



Are postoperative standing radiographs relevant before hospital discharge in adolescent idiopathic scoliosis?

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Abstract

Purpose Postoperative standing radiographs are usually performed before hospital discharge after AIS fusion. However, patients are often still painful and have not recovered yet their physiological balance. The aim of this study was therefore to evaluate the relevance of such early radiographs and more specifically investigate whether postoperative alignment could be analyzed.

Methods All consecutive AIS patients operated between January 2015 and December 2015 were included. All patients underwent biplanar stereoradiographs before hospital discharge, at 4 months postoperative and at last follow-up. Fifteen parameters (eight coronal and seven sagittal), reflecting correction and spinal alignment were measured and compared. The incidence of implant misplacement, requiring or not surgical revision, was recorded.

Results In total, 100 patients were included. A significant difference was found for 12 out of the 15 (80%) parameters between the first erect radiograph and the 4-month follow-up visit, including the CVA and the SVA, which are commonly used to assess postoperative alignment. Clavicle, UIV and LIV tilts also decreased significantly at 4 months postoperative. In opposition, no significant change occurred for the same parameters between the 4-month visit and latest follow-up. In nine patients, a pedicle screw was considered misplaced on the first radiograph, but all patients remained asymptomatic and no revision was performed.

Conclusion There is no need for additional immediate postoperative radiographs in AIS, if an intraoperative radiograph has already been taken. This finding could help reducing radiation exposure in immature patients and should be further studied in other etiologies.

Graphical abstract

These slides can be retrieved under Electronic Supplementary Material.

Measurements	Early X-ray	4-month postoperative	p value
Frontal plane			
Main Cobb angle (°)	10.0 ± 9.0	20.5 ± 9.2	p<0.05
Secondary Cobb angle (°)	15.2 ± 8.8	16.0 ± 7.8	0.09
CVA (mm)	15.0 ± 13.9	9.6 ± 9.1	p<0.05
T1 Tilt (°)	5.4 ± 4.0	5.1 ± 4.3	0.38
Clavicle Tilt (°)	3.2 ± 2.3	2.2 ± 1.8	p<0.05
LIV Tilt (°)	6.6 ± 4.5	5.7 ± 4.4	p<0.05
LIV Tilt (°)	5.2 ± 3.8	4.1 ± 3.5	p<0.05
Frontal angle of the first non instrumented lumbar disk (°)	2.3 ± 2.4	2.5 ± 2.5	0.39
Sagittal plane			
T1-T12 Kyphosis (°)	30.9 ± 9.7	39.4 ± 11.0	p<0.05
L1-L5 Lordosis (°)	30.1 ± 10.2	54.3 ± 9.7	p<0.05
SVA (mm)	10.0 ± 25.6	-4.8 ± 16.6	p<0.05
CAPE (mm)	29.7 ± 27.1	16.0 ± 39.0	p<0.05
Junctional Kyphosis (°)	6.1 ± 4.7	8.5 ± 4.3	p<0.05
Non instrumented lumbar (°)	31.1 ± 9.6	38.1 ± 10.5	p<0.05
Sagittal angle of the first non instrumented lumbar disk (°)	5.1 ± 3.2	6.3 ± 3.8	p<0.05

Keywords Adolescent idiopathic scoliosis · Posterior fusion · Spinal balance

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Extended author information available on the last page of the article

Introduction

The objective of spinal fusion in adolescent idiopathic scoliosis (AIS) is to restore both coronal and sagittal alignments, in order to provide satisfactory long-term functional outcomes [1–3]. Sagittal balance is to date mainly assessed by long-length standing radiographs, on which numerous spino-pelvic parameters can be measured [4]. There is currently a growing concern regarding radiation exposure in immature patients, and practitioners now have a tendency to limit imaging prescriptions in children and adolescents during follow-up [5–7]. In our current practice, scoliotic patients are evaluated twice a year using low-dose biplanar stereoradiographs (EOS Imaging, Paris, France) and usually undergo supine bending \pm traction films if surgery is considered [8]. During the spinal fusion procedure, two additional posteroanterior radiographs are performed on a radiolucent operating table: one at the end of exposure to analyze the frontal tilt of the planned lower instrumented vertebra (LIV) and confirm the instrumentation level, and a second one at the end of correction to assess T1, upper instrumented vertebra (UIV) and LIV residual tilts, but also to detect any implant misplacement [9].

Hospital stays are now reduced to 4–5 days in AIS, but standing radiographs are still traditionally performed before discharge. Most patients are still painful at that time, and the authors have noticed that analyzing postoperative alignment on such early radiographs was often challenging. The goal of this study was therefore to investigate the relevance of early standing postoperative radiographs after AIS posterior fusion.

Materials and methods

Patients

After IRB approval, all consecutive AIS patients (Lenke 1 to 6) who underwent posterior fusion between January 2015 and December 2015 were prospectively included. A minimum 2-year follow-up was required, and patients with previous spine or lower limb surgery were excluded. Patients were operated using hybrid constructs, combining lumbar pedicle screws (up to T11), thoracic sublaminar bands (from T4 to T10) and autostable claws for the proximal fixation (Zimmer Biomet, Warsaw, Indiana, USA, or Implanet, Bordeaux, France). No selective thoracic fusion was performed, and all LIV were located between L2 and L4.

Radiological measurements and analysis

Low-dose standing stereoradiographs were performed in all cases before hospital discharge (early X-ray), between the 4th and the 6th postoperative day, according to a previously reported protocol [10]. Subsequent clinical and radiological

follow-up visits were organized at 4 months postoperative, 1 year and 2 years after surgery. Frontal and sagittal alignments were evaluated before discharge, on the first postoperative evaluation and at latest follow-up.

A validated visualization tool (Carestream Health, Rochester, NY, USA) was used to measure angles and distances on digitalized radiographs from the picture archiving and communication system (PACS) [11]. Fifteen parameters assessing spinal alignment (eight coronal and seven sagittal, summarized in Table 1) were measured two times by the same experienced observer on each radiograph, and the mean value was kept for analysis. In addition, any case of implant misplacement or migration was recorded.

Statistical analysis

Radiological parameters were compared between the three evaluation periods using paired student *t*-tests (Excel, Addinsoft SARM, Paris, France). $P < 0.05$ was considered significant.

Results

Patients

One hundred AIS patients (89 girls and 11 boys) were included. Mean age at surgery was 16 years (± 2). According to Lenke's classification, there were 47 Type 1, 16 type 2, 15 type 3, 2 type 4, 17 type 5 and 3 type 6 [12]. The UIV was located on T2 or T3 in 88% (Fig. 1). The LIV was L2 for 27 patients, L3 for 50 patients and L4 for the remaining 23 cases. The mean length of hospitalization was 5 (± 1) days.

Radiological analysis

Significant differences between the early X-ray and the 4-month control were found for 12 out of the 15 radiological parameters measured (80%) (Table 2). In opposition, only three measurements were significantly modified between the 4-month radiograph and latest follow-up (Table 3). The most significant change occurred in the distal non-instrumented lordosis, but the difference only averaged 2.8° ($p < 0.05$).

Comparison between early X-ray and 4-month control showed that parameters analyzing global spinal balance in both coronal and sagittal planes (CVA, SVA and CAEPL) improved significantly over time (Table 3) (Figs. 2, 3). The main coronal parameters investigated (CVA and clavicle tilt) also significantly improved during the 4 months postoperative (Fig. 2). In opposition, all sagittal parameters reflecting the non-instrumented spine and the adjacent compensation above or below the fusion mass significantly increased (Fig. 3).

Table 1 Coronal and sagittal radiological measurements

Radiological parameter	Description
Coronal parameter	
Main and secondary Cobb angles	
CVA	Horizontal distance between the center of C7 and a vertical line through the middle of S1
Tilt of T1	Angle between the upper endplate of T1 and a horizontal line
Clavicles angle	Angle measured between a line through the lateral extremities of the clavicles and a horizontal line
UIV tilt angle	Angle measured between the upper endplate of UIV and a horizontal line
LIV tilt angle	Angle measured between the lower endplate of LIV and a horizontal line
Angle of the last non-instrumented intervertebral disk	Angle measured between the lower endplate of LIV and the upper endplate of LIV-1
Sagittal parameter	
T1–T12 thoracic kyphosis	
L1–L5 lumbar lordosis angle	
SVA	Horizontal distance between the vertical line from the center of C7 and the posterosuperior corner of S1
CAEPL	Horizontal distance between the posterosuperior angle of S1 and a plumb line drawn from the middle of the segment uniting external auditory canals
Junctional kyphosis: UIV – UIV + 2 angle	Angle measured between the upper endplate of UIV and the upper endplate of UIV + 2
Non-instrumented lordosis: LIV – S1 angle	Angle measured between the lower endplate of LIV and the upper endplate of S1
Angle of the first non-instrumented lumbar intervertebral disk	Angle measured between the lower endplate of LIV and the upper endplate of LIV-1

CVA Coronal vertical axis; CSVL central sacral vertical line; UIV upper instrumented vertebra; LIV lower instrumented vertebra; SVA sagittal vertical axis; CAEPL external auditory canal plumb line

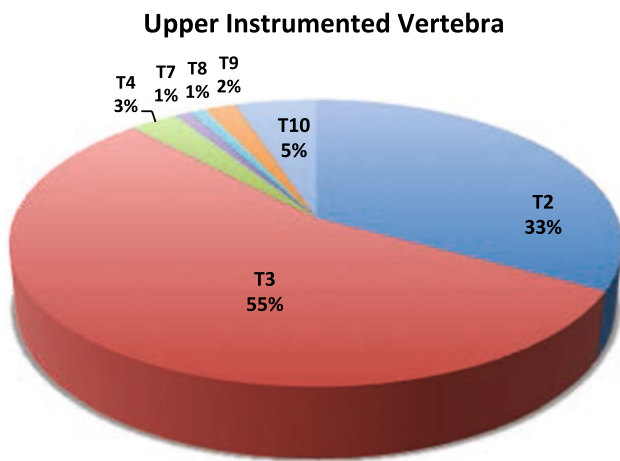


Fig. 1 Distribution of upper instrumentation level in the cohort

Results of the comparison between the 4-month and last follow-up examinations are summarized in Table 2. Parameters analyzing the global spinal balance in coronal and sagittal plane (CVA, SVA and CAEPL) were not significantly modified. The only three parameters that significantly

increased were: L1–L5 sagittal Cobb, the non-instrumented lordosis and the sagittal angle of the first non-instrumented lumbar intervertebral disk.

Implant misplacements

An implant misposition was reported in nine patients on the early X-rays (9%). Lumbar pedicle screws were involved in all cases, either too cephalad or too lateral, but no symptom was reported and none of them was changed because the LIV was properly instrumented in all cases. No modification of the intraoperative somatosensory/motor-evoked potentials occurred, and no neurological complication was recorded. No patient underwent revision surgery during the follow-up period.

Discussion

Goals of surgery

Most AIS patients are asymptomatic, and the surgical indication is often driven by patients’ cosmetic concerns. This

Table 2 Comparison between early X-ray and 4-month control measurements (mean \pm SD)

	Early X-ray	4 Months postoperative	<i>P</i> value
<i>Frontal plane</i>			
Main Cobb angle (°)	19.0 \pm 9.0	20.5 \pm 9.2	<i>p</i> < 0.05
Secondary Cobb angle (°)	15.2 \pm 8.8	16.0 \pm 7.8	0.09
CVA (mm)	15.0 \pm 13.9	9.6 \pm 9.1	<i>p</i> < 0.05
T1 tilt (°)	5.4 \pm 4.0	5.1 \pm 4.3	0.38
Clavicle tilt (°)	3.2 \pm 2.3	2.2 \pm 1.8	<i>p</i> < 0.05
UIV tilt (°)	6.6 \pm 4.5	5.7 \pm 4.4	<i>p</i> < 0.05
LIV tilt (°)	5.2 \pm 3.8	4.1 \pm 3.5	<i>p</i> < 0.05
Frontal angle of the first non-instrumented lumbar disk (°)	2.3 \pm 2.4	2.5 \pm 2.5	0.39
<i>Sagittal plane</i>			
T1–T12 kyphosis (°)	30.9 \pm 9.7	39.4 \pm 11.0	<i>p</i> < 0.05
L1–L5 lordosis (°)	50.1 \pm 10.2	54.3 \pm 9.7	<i>p</i> < 0.05
SVA (mm)	10.0 \pm 25.6	−4.8 \pm 16.6	<i>p</i> < 0.05
CAEPL (mm)	29.7 \pm 27.1	16.0 \pm 19.0	<i>p</i> < 0.05
Junctional kyphosis (°)	6.1 \pm 4.7	8.5 \pm 4.3	<i>p</i> < 0.05
Non-instrumented lordosis (°)	33.1 \pm 9.6	38.1 \pm 10.5	<i>p</i> < 0.05
Sagittal angle of the first non-instrumented lumbar disk (°)	5.1 \pm 3.2	6.3 \pm 3.8	<i>p</i> < 0.05

CVA Coronal vertical axis; UIV upper instrumented vertebra; LIV last instrumented vertebra; SVA sagittal vertical axis; CAEPL external auditory canal plumb line

Table 3 Comparison between 4-month control and latest follow-up measurements (mean \pm SD)

	4 Months postoperative	Latest follow-up	<i>p</i> value
<i>Frontal plane</i>			
Main Cobb angle (°)	20.5 \pm 9.2	21.3 \pm 9.2	0.37
Secondary Cobb angle (°)	16.0 \pm 7.8	16.5 \pm 9.0	0.14
CVA (mm)	9.6 \pm 9.1	8.5 \pm 7.7	0.19
T1 tilt (°)	5.1 \pm 4.3	5.5 \pm 4.0	0.40
Clavicle tilt (°)	2.2 \pm 1.8	2.1 \pm 1.9	0.58
UIV tilt (°)	5.7 \pm 4.4	6.1 \pm 4.2	0.06
LIV tilt (°)	4.1 \pm 3.5	4.2 \pm 3.9	0.80
Frontal angle of the first non-instrumented lumbar disk (°)	2.5 \pm 2.5	2.8 \pm 2.4	0.11
<i>Sagittal plane</i>			
T1–T12 kyphosis (°)	39.4 \pm 11.0	40.4 \pm 11.8	0.06
L1–L5 lordosis (°)	54.3 \pm 9.7	56.9 \pm 8.5	<i>p</i> < 0.05
SVA (mm)	−4.8 \pm 16.6	−11.1 \pm 24.6	0.051
CAEPL (mm)	16.0 \pm 19.0	9.6 \pm 23.1	0.053
Junctional kyphosis (°)	8.5 \pm 6.3	9.4 \pm 7.1	0.57
Non-instrumented lordosis (°)	38.1 \pm 10.5	40.9 \pm 8.9	<i>p</i> < 0.05
Sagittal angle of the first non-instrumented lumbar disk (°)	6.3 \pm 3.8	7.6 \pm 3.1	<i>p</i> < 0.05

CVA Coronal vertical axis; UIV upper instrumented vertebra; LIV last instrumented vertebra; SVA sagittal vertical axis; CAEPL external auditory canal plumb line

surgery remains at risk and many complications, such as proximal junctional kyphosis, distal junctional kyphosis and adding-on are partly iatrogenic, due to a wrong fusion level or unbalanced arthrodesis. The aim of surgery is therefore to obtain a mass of fusion centered over the pelvis, while

restoring the cosmetic aspect of the trunk and shoulders balance, and maintain or restore sagittal alignment, which has been correlated with long-term quality of life [13–16]. Despite the recent emphasis on sagittal analysis, respecting the frontal alignment is also of great importance, since

Fig. 2 Preoperative (a), early X-ray (b) and control at 4 months (c) after surgical correction of a Lenke 1 AIS, showing the spontaneous readjustment of CVA (from 14 to 4 mm) and clavicle tilt (from 18° to 3°)

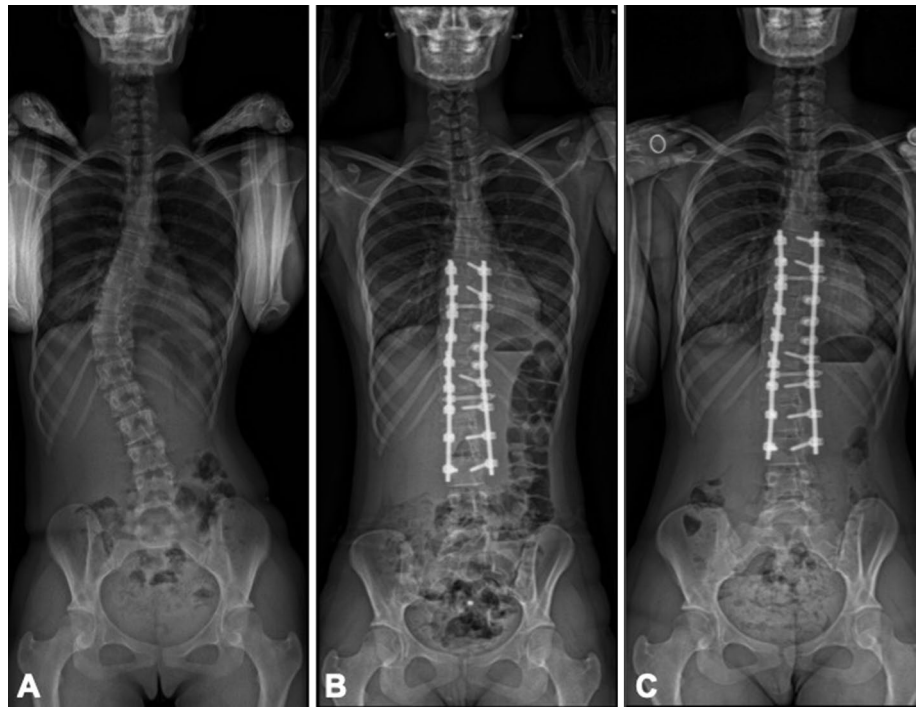
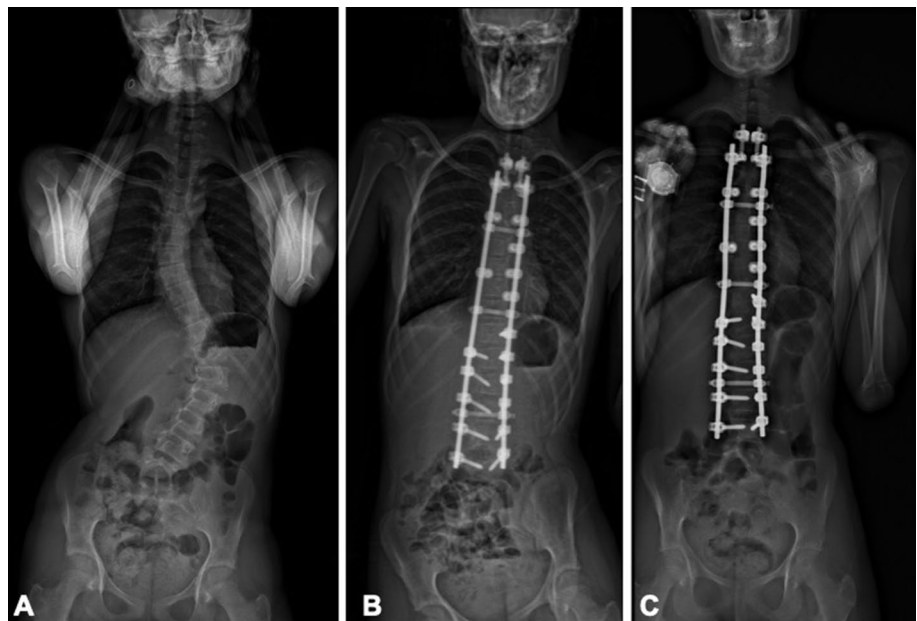


Fig. 3 Preoperative (a), early X-ray (b) and control at 4 months (c) after surgical correction of a Lenke 5 AIS, showing the spontaneous readjustment of CVA and clavicle tilt

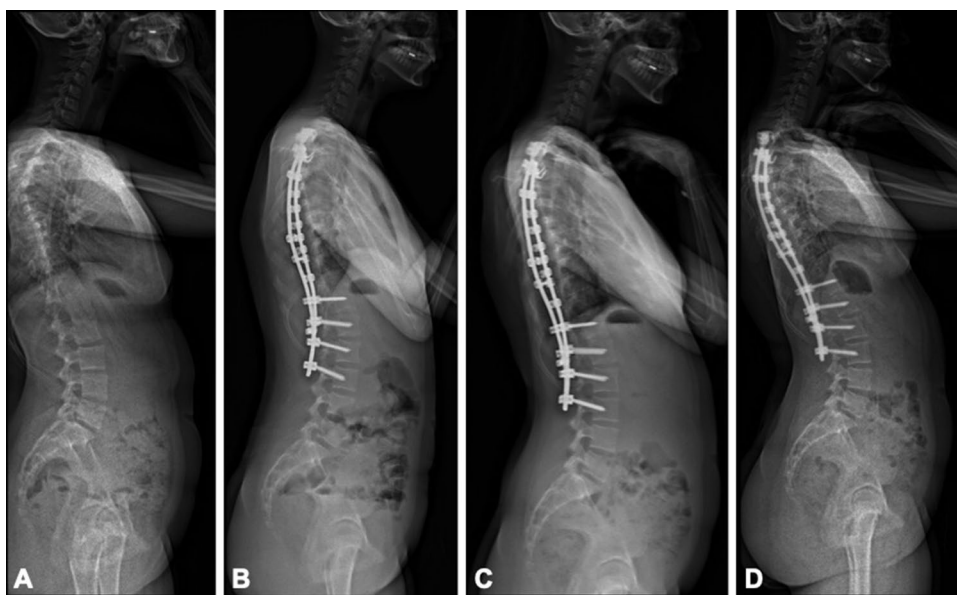


residual LIV tilts $>5^\circ$ or LIV translation >2 cm have been associated with higher risk of adding-on and distal disk degeneration [3, 16].

Unfortunately, the intraoperative radiological control of sagittal alignment remains currently insufficient, mainly limited by the feasibility of a long-length cassette X-ray, as well as the poor visibility of the upper thoracic spine, hidden by the shoulders and the arms. In opposition, posteroanterior radiographs during surgery have proved to be helpful during

surgery to adjust shoulders levels and residual frontal tilts at both ends of the construct [9]. They can also detect early implant misplacement, even without significant change in neuromonitoring that can lead to screw trajectory modification. This intraoperative frontal X-ray continues to be for us necessary and of great importance, but it clearly does not reflect the future global standing alignment and subsequent radiographs need to be considered to analyze postoperative balance. For that reason, and because we have since 2007

Fig. 4 Preoperative (a), early X-ray (b), control at 4 months (c) and 2 years (d) after surgical correction of a Lenke 1 AIS. It illustrates the spontaneous rebalancing backward of SVA, from 28 mm (b) to 0 (c) then to -15 mm (d) with a concomitant increase in non-instrumented lordosis, from 30° (b) to 42° (c) then to 48° (d)



a low-dose stereoradiographic system, EOS images were systematically acquired before hospital discharge. However, since the recent development of rapid recovery pathway (RRP) protocols, the average length of stay after AIS surgery has decreased in our department from 7–10 days to 4–5 days. Even though patients are capable to walk and stand still for couple minutes in the EOS system after 3 or 4 days, they are still under pain medication, and have not recovered yet their physiological balance. For that reason, and because high concerns have been expressed in young patients regarding radiation exposure and the risk of cancer, the relevance of such early radiographs has been progressively questioned [5–7, 17].

Relevance of radiological analysis before discharge

Results of the current study confirm that early X-rays performed before discharge are not relevant to analyze postoperative global spinal alignment. There is therefore no need for additional immediate postoperative radiographs, if an intra-operative X-ray has already been taken. Indeed, important parameters in both frontal and sagittal planes, such as CVA, SVA and CAEPL, were significantly modified between the first radiograph and the control at 4 months postoperative (Table 3). In opposition, these parameters remained stable over time after that period, without significant change at final follow-up.

The main finding was that patients initially had a tendency to reduce their lumbar lordosis, probably due to muscle pain, with subsequent anterior shift of both SVA and CAEPL. Patients progressively increased their lordosis in the unfused lumbar segments (5° on average) and reached their final alignment at 4 months (Tables 2 and 3, Fig. 3).

Similarly, T1–T12 kyphosis significantly increased during follow-up, mainly due to a 2.5° increase in the two segments above the UIV. This finding confirms that rates of PJK can efficiently be assessed at 3–4 months postoperative, when patients have found their final position above and below the fusion mass.

In the frontal plane, both UIV and LIV residual tilts significantly decreased during the first 4 months (Table 2), and the clavicle tilt reflecting shoulder balance also significantly improved. These parameters remained stable at latest examination. Despite the current findings, we still believe that the radiological assessment at 4 months remains necessary. First, the patient and his caregivers can visualize the spinal correction, which is a source of satisfaction. Second, some early radiological complications can be detected, such as PJK or distal adding-on, while they are still asymptomatic. Finally, it is important to be able to measure alignment parameters and therefore quantify postoperative outcomes (Fig. 4).

Limitations

The main limitation of this study is the lack of intra- and interobserver reliability assessment on radiological measurements. However, measurements were taken twice by an experienced spine surgeon, using a validated tool with image enhancement. In addition, the delay for postoperative X-rays was not standardized, and they were performed between the third and fifth day postoperative. For practical reason, the first radiological control after discharge was only performed at 4 months, so we were not able to determine the exact delay to recover a global alignment close to the definitive one. As a matter of fact, the unfused lumbar lordosis

continued to increase until final follow-up, and shoulders are known to readjust until 2 years postoperative. The gravity line, now assessable from EOS 3D reconstructions, was not used in the current study, but this parameter associated with a forces platform will be further studied [18–20].

In conclusion, intraoperative radiographs remain necessary to detect implant misplacements and verify that the objectives of surgical planning had been reached. However, early standing X-rays performed before discharge are not relevant to assess postoperative alignment in AIS and could be postponed to the first postoperative visit to reduce radiation exposure. The current findings are only applicable to idiopathic scoliosis but should be studied in other spinal deformities.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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