems to cause a slight further posterior imbalance, especially in Lenke 1 type curves and in patients with hypokyphosis. The clinical significance of this slight imbalance must be carefully evaluated. Further studies are necessary to better establish which could be the best surgical strategy to obtain an optimal spinal sagittal balance.

Keywords Sagittal balance · Adolescent idiopathic scoliosis · Pelvic incidence · Sacral slope · C7 plumb line

Introduction

The importance of the sagittal profile and of a proper balance of the spine on both the sagittal and coronal planes is now widely known.

Since the first published work of Duval-Beaupère [1, 2] about the importance of pelvic indexes and their relationship ($PI = PT + SS$), many works have been published in the literature about the importance of the relationship between pelvic indexes and sagittal profile.

Pelvic incidence (PI) is a fundamental anatomical parameter; it is unique for each individual and does not depend on the position or spatial orientation of the pelvis. PI is closely related to sacral slope (SS) and pelvic tilt (PT), so that an increase in SS must be compensated by a similar reduction of PT, as shown in Duval-Beaupère formula, $PI = SS + PT$.

Pelvic incidence in the normal population remains relatively constant during childhood; it increases significantly during adolescence, reaching its maximum value in adulthood [3]. This means that during adolescence the value of PI varies even if only slightly. Nevertheless, if we consider a population of adolescents affected by scoliosis there is an increase in the PI average value [4].

Lumbar lordosis (LL) is closely related to the orientation of the pelvis, expressed by the sacral slope, which is strongly influenced by pelvic incidence.

A significant chain of interdependence exists between the pelvic and spinal parameters. Pelvic incidence, which is the only independent and anatomical parameter, determines pelvic orientation and the size of the lordosis, which is closely correlated with it. A low value of pelvic incidence implies low values of pelvic parameters and a flattened lordosis; a high value implies well-tilted pelvic orientation and pronounced lordosis [2].

Legaye [2] found that in the normal population, LL is more or less the sum of PI plus ten degrees, while TK can be considered as the PI value itself.

Vialle et al. [5] published a radiographic analysis of the sagittal spinal alignment on asymptomatic subjects and found linear correlations between the main spinal and pelvic parameters, so that $PT = -7 + 0.37 PI$.

If we consider these two published very important relations [2, 5] in between the pelvic and the spinal parameters, we can easily obtain from the PI value of the patient two other important information about his optimal LL and the ideal PT; ultimately, we can get important information about the global balance of the spine.

The evaluation of the other parameters considered is necessary to explain how we proceeded to their measurement. Lumbar lordosis (LL) and thoracic kyphosis (TK) were calculated in relation to the position of the inflexion point and found at the limit where one curve transitioned into another, as well described by Roussouly et al. [6].

Spino-sacral angle (SSA) and C7 plumb line (C7PL) were considered as indicators of the overall balance of the spine. The first was calculated as the angle between the sacral plateau and the line connecting the center of the C7 vertebral body with the midpoint of the sacral plate, while the second would be very easy to detect but more difficult to compare. In fact, C7PL can be considered as very stable at the level of the posterior edge of the sacral plateau, while it becomes unstable when it is in front or behind this position. The measurement of the C7PL displacement is easy to obtain, but difficult to compare because it needs calibrated X-rays. Barrey described a ratio: the distance between C7PL and femoral heads compared with the distance between femoral heads and the posterior limit of the sacral plateau; this is able to solve the problem [7]. Considering the C7PL measurement system proposed by Barrey to be too complex, we decided to calculate the position of C7PL in relation to the position of the femoral heads of the patient. Doing so, the C7PL values become positive or negative, respectively, if C7PL falls in front of or behind the sacrum and then their values are judged in relation to the distance between the posterior edge of the sacral plateau and the femoral heads of the patient. A C7PL that falls in front of the posterior edge of the sacrum but in between the distance with the femoral head must be considered as +, while if it falls in front of the femoral head of the patient, it must be considered as ++. The same relation, but with negative values, is to be considered if the C7PL falls behind the sacrum (Fig. 1).

The importance of obtaining a good sagittal profile in the planning of surgery for AIS is well known, but up to now there are few published work in the literature concerning the effect of surgical correction of the deformity on the spino-pelvic parameters [8].

We propose a retrospective analysis on the effect of surgery on the sagittal profile in a population of 76 adolescents affected by idiopathic scoliosis.

Fig. 1 Proposal of a new scheme of C7PL representation. +, if it falls between sacrum and femoral heads; ++, if it falls over the femoral heads; −, if it falls between the sacrum and the rear projection of the femoral heads; −−, if it falls behind the rear projection of the femoral heads

Materials and methods

This is a retrospective unicentric cohort study, with level of evidence III. A cohort of 76 patients aged between 10 and 22 years was analyzed. Inclusion criteria were an admission diagnosis of adolescent idiopathic scoliosis with no other pathological conditions, age between 12 and 22 years and no previous spine surgery.

All patients underwent a one-stage posterior surgical correction and fusion at the same institution by two senior surgeons. The same surgical correction technique was used by only posterior approach with derotation maneuver after placement of hybrid (screws/hooks) or all screws construct.

There were 8 boys and 68 girls with a mean age of 16.5 years (range 10–22 years) and the mean primary Cobb angle was 60.1°. The average follow-up between pre- and post-operative evaluation was 18 months.

The population ($n = 76$) was then divided into Lenke types as follow: 47 Lenke type 1, 3 Lenke type 2, 14 Lenke type 3, 1 Lenke type 4, 7 Lenke type 5 and 4 Lenke type 6.

The cohort was also classified according to the amount of thoracic kyphosis: hypo, hyper and normokyphotic as described by Lenke et al. [9].

The radiological evaluation was done by the same independent observer on standard long AP and LL X-rays in standing position of the patient, immediately before the surgery and at the last follow-up available.

All major pelvic and spino-pelvic indexes were detected according to the literature [10], while C7PL was measured as positive or negative distance from the posterior edge of the sacral plateau, according to the new scheme we proposed (Fig. 1).

We believe that the measurement of C7PL displacement is easy to obtain, but difficult to compare because it needs calibrated X-rays. Considering the Barrey ratio too complex to measure and also to compare, we proposed a new scheme of measurement of the C7PL (Fig. 1). On doing so, the C7PL values become positive or negative, respectively, if C7PL falls in front of or behind the sacrum and then their values are judged in relation to the distance between the posterior edge of the sacral plateau and the femoral heads of the patient. More specifically, the measurements were divided into: + if included within the distance to the femoral heads; ++ if passing over the femoral head; on the other hand, − if included within the same distance from the femoral heads as reported back; −− if over this distance. The scheme we propose (Fig. 1) for the evaluation of C7PL identifies four situations of spine balance as follows: + slightly unbalanced forward, ++ very unbalanced forward, − slightly unbalanced behind, −− very unbalanced behind.

For each patient the ideal values of TK, LL and PT were calculated before and after the surgery to try to understand if the patients affected by scoliosis were well balanced or not and also if the surgical procedure of scoliosis correction tended to modify the spino-pelvic alignment.

Lumbar lordosis and thoracic kyphosis were calculated with regard to the position of the inflexion point and found at the limit where one curve transitions into another, as well described by Roussouly [6].

Statistical analysis between the pre-operative and post-operative values were performed for each parameters; where calculated (PT, TK, LL), the ideal derived values were included in the comparison.

All the statistical analysis was carried out using the GraphPad Prism software (GraphPad Software, Inc). To establish whether or not each parameter group represented a normal distribution, a D'Agostino–Pearson normality test was performed. The comparison between those parameter groups showing a Gaussian distribution was performed with Student's t test; otherwise a Wilcoxon matched pairs test was applied. In all comparisons performed, the statistical significance level was set up to $p = 0.05$.

Results

Table 1 summarizes the mean pre- and post-operative radiological values for all the patients ($n = 76$), including standard deviations and the p value of the Student's t test applied to each variable. It includes also the ideal theoretical values and the differences with the respective pre- and post-operative values (Δ pre/post-derived). Lordosis was considered as positive, while kyphosis was evaluated as negative.

Table 1 Data regarding global assessment

Variable	N	Mean	SD	p
PI	76	48.89	11.24	
Cobb primary curve				
Pre-op	76	60.13	13.6	<0.0001*
Post-op	76	28.18	13.22	
PT				
Pre-op	76	11.51	10.76	0.0034*
Post-op	76	13.89	11.62	
Ideal value	76	11.09	4.13	
Δ (pre-ideal)	76	0.42	8.52	0.4512
Δ (post-ideal)	76	2.8	9.20	0.0014*
LL				
Pre-op	76	49.76	11.88	0.5091
Post-op	76	51.38	10.89	
Ideal value	76	58.89	11.16	
Δ (pre-ideal)	76	−9.13	16.64	<0.0001*
Δ (post-ideal)	76	−7.51	17.32	<0.0001*
TK				
Pre-op	76	−30.04	13.55	0.3902
Post-op	76	−31.26	11.05	
Ideal value	76	−48.89	11.16	
Δ (pre-ideal)	76	18.85	17.19	<0.0001*
Δ (post-ideal)	76	17.63	15.38	<0.0001*
SS				
Pre-op	76	37.42	8.72	0.0703
Post-op	76	35.13	9.02	
SSA				
Pre-op	76	131.1	8.55	0.0514*
Post-op	76	129.5	9.30	
C7PL				
Pre-op	76	−24.47	26.29	0.6995
Post-op	76	−23.46	25.43	
Overhanging				
Pre-op	76	16.6	10.8	0.7930
Post-op	76	14.86	11.92	

Asterisk indicates statistically significant values

The mean pelvic incidence (PI) of the cohort was 48.89° (± 11.24), with a mean Cobb angle for the main curve of 60.13° (± 13.6). The mean value of residual scoliosis after surgery was 28.18° (± 13.22) with an average improvement of the curve in the frontal plane of 53.2 %. The difference between the pre-operative and post-operative Cobb angles was statistically significant ($p < 0.0001$).

After surgery, we observed an increasing amount of mean PT value from 11.51° to 13.89° (average delta value + 2.38°), and consequently a reduction in the SS amount, with high statistical correlation only for the increase in PT ($p = 0.0034$).

Comparing now the mean ideal PT value (11.09°) with the pre- and post-operative mean true PT values, we observed statistical significance only for the post-operative one ($p = 0.0014$).

Concerning lumbar lordosis, we found a slight increase in the post-operative mean values (from 49.76° to 51.38°), but the difference was not statistically significant ($p = 0.5091$).

The ideal mean LL value was calculated as 58.89° (± 11.16), which means that patients were in hypolordotic condition. If we compare this value with the pre- and post-operative ones, we found a highly significant difference for both parameters ($p < 0.0001$).

The mean pre-operative thoracic kyphosis was −30.04° (± 13.55), while the post-operative one was −31.26° (± 11.05) and the difference was not statistically significant.

The ideal calculated value of TK (TK = PI) was −48.89° (± 11.16), which means that patients were in a condition of hypokyphosis. If we compare this value with the pre- and post-operative ones, we found a high significant difference for both parameters ($p < 0.0001$).

The average SSA before the surgery was 131.1° (± 8.55), and after surgical correction the mean value was 129.5° (± 9.30). We found that this slight difference (delta −1.6°) had a very low statistical significance ($p = 0.0514$).

Considering C7PL we found a pre-operative average value of −24.47 mm (± 26.29), while the post-operative one was −23.46 mm (± 25.43), with no statistical significance. This data showed us how the patients were in a state of posterior sagittal imbalance, both before and after surgery.

In fact, following our classification system of sagittal imbalance (Fig. 1; Table 4), only two patients had balance before surgery, 39 were with slight imbalance (it means in the — plumb line zone) and 11 were with serious imbalance (it means in the — — plumb line zone). In only ten patients, we found C7PL falling in the positive area of classification. After surgery, there were 49 patients with slight posterior imbalance, while patients with serious imbalance were reduced to 4, which means that after surgery a general situation of posterior imbalance remains, but with a significant reduction of its gravity. After surgery, none of the patients had perfect balance.

In Table 2 we report the results concerning the Lenke 1 subgroup ($n = 47$). As shown, there is a mean PI value of 50.54° (± 11.45) which is higher than the one reported in the global assessment. In this subgroup we observed a similar reduction in the mean SS values (delta 2.3°) to the general group, but a significant variation in C7PL. In fact despite that in the global group we observed a slight improvement in posterior imbalance (delta 1.01), in the Lenke 1 group it significantly worsened (delta −6.79).

Table 2 Data regarding the Lenke 1 subgroup

Variable	N	Mean	SD	p
PI	47	50.54	11.45	
Cobb primary curve				
Pre	47	58.31	12.16	<0.0001*
Post	47	28.86	11.92	
SS				
Pre	47	38.03	8.13	0.0094*
Post	47	35.73	9.057	
LL				
Pre	47	52.77	10.57	0.0453
Post	47	50.76	10.15	
TK				
Pre	47	−28.13	13.44	0.7595
Post	47	−28.78	11.5	
SSA				
Pre	47	132	8.593	0.0736
Post	47	130.3	8.718	
C7PL				
Pre	47	−21.05	25.31	0.0042*
Post	47	−27.84	22.31	
Overhanging				
Pre	47	14.19	10.62	0.2331
Post	47	12.07	10.53	

Asterisk indicates statistically significant values

In Lenke 1 group, we found a statistical significance between pre- and post-surgery for the Cobb primary curve, as found in the general assessment, and also for SS and C7PL.

In Table 3, we report the mean values available for the subgroups of Lenke 3 ($n = 14$), normokyphosis N ($n = 49$), hyperkyphosis + ($n = 15$) and also hypokyphosis − ($n = 12$).

The first consideration is that PI are higher in the hypokyphotic group (mean value of PI = 51.9°) as also shown by the Lenke 1 group (mean value of PI = 50.54°) when compared with the mean value of the whole group (mean value of PI = 48.89°) and also of the other groups.

We also found that the mean SS value remains relatively stable after surgery in the different groups considered except in the hypokyphotic one, in which there is a larger decrease of its mean value ($\Delta = 4.18^\circ$). The magnitude of SS difference between pre- and post-surgery data is also higher than the one observed in the Lenke 1 group. C7PL remains relatively stable only in the normokyphotic group, while it tends to move behind in the other three groups (Table 3).

At the end of the analysis, we tried to summarize in Table 4 the data according to our new scheme of C7PL evaluation (Fig. 1) for the global assessment and for the

Table 3 Mean values for the subgroups Lenke 3, N normokyphosis, + hyperkyphosis, − hypokyphosis

	Lenke 3 ($n = 14$)	N ($n = 49$)	+($n = 15$)	−($n = 12$)
PI	45.33	47.72	47.73	51.9
Cobb primary curve				
Pre	65.01	61.35	59.25	57.32
Post	31.51	27.55	27.64	32.65
SS				
Pre	35.85	36.87	35.03	41.05
Post	34.87	34.54	35.02	36.87
LL				
Pre	50.91	50.31	54.46	52.99
Post	53.02	50.75	54.84	50.63
SSA				
Pre	129.7	130.8	129.8	133.5
Post	129.4	129.3	129.5	130.2
C7PL				
Pre	−29.79	−27.67	−25.81	−16.53
Post	−24.88	−27.92	−15.34	−19.77

Table 4 C7PL position in relation to the femoral heads of the patient as shown in Fig. 1

	++	+	balance	−	−
Global ($n = 62$)					
Pre	7	3	2	39	11
Post	8	1	0	49	4
Lenke 1 ($n = 38$)					
Pre	4	3	2	24	5
Post	3	0	0	31	4

Lenke 1 group. We found that only few patients were well balanced before surgery (only two patients for each group) and that after surgery there was an increasing amount of patients with slight imbalance behind (ten patients for the general group and seven for the Lenke 1 group).

Discussion

The purpose of this radiological study is to assess the sagittal spino-pelvic alignment in adolescents affected by idiopathic scoliosis before and after a posterior surgical correction and fusion.

A balanced posture is obtained when the spine and the pelvis are aligned so that energy expenditure is minimized. Sagittal spinal alignment has been reported in several studies, because thorough knowledge of the normal anatomy is the key when evaluating patients with spinal

pathologies. More recently, major efforts have also been undertaken to study sagittal sacro-pelvic alignment, in accordance with the intimate link that exists between the spine and sacro-pelvis. Pelvic morphology, as measured by the pelvic incidence angle, tends to increase during childhood and adolescence before stabilizing into adulthood, most likely to maintain an adequate sagittal balance in view of the physiologic and morphologic changes occurring during growth. C7PL tends to move backward from childhood to adulthood, where it stabilizes or slightly moves forward secondary to degenerative changes [11].

PI is the most widely used parameter because it is directly related to PT and SS ($PI = PT + SS$). PI is an individual anatomical parameter and the higher its value, the greater is the ability of pelvic compensation.

In their evaluation on 341 normal children and adolescents, Mac-Thiong et al. have found mean PI values of $49^\circ \pm 11^\circ$, $8^\circ \pm 8^\circ$ for PT and $41^\circ \pm 8^\circ$ for SS [12].

In our series of 76 adolescents affected by AIS, we reported mean PI values of $48.89^\circ \pm 11.24^\circ$, as reported by Mac-Thiong for normal adolescents, with a mean pre-operative SS of $37.42^\circ \pm 8.72^\circ$ that is slightly lower than the $41^\circ \pm 8^\circ$ reported by Mac-Thiong [13].

After the surgery we observed a reduction in the mean values of SS to a mean value of $35.13^\circ \pm 9.02^\circ$, according to data reported by Roussouly et al. [8], with a consequent increase in PT.

The increasing amount of PT after surgery (delta pre-post = 2.38°) suggests the activation of pelvic compensation mechanisms to try to restore the balance of the spine.

If we consider the ideal value of PT that is 11.09° , we found that this value is quite the same as the pre-operative one, that is 11.51° . But if we compare the ideal value of PT with the mean post-operative one that is 13.89° , we found about 3° of difference (delta ideal-post = 2.76°) with a high statistic significance.

We can conclude that adolescents affected by scoliosis are more or less in an ideal condition of PT, which means that they do not have any compensatory mechanism, and that the correction surgery causes the activation of a compensatory mechanism in the pelvis.

The mean pre-operative LL was 49.76° that is about 9° less than the ideal value of 58.89° (delta ideal-pre = -9.13°), which means that adolescents affected by scoliosis are in a hypolordotic condition.

Surgery slightly increases the mean value of LL to 51.38° , which is always a lower value than the ideal situation calculated as 58.89° (delta ideal-post = -7.51°), meaning that after surgery patients still remain in a hypolordotic condition.

On comparing the ideal value of LL with the pre- and post-operative ones, we found a high significant difference for both parameters ($p < 0.0001$).

We can conclude that adolescents affected by scoliosis are hypolordotic and that they remains hypolordotic after the surgery with a difference from the ideal value of about 9° before and more than 7° after the surgery. Both differences from the ideal condition are statistically significant.

Our study documented also lower amount of thoracic kyphosis in the AIS population, compared with normal adolescents ($-30.4^\circ \pm 13.64^\circ$ vs. $-44^\circ \pm 10^\circ$) as reported by Mac-Thiong et al. [12]. Analogous values of thoracic kyphosis are reported by Roussouly also on AIS patients, supporting the hypothesis that hypokyphosis should be involved in the development of thoracic AIS [13].

In our population of adolescents affected by scoliosis, we found both pre- and post-operatively a high amount of hypokyphosis compared with the ideal value of TK calculated, that is -48.89° (delta, respectively, of 18.34° and 17.67°). The difference in both cases was statistically significant with a high correlation, which means that adolescents with scoliosis are hypokyphotic and remain so after surgery.

Considering the Lenke 1 subgroup, we found mean values of $50.54^\circ \pm 11.45^\circ$ for PI, $38.03^\circ \pm 8.13^\circ$ for SS, $52.77^\circ \pm 10.57^\circ$ for LL and $-28.13^\circ \pm 13.44^\circ$ for TK.

After surgical correction also in the Lenke 1 subgroup, there was a decrease in the mean values of SS to $35.73^\circ \pm 9.057^\circ$ with an increase in PT, as shown in the general group.

The reduction of SS observed in the post-operative period in both groups suggests that posterior surgery, done with hybrid or all screws construct, influences the pelvic alignment, increasing the mean values of PT. The increasing amount of PT coupled with the reduction of SS determines a pelvic retroversion; that is to say that surgery activates a series of compensatory mechanisms in the pelvis, the primary goal of which is to maintain the balance of the spine.

This finding is particularly true for the Lenke 1 curves and the hypokyphotic subgroup in which we observed mean PI values of 50.54° and of 51.9° , respectively, the highest values found in our series, suggesting that these patients were naturally predisposed to a higher possibility of pelvic compensation. In fact in these subgroups, we observed also the highest amount of reduction in the mean values of SS (delta = 4.18° for the hypokyphotic group; delta = 2.3° for the Lenke1 group) and consequently an important increase in the mean PT values as a compensatory mechanism (Table 3).

Considering the global spino-pelvic alignment, we found negative C7PL in the general assessment with mean pre-operative values of $-24.47 \pm 26.29^\circ$. C7PL in the general group remains substantially stable after surgery with a negative balance. In Lenke 1 and hypokyphotic subgroups, we instead observed a worsening of the

Fig. 2 Pre-operative clinical and radiographic assessment of a Lenke 1 curve. The clinical and radiographic lateral views showed a good sagittal balance of the spine

Fig. 3 Post-operative clinical and radiographic assessment of the patient shown in Fig. 2. The lateral views demonstrate a slight posterior imbalance of the spine

posterior imbalance with mean post-operative delta of 6.79 and of 3.24, respectively (Tables 2, 3).

In Table 4, we reported available data according to our new scheme of C7PL evaluation (Fig. 1). It reports the number of patient's balance and imbalance for the global assessment and for the Lenke 1 group before and after surgical correction of scoliosis. We found that only few patients were well balanced before surgery (only two patients for each group) and that after surgery there was an increasing number of patients with slight imbalance behind in both groups.

The posterior instrumentation adopted to treat AIS seems to create a posterior strength that at the end reduces SS and increases PT with a slightly posterior decompensation of the spino-pelvic balance particularly of C7PL (Figs. 2a–f, 3a–d).

Conclusion

The sagittal balance in the evaluation of AIS plays a key role in planning the best surgical strategy. Our experience suggests that adolescents affected by scoliosis are in a particular condition of slightly posterior imbalance.

The posterior surgical procedure, necessary to correct scoliosis, appears to act in the sense of a slight further posterior imbalance for all the patients and especially for Lenke 1 type curves and for patients with hypokyphosis. Fortunately, these patients are those that have the highest values of PI, as if nature had them naturally predisposed to a greater possibility of pelvic compensation. The clinical significance of this slight imbalance must still be carefully evaluated.

Further studies are necessary to better establish which could be the best surgical strategy to obtain an optimal spinal sagittal balance.

Conflict of interest None.

References

1. Duval-Beaupère G, Schmidt C, Cosson P (1992) A barycentric study of the sagittal shape of spine and pelvis: the conditions required for an economic standing position. *Ann Biomed Eng* 20:451–462
2. Legaye J, Duval-Beaupère G, Hecquet J et al (1998) Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. *Eur Spine J* 7:99–103

3. Mac-Thiong JM, Labelle H, Berthonnaud E, Dimar J, Betz R (2004) Sagittal alignment of the spine and pelvis during growth. *Spine* 29(15):1642–1647
4. Mac-Thiong JM, Labelle H, Charlebois M, Huot MP, de Guise JA (2003) Sagittal plane analysis of the spine and pelvis in adolescent idiopathic scoliosis according to the coronal curve type. *Spine* 28:1404–1409
5. Vialle R, Levassor N, Rillardon L, Templier A et al (2005) Radiographic analysis of the sagittal alignment and balance of the spine in asymptomatic subjects. *J Bone Joint Surg Am* 87(2):260–267
6. Roussouly P, Gollogly S, Berthonnaud E, Dimnet J (2005) Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. *Spine* 30(3):346–353
7. Barrey C, Roussouly P, Perrin G, Le Huec JC (2011) Sagittal balance disorders in severe degenerative spine. Can we identify the compensatory mechanism? *Eur Spine J* 20(Suppl 5):626–633
8. Roussouly P, Labelle H, Rouissi J, Bodin A (2012) Pre and post-operative balance in idiopathic scoliosis: a comparison over the ages of two cohorts of 132 adolescents and 52 adults. *Eur Spine J* (published on line November 2012)
9. Lenke LG, Betz RR, Harms J et al (2001) Adolescent idiopathic scoliosis. A new classification to determine extent of spinal arthrodesis. *J Bone J Surg Am* 83:1169–1181
10. Le Huec JC, Aunoble S, Leijssen P, Pellet N (2011) Pelvic parameters: origin and significance. *Eur Spine J* 20(Suppl 5):S564–S571
11. Mac-Thiong JM, Labelle H, Roussouly P (2011) Pediatric sagittal alignment. *Eur Spine J* 20(Suppl 5):586–590
12. Mac-Thiong JM, Labelle H, Berthonnaud E, Betz RR, Roussouly P (2007) Sagittal spinopelvic balance in normal children and adolescents. *Eur Spine J* 16:227–234
13. Dickson RA, Lawton JO, Archter IA et al (1984) The pathogenesis of idiopathic scoliosis: biplanar spinal asymmetry. *J Bone Joint Surg Br* 66:8–15