# Early dynamic changes within the spine following posterior fusion using hybrid instrumentation in adolescents with idiopathic scoliosis: a gait analysis study

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## Abstract

**Introduction** In adolescent idiopathic scoliosis (AIS) patients, mechanical consequences of posterior spinal fusion within the spine remain unclear. Through dynamic assessment, gait analysis could help elucidating this particular point. The aim of this study was to describe early changes within the spine following fusion with hybrid instrumentation in adolescents with idiopathic scoliosis, using gait analysis

**Materials and methods** We conducted a single-centre prospective study including AIS patients scheduled for posterior spinal fusion (PSF) using hybrid instrumentation with sublaminar bands. Patients underwent radiographic and gait analyses preoperatively and during early postoperative period. Among gait parameters, motion of cervicothoracic, thoracolumbar and lumbosacral junctions was measured in the three planes.

**Results** We included 55 patients (mean age 15 years, 84% girls). Fusion was performed on 12 levels and mean follow-up was 8 months. There was a moderately strong correlation between thoracolumbar sagittal motion and lumbosacral junction pre- and postoperatively ($R = -0.6413$ and $R = -0.7040$, respectively, all $p < 0.001$), meaning that the more thoracolumbar junction was in extension, the more lumbosacral extension movements decreased. There was a trend to significance between postoperative SVA change and thoracolumbar sagittal motion change ($R = -0.2550$, $p = 0.059$).

**Discussion** This is the first series reporting dynamic changes within the spine following PSF using hybrid instrumentation in AIS patients. PSF led to symmetrization of gait pattern. In the sagittal plane, we found that thoracolumbar extension within the fused area led to decreased extension at cervicothoracic and lumbosacral junctions. Even though consequences of such phenomenon are unclear, attention must be paid not to give a too posterior alignment when performing PSF for AIS patients.

**Keywords** Adolescent idiopathic scoliosis · Gait analysis · Posterior spinal fusion · Sublaminar bands · Hybrid instrumentation · Segmental analysis

## Introduction

Adolescent idiopathic scoliosis (AIS) is the most common spinal condition encountered in children and adolescents. It has been reported that 2–3% of the population was concerned by this three-dimensional spinal deformity [1]. Vertebral rotation is the princeps deformity, causing the classical S-shaped coronal deviation of the spine. Sagittal disorders are regularly seen, with frequent flattening of sagittal curvatures of the spine. AIS occurs during late childhood or adolescence, with a peak of progression during growth spurt. Nevertheless, it was reported that deformity can worsen during adulthood, especially when curve was very progressive during adolescence [2].

If so, surgical treatment is recommended to prevent curve worsening.

To date, posterior spinal fusion (PSF) is the gold standard treatment for progressive AIS. In addition of obtaining intervertebral fusion, it mainly aims to correct spinal coronal deformity. However, it is known that it is of major importance to restore sagittal plane as well, as sagittal malalignment has been reported to be the most disabling condition in adults [3]. Long-term effects of spinal fusion are satisfying even if some authors have raised concerns about disc degeneration appearing on MRI, most of the time without clinical symptoms [4]. However, mechanical consequences of such treatment within the spine remain unclear. Static assessment with standard radiographs appears to be incomplete to investigate this particular area [5]. Moreover, some of major radiographic parameters, such as sagittal vertical axis, seem to be uncorrelated to daily-life spine functioning, and therefore, may be misleading when trying to understand dynamic consequences of spinal fusion.

During the past 3 decades, quantitative gait analysis has been largely developed. Several studies show its ability to describe trunk motion [6, 7]. Some authors have described gait impairment in AIS patients, either preoperatively or after spinal fusion [8–12]. But to the best of our knowledge, most of reported results used protocols considering the spine as a unique rigid segment, whereas in reality, this is a polyarticular chain. In 2012, we developed a gait analysis protocol able to catch motion within the spine by adding 4 markers to the classic Helen Hayes protocol [13]. This protocol has shown good reproducibility and reliability to classical radiographic parameters [14, 15].

Therefore, the aim of this study was to describe early changes within different spinal segments following spinal fusion with hybrid instrumentation in adolescents with idiopathic scoliosis, using gait analysis.

## Materials and methods

### Ethics statement and study design

From 2017 to 2019, we conducted a single-centre prospective study. Prior to inclusion, we obtained approval from our institutional ethics committee. Informed consent was obtained from patients and their legal representative. We enrolled patients aged under 18 years and scheduled for surgical correction of AIS. In our institution, protocol calls for surgery when Cobb angle is over 45° in the thoracic area and 35° in the lumbar area. Patients with previous spine surgery, history of major trauma or orthopaedic condition or transitional vertebrae were excluded from our study.

### Surgical procedure

Patients underwent surgical correction using posterior spinal fusion with hybrid instrumentation (Fig. 1). Distal limit of fusion was set at the stable vertebra. A standard midline posterior approach was performed. Bilateral lamino-laminar claw was set on the two upper instrumented vertebras. Then pedicle screws were inserted in the lumbar area, and two 5.5 titanium rods were connected. In the thoracic area, sublaminar polyester bands were passed at every thoracic vertebra, connected to the concave rod and finally gradually tightened

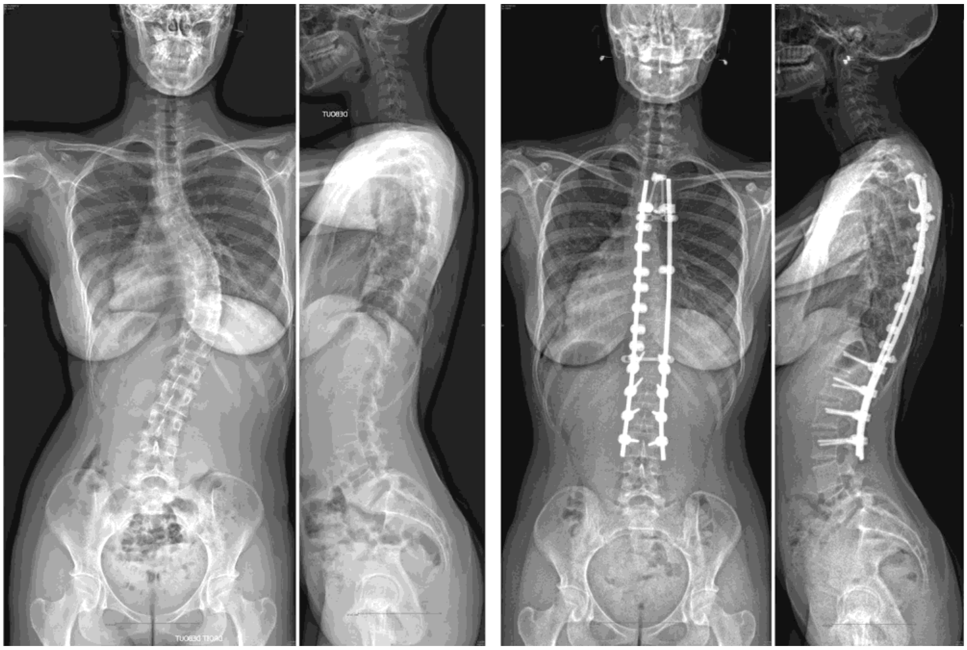

**Fig. 1** Clinical example of a 16-year-old adolescent girl before (left) and after surgical correction using hybrid instrumentation (right). The surgery lead to an increase of thoracic kyphosis by 20° associated with a coronal correction rate of 74%

to pull the spine in a posteromedial direction (posteromedial translation technique). First erect was allowed from postoperative day 1 and early rehabilitation was started. Patients were not asked to wear a brace postoperatively.

## Study protocol

Patients underwent radiographs and gait analysis the day before surgery and at early postoperative stage, between 3 and 12 months after surgery. Several parameters were measured on full standing anteroposterior and lateral radiographs. On AP view, we assessed Cobb angles, the Coronal Vertical Axis (CVA) and clavicle angle, and on lateral view, the Sagittal Vertical Axis (SVA), the C2–C7 cervical lordosis, the T2–T12 thoracic kyphosis, the L1–S1 lumbar lordosis, the T10–L2 thoracolumbar lordosis and finally pelvic parameters (pelvic incidence, pelvic tilt and sacral slope).

Concerning gait analysis, we used the 36 marker-protocol we described in 2012, including 6 markers for spine assessment. Markers motion was caught by 6 HiRes infrared cameras. Patients were asked to walk barefoot on a 9-m walkway, at a self-selected speed. Several parameters were measured (Fig. 2). In the frontal plane, we measured Dynamic Thoracic and lumbar Cobb angle and Dynamic CVA. In the sagittal plane, we assessed Dynamic Thoracic kyphosis, Dynamic Lumbar lordosis, Dynamic Pelvic tilt and Dynamic SVA. Finally, in the transversal plane, we measured Dynamic Shoulder-line rotation, Dynamic Pelvic

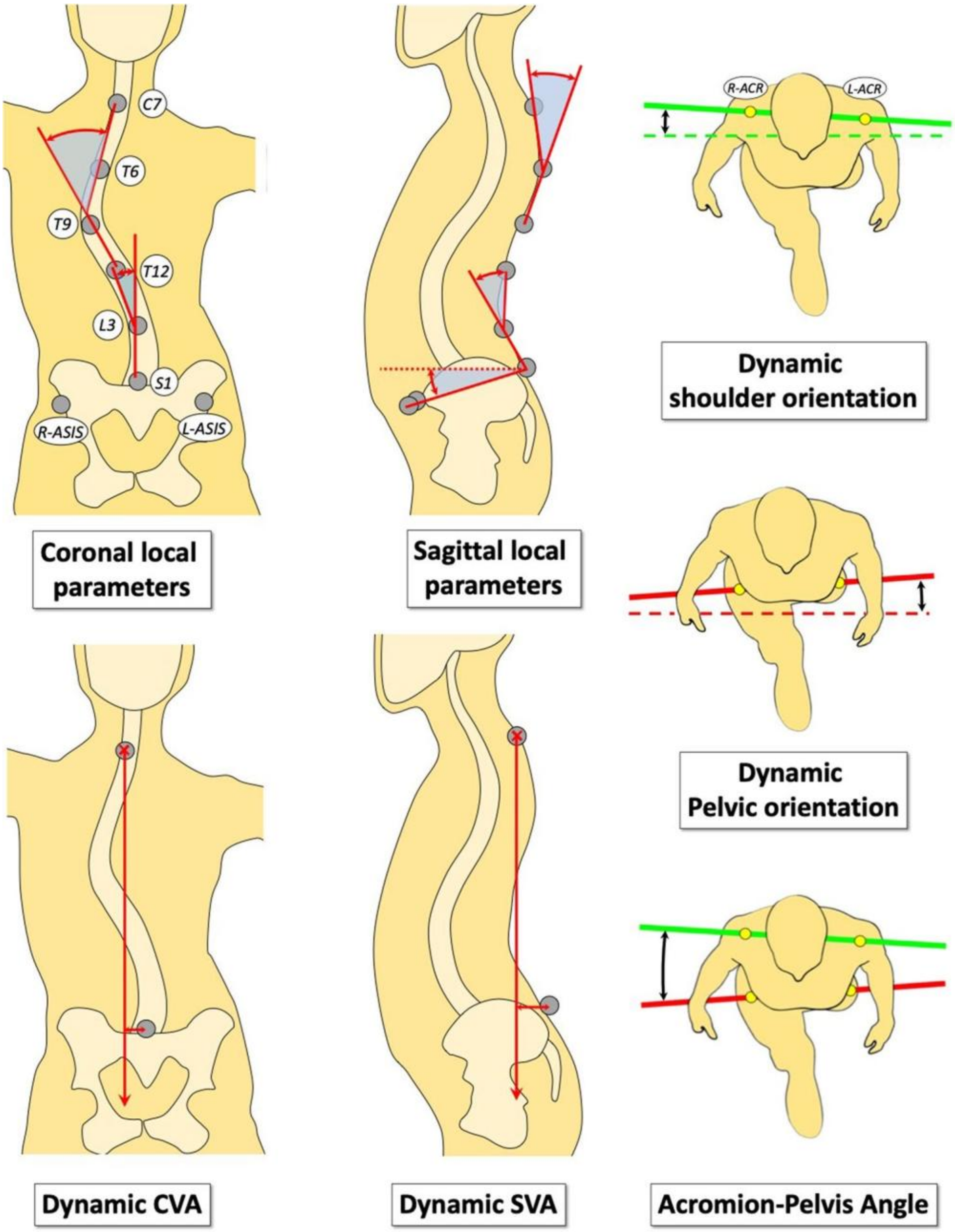

**Fig. 2** Gait parameters calculating using the Blondel et al. protocol

rotation and Acromio-Pelvis Angle (APA). In addition, spine parameters were measured at the cervicothoracic (CTh), thoracolumbar (ThL) and lumbosacral (LS) junctions in the 3 planes of the space: coronal (lateral bending), sagittal (flexion–extension) and transversal (torsion). CTh was the relative motion of Vertex-C7 line with regards to C7–T12 line; ThL was the relative motion of C7–T12 line with regards to T12–S1 line; and LS was the relative motion of T12–S1 line with regards to the pelvis.

### Statistical analysis

Values are presented as means and ranges. As previously reported, there is no difference between right and left gait cycles for trunk parameters in AIS patients [16]. Therefore, by convention, gait parameters were measured at every percentage of the right gait cycle and averaged. For means interpretation, a value close to 0 reflected a symmetric gait pattern. The range of motion of gait parameters was calculated as the difference between the maximum and the minimum values that a parameter takes during a full gait cycle. Pre- to postoperative comparisons were performed using paired Student *t* tests. The influence of ThL extension on gait parameters was assessed using Pearson correlation tests. For statistical analyses, level of significance was set at 5% (i.e. $p < 0.05$).

## Results

### Study population

During the inclusion period, we recruited 55 patients. There were 46 females (84%), mean age was 15.4 years (±2 years). According to Lenke classification [17], there were 41 main thoracic curves (Lenke 1 or 2) (75%), 9 main lumbar or thoracolumbar curves (Lenke 5) (16%) and 5 double major curves (Lenke 3 or 6) (9%). Overall, 23 patients had a lumbar modifier A (42%) and 32 a lumbar modifier B or C (58%). Mean follow-up was 7.7 months (±3 months) and the average number of level fused was 11.8 (±2). Concerning fusion levels, 49 patients (91%) had the upper instrumented vertebra (UIV) located at T5 or higher. The lower instrumented vertebra (LIV) was L1 in 5 patients (9%), L2 in 11 patients (20%), L3 in 30 patients (55%) and L4 in 9 patients (16%).

### Radiographic parameters

Radiographic data are summarized in Table 1. The main Cobb angle significantly improved from 60° to 23° ($p < 0.001$), representing a mean correction rate of 62%. Thoracic kyphosis was restored from 25° preoperatively to 40° postoperatively ($p < 0.001$).

**Table 1** Results from radiographic analysis

| | Preop | Postop | *p* |
|---|---|---|---|
| CVA (absolute value) | 13.5 (±9.2) | 11.2 (±8) | 0.071 |
| Main Cobb angle | 60.2 (±12.8) | 22.8 (±8.1) | **<0.001** |
| Proximal curve Cobb angle | 32.2 (±10.8) | 14.9 (±10.7) | **<0.001** |
| Distal curve Cobb angle | 35.8 (±12.9) | 18 (±9.4) | **<0.001** |
| Clavicle angle | 1.9 (±1.7) | 3.6 (±2) | **<0.001** |
| SVA | | | |
| C2C7 lordosis* | − 9.1 (±17) | 6.4 (±18.4) | **<0.001** |
| T2T12 kyphosis | 24.6 (±12.8) | 40.3 (±11.8) | **<0.001** |
| L1S1 lordosis | 56.3 (±12.5) | 61.1 (±9) | **0.001** |
| T10L2 lordosis | 2 (±12.6) | 13.9 (±8) | **<0.001** |
| Pelvic incidence | 49.1 (±10.4) | 49.9 (±11.1) | 0.619 |
| Pelvic tilt | 5.7 (±7.6) | 6.4 (±7.8) | 0.246 |
| Sacral slope | 43.5 (±9) | 43.5 (±7.8) | 0.510 |

Bold values indicate statistical significance under 5%

*Negative values indicate kyphosis

### Gait data

Results from gait analyses are presented in Tables 2 and 3.

1. Coronal plane

    There was an improvement of trunk global balance during gait with a more symmetric gait pattern (decrease of mean dynamic CVA from 14 to 10 mm, $p = 0.007$). Thoracic and lumbar dynamic Cobb angles improved. On the other hand, we found no change in shoulder line coronal inclination. Within the spine, PSF mainly lead to a symmetrization of coronal motion at LS junction (from 5.3 to 0.9°, $p < 0.001$).

2. Sagittal plane

    There was a significant decrease of trunk anterior tilt (SVA decrease from 45 to 39 mm, $p = 0.036$). PSF led to a slight pelvic anteversion (9.9° vs. 11.3°, $p = 0.012$). Within the spine, thoracolumbar junction showed less flexion than preoperatively (− 9.1 vs. − 6.5°, $p = 0.005$). There was a significant negative correlation between thoracolumbar change and lumbosacral change ($R = -0.6158$, $p < 0.001$), meaning that extension at the thoracolumbar junction led to flexion at the lumbosacral junction (Fig. 3). There was a strong correlation between thoracolumbar sagittal motion and lumbosacral junction pre and postoperatively ($R = -0.6413$ and $R = -0.7040$, respectively, all $p < 0.001$), meaning that the more thoracolumbar extension increased, the more lumbosacral extension decreased (Fig. 4). In a lesser proportion, the same relation was found between cervicothoracic and thoracolumbar junctions preoperatively ($R = -0.3963$, $p = 0.002$). Of note, the relation was not significant anymore postoperatively ($R = -0.2092$, $p = 0.112$). Finally,

**Table 2** Results of gait parameters statistical comparisons

| | Preop | Postop | *p* |
|---|---|---|---|
| Dynamic CVA** | − 3 (± 18) | − 3 (± 11.8) | 0.990 |
| Dynamic CVA *(absolute value)* | 14.1 (± 11.4) | 9.6 (± 7.8) | **0.007** |
| Dynamic shoulder line coronal inclination | 0.3 (± 3.1) | 0.2 (± 3.8) | 0.905 |
| Dynamic lumbar cobb angle** | − 8.3 (± 8.7) | 0.4 (± 5.2) | **< 0.001** |
| Dynamic thoracic cobb angle** | 11.7 (± 12.3) | − 4.7 (± 7.1) | **< 0.001** |
| Dynamic pelvis coronal inclination** | − 0.3 (± 1.8) | − 0.1 (± 1.5) | 0.499 |
| CTh coronal motion (inflexion) ** | − 4 (± 5) | − 2.6 (± 4.2) | 0.083 |
| ThL coronal motion (inflexion) ** | − 0.1 (± 1.5) | 0.5 (± 0.8) | **0.010** |
| LS coronal motion (inflexion) | 5.3 (± 4.1) | 0.9 (± 3.2) | **< 0.001** |
| Dynamic SVA | 44.5 (± 24.7) | 38.6 (± 20.1) | **0.036** |
| Dynamic lumbar lordosis | 18.7 (± 6.5) | 18.7 (± 5.8) | 0.932 |
| Dynamic thoracic kyphosis | 28.5 (± 7.1) | 26.8 (± 7.9) | 0.119 |
| Dynamic sagittal pelvic tilt | 9.9 (± 5.3) | 11.3 (± 4.6) | **0.012** |
| CTh sagittal motion (flexion–extension) * | − 5 (± 10) | − 6.5 (± 8.9) | 0.257 |
| ThL sagittal motion (flexion–extension) * | − 9.1 (± 8.9) | − 6.1 (± 7.6) | **0.005** |
| LS sagittal motion (flexion–extension) * | 10.6 (± 7.7) | 11.4 (± 7.4) | 0.328 |
| APA** | − 7.1 (± 5) | − 1.2 (± 4.3) | **< 0.001** |
| Dynamic shoulder line rotation** | − 5.9 (± 5.2) | − 1 (± 4.4) | **< 0.001** |
| Dynamic pelvis rotation** | − 1.2 (± 2.9) | − 0.2 (± 2.7) | **0.001** |
| CTh transversal motion (rotation) | 3.9 (± 4.3) | 1.3 (± 4.2) | **< 0.001** |
| ThL transversal motion (rotation) ** | − 2.2 (± 4.9) | 4.4 (± 4.5) | **< 0.001** |
| LS transversal motion (rotation) ** | 0.2 (± 4.3) | − 3.2 (± 3.6) | **< 0.001** |

Bold values indicate statistical significance under 5%. * Negative values indicate flexion. ** Negative values indicate deviation towards the left side

**Table 3** Range of motion (ROM) of gait parameters statistical comparisons

| | Preop | Postop | *p* |
|---|---|---|---|
| Dynamic CVA ROM | 26.4 (± 11.8) | 21.5 (± 8.1) | **0.011** |
| Dynamic shoulder line coronal inclination | 2.8 (± 1.5) | 2.3 (± 1) | 0.087 |
| Dynamic thoracic Cobb ROM | 7.3 (± 3.1) | 5.1 (± 2.3) | **< 0.001** |
| Dynamic lumbar Cobb ROM | 6 (± 2) | 5.8 (± 2.6) | 0.833 |
| Dynamic pelvis coronal inclination ROM | 7.6 (± 2.8) | 8.2 (± 3) | 0.155 |
| CTh coronal motion ROM (inflexion) | 4.2 (± 2.3) | 4.5 (± 2.1) | 0.748 |
| ThL coronal motion ROM (inflexion) | 0.8 (± 0.7) | 0.5 (± 0.4) | **0.029** |
| LS coronal motion ROM (inflexion) | 10 (± 3.8) | 7.6 (± 2.9) | **0.001** |
| Dynamic SVA ROM | 24.9 (± 7.5) | 27.2 (± 7.8) | 0.072 |
| Dynamic thoracic kyphosis ROM | 4.5 (± 2.2) | 2.2 (± 1.2) | **< 0.001** |
| Dynamic lumbar lordosis ROM | 4.7 (± 2.1) | 3.7 (± 2.4) | **0.020** |
| Dynamic sagittal pelvic tilt ROM | 2.9 (± 1.2) | 2.9 (± 1) | 0.973 |
| CTh sagittal motion ROM (flexion–extension) | 4.9 (± 3.1) | 4.9 (± 2.7) | 0.931 |
| ThL sagittal motion ROM (flexion–extension) | 2.7 (± 1.2) | 1.9 (± 0.6) | **< 0.001** |
| LS sagittal motion ROM (flexion–extension) | 4 (± 1.6) | 3.9 (± 1.3) | 0.658 |
| APA ROM | 11.8 (± 4.7) | 8.7 (± 3.4) | **< 0.001** |
| Dynamic shoulder line rotation ROM | 8 (± 2.8) | 7.5 (± 2.5) | 0.441 |
| Dynamic pelvis rotation ROM | 8.1 (± 3) | 7.4 (± 3.1) | 0.330 |
| CTh transversal motion ROM (rotation) | 4 (± 1.9) | 3.7 (± 1.7) | 0.186 |
| ThL transversal motion ROM (rotation) | 4.4 (± 1.9) | 3.5 (± 1.4) | **0.003** |
| LS transversal motion ROM (rotation) | 6.4 (± 2) | 6.7 (± 1.9) | 0.613 |

Bold values indicate statistical significance under 5%

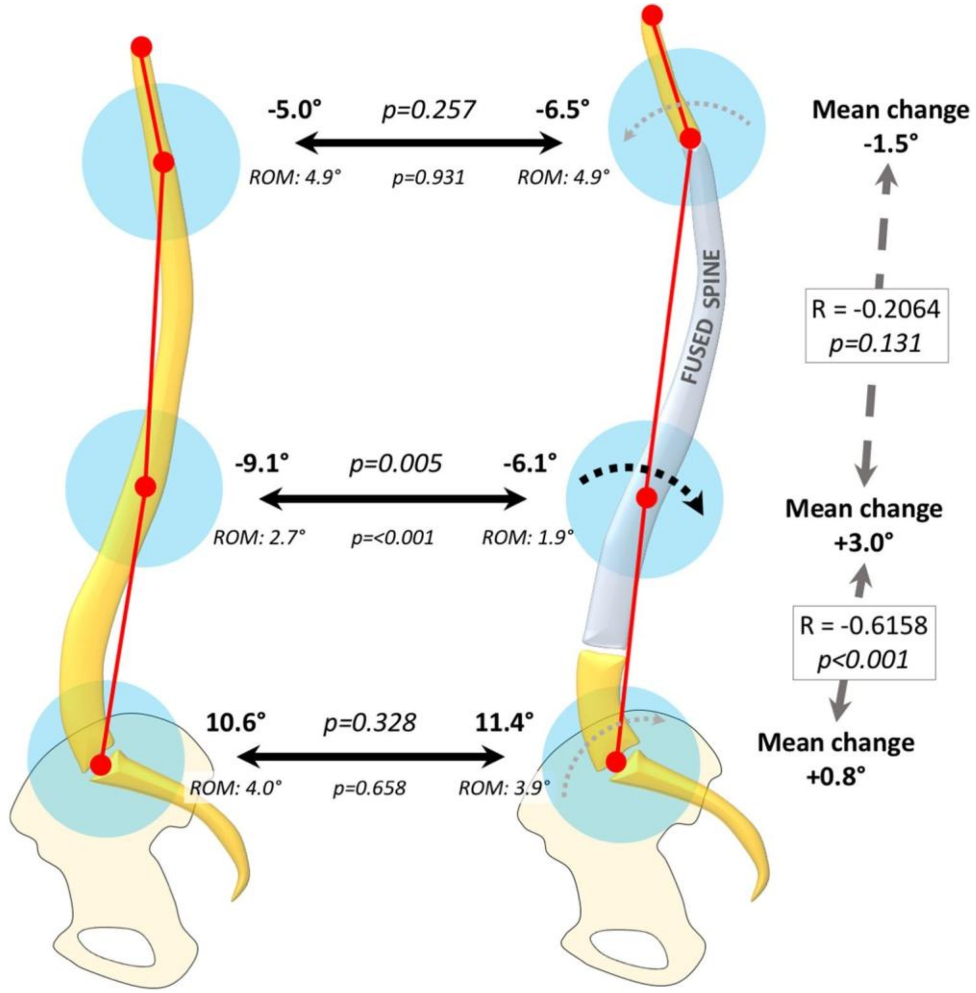

**Fig. 3** Schematization of changes within the spine in the sagittal plane following spinal fusion

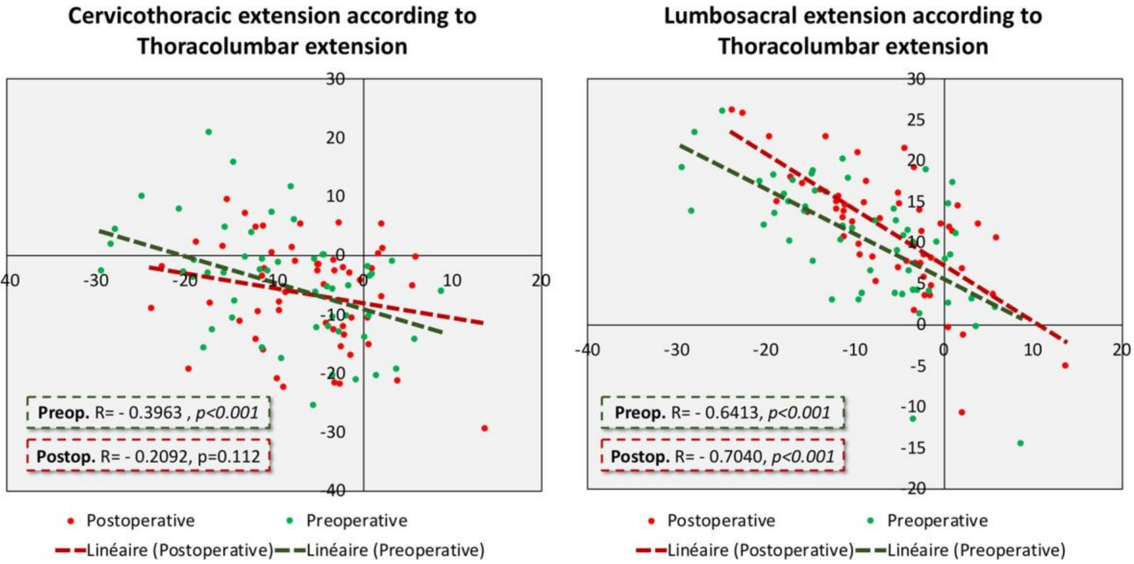

**Fig. 4** Influence of thoracolumbar junction sagittal motion and over and underlying junctions

there was a trend to significance between postoperative SVA change and thoracolumbar sagittal motion change ($R = -0.2550$, $p = 0.059$), meaning that SVA tended to decrease when thoracolumbar junction was extended after fusion.

3. Transversal plane

   All transversal parameters were significantly improved from a left-sided gait pattern to a symmetric gait pattern, with significant decrease of shoulder line and pelvis rotation and APA (Fig. 5).

4. Range of motion

   PSF led to global decrease of ROM (Table 3). This was particularly true in the thoracic area, with a decreased thoracic Cobb angle ROM (7.3 vs. 5.1°, $p < 0.001$), dynamic thoracic kyphosis (4.5 vs. 2.2°, $p < 0.001$) and APA ROM (11.8 vs. 8.7°, $p < 0.001$). Logically, ThL junction ROM significantly decreased in all 3 planes.

## Discussion

To the best of our knowledge, this is one of the largest series ever reported of postoperative analysis of AIS patients using gait analysis. Our results show that PSF led to significant improvement of kinematic parameters, especially in the transversal plane. Preoperatively, we found a typical AIS gait pattern, with the upper trunk rotated towards the left side reflected by negative APA and SL rotation. These results are consistent with previously published series [10, 12, 18–21]. Postoperatively, transverse plane kinematics were improved: APA and SL rotation were closest to 0 than preoperatively, being reflective of a symmetric gait pattern in the transversal plane. These results have been previously reported by some authors, but this is the first report of such results in hybrid technique. In the coronal plane, we found no improvement of global trunk balance. This is consistent with usual radiographic observations, as coronal balance improvement usually takes up to 2 years after surgery [22]. Our results suggest similar mechanisms for dynamic improvement. Indeed, we found a decreased lateral trunk imbalance but correction was incomplete and lateral imbalance remained. Longer follow-up will probably allow to prove coronal balance improvement, as shown by Lenke et al. with 2-year follow-up and Paul et al. who reported a decreased lateral excursion of the centre of mass following spinal fusion [23, 24]. In the sagittal plane, the main consequence of PSF was decreased anterior trunk tilt during gait, probably reflective of an "uncomfortable" gait due to stiffness secondary to surgery. However, it is difficult to know if this change in the sagittal motion is definitive. Indeed, the early follow-up makes that it is too early for the over

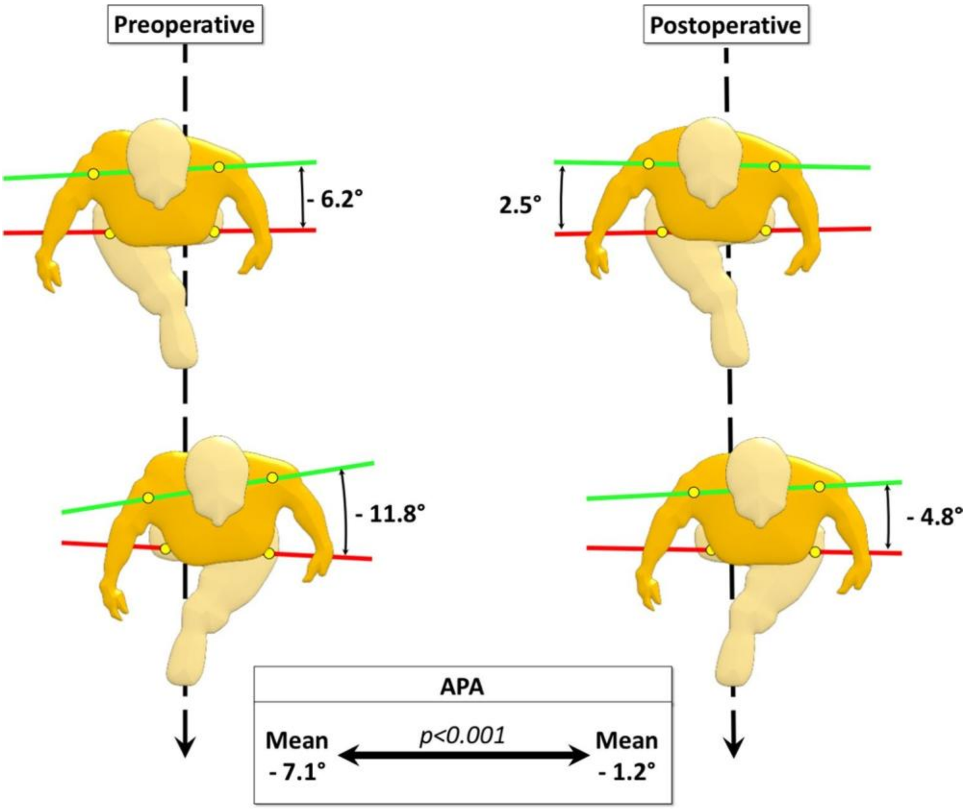

**Fig. 5** Improvement of transversal plane gait parameters following posterior spinal fusion

and underlying compensation mechanisms to occur. Further research involving patients with longer follow-up are necessary to understand how dynamic spinal balance will be modified by PSF.

To date, only few studies have reported consequences of PSF on gait in AIS patients [23–27]. Our results are quite in line with most of the previously reported series. Nevertheless, our protocol has the advantage of providing segmental assessment of the spine. At the cervicothoracic junction, there was a trend towards symmetric motion in coronal and transversal planes but no significant change in sagittal motion. At the thoracolumbar junction, we demonstrated changes in all the 3 planes, but the main changes occurred in the sagittal plane where decreased overall flexion of the spine was found. This was in line with our radiographic results, as in most of the cases, thoracolumbar junction was fused with more lordosis than at baseline. Of note, there was a clear relationship between thoracolumbar and lumbosacral junctions: thoracolumbar extension led to more lumbosacral flexion. Such phenomenon should call for further research, because of its potential implication in distal lumbar discs degeneration.

This was not true at the cervicothoracic junction postoperatively. However, thoracolumbar extension could become a concern as it could lead to compensatory cervicothoracic flexion. Our series taking place at the early postoperative stage could be the reason why this phenomenon was not observed here. Though, if confirmed, it could potentially be an explanation for mechanical complication such as proximal junctional kyphosis, which could appear as a compensatory mechanism for a too posterior sagittal alignment. However, this is purely hypothetical and further research should focus on shedding light on this point.

Our study has some limitations. First, we decided to include different scoliotic deformities, with thoracic and lumbar curves. This could be confusing, especially concerning coronal balance, as we previously demonstrated that thoracic and lumbar curves had opposite coronal imbalance. However, there were not enough lumbar curves in our series to perform subgroup analysis. On the other hand, we previously shown that transversal plane impairment was the same, wherever the curve was located. Second, the influence of LIV was not assessed because of the homogeneity of our population in terms of LIV location. In our cohort, LIV was relatively distal, which could be explained by the high proportion of Lumbar modifiers B or C. Multicentric study with more heterogeneity in LIV selection could help to shed light on this particular point.

In conclusion, this is the largest series reporting the results of gait analysis after PSF using hybrid instrumentation. We found significant improvement of gait parameters, especially in the transversal plane. However, this improvement occurred at the cost of decrease of range of motion of the thoracic spine. PSF also led to decreased anterior trunk tilt, but so far, the consequences of this phenomenon remain unclear. Further investigation is clearly necessary to understand the influence of too posterior dynamic balance on functional results after PSF.

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## Declarations

**Conflict of interest** The authors declare they have no conflict of interest related to this work.

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