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REVIEW

Sagittal balance and idiopathic scoliosis: does final sagittal alignment influence outcomes, degeneration rate or failure rate?

Brice Ilharreborde[1]

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Abstract

Introduction In the last decade, spine surgeons have been impacted by the "sagittal plane analysis revolution". Significant correlations have been found in adult spinal deformity (ASD) between sagittal lumbo-pelvic parameters and functional outcomes, but most of them do not apply in adolescent idiopathic scoliosis (AIS). Meanwhile, instrumentation and reduction strategies have considerably evolved. This paper aims to describe the preoperative sagittal alignment in AIS, and to report literature evidence regarding the influence of postoperative sagittal balance on complication rates, low back pain incidence and disc degeneration.
Methods A bibliographic search in Medline and Google database from 1984 to May 2017 was performed. The keywords included 'adolescent idiopathic scoliosis', 'adult scoliosis', 'sagittal alignment', 'proximal junctional kyphosis', 'distal junctional kyphosis', 'outcomes', 'low back pain' and 'complication', used individually or in combination.
Results Algorithms of sagittal balance analysis and treatment decision have been reported in ASD, but the clinical situation is very different in children. Sagittal alignment greatly varies in AIS among the various Lenke types. Most patients are clinically balanced before surgery, but the spinal harmony is altered, with overgrowth of the anterior column and global sagittal flattening (undersestimated in 2D). The exact role of pelvic incidence and whether or not patients also use pelvic compensation to maintain balance still require further clarification. The incidence of radiological junctional failures remains highly variable, depending on definitions, cohort size and follow-up. Preoperative hyperkyphosis seems to be a consistent and relevant risk factor. Current literature does not support the recent trend to save motion segments (selective fusion), and no significant association was found between the distal level of fusion and the incidence of low back pain. Postoperative sagittal alignment seems to be more important than LIV selection to avoid disc degeneration at mid-term follow-up.
Conclusion It is clear now that sagittal alignment plays a major role in clinical outcomes and should not be neglected in AIS. Seven key guidelines that should be considered for each patient before surgery are reported (Table 2). Personalized planning using 3D technology is gaining popularity and might help in the future reducing complications.

Keywords Adolescent idiopathic scoliosis · Sagittal alignment · Review · Proximal junctional kyphosis, distal junctional kyphosis

Introduction

Several long-term outcome studies have recently questioned the impact of Adolescent Idiopathic Scoliosis (AIS) and its corrective surgery on patients' health-related quality of life (HRQOL) [1]. Indeed, self-image seems to be the only domain that clinically differs between untreated AIS and healthy controls, except for severe curves (3D Cobb > 80°, 3D thoracic lordosis and apical rotation > 25°) which can be associated with pulmonary restrictive syndrome [2–4]. Interestingly, evidence also suggests that the only domain that can be significantly improved after surgical correction is patient self-image, while the impact on other domains at long-term follow-up remains unclear [5]. There is, therefore, a real correlation between patients' expectations and the benefit of surgery, that might favor fusions for moderate curves, mainly for cosmetic reasons. However, one has to remember that most AIS patients are asymptomatic and

✉ Brice Ilharreborde
brice.ilharreborde@aphp.fr

1 Department of Pediatric Orthopaedic Surgery, Robert Debré Hospital, AP-HP, Paris Diderot University, 48 Bd Sérurier, 75019 Paris, France

balanced preoperatively, while corrective procedures always carry some risk. Except for neurological and infectious early complications, the most frequent critical situations to address at short and/or mid-term follow-up are due to iatrogenic sagittal misalignments, with proximal and distal junctional kyphosis (PJK and DJK, respectively). Their pathogenesis remains unclear and multifactorial, involving fusion levels selection, correction technique and approach, and finally postoperative sagittal alignment.

The main limitation to existing literature is that the field of AIS surgery has been in constant evolution since the use of Harrington rods in the 1970s. Oldest series always report outcomes of an obsolete surgical technique, and any relevant information on innovative techniques often suffers from limited follow-up. In addition, postoperative alignment is generally poorly described in long-term follow-up studies, since long-length standing radiographs were rarely used, and because most of the relevant lumbo-pelvic parameters of sagittal alignment analysis have only been adopted worldwide in the last 15 years [6–11].

The development and rapid expansion of pedicle screws in AIS after the mid-1990s have increased constructs stability, improving early postoperative care and fusion rates, but has also allowed the application of greater reduction forces with direct vertebral rotation techniques [12, 13]. However, this gain in frontal and axial corrections has been obtained at the expense of postoperative sagittal alignment [14–17]. As a matter of fact, all techniques emphasizing apical axial correction tend to place the anterior and convex higher vertebral wall in a more ventral position, thus increasing the length of the anterior column and therefore flattening the spine [18]. The spine community must admit that the increased complexity of AIS surgical correction procedures has been associated not only with better initial outcomes, but also with more postoperative complications [19]. For example, PJK was rarely described after CD instrumentation using hooks and hybrid constructs, while it is now considered a “hot topic” still not fully understood [20].

Algorithms of sagittal balance analysis and treatment decision have been reported in adult spinal deformity (ASD), but the clinical situation is very different in children [11, 21]. There is, therefore, a need to better describe and understand both the preoperative sagittal alignment in AIS as well as the impact of surgery and the subsequent consequences on functional outcomes and complications rates.

Methods

A bibliographic search in Medline and Google database from 1984 to May 2017 was performed. The keywords included ‘adolescent idiopathic scoliosis’, ‘adult scoliosis’, ‘sagittal alignment’, ‘proximal junctional kyphosis’, ‘distal junctional kyphosis’, ‘outcomes’, ‘low back pain’, ‘complication’ and ‘disc degeneration’, used individually or in combination. Relevant literature was analyzed, summarized, and discussed based on author’s experience.

Results

Preoperative sagittal alignment in AIS

The Lenke classification system, developed in 2001, is to date the most popular to provide a comprehensive and reliable means to categorize AIS and guide treatment. Major and minor curves are distinguished, and their structurality is mainly based on flexibility tests [22]. The only preoperative sagittal parameters included in the classification are segmental (T2T5 and T10L2 kyphosis), and three sagittal modifiers (+, − or N) have been described according to T5T12 kyphosis measurement. The sagittal assessment is, therefore, purely descriptive, and treatment recommendations do not take into account spinal and pelvic sagittal parameters. This might partly explain the high rate of rule-breakers (up to 26%), recently reported in a multicenter study [23].

We know from the adult literature that postoperative alignment needs to be properly restored to improve functional outcomes. In ASD, most patients have a progressive reduction of lumbar lordosis (LL), compensated by pelvic retroversion, a more or less flexible thoracic spine, and sometimes by lower limbs [24]. If compensation mechanisms are insufficient, anterior imbalance occurs, associated with cervical hyperlordosis and correlated to functional scores [21, 24].

The preoperative situation is not as clear in AIS, and does not correspond to any preoperative pattern described in adults [10]. In Lenke 3 and 4 curves, the overall sagittal alignment is often respected. In major thoracolumbar/lumbar curves (Lenke 5 and 6), the spine is translated posteriorly and laterally, resulting in a reduced lumbar lordosis and thoracolumbar kyphosis (Fig. 1). The most frequent and difficult curves to analyze remain Lenke 1 and 2 (main and double thoracic, respectively). As a matter of fact, most of the studies describe a thoracic spine flattening which is challenging to restore (Fig. 2) [25]. Even though most of the patients are clinically balanced, up to 50% of slight posterior radiological imbalance have been reported, especially in severe hypokyphotic patients, but the clinical relevance of such a finding in asymptomatic patients remains unclear [26, 27]. In opposition, Ries et al. recently analyzed the baseline sagittal profiles of 50 Lenke 1 and 2 AIS, and found no difference with age-matched controls prior to surgery, but this conclusion might be due to a smaller sample size [28].

Overall, it seems that most AIS patients are clinically balanced in the sagittal plane before surgery. However, the

Fig. 1 Anteroposterior and lateral standing radiographs of a Lenke 5 AIS curve with thoracolumbar kyphosis. The regional T10–L2 kyphosis should be restored (close to 0°) and the selected upper instrumented vertebra should not be located above a kyphotic disc (risk for proximal junctional kyphosis)

spinal harmony is altered, with overgrowth of the anterior column and global flattening of the sagittal alignment (undersestimated in 2D), traducing spinal compensation mechanisms [29–31]. The exact role of pelvic incidence, and whether or not patients also use pelvic compensation to maintain balance still require further clarification [27].

Influence of postoperative sagittal alignment on complications (PJK, DJK)

The rates of postoperative complications have increased with surgical procedures complexity [19]. Current literature in pediatric scoliosis is limited by the fact that modern reduction techniques have only started 30 years ago, with the development of CD instrumentation in 1984, which was the first system to allow sagittal alignment maintenance and/or restoration [32]. Previous long-term series, reporting Harrington distraction rods experience, were, therefore, able to focus on the influence of the distal level of fusion, but did not contribute to investigate the consequences of postoperative alignment on functional outcomes. Most recent all-pedicle screw or hybrid constructs are only 10–20 years old, and the spinopelvic sagittal analysis has considerably progressed during that period.

Ideal values for regional and global sagittal parameters are now determined to achieve good clinical outcomes in ASD. Restoring low sagittal vertical axis (< 40 mm) and pelvic tilt (< 20°) are critical goals, and must be combined with proportional lumbar lordosis to pelvic incidence (PI-LL < 9°) [21, 33, 34]. However, these goals cannot be transposed in the pediatric population, because patients are initially balanced and fusions never extend below L4.

The most frequent complications and/or failures after AIS surgery occur at the levels adjacent to fusion. Distal junctional kyphosis (DJK) has been reported since the beginning of Harrington rods experience, but still exists with modern instrumentation [35]. In a multicenter series of 375 patients with thoracic curves, Lowe et al. reported an incidence of 7% after anterior fusion and 14.6% after posterior correction. Except from the approach, the main risk factors identified were a residual T10L2 kyphosis, as well as the non-inclusion of the junctional level in the instrumentation [35].

Incidence of proximal junctional kyphosis (PJK) greatly varies in the literature, ranging from 0 to 46% in AIS

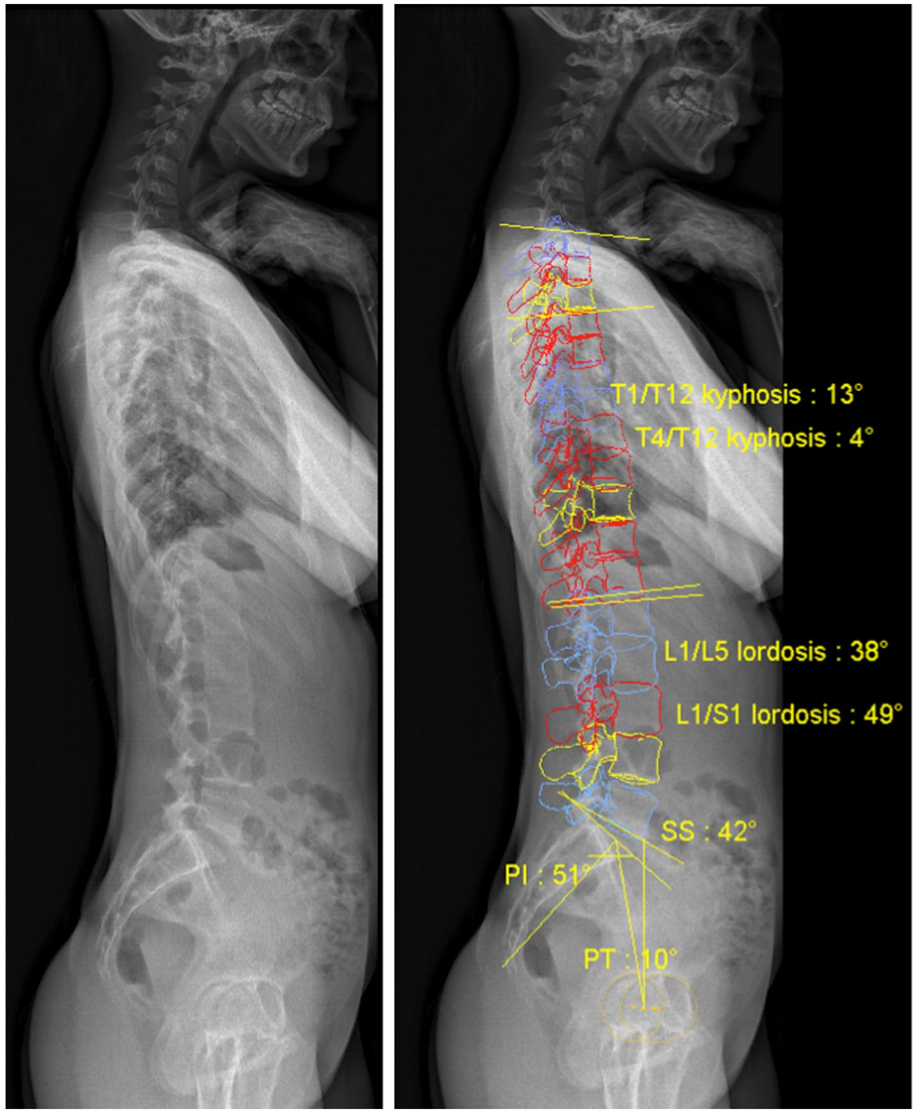

Fig. 2 Preoperative lateral radiographs and 3D reconstruction of a Lenke 1 AIS curve, with thoracic hypokyphosis and subsequent cervical and lumbar hypolordosis. Based on the pelvic incidence, L1S1 sagittal Cobb could be as high as 60°. The most difficult part of the sagittal correction will be the increase in T4T12 kyphosis. The gain in the upper lumbar lordosis (L1–L3) should be balanced and adapted to the latter, to avoid a posterior shift of the fusion mass, increasing the risk of proximal junctional kyphosis

[36–38]. This high variability can be explained by differences in radiological definition, instrumentation technique, cohort size and length of follow-up. In addition, proper measurement of the sagittal Cobb between the upper instrumented vertebra (UIV) and UIV + 2 is often difficult on standing radiographs, and the real PJK frequency is probably undersestimated [39]. However, few revisions for symptomatic PJK have been reported, and most authors agree that radiological PJK is not associated with poorer functional scores at short- and mid-term [36, 37]. The most significant risk factors are either patient related (male gender and high body mass index), or technique related (use of thoracic pedicle screws). Some technical issues, such as the resection of the interspinous ligament between the UIV and UIV + 1, or the type of rod material used for correction are still under investigation.

The most critical sagittal parameter to evaluate is the T5T12 sagittal Cobb. Patients with preoperative hyperkyphosis (Lenke's + sagittal modifier) seem to be at higher risk for PJK, especially if the thoracic sagittal alignment is flattened postoperatively (Fig. 3). In a recent multicenter study using mostly thoracic pedicle screws, Lonner et al. reported an overall PJK incidence of 7.05%, depending on Lenke types. In thoracic curves, they found that the risk of developing PJK increased by 7.1% with each lost degree of kyphosis compared with preoperation that occurred after the instrumentation was placed (Fig. 4) [20]. In Lenke 5 and 6 curves, PJK incidence was higher (8.5 and 11.6%, respectively) and the main risk factors were preoperative hyperkyphosis and a UIV more cephalad than the upper end vertebra (UEV). No significant correlation was found between sagittal pelvic parameters and PJK incidence. However, in our experience, selective lumbar fusions using all-pedicle screws have a tendency to increase the LL during the derotation maneuver, and surgeons must pay attention not to overcorrect the sagittal

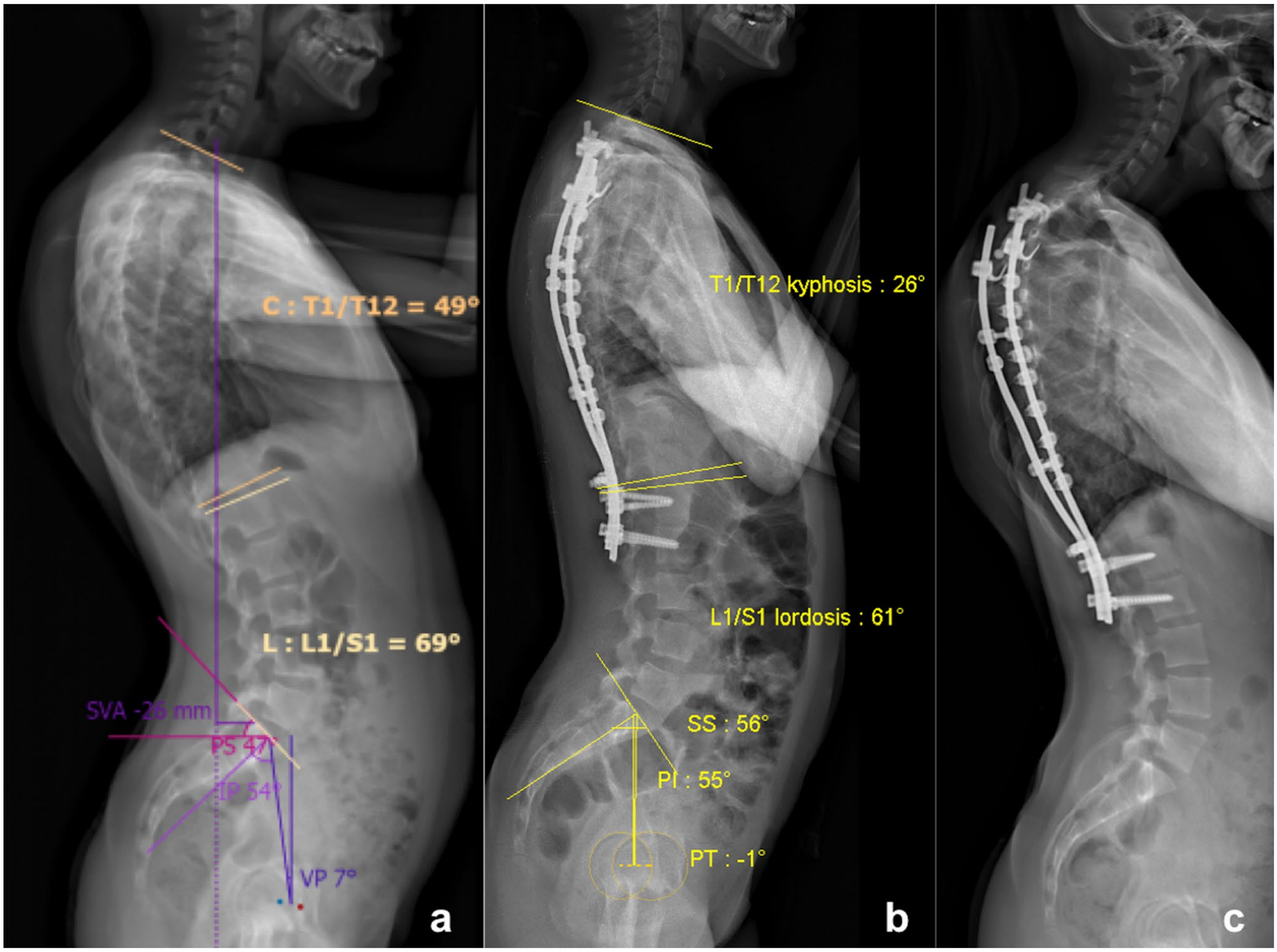

Fig. 3 Preoperative (**a**), early postoperative (**b**) and 6-month follow-up (**c**) lateral radiographs of a hyperkyphotic Lenke 1 AIS patient, who developed proximal junctional kyphosis (PJK) due to an excessive decrease of the preoperative T5T12 sagittal Cobb and a postoperative anterior shift of the upper instrumented vertebra

alignment of the lumbar spine, especially in patients with low PI (Fig. 5) [40].

Influence of postoperative sagittal alignment on low back pain

Anytime a long fusion is considered in adolescents, the main concern is the risk of long-term adjacent degeneration and subsequent low back pain (LBP). However, most of the series with more than 20 years of follow-up concluded that operated AIS had no more LBP than normal straight controls [41–44]. Literature, therefore, shows that surgery (both anterior and posterior approaches) has no demonstrable adverse effects on pain and mental health in middle-aged AIS patients. In addition, evidence does not support the natural tendency to try to save motion segments, and a recent meta-analysis found no significant association between the distal level of fusion and the incidence of LBP [45–47]. The only sagittal parameters that have been associated to date with poorer functional outcomes are thoracic flat back, that can be favored by pedicle screws, and postoperative anterior imbalance (so-called positive sagittal balance), but this situation remains rare after AIS surgery [41, 48].

MRI investigation of disc degeneration after AIS surgery

The most efficient method to investigate adjacent disc degeneration after a long fusion remains to date MRI investigation. Open MRI allowing standing position would be ideal but still suffers from limited access. Recent studies using supine MRI and standing radiographs tend to show that postoperative sagittal balance is more important than LIV selection at mid-term follow-up (5–10 years) [48, 49]. Indeed, Bernstein et al. showed that both postoperative anterior imbalance and thoracic hypokyphosis were significantly associated with greater disc degeneration on MRI at 7.5-year follow-up,

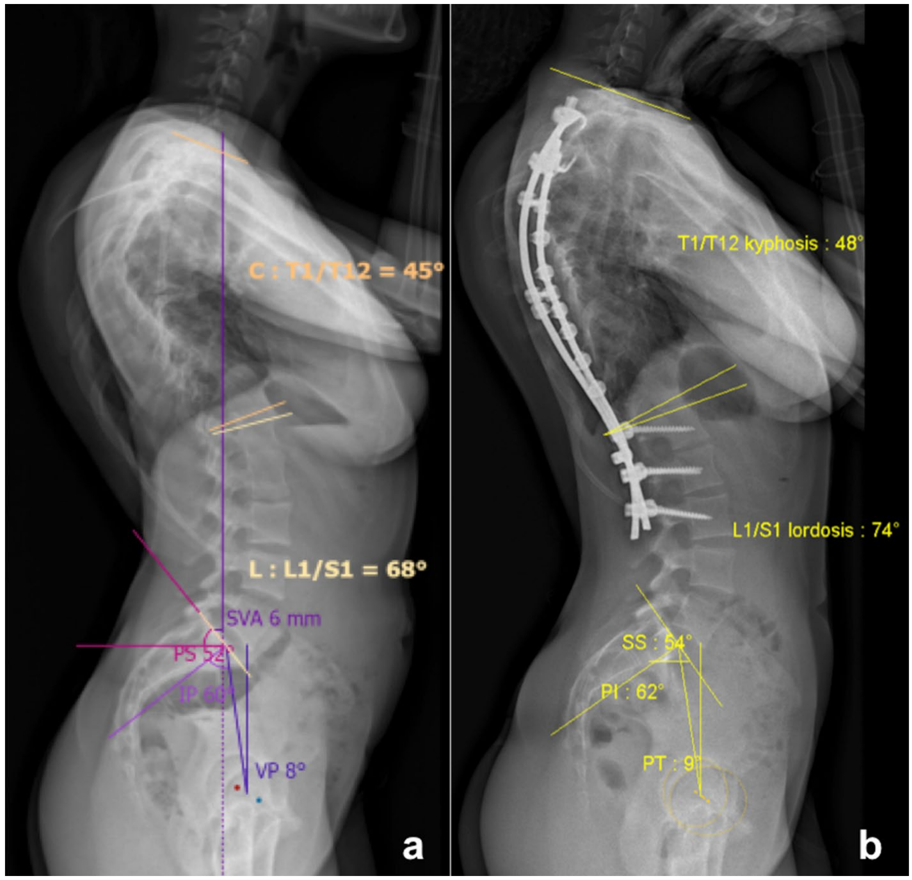

Fig. 4 Preoperative (**a**) and postoperative (**b**) lateral radiographs of a Lenke 1 AIS patient with initial + sagittal modifier, in whom hyperkyphosis was maintained after surgery and who did not develop proximal junctional kyphosis

warning against a potential deletery effect of pedicle screws [48]. Similarly, Perez-Grueso et al. found that if a physiological sagittal contour had been restored or maintained after surgery, no difference could be observed between operated AIS and normal controls in terms of degenerative change, quality of life and daily activities [50]. Interestingly, disc degeneration seems to be unrelated to LIV selection, and L5S1 remains the most affected segment, as in the general non-operated population. Green et al. only reported a moderate deterioration of the Pfirrmann score of uninstrumented levels (from 1.1 preop to 1.8 postop), even at 11-year follow-up after selective fusions ending on L1 [51].

Abelin-Genevois et al. reported a significant and sustainable improvement of disc hydration content after AIS surgery, especially in patients with low PI (< 55°) [52]. They also found that as in ASD, the restoration of the lumbo-pelvic congruence helped to limit early degenerative changes in the free-motion segments, emphasizing the role for preoperative PI analysis.

Discussion

Objectives of surgery in sagittal plane

Frontal plane analysis has been the center of attention for many years in AIS decision making, defining Cobb angles, end and apical vertebrae, and finally Lenke's type. It is clear now that sagittal alignment plays a major role in clinical outcomes and should not be neglected in AIS. Many different clinical situations exist under this condition, and the answers to the three preoperative questions proposed by Le Huec et al. are, therefore, summarized in Table 1 [11].

The main current issue in AIS remains the lack of physiological sagittal parameters values in healthy controls, mostly for ethical reasons; so the goals to reach after surgery are still unclear and deducted from adult literature. The objectives described by Schwab et al. in ASD can obviously not be simply transposed to AIS [21]. As a matter of fact, fusions never extend to the pelvis and rarely below L4; so the influence on pelvic tilt and the 2/3 of the lumbar lordosis (below L4) remains limited. In addition, creating a postoperative imbalance greater than 4 cm in a previously balanced patient seems almost impossible for an experienced AIS surgeon.

Fig. 5 Differences in postoperative lumbar sagittal alignment between a patient with high pelvic incidence (62°) (**a**) and one with low pelvic incidence (41°) (**b**)

Table 1 Answers for the AIS population to the three preoperative questions proposed by Le Huec et al. [11]

Preoperative questions to address	Answers from literature in AIS
What is the pelvic incidence?	Greatly varies, but should be considered to restore lumbo-pelvic congruence
Is the patient balanced?	Yes in the sagittal plane
Are there compensatory mechanisms?	None sometimes (Lenke 3C and Lenke + sagittal modifier) or only spinal Attention must be paid to thoracolumbar kyphosis in Lenke 5, 6 cervical kyphosis, T5T12 hypokyphosis and lumbar hypolordosis in Lenke 1, 2, 3A–B, 4

Table 2 Preoperative recommendations regarding sagittal alignment for AIS surgical planning

Recommendations	Rationale
Primum non nocere	Patients are preoperatively balanced, so any significant change in postoperative sagittal alignment can generate junctional problems
Measure pelvic incidence	Lumbo-pelvic congruence should be respected or restored in order to avoid back pain and disc degeneration. Lumbar lordosis should not be overcorrected in patients with low PI
Fusion should end caudally above a lordotic disc	Higher risk of DJK have been reported when the junctional level is not included in fusion
Consider T1T4 sagittal alignment for UIV selection	Higher risk of PJK exists when UIV is located below a hyperkyphotic T1T4 segment
Restore T5T12 kyphosis as much as possible	Thoracic flat back is associated with poorer outcomes and lower pulmonary function
Respect spinal harmony	The respective corrections of thoracic kyphosis and lumbar lordosis should be equivalent, and the inflection point (transition lordosis-kyphosis) should be located between T10 and L1. T10–L2 sagittal Cobb should be around 0°
Do not shift the fusion mass posteriorly	Recent 3D studies including axial views show that any mismatch between thoracic and lumbar alignment restoration tend to shift the UIV posteriorly, with greater risk of PJK

PJK proximal junctional kyphosis, *DJK* distal junctional kyphosis, *UIV* upper instrumented vertebra, *PI* pelvic incidence

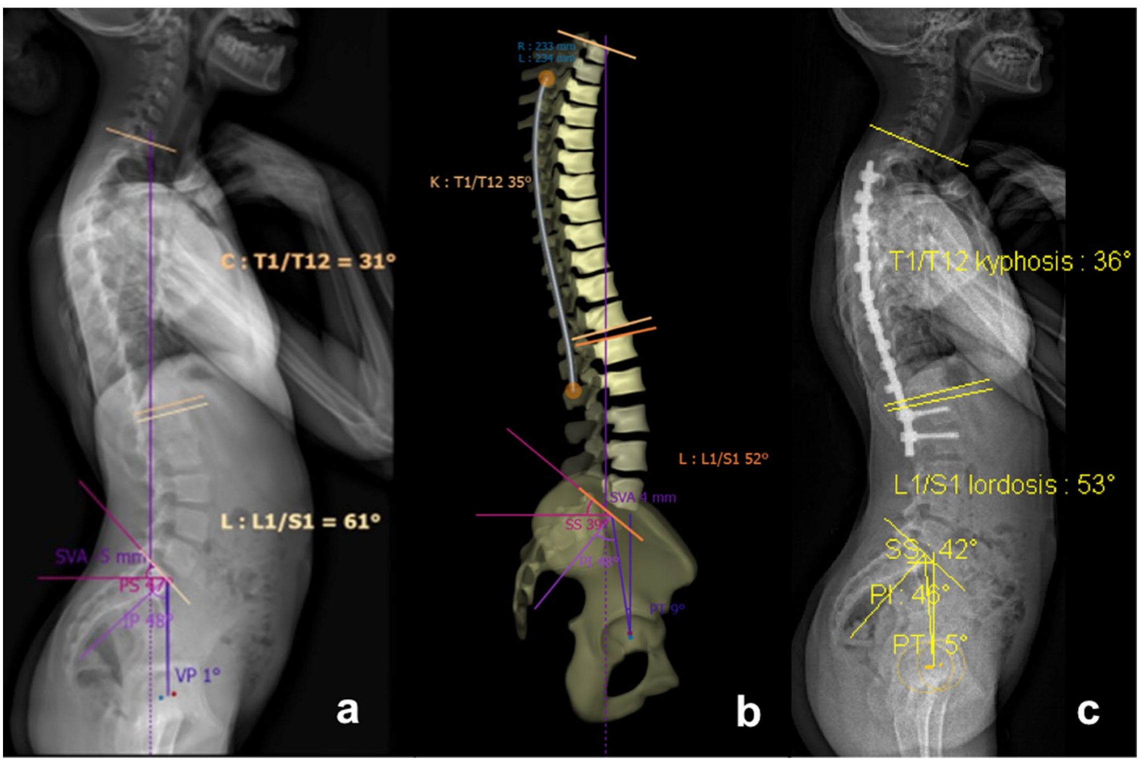

Fig. 6 Preoperative (**a**), surgical planning (**b**) and postoperative (**c**) lateral views of a Lenke 1 AIS patient using SpineEOS software (EOS Imaging, Paris, France)

Based on literature analysis, some recommendations for preoperative planning in regards to sagittal alignment can, therefore, be proposed (Table 2). These seven key guidelines should be considered for each patient to choose the optimal and most appropriate surgical technique (approach, implant, reduction strategy).

Future directions to improve planning and outcomes

In the last decade, the spinal deformity community has been impacted by the so-called "sagittal plane analysis revolution", which has led to the development of complex osteotomies [53]. Some significant correlations have been found in ASD between sagittal lumbo-pelvic parameters and functional outcomes, but most of them do not apply in

AIS surgery. More references are still needed in children for physiological values and long-term outcomes after correction with modern techniques, to better understand and address the stakes of sagittal alignment restoration. Appropriate and personalized preoperative planning is essential, and can be helped by new imaging technologies, such as EOS low-dose system allowing 3D axial views and reconstructions (Fig. 6) [54]. Illes et al. have described the vectors method, in which each vertebral body is represented on a "top view" by an arrow illustrating its location and rotation [55]. The method can be very helpful to better understand the effect of surgery and might be used in the future to clarify the pathogenesis of PJK. In addition, assessment of preoperative sagittal flexibility and accurate intraoperative control of sagittal correction are still lacking and should be studied. Finally, the correction of thoracic hypokyphosis remains challenging and pedicle screws are not efficient in this indication [56]. Some innovative techniques such as the use of sublaminar bands or super-elastic Nickel–Titanium rods require further attention and investigation [57–59].

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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