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ORIGINAL ARTICLE

# Restoring the ideal Roussouly sagittal profile in adult scoliosis surgery decreases the risk of mechanical complications

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## Abstract

**Purpose** There are still no data proving whether restoring the ideal sagittal profile (according to Roussouly classification) in adult scoliosis (AS) patients leads to any additional benefit, especially regarding mechanical complications.

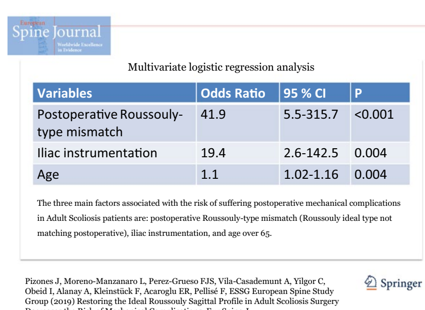
**Methods** Retrospective analysis of operated AS patients recorded in a prospective multicenter database. Demographic and radiographic (preoperative and 6-week postoperative) data were analyzed. Patients with and without mechanical complications were compared looking especially at the surgical restoration of the ideal (based on Pelvic Incidence) sagittal profile. Univariate and multivariate analysis was performed to identify causes of mechanical complications at 2-year minimum follow-up.

**Results** Ninty-six AS patients were analyzed. Thirty-nine patients suffered a mechanical complication (18 PJK, 11 pseudoarthrosis, 10 screw pull-out), and 57 patients had no mechanical complications. Postoperatively, 72% of patients not matching the ideal Roussouly-type suffered mechanical complications compared to 15% of matched patients ($P<0.001$). Univariate analysis showed that older patients 64.9 ± 13 versus 40.7 ± 15.6 years ($P<0.001$), higher postoperative Global Tilt (27° vs. 14.7°) and Pelvic Tilt (25° vs. 16°) ($P<0.001$), upper instrumented vertebra at the thoracolumbar junction (62% vs. 21%) ($P<0.001$), fixation to the Iliac (76% vs. 6%) ($P<0.001$), and postoperative Roussouly-type mismatch (72% vs. 15%) ($P<0.001$) significantly increased the rate of mechanical complications. Multivariate logistic regression analysis selected: postoperative Roussouly-type mismatch (OR = 41.9; 95%CI = 5.5–315.7; $P<0.001$), iliac instrumentation (OR = 19.4; 95%CI = 2.6–142.5; $P=0.004$), and age (OR = 1.1; 95%CI = 1.02–1.16; $P=0.004$), as the most important variables.

**Conclusions** Adult scoliosis surgery should restore the ideal Roussouly sagittal profile to decrease the rate of mechanical complications, especially in patients older than 65, instrumented to the pelvis.

## Graphical Abstract

These slides can be retrieved under Electronic Supplementary Material.



**Electronic supplementary material** The online version of this article (https://doi.org/10.1007/s00586-019-06176-x) contains supplementary material, which is available to authorized users.

Extended author information available on the last page of the article

**Keywords** Adult scoliosis · Roussouly classification · Sagittal profiles · Mechanical complications · Adult deformity surgery

## Introduction

Adult scoliosis (AS) deforms the spine in the three dimensions. Frontal deformity received all our attention in the past, with coronal correction being the principle concern. The apical rotation component depends on the etiology, which is usually greater in idiopathic deformities. Rotation affecting the thoracolumbar junction typically creates a rotational kyphosis in that particular segment, altering the sagittal profile. Adult scoliosis is deeply affected by the lower end vertebrae rotatory listhesis. Thus, when the lower end disk fails, the frontal plane eventually collapses [1]. Surgical correction should try to address all these three dimensions [2–5].

These last years, we are giving special attention to the sagittal plane deformity. Lumbar degeneration decreases lordosis, modifying the sagittal alignment [6], pushing the patient out of the conus of economy [7], and changing patient's ideal (based on pelvic incidence—PI-) sagittal profile [8–10]. The thoracolumbar rotational kyphosis of degenerative scoliotic curves is able to change the ideal Roussouly sagittal profile, flattening the upper arch of the lordosis, modeling a different lordosis distribution [2]. So in one-third of AS patients, degeneration and deformity modify patient's ideal sagittal profile dictated by PI [11].

Thus, there is an increasing interest in restoring the proper sagittal profile in adult deformity to improve patient's quality of life [5, 12] and decrease the rate of mechanical complications [3, 5, 10, 13]. On the other hand, it is known that patients with mainly coronal deformity improve principally because of coronal correction, as sagittal alignment is rarely affected preoperatively [14]. However, even assuming this fact, our hypothesis is that if the sagittal shape distribution is not adequately addressed in AS surgery, it could have an impact on the clinical outcomes and on mechanical complications. There is still no data proving the benefit of placing the AS patient back to its ideal sagittal profile.

The objective of our study was to determine whether surgically restoring the ideal sagittal profile of AS patients according to the Roussouly 4-sagittal profile classification could decrease the incidence of mechanical complications.

## Methods

We conducted a retrospective analysis of prospective data collected in an adult international multicenter deformity database European Spine Study Group (ESSG). This database includes patients ≥ 18 years of age, having a coronal spinal curvature ≥ 20°, or sagittal vertical axis (SVA) > 5 cm, or a pelvic tilt > 25°, or thoracic kyphosis > 60°. Institutional review board approval was obtained at each participating institution prior to patient enrollment into the database.

The database was searched to identify patients operated on adult scoliosis (AS), with no missing data, and a minimum 2-year follow-up. Other types of scoliosis were excluded: neuromuscular, congenital, and syndromic, as well as previously operated patients. The group was later divided into patients with and without mechanical complications.

Several variables were collected. Age and scoliosis etiology (following the three types established by Aebi [1]) were recorded. Preoperative and immediate postoperative (6 weeks) sagittal radiographs were analyzed by a trained research coordinator and a senior surgeon using the KEOPS® (SMAIO, Lyon, France) software to measure different variables. When discrepancies arose, a consensus was taken by both coauthors after thorough discussion.

Pelvic parameters (PI—pelvic incidence, PT—pelvic tilt, SS—sacral slope), lumbar L1-S1 lordosis (LL), thoracolumbar kyphosis (T10-L2 angle), L4-S1 angle, the number of vertebrae included in the lordosis (NVL), the lumbar sagittal apex (which divides upper and lower lumbar arches), and the inflexion point (the cranial vertebra in the transition between lordosis and kyphosis) were also recorded. Lumbar mismatch was calculated as PI-LL. With the LL and the L4-S1 angle, the percentage of L4-S1 contribution to the total lordosis was calculated as the lordosis distribution index (LDI) [15].

With all the collected data, patients were classified following Roussouly's sagittal shape classification in four types [8]. The ideal sagittal profile of each patient was determined by his/her PI, as published by Laouissat [9]. Being PI considered a constant parameter, no matter whether deformity or surgery changes this ideal shape, PI still dictates the ideal shape the patient should have: type 1 and 2 corresponded to PI < 45°, type 3 to PI between 45°–60°, and type 4 to PI > 60°.

Afterward, we analyzed the preoperative sagittal profile (the one the patient has with the coronal deformity), and the postoperative sagittal profile (which is the one restored after surgery). If these profiles did not match the ideal sagittal profile that the patient was supposed to have, patients were then considered as unmatched from ideal.

Sagittal unmatched patients differ from the ideal standard values on the following parameters that conform each Roussouly sagittal profile: sacral slope, inflexion point, lumbar sagittal apex, number of vertebrae in the lordosis, and lordosis distribution LDI, and the sagittal shape will then differ from the original drawings published by Roussouly [8]. Standard normal values of these parameters for each Roussouly-type are shown in Table 1, as reported previously in the literature [9, 11, 16].

Instrumented levels were also recorded with special attention to the upper (UIV) and lower instrumented levels (LIV). The presence and type of mechanical complications were documented (PJK—proximal junctional kyphosis, pseudoarthrosis/rod brakeage, screw pull-out/brakeage). The following Patient Recorded Outcomes Measures (PROMs) were prospectively collected preoperatively, and at 6 months, 1 year and 2 years postoperatively: (ODI, SF-36, and SRS-22).

We analyzed the influence of the different variables in the incidence of mechanical complications, by comparing the groups with and without complications.

Statistical analysis was carried out using the SPSS software (version 20, SAS Institute Inc., Cary, NC). The distribution of variables was given as mean and standard deviation. Agreement between the distribution of the different types comparing "ideal" and "postoperative" sagittal profiles, was performed using Chi2 and applying McNemars-Bowker test. Normality of the variables was tested using Kolmogorov–Smirnov test. Univariate analysis was performed comparing qualitative variables using the Chi-square test, and quantitative variables using Student's t test. The significance threshold was set at 5% ($P<0.05$). We performed multivariate logistic regression analysis with backward stepwise regression methods to determine the importance of different variables affecting mechanical complications. For regression analysis, we gave the odds ratio (OR) and 95% confidence interval.

## Results

In total, 96 AS patients were analyzed. Thirty-four patients were classified as type 1 (primary degenerative scoliosis), 54 as type 2 (progressive idiopathic scoliosis), and 8 as type 3 (secondary degenerative scoliosis) (Table 2). The mean age of the whole sample was 50.5 ± 18.8 years. Forty-seven patients were instrumented to the pelvis (Iliac fixation), while 49 had the LIV above sacrum (L2-L5). Forty-five patients had the UIV at the thoracolumbar (ThL) junction (T9-L2), while 51 patients had it at the upper thoracic segment (T2-T5). Thirty-nine patients suffered a mechanical complication (18 PJK, 11 pseudoarthrosis/rod breakage, 10 screw pull-out/breakage) during the postoperative follow-up (mean 284 days, range 7–1016), and 57 patients did not suffer any mechanical complication.

The rate of mismatches between postoperative and ideal sagittal profiles was 44.8% (43 patients). 72% of postoperatively unmatched patients suffered mechanical complications compared to 15% of postoperatively matched patients

**Table 2** Preoperative baseline data from the whole cohort

| Variable | Mean or % | SD |
|---|---|---|
| Age (years) | 50.55 | 18.8 |
| Main thoracic Cobb angle (°) | 37 | 23.8 |
| Lumbar Cobb angle (°) | 43.9 | 19.4 |
| Global tilt (°) | 23.13 | 16.5 |
| PI-LL mismatch (°) | 3.9 | 18.9 |
| Pelvic incidence (°) | 55.8 | 13.7 |
| Pelvic tilt (°) | 20.52 | 10.6 |
| Sacral slope (°) | 35.4 | 13.7 |
| *Preoperative sagittal profile* | | |
| Roussouly-type 1 (%) | 36.5 | |
| Roussouly-type 2 (%) | 21.9 | |
| Roussouly-type 3 (%) | 17.7 | |
| Roussouly-type 4 (%) | 24 | |
| *Coronal curve etiology* | | |
| Type 1 degenerative scoliosis (%) | 35.4 | |
| Type 2 idiopathic scoliosis (%) | 56.3 | |
| Type 3 secondary scoliosis (%) | 8.3 | |
| *Upper instrumented vertebra* | | |
| Proximal Th (T2-T5) (%) | 53.1 | |
| ThL junction (T9-L2) (%) | 46.9 | |
| *Lower instrumented vertebra* | | |
| Iliac (%) | 49 | |
| Above iliac (%) | 51 | |

*PI-LL* pelvic incidence minus lumbar lordosis

**Table 1** Ideal values of the different parameters that conform each Roussouly sagittal profile

| Roussouly-type | PI | SS | LL | NVL | LDI (%) | Lumbar Apex | Inflexion point |
|---|---|---|---|---|---|---|---|
| 1 | < 45° | < 35° | 45° | 3 | 90 | L5 | L3 |
| 2 | < 45° | <35° | 50° | 4 | 80 | L4-5 disk | L2 |
| 3 | 45°–60° | 35–45° | 55° | 5 | 70 | L4 | L1 |
| 4 | > 60° | > 45° | 65° | 6 | 60 | L3-4 disk | T12 |

*PI* pelvic incidence, *SS* sacral slope, *LL* lumbar lordosis, *NVL* number of vertebrae in the lordosis, *LDI* lordosis distribution index

**Table 3** Comparison of postoperative parameters

| | Mechanical complications | No mechanical complications | *P* value |
|---|---|---|---|
| *Sagittal parameters* | | | |
| Pelvic incidence (°) | 55.1° ± 13.6 | 56.7° ± 12.8 | 0.538 |
| Pelvic tilt (°) | 25.4° ± 8.8 | 16.4° ± 9.7 | 0.000* |
| Sacral slope (°) | 29.3° ± 11.4 | 40° ± 10.3 | 0.000* |
| PI-LL mismatch (°) | 6.9° ± 16.4 | 2° ± 20.1 | 0.217 |
| Global Tilt (°) | 27.1° ± 13.7 | 14.7 ± 10.6 | 0.000 * |
| *Postoperative sagittal profile matching* | | | |
| Match | 15.1% | 84.9% | 0.000* |
| Unmatch | 72% | 27.9% | |
| *Upper instrumented vertebra* | | | |
| Proximal Th (T2-T5) | 21.6% | 78.4% | 0.000* |
| ThL junction (T9-L2) | 62% | 37.8% | |
| *Lower instrumented vertebra* | | | |
| Iliac | 76.6% | 23.4% | 0.000* |
| Above iliac | 6.1% | 93.9% | |
| *Postoperative Roussouly-type* | | | |
| Higher than ideal | 77.4% | 22.6% | 0.000* |
| Same as ideal | 15.1% | 84.9% | |
| Lower than ideal | 58.3% | 41.7% | |
| *Postoperative lumbar apex* | | | |
| Cranial from ideal | 55.6% | 44.4% | 0.009* |
| Same as ideal | 20% | 80% | |
| Caudal from ideal | 38.1% | 61.9% | |
| *Postoperative inflexion point* | | | |
| Cranial from ideal | 40.6% | 59.4% | 0.126 |
| Same as ideal | 29.4% | 70.6% | |
| Caudal from ideal | 57.9% | 42.1% | |

*Statistical significance

($P < 0.001$) (Table 3). 79.5% of the patients who suffered a mechanical complication were postoperatively unmatched. 77.4% of the patients who had a postoperative Roussouly-type "higher" than ideal (overcorrection) developed mechanical complications compared to 15% of those who were matched to their ideal shape, or to 58% of those who ended up postoperatively with a "lower" than ideal Roussouly shape (undercorrection) ($P < 0.001$). When a subgroup of patients older than 50 years of age was selected, shaping with a "higer" Roussouly-type than ideal resulted in a 95% chance of having a mechanical complication ($P < 0.001$).

When univariate analysis for complications was performed (Table 3), results ($P < 0.001$) showed that higher postoperative global tilt (27° vs. 14.7°) and pelvic tilt (25° vs. 16°) ($P < 0.001$), postoperative Roussouly-type mismatch (72% vs. 15%) ($P < 0.001$), UIV at the thoracolumbar junction (62% vs. 21%) ($P < 0.001$), and LIV to the iliac (76% vs. 6%) ($P < 0.001$), significantly increased the rate of complications. Importantly, the location of the lumbar sagittal apex related to its ideal was more influential on mechanical complications than the location of the inflexion point or the ideal LDI.

**Table 4** Comparison of preoperative parameters

| | Mechanical complications | No mechanical complications | *P* value |
|---|---|---|---|
| Age (year) | 64.9 ± 13 | 40.7 ± 15.6 | 0.000* |
| *Coronal parameters* | | | |
| MT Cobb (°) | 22° ± 19.6 | 45.3° ± 21.8 | 0.000* |
| L Cobb (°) | 35.5° ± 17.5 | 48.4° ± 19 | 0.003* |
| *Sagittal parameters* | | | |
| Pelvic incidence (°) | 55.1° ± 14 | 56.2° ± 13.6 | 0.704 |
| Pelvic tilt (°) | 27.9° ± 8.5 | 15.4° ± 8.7 | 0.000* |
| Sacral slope (°) | 27.5° ± 13.5 | 40.8° ± 11 | 0.000* |
| PI-LL mismatch (°) | 7.4° ± 16.9 | 1.5° ± 20 | 0.141 |
| Global tilt (°) | 35.9° ± 14.1 | 14.7 ± 11.9 | 0.000 * |
| *Preoperative Roussouly-type matching* | | | |
| Unmatch | 37.7% | 62.3% | 0.522 |
| Match | 44.2% | 55.8% | |
| *Preoperative sagittal profile* | | | |
| Roussouly-type 1 | 54.3% | 45.7% | 0.025* |
| Roussouly-type 2 | 47.6% | 52.4% | |
| Roussouly-type 3 | 11.8% | 88.2% | |
| Roussouly-type 4 | 34.8% | 65.2% | |

*Statistical significance

Univariate analysis of preoperative data (Table 4) showed that there were higher risks of complications in older patients (age 64.9 ± 13 vs. 40.7 ± 15.6 years) ($P < 0.001$), worse preoperative sagittal alignment parameters, and a low-type preoperative sagittal profile ($P = 0.025$). Curve etiology and preoperative and postoperative PI-LL mismatch were not associated with mechanical complications ($P > 0.05$).

Multivariate logistic regression analysis for complications was performed. After controlling for confounders, the model chose three main variables that were independently impacting mechanical complications: postoperative Roussouly-type mismatch (OR = 41.9; 95%CI = 5.5–315.7; $P < 0.001$), iliac instrumentation (OR = 19.4; 95%CI = 2.6–142.5; $P = 0.004$), and age (OR = 1.1; 95%CI = 1.02–1.16; $P = 0.004$).

Analyzing distal fixation, 63% of iliac instrumented patients were unmatched regarding its sagittal profile postoperatively versus 26% of those instrumented above the iliac ($P < 0.001$). However, both groups were equally unmatched preoperatively. Iliac fixated patients were significantly older 63.7 years versus 37.8 ($P < 0.001$). However, age did not influence the rate of preoperative or postoperative Roussouly-type unmatching ($P > 0.05$).

Postoperative Roussouly-type unmatched patients had initially worse ODI and Sf-36 PCS (physical function) scores compared with matched patients; SRS-22 total scores and SF-36 MCS (mental scores) showed no statistical difference between groups at the beginning. Postoperative unmatched patients had worse ODI scores at 6 months, and worse ODI and SF-36 physical function scores at 1 and 2 years compared with matched patients. However, both groups had similar improvement of these scores from preoperative to all the postoperative time points, and differences did not reach MCID. Unmatched patients had worse SF-36 MCS scores and fewer mental improvement than matched patients at 6 months, but this difference disappeared with follow-up. SF-36 physical function scores were worse in unmatched patients at 1 and 2 year follow-up. Table 5.

Patients suffering postoperative mechanical complications started with worse PROMs at baseline and that difference was maintained in all time points postoperatively. The postoperative improvement in SRS-22, SF-36 PCS, and MCS scores was similar between groups. However, patients suffering complications showed significantly less improvement at the 6 months ODI and SF-36 physical function scores compared to those not suffering complications, and a trend toward half of the improvement in SRS-22 total scores. With follow-up, these differences disappeared. Table 6.

**Table 5** Comparison of PROMs between patients postoperatively matched or unmatched with the ideal Roussouly-type

| | Unmatched | Matched | *P* value |
|---|---|---|---|
| *Base line* | | | |
| ODI first visit | 46.6 ± 23.9 | 32.46 ± 20.5 | 0.004* |
| SRS total first visit | 2.73 ± 0.8 | 2.96 ± 0.8 | 0.164 |
| SF-36 PCS first visit | 33.14 ± 10 | 38.76 ± 10.3 | 0.013* |
| SF-36 MCS first visit | 41.6 ± 11 | 43.5 ± 12.3 | 0.475 |
| *6 months postop* | | | |
| ODI 6 m | 38.5 ± 18.2 | 27.9 ± 18.5 | 0.009* |
| ΔODI 6 m | − 9.6 ± 16.7 | − 4.2 ± 13.8 | 0.120 |
| SRS total 6 m | 3.33 ± 0.8 | 3.44 ± 0.8 | 0.532 |
| Δ SRS total 6 m | 0.7 ± 0.9 | 0.5 ± 0.7 | 0.506 |
| SF-36 PCS 6 m | 37.8 ± 8 | 40.8 ± 10.2 | 0.147 |
| Δ SF-36 PCS 6 m | 5.4 ± 8.1 | 2.1 ± 7.8 | 0.087 |
| SF-36 MCS 6 m | 42.5 ± 11.4 | 48 ± 13 | 0.048* |
| Δ SF-36 MCS 6 m | − 0.5 ± 9.5 | 5.5 ± 10.5 | 0.014* |
| *1 year postop* | | | |
| ODI 1 year | 38 ± 20 | 24.1 ± 18.6 | 0.001* |
| ΔODI 1 year | − 9 ± 13.9 | − 8.2 ± 12.4 | 0.766 |
| SRS total 1 year | 3.32 ± 0.6 | 3.58 ± 0.7 | 0.799 |
| Δ SRS total 1 year | 0.6 ± 0.7 | 0.6 ± 0.7 | 0.733 |
| SF-36 PCS 1 year | 38.98 ± 9.3 | 43.3 ± 11.3 | 0.049* |
| Δ SF-36 PCS 1 year | 5.1 ± 8.9 | 4.3 ± 7.6 | 0.657 |
| SF-36 MCS 1 year | 43.5 ± 11.5 | 48.2 ± 12.7 | 0.067 |
| Δ SF-36 MCS 1 year | 2.2 ± 13.3 | 3.7 ± 10 | 0.588 |
| *2 year postop* | | | |
| ODI 2 year | 37.6 ± 22 | 24.9 ± 21.5 | 0.008* |
| ΔODI 2 year | − 9.1 ± 18 | − 6.4 ± 14.1 | 0.457 |
| SRS total 2year | 3.24 ± 0.7 | 3.58 ± 1 | 0.074 |
| Δ SRS total 2year | 0.4 ± 0.6 | 0.6 ± 0.8 | 0.213 |
| SF-36 PCS 2year | 38.5 ± 10.6 | 43.5 ± 11.2 | 0.040* |
| Δ SF-36 PCS 2year | 4.9 ± 10.9 | 4.5 ± 8.9 | 0.830 |
| SF-36 MCS 2year | 43.7 ± 11.1 | 49 ± 13.6 | 0.053 |
| Δ SF-36 MCS 2year | 1 ± 14 | 4.5 ± 12.7 | 0.262 |

*Statistical significance

**Table 6** Comparison of PROMs between patients with and without postoperative mechanical complications

| | Mechanical complications | No mechanical complications | *P* value |
|---|---|---|---|
| *Base line* | | | |
| ODI first visit | 55.1 ± 17 | 27.98 ± 19.9 | 0.000* |
| SRS total first visit | 2.4 ± 0.6 | 3.1 ± 0.7 | 0.000* |
| SF-36 PCS first visit | 31.4 ± 6.9 | 39.8 ± 11.2 | 0.000* |
| SF-36 MCS first visit | 38.2 ± 10.1 | 45.7 ± 11.9 | 0.003* |
| *6 months postop* | | | |
| ODI 6 m | 43 ± 16.6 | 24,9 ± 17.1 | 0.000* |
| ΔODI 6 m | − 11.9 ± 16.6 | − 2.8 ± 13.2 | 0.008* |
| SRS total 6 m | 3.19 ± 0.8 | 3.54 ± 0.7 | 0.034* |
| Δ SRS total 6 m | 0.8 ± 0.8 | 0.4 ± 0.7 | 0.06 |
| SF-36 PCS 6 m | 36.1 ± 5.8 | 41.9 ± 10.6 | 0.005* |
| Δ SF-36 PCS 6 m | 6.5 ± 1.2 | 8.7 ± 1.3 | 0.047* |
| SF-36 MCS 6 m | 40.2 ± 11.8 | 49.3 ± 11.7 | 0.001* |
| Δ SF-36 MCS 6 m | 0.5 ± 11.4 | 4.8 ± 9.6 | 0.091 |
| *1 year postop* | | | |
| ODI 1 year | 43.6 ± 15.8 | 20.8 ± 17.9 | 0.000* |
| ΔODI 1 year | − 10.6 ± 13.8 | − 7.2 ± 12.4 | 0.238 |
| SRS total 1 year | 3.13 ± 0.6 | 3.7 ± 0.7 | 0.000* |
| Δ SRS total 1 year | 0.6 ± 0.6 | 0.6 ± 0.7 | 0.733 |
| SF-36 PCS 1 year | 36.2 ± 7.7 | 45 ± 10.9 | 0.000* |
| Δ SF-36 PCS 1 year | 7.9 ± 1.3 | 8.3 ± 1.2 | 0.586 |
| SF-36 MCS 1 year | 40.2 ± 10.7 | 50.3 ± 11.8 | 0.000* |
| Δ SF-36 MCS 1 year | 2.2 ± 13.7 | 3.7 ± 9.5 | 0.561 |
| *2 year postop* | | | |
| ODI 2 year | 46.2 ± 19.2 | 20.6 ± 18.6 | 0.000* |
| ΔODI 2 year | − 7.7 ± 19.1 | − 7.4 ± 13.7 | 0.943 |
| SRS total 2 year | 2.97 ± 0.8 | 3.72 ± 0.8 | 0.000* |
| Δ SRS total 2 year | 0.4 ± 0.7 | 0.6 ± 0.8 | 0.212 |
| SF-36 PCS 2 year | 36.4 ± 9.4 | 44.4 ± 11.1 | 0.001* |
| Δ SF-36 PCS 2 year | 9.8 ± 1.8 | 9.7 ± 1.4 | 0.906 |
| SF-36 MCS 2 year | 40.2 ± 11.7 | 50.7 ± 11.9 | 0.000* |
| Δ SF-36 MCS 2 year | 0.1 ± 14.2 | 5.1 ± 12.4 | 0.108 |

*Statistical significance

## Discussion

Roussouly defined four basic shapes of normal sagittal spine alignment in healthy population based on the sacral slope angle (SS) [8]. However, degenerative lumbar changes and thoracolumbar coronal deformity can modify lumbar lordosis [6] and consequently SS and the ideal Roussouly sagittal shape [3, 10, 11]. SS then becomes an inadequate tool to classify sagittal types in pathologic patients. Instead of that, we need to rely on PI [9, 13], which is considered (unless until now) that does not vary with age, pathology, or compensation [17].

PI can then define the ideal sagittal profile to which the patient belongs to, regardless of the changes in this profile induced by deformity or surgery [9, 13]. Each Roussouly-type having a specific lumbar sagittal apex, level of inflexion point, and NVL [8, 11, 16, 18] (see Table 1), that we should take into account when restoring the ideal sagittal profile. It has been suggested that failing to restore the sagittal lumbar apex to its ideal value in general adult deformity could be a radiological predictor factor for rod breakage and PJK [19]. However, this is the first study looking deeply into this belief in patients with adult scoliosis and analyzing its impact on postoperative mechanical complications.

We studied a cohort of AS patients with coronal deformity and overall good sagittal global alignment (normal preoperative Global Tilt, and no pelvic compensation). Our results showed that in over one-third of AS patients, surgery was not able to bring patients back into their ideal sagittal profile. This could be due to two reasons: either that by the time that these patients were operated on we were not aware of this fact or that we were not able to restore the ideal profile even if aiming to do so.

We have also proven that there is a high possibility (72%) of suffering mechanical complications if the ideal sagittal profile is not restored after surgery, and this fact gets much worse (95%) in patients over the age of 50. Setting the patient postoperatively in overcorrection (a shape resembling a "higher" Roussouly-type than ideal) increases this risk for mechanical complication (77.4%), and it is worse than undercorrection (setting the patient in a shape resembling a "lower" profile than ideal), which has a 58% rate of mechanical complications. This concept agrees with reports stating that moderate PJK in AS surgery has been observed with undercorrection of the sagittal balance, and severe PJK with overcorrection [20, 21]. Accordingly, placing the lumbar sagittal apex cranial from its ideal position is worse than placing it caudal from its ideal position, and of course on its ideal position. With the data we had, we were not able to prove the importance of the placement of the inflexion point or the restoration of the ideal LDI. Even though both parameters seemed intuitively important when restoring the ideal sagittal shape.

Our results also showed that older patients, higher postoperative GT and PT, UIV at the thoracolumbar junction, LIV at the pelvis (Iliac), and postoperative Roussouly-type mismatch, significantly increased the rate of mechanical complications. However, after controlling for confounders, multivariate analysis showed that the three main variables impacting the rate of suffering mechanical complications were: LIV at the Iliac; older than 65 years old; and not restoring the proper ideal Roussouly-type (Fig. 1). The

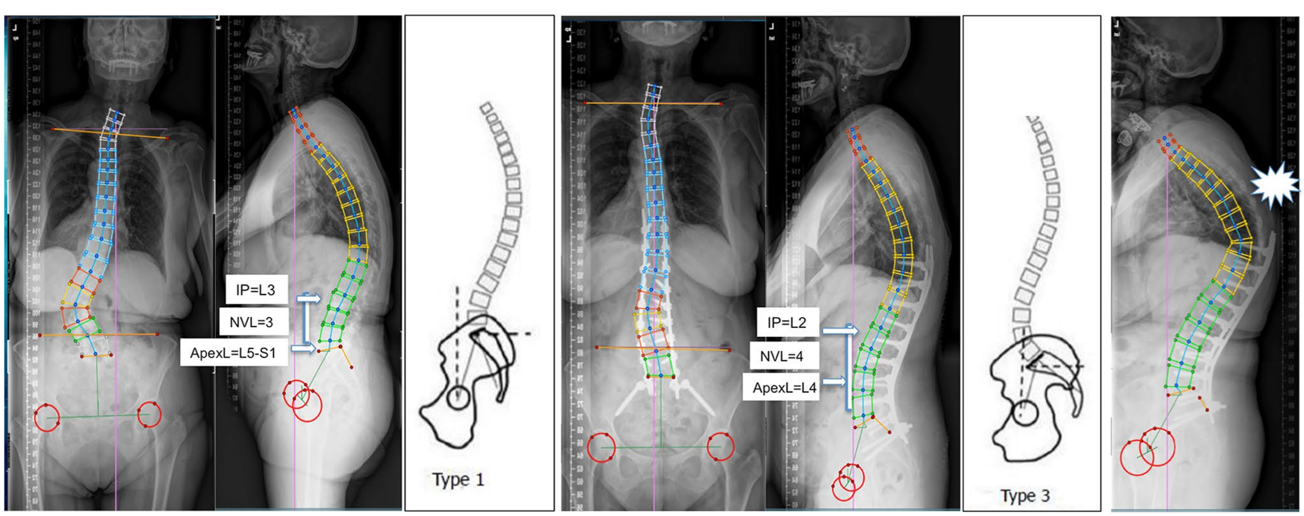



**Fig. 1** 70-year-old patient. PI = 41°, so ideal Roussouly-type is 1. Ideal lumbar apex L5-S1, ideal NVL 3, ideal inflexion point L3. Postoperative T10-Iliac fusion. Lumbar apex and inflexion point were placed cranial from ideal. R-type is unmatched with the ideal sagittal profile, which is more similar to a type 3. PJF developed at postoperative day 90

first two factors are commonly addressed in the literature as causes of PJK and mechanical complications in adult deformity [20–24] .

One concern is whether we can mold the desired postoperative Roussouly-type if not instrumenting the pelvis, and this can be seen as a flaw in our study. The answer however surprises. Knowing that most of the lordosis is provided by distal lumbar vertebrae and disks, and this influences the overall balance in a high magnitude, ending the instrumentation at L2 or L3 can also have its effect on lordosis distribution because we are acting on the upper arch of the lordosis. It may not necessarily change our lumbar sagittal apex, but it may shift the inflexion point and decrease the upper lumbar arch kyphosis, changing the global lumbar shape [25]. We also have to take into account the possibility of alignment and shape compensation from the free levels below the instrumentation, and the reciprocal changes between thoracic kyphosis and lumbar lordosis, due to thoracic instrumentation [26]. As shown by our results, regardless of the LIV, patients were equally preoperatively unmatched with the ideal profile, and the sagittal profile was equally changed by surgery. However, a higher rate of Iliac instrumented patients were unmatched postoperatively compared to those instrumented above the iliac, and as said above, many developed postoperative mechanical complications. Other authors have seen a higher incidence of PJK with increased age and fusion to sacrum in AS patients [20, 21]. Iliac fixated patients were significantly older, but age did not influence the rate of preoperative or postoperative Roussouly-type unmatching. What we learn from this is that when instrumenting an older patient to the pelvis, be very exquisite regarding lumbar modeling, and adjust the patient to the ideal sagittal shape dictated by PI, carefully positioning the lumbar apex, and secondarily the inflexion point and the LDI (Fig. 2). In patients instrumented to pelvis, even though correction is more predictable, PT decreases in a more effective way [27], and there are less risks of pseudoarthrosis, and no spontaneous mobility for compensation is expected. On the other hand, stopping at the sacrum and leaving the SI joint free can cause pain due to mechanical stress on the joint and provoke an unwanted rate of pseudoarthrosis at the L5-S1 level [28], especially in adult scoliosis surgery, which rises to 24% [29].

Apart from the Roussouly classification to plan our goals during surgery, another alternative is the Proportion (GAP) Score [5] that uses PI-based individualization of the sagittal plane parameters to quantify the shape and alignment of the sagittal plane. This tool is being used to predict mechanical complications depending on the sagittal proportion or degree of disproportion that is obtained after surgery [5]. In the end, both strategies (Roussouly shapes and GAP score) are based on similar principles to obtain the best-fitted spinopelvic alignment: restore the

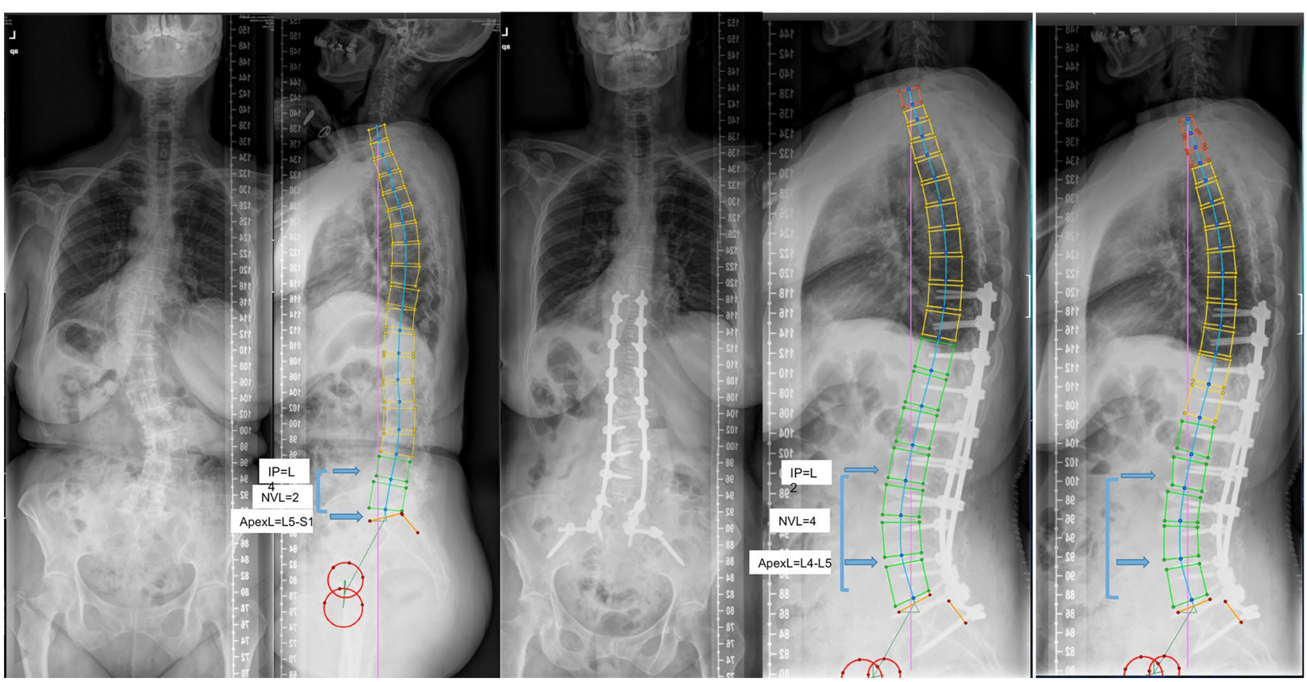



**Fig. 2** 69-year-old patient. PI = 45°, ideal Roussouly-type is 2. Ideal lumbar apex L4-L5, ideal NVL 4, ideal inflexion point L2. Postoperative T9-iliac fusion. Lumbar apex, inflexion point, and R-type were matched postoperatively to ideal. Last image shows sagittal alignment 4 years after surgery, no mechanical complications occurred

ideal pelvic version, the ideal LL, and the ideal lordosis distribution (lumbar apex, inflexion point, and LDI).

We were not able to demonstrate with our study that postoperative unmatched patients had worse clinical results or less clinical improvement postoperatively when compared to matched patients. Although function and disability scores were lower in postoperative unmatched patients, this could be due to the fact that baseline scores were also worse. However, surgery improved all scores similarly in patients correctly or incorrectly matched with the ideal profile. We should point out that patients having mechanical complications showed significantly less clinical improvement in the majority of the studied PROMs 6 months after surgery; however, these differences disappeared with time. The mean time for complications was 9 months, and patients might have been showing discomfort by that time.

This study has several limitations. Sagittal alignment categorization in only four different sagittal profiles seems an artificial way of distributing a continuum. The infinite values of PI should make the ideal sagittal shape fall into infinite categories. However, this problem is inherent to every classification. Second, this AS cohort is conformed of different ages, all being adult but with a high range of age variability. To overcome this situation, a subanalysis was performed of only patients over 50 years of age. Although sample size decreased, data had enough power to describe the same results as in the whole cohort. Third, one can argue that we cannot compare the final lordosis shape of patients instrumented to the Iliac with those with the lower instrumented level in the upper lumbar spine. However, we have already explained that even the patients instrumented to the upper lumbar spine have sagittal shape changes after surgery that affect their entire sagittal profile including changing their morphologic Roussouly-type. The primary strength of the current analyses include the use of data derived from multiple centers from different countries, which enhances the generalizability of the findings.

In conclusion, adult scoliosis surgery should restore the ideal Roussouly sagittal shape dictated by PI to decrease the rate of mechanical complications. It is important to carefully position the lumbar sagittal apex, especially in older patients planned to be instrumented to the pelvis.

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## Compliance with ethical standards

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

**Ethical approval** This study has institutional review board (IRB) approval/research ethics committee approval.

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