Eur Spine J
DOI 10.1007/s00586-015-4048-1

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ORIGINAL ARTICLE

# Analysis of an unexplored group of sagittal deformity patients: low pelvic tilt despite positive sagittal malalignment

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Received: 7 October 2014 / Revised: 19 March 2015 / Accepted: 23 May 2015


**Abstract**
*Purpose* In adult spinal deformity (ASD), patients increase pelvic tilt (PT) to maintain standing alignment. Previously, ASD patients with low PT and high disability were described. This study investigates this unusual population in terms of demographic, radiographic, and clinical features after three-column osteotomy (3CO).
*Methods* In this multicenter retrospective study, ASD patients underwent single lumbar 3CO. Since PT is proportional to pelvic incidence (PI), the low PT group (LowPT) was defined as having a baseline (BL) PT/PI <25th percentile. HRQOL and full spine x-rays were analyzed at BL and 1 year. LowPT patients were compared to those with high PT/PI (HighPT) in a matched range of T1 pelvic angle.
*Results* LowPT group had PT/PI <0.4 ($n = 31$). High disability was reported at baseline for both groups with significant improvement postoperatively, but without difference between groups. LowPT had significantly smaller lack lumbar lordosis but larger SVA, T1 spinopelvic inclination. Postoperatively, there were improvements in all sagittal modifiers except PT in LowPT. 33 % of LowPT had an increase in PT (>5°) postoperatively. This subset had more deformity at baseline, achieving good T1SPi postoperative correction but without achieving the SRS-Schwab target SVA at 1 year.
*Conclusion* LowPT group had high levels of disability. After 3CO surgery, low PT patients experience only partial improvements in sagittal vertical axis (SVA) and 33 % of the group increased their PT. Further work is necessary to determine optimal realignment approaches for this unusual set of patients. It is unclear if neuromuscular pathology plays a role in the setting of high SVA without pelvic retroversion.

**Keywords** 3 column osteotomy · Sagittal alignment · Pelvic tilt · Clinical outcomes · Compensatory mechanism

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## Introduction

Adult spinal deformity (ASD) has been reported to be associated with pain and disability [1]. To better understand these deformities, multiple studies have investigated the relationships between radiographic parameters and standardized measures of health-related quality of life (HRQOL) [1–5]. These efforts have culminated in the development of a classification for ASD based on the three

Published online: 31 May 2015

radiographic sagittal parameters that have the strongest correlations with patient-reported outcomes [6]: sagittal vertical axis (SVA), mismatch between pelvic incidence and lumbar lordosis (PI-LL), and pelvic tilt (PT) [7].

While pelvic incidence (PI) is a morphologic parameter that remains relatively static upon achievement of skeletal maturity, PT is a positional parameter. When elevated, PT reflects a compensatory pelvic retroversion in response to positive sagittal spinal malalignment and has been associated with worse HRQOL [3, 5, 8–12].

Collectively, these findings suggest that singular measures of spinal malalignment may fail to fully account for a patient's pain and disability. For example, Lafage categorized ASD patients based on PT and SVA. The patients who had high SVA/low PT or high SVA/high PT had worse pain and disability scores than patients with high PT/low SVA or low PT/low SVA. In an effort to conjointly evaluate PT and SVA, Protopsaltis recently described the T1 pelvic angle (TPA) [13]. Defined as the angle subtended by a line from the center of the T1 vertebral body to the femoral heads and a line from the femoral heads to the center of the sacral endplate, TPA takes information from both the trunk inclination and PT to directly measure global spinal deformity (Fig. 1) Furthermore, TPA is correlated with health disability outcome scores and using regression analysis a TPA above 20° was associated with high disability [14].

While three-column osteotomy (3CO) has been presented as effective technique to restore coronal and sagittal alignment [15–21], anticipating the postoperative alignment such as change in PT and SVA following 3CO remains challenging. To our knowledge, no studies in the literature have specifically analyzed the efficacy of 3CO for patients with anterior malalignment who have a low preoperative PT, despite an abnormally elevated SVA. The present study investigates this unique population that fails to recruit pelvic retroversion in the setting of sagittal plane deformity. Additionally, we compare the clinical and radiographic results after 3CO surgery between this population and ASD patients with sagittal malalignment who do utilize pelvic retroversion as a compensatory mechanism.

## Methods

### Patient population

This is a retrospective review of a multicenter database of patients who underwent 3CO for sagittal plane malalignment between 2004 and 2012. The institutional review board at each contributing site provided study approval. Specific inclusion criteria for the present study included age >18 years at time of surgery, TPA greater than 20°, and documented spinal deformity with surgical treatment

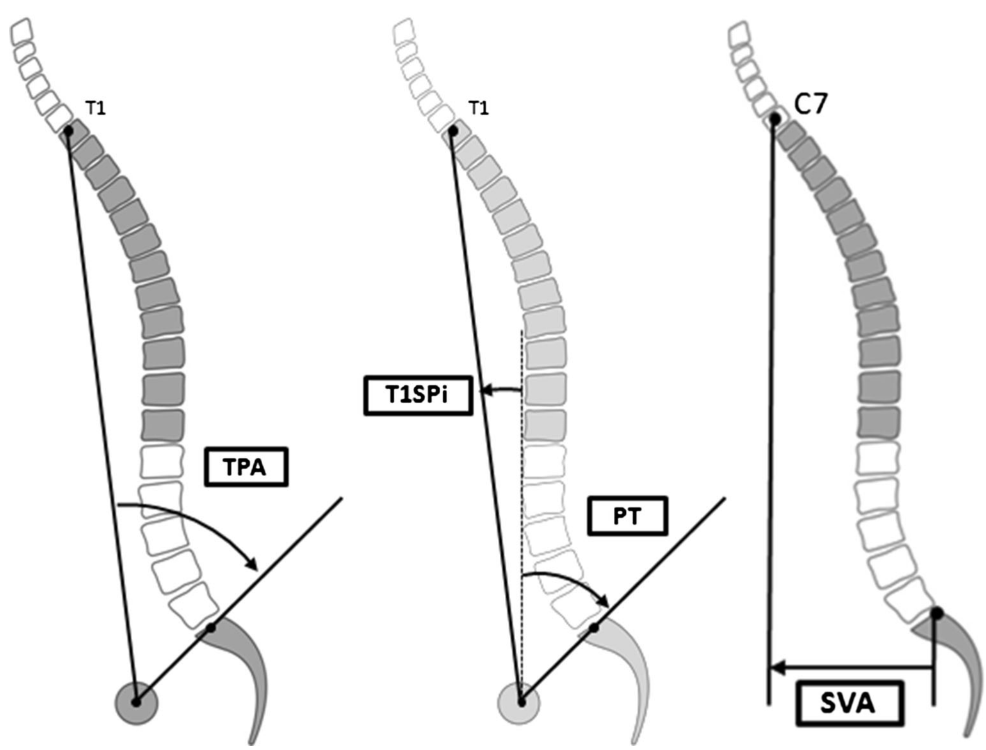


**Fig. 1** T1 pelvic angle (TPA), T1 spinopelvic inclination angle (T1SPi), and sagittal vertical axis (SVA)

that included a single-level lumbar 3CO (any level from L1 to L5). Exclusion criteria included the presence of underlying neurological etiology for the spinal deformity, surgical treatment that included more than one 3CO, and performance of a thoracic 3CO.

### Data collection

Data collection included preoperative, and 1-year postoperative follow-up radiographic spinal evaluation in free-standing position, with arms positioned at 45° and fingertips on clavicles. In addition to the sagittal radiographs, data collection included demographic parameters [age, sex, and body mass index (BMI)]. HRQOL scores were recorded, including modified Oswestry disability index (ODI), short form 36 mental (SF36-MCS), and physical (SF36-PCS) component scores.

### Radiological measurements

Radiographs were analyzed using dedicated and validated software (Spineview, ENSAM, Paris, France) [22]. Sagittal spinopelvic radiographic parameters included cervical lordosis (CL, C2–C7), thoracic kyphosis (TK, T2–T12), lumbar lordosis (LL, L1–S1), and pelvic parameters [PI, PT, and sacral slope (SS)] [23]. The lack of lumbar lordosis was assessed based on the PI-LL mismatch [6]. Global sagittal alignment parameters included SVA, T1, and T9 spinopelvic inclination (T1SPi and T9SPi, angle between a line drawn from the center of the T1 or T9 vertebral body, respectively, to the center of the bicoxofemoral axis and a vertical reference line) and TPA [14, 23] (Fig. 1).

The 3CO resection angle was radiographically measured and defined as the change of the angle formed by the lower vertebral endplate of the adjacent cephalic vertebra and the upper vertebral endplate of the adjacent caudal vertebra.

### Statistical analysis

Data were statistically analyzed using Stata software 13.0 (Statacorp, College Station, Texas). Normal distribution of the data was assessed with Shapiro–Wilk test.

In an effort to evaluate the relationship between spinopelvic parameters and a morphologic parameter characteristic of each individual (PI), the ratio of PT to PI (PT/PI) was also calculated. As described by Legaye and Duval-Beaupère, PT is proportional to PI [10]. Based on this relation, Mac Thiong previously used PT/PI ratio to describe sacropelvic morphology of asymptomatic adults [24]. Consequently based on the normal distribution of PT/PI value, the low PT group (LowPT) was defined as having a baseline PT/PI <25th percentile [10].

LowPT patients were compared to those with high PT/PI (HighPT defined as having a PT/PI >25th percentile). Patients were compared in a matched range of T1 pelvic angle (TPA) greater than 20° corresponding to a large anterior malalignment [13]. At baseline and at follow-up, to investigate differences between LowPT and HighPT patients, and comparisons between preoperative and postoperative data in each group paired *T* tests for parametric data and Kruskal–Wallis test for nonparametric data were performed.

Postoperatively, the subset of LowPT patients with an increase in PT of more than 5° (threshold for clinical significance of radiographic measurement) was further analyzed and compared to the other LowPT patients [25].

For all statistical analysis, the level of significance was set at $p < 0.05$.

## Results

### Demographic data

A total of 234 patients with single-level lumbar PSO were identified. Among this population, 31 (13 %) were categorized into the LowPT group and 203 (87 %) into the HighPT group (Fig. 2). There were no significant differences in demographic data (age, gender, BMI) between the two groups (Table 1). A majority of patients had a history

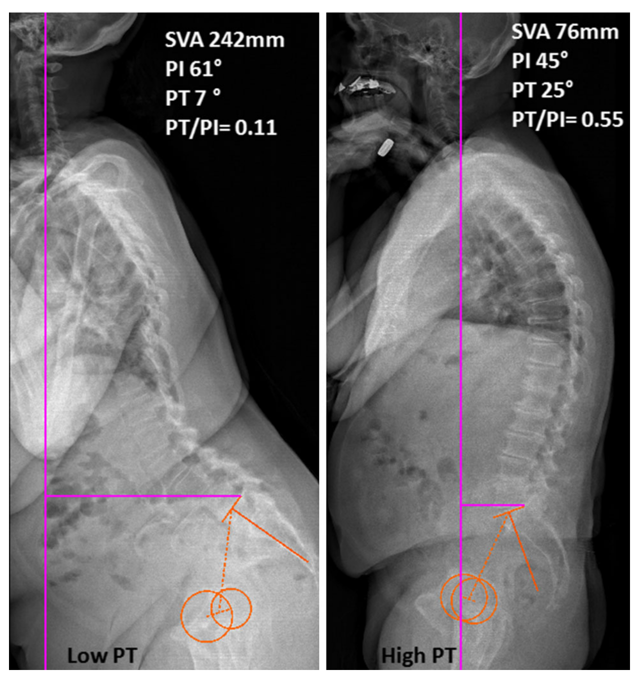


**Fig. 2** Sagittal x-rays of a LowPT and a HighPT patients with SVA and pelvic parameters

**Table 1** Demographic data and health-related quality of life scores stratified based on low versus high pelvic tilt (PT) groups for both pre- and postoperative time points

| | Preoperatively | | | | | 1 year postoperatively | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | LowPT ($n = 31$) | | HighPT ($n = 203$) | | $p$ | LowPT ($n = 15$) | | HighPT ($n = 93$) | | $p$ |
| | Mean | SD | Mean | SD | | Mean | SD | Mean | SD | |
| Age | 60.9 | 11.0 | 60.5 | 10.9 | 0.42 | – | – | – | – | – |
| Gender (female, %) | 61 | – | 71 | – | 0.24 | – | – | – | – | – |
| BMI (kg/m$^2$) | 28.7 | 8.8 | 27.5 | 5.9 | 0.20 | – | – | – | – | – |
| Primary surgery (%) | 24 | – | 15 | – | 0.25 | – | – | – | – | – |
| ODI | 49.3 | 13.7 | 50.2[a] | 17.2 | 0.82 | 35.9 | 16.3 | 35.1[a] | 21.5 | 0.90 |
| SF36-PCS | 31.8[a] | 12.0 | 28.1[a] | 8.2 | 0.15 | 34.9[a] | 5.3 | 37.7[a] | 9.6 | 0.29 |
| SF36-MCS | 44.0 | 17.7 | 44.7 | 15.8 | 35.9 | 48.0 | 9.3 | 48.1 | 13.1 | 0.96 |

*BMI* body mass index, *ODI* Oswestry disability index, *SF36-PCS* short form 36 physical component summary, *SF36-MCS* mental component summary

[a] Significant difference between pre- and postoperative results

of previous spine surgery. The proportion of patients undergoing primary versus revision surgery were not significantly different between LowPT and HighPT groups (Table 1).

## HRQOL scores

Fifteen LowPT patients and 93 HighPT patients had HRQOL data available at 1-year follow-up. Comparing the two groups based on clinical scores (Table 1) demonstrated no differences at baseline or at 1-year following surgery. At baseline, both groups were deemed to be highly disabled based on HRQOL measures (ODI, SF36-MCS, and SF36-PCS). For both groups, at 1-year follow-up, SF36-PCS scores improved but SF36-MCS did not improve significantly. Additionally, in the LowPT group, 1-year postoperative ODI scores did not significantly improve, whereas ODI scores did improve significantly in HighPT patients (Table 1).

## Radiographic parameters

In the LowPT group, PT/PI was lower than 0.4, and in the HighPT group, it was greater than 0.4 (Table 2). Consistent with how the groups were defined, the mean preoperative PT was significantly lower in the LowPT group than in the HighPT group (23.3° vs 35.3°, $p < 0.001$). PI was not significantly different between the LowPT group and the HighPT group. In each group, PT and PI had a large range: PT [LowPT (6.9°; 30.3°), HighPT (15.2°; 67.9°)] and PI [LowPT (41.3°; 87.5°), HighPT (30.1°; 127.5°)].

Preoperative global sagittal parameters, including SVA, T1SPi, and T9SPi, were significantly greater in the LowPT group, which reflected greater positive sagittal malalignment in this group compared with the HighPT group. In the HighPT group, lack of lumbar lordosis was significantly more prevalent than in the LowPT group (PI-LL mismatch of 38.8° vs 27.6°, respectively, $p = 0.002$). Also of note, CL was significantly less in the LowPT group than in the HighPT group (10.5° vs 19.3°, $p = 0.03$), but there was no significant difference in thoracic kyphosis between the groups.

Preoperatively, two of the SRS-Schwab modifiers differed between the two groups: worse PT and PI-LL modifiers were seen more frequently in the HighPT group (PT 64 % vs 7 %, $p < 0.001$ and PI-LL 87 vs 62 %, $p = 0.001$). However, with respect to SVA modifier, there was no significant difference between groups (Table 3; Fig. 3).

Postoperatively, the HighPT group was found to have improvements in all key radiographic deformity parameters, with decreases in PI-LL mismatch, PT, and global sagittal alignment measures (SVA, T1SPi, T9SPi, and TPA). In contrast, for the LowPT group, there were no significant changes observed for the PT/PI ratio, PT, CL, or T9SPi (Table 2). The distribution of postoperative SRS-Schwab modifier grades between the LowPT and HighPT groups was not significantly different for any of the modifiers. Postoperatively, there was significant improvement in PT ($p = 0.03$), PI-LL ($p = 0.01$), and SVA ($p = 0.001$) modifiers in the HighPT group, whereas there was only improvement in PI-LL ($p = 0.02$) and SVA ($p = 0.001$) modifiers in the LowPT group (Table 3).

While the mean degrees of 3CO resection were similar in the two groups, the amount of correction was significantly greater in HighPT group for the following parameters: PT (LowPT −1.1° ± 6.0°, HighPT −9.1° ± 8.6°, $p < 0.001$), PI-LL (LowPT −19.7° ± 14.6°, HighPT −30.1° ± 17.7°, $p < 0.001$). The amounts of SVA and T1SPTi correction were not significantly different between the groups.

**Table 2** Comparison in pre- and postoperative radiographic parameters between groups

| | Preoperatively | | | | | 1 year postoperatively | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | LowPT ($n = 31$) | | HighPT ($n = 203$) | | $p$ | LowPT ($n = 31$) | | HighPT ($n = 203$) | | $p$ |
| | Mean | SD | Mean | SD | | Mean | SD | Mean | SD | |
| PT/PI | 0.34 | 0.06 | 0.61[a] | 0.15 | **<0.001** | 0.36 | 0.13 | 0.42[a] | 0.13 | **0.037** |
| PI (°) | 64.6 | 12.0 | 61.2 | 16.0 | 0.08 | – | – | – | – | – |
| PT (°) | 23.3 | 7.9 | 35.3[a] | 9.8 | **<0.001** | 23.7 | 10.9 | 26.3[a] | 10.6 | 0.27 |
| L1–S1 (°) | 39.4[a] | 17.3 | 22.6[a] | 20.9 | **<0.001** | 58.7[a] | 14.2 | 53.4[a] | 15.1 | **<0.001** |
| PI-LL (°) | 27.6[a] | 17.2 | 38.8[a] | 18.8 | **0.002** | 7.8[a] | 16.4 | 8.2[a] | 16.9 | 0.89 |
| T1–T12 (°) | 30.3[a] | 20.8 | 31.2[a] | 21.5 | 0.83 | 47.5[a] | 15.7 | 46.6[a] | 18.1 | 0.81 |
| C2–C7 (°) | 10.5 | 16.1 | 19.3[a] | 16.5 | **0.03** | 15.6 | 16.3 | 13.3[a] | 15.2 | 0.50 |
| SVA (mm) | 180.2[a] | 80.5 | 149.6[a] | 71.5 | **0.04** | 72.7[a] | 62.6 | 46.3[a] | 59.6 | **0.041** |
| TPA (°) | 33.6[a] | 10.5 | 39.9[a] | 12.0 | **0.004** | 24.1[a] | 12.4 | 22.8[a] | 11.7 | 0.41 |
| T1SPi (°) | 10.2[a] | 8.2 | 4.5[a] | 6.8 | **0.001** | −0.2[a] | 6.2 | −3.5[a] | 5.4 | **0.004** |
| T9SPi (°) | 1.9 | 8.1 | −6.3[a] | 7.9 | **<0.001** | −7.9 | 6.3 | −11.8[a] | 5.9 | **0.002** |
| 3CO angle (°) | – | – | – | – | – | 20.3 | 14.4 | 25.6 | 13.5 | 0.06 |

Bold values correspond to significant differences between groups

*PI* pelvic incidence, *PT* pelvic tilt, *L1–S1* lumbar lordosis, *PI-LL* pelvic incidence minus lumbar lordosis, *T1–T12* thoracic kyphosis, *C2–C7* cervical lordosis, *SVA* sagittal vertical axis, *TPA* T1 pelvic angle, *T1SPi* T1 spinopelvic inclination, *T9SPi* T9 spinopelvic inclination, *3CO* three-column osteotomy

[a] Significant difference between pre- and postoperative results

**Table 3** Pre- and postoperative SRS-Schwab classification, comparison between LowPT and HighPT patients

| | Preoperatively | | | 1 year postoperatively | | |
|---|---|---|---|---|---|---|
| | LowPT ($n = 31$), % | HighPT ($n = 203$), % | $p$ | LowPT ($n = 31$), % | HighPT ($n = 203$), % | $p$ |
| PT (°) | | | | | | |
| <20 | 38 | 2 | **<0.001** | 36 | 27 | 0.284 |
| 20–30 | 55 | 34 | | 46 | 42 | |
| >20 | 7 | 64 | | 18 | 31 | |
| PI-LL (°) | | | | | | |
| <10 | 21 | 5 | **0.001** | 68 | 60 | 0.409 |
| 10–20 | 17 | 8 | | 21 | 18 | |
| >20 | 62 | 87 | | 11 | 22 | |
| SVA (mm) | | | | | | |
| <45 | 0 | 6 | 0.179 | 30 | 46 | 0.262 |
| 45–90 | 7 | 16 | | 48 | 36 | |
| >90 | 93 | 78 | | 22 | 18 | |

Bold values correspond to significant differences between groups

*PT* pelvic tilt, *PI-LL* pelvic incidence minus lumbar lordosis, *SVA* sagittal vertical axis

At 1 year postoperatively, 10 LowPT patients (33 % of the LowPT subset) had an increase in PT of more than 5° (group DifPT >+5). At baseline, the subset of LowPT patients who increased their PT did not have significantly different PT or PI-LL than the other LowPT patients. However, these 10 patients had significantly greater global-positive sagittal malalignment at baseline, including significantly greater SVA, T1SPi. Postoperatively, their PT/PI ratio increased (0.34–0.46, $p = 0.001$) and they had a significantly greater PT (25.3°–32.3°, $p = 0.03$), whereas these 10 patients had significant decreases in PI-LL, SVA, T1SPi, and T9SPi. For the subset of LowPT patients who increased their PT, the postoperative PI-LL mismatch remained significantly greater than in the LowPT patients who did not increase their PT (Table 4; Fig. 4).

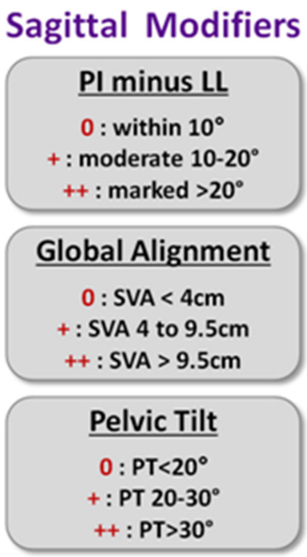


**Fig. 3** SRS-Schwab classification for adult spinal deformity with sagittal vertical axis, pelvic tilt, and PI-LL mismatch

## Discussion

The present study demonstrated that ASD patients with positive sagittal malalignment but low PT (lack of compensatory pelvic retroversion) had lower baseline PI-LL mismatch and greater SVA and T1SPi, but had similarly poor HRQOL scores as ASD patients with positive sagittal malalignment and high PT. Moreover, among the patients with baseline low PT, postoperative PT was unchanged and SVA was significantly improved but remained under-corrected (SVA >+50 mm). Notably, a subset of LowPT patients demonstrated an increase in PT at 1 year and had SVA and PI-LL mismatch values corresponding to SRS-Schwab classification grade one ("moderately abnormal").

### Baseline comparison

To more effectively define the groups in this study, instead of using a fixed threshold for PT, we used a ratio of PT/P [24]. The wide distributions of PT and PI [(6.9°; 30.3°) and (41.3°; 87.5°), respectively] in our LowPT population were the primary reason for using such a ratio. Moreover, since PT is proportional to PI and PI is a morphological fixed parameter, it is arguably more meaningful to assess the ratio of PT to PI pre- and postoperatively for the purposes of comparisons across patients [10]. Vialle's developed a formula between PT and PI (PT $= -7 + 0.37$ PI) [23]. This formula was not usable in this study since all these surgically indicated ASD patients had a PT which was higher than theoretical ideal PT using Vialle's "normative" formula.

At baseline, the PT/PI ratio was 0.34 in LowPT groups; although this ratio was lower than the overall ASD study population, it remains higher than the PT/PI ratio of 25 % that has been previously reported for an asymptomatic population [24]. The LowPT group had significantly less PI-LL mismatch but had greater global anterior sagittal malalignment as assessed by SVA, T1SPi, and T9SPi. This sagittal malalignment could be explained by insufficient pelvic compensation in this group. The sagittal malalignment based on T9SPi observed for the LowPT patients compared with the HighPT patients (1.9° vs −6.3°, $p < 0.001$) may result from a greater flattening of the

**Table 4** Comparison in pre- and postoperative spinopelvic parameters between LowPT patients with or without a postoperative increase in PT

| | Preoperatively | | | | | 1 year postoperatively | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | difPT <−5 (*n* = 21) | | difPT >+5 (*n* = 10) | | *p* | difPT <−5 (*n* = 21) | | difPT >+5 (*n* = 10) | | *p* |
| | Mean | SD | Mean | SD | | Mean | SD | Mean | SD | |
| PT/PI | 0.35 | 0.1 | 0.34 | 0.1 | 0.39 | **0.30** | **0.1** | **0.46** | **0.1** | **0.001** |
| PI (°) | 63.9 | 12.1 | 65.8 | 12.6 | 0.86 | – | – | – | – | – |
| PT (°) | 22.3 | 4.9 | 25.3 | 12.0 | 0.86 | **19.4** | **8.9** | **32.3** | **9.8** | **0.004** |
| PI-LL (°) | 23.3 | 15.0 | 36.0 | 19.1 | 0.06 | **3.10** | **15.5** | **17.3** | **14.4** | **0.02** |
| T1–T12 (°) | 28.2 | 17.6 | 34.8 | 27.4 | 0.44 | 46.6 | 16.9 | 49.2 | 13.8 | 0.68 |
| C2–C7 (°) | 11.7 | 16.1 | 7.9 | 17.3 | 0.64 | 16.4 | 17.2 | 14.0 | 15.2 | 0.77 |
| SVA (mm) | 158.8 | 58.6 | 227.6 | 104.3 | 0.09 | 69.5 | 64.7 | 80.2 | 60.8 | 0.75 |
| TPA (°) | **30.5** | **7.0** | **40.5** | **13.9** | **0.047** | **20.1** | **11.0** | **31.7** | **11.7** | **0.013** |
| T1SPi (°) | **7.9** | **6.5** | **15.5** | **9.3** | **0.01** | 0.4 | 6.8 | −1.4 | 4.4 | 0.49 |
| T9SPi (°) | 0.2 | 6.4 | 5.4 | 10.1 | 1.09 | −6.6 | 6.6 | −11.5 | 3.6 | 0.06 |
| 3CO angle (°) | – | – | – | – | – | 22.5 | 11.8 | 14.7 | 19.2 | 0.19 |

Bold values correspond to significant differences between groups

*PI* pelvic incidence, *PT* pelvic tilt, *L1–S1* lumbar lordosis, *PI-LL* pelvic incidence minus lumbar lordosis, *T1–T12* thoracic kyphosis, *C2–C7* cervical lordosis, *SVA* sagittal vertical axis, *TPA* T1 pelvic angle, *T1SPi* T1 spinopelvic inclination, *T9SPi* T9 spinopelvic inclination, *3CO* three-column osteotomy

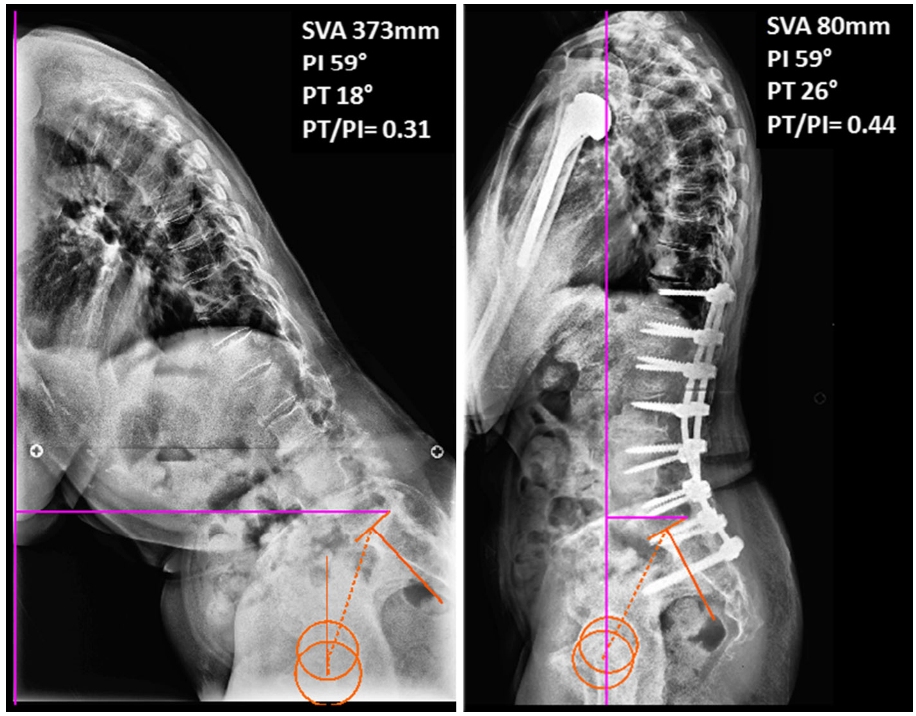


**Fig. 4** Pre- and postoperative x-rays of a LowPT patient who increases his PT postoperatively with SVA and pelvic parameters

thoracic spine. Moreover, cervical lordosis was significantly less for the LowPT group compared with the HighPT group, suggesting that LowPT patients also had limited compensation for positive sagittal malalignment through the cervical spine [26].

With respect to clinical outcome measures, baseline ODI and SF36 demonstrated significant disability in both the LowPT and HighPT groups. However, these measures did not significantly differ between the two groups. Lafage et al., in 2009, in a combined analysis between SVA and PT in ASD patients, reached a similar conclusion [5]. Smith et al., in their population of ASD patients with high PT and low SVA, also found a high prevalence of disability [27].

### Postoperative comparison

Regarding the three SRS-Schwab parameters, all were significantly improved postoperatively in the HighPT group. In the LowPT group, while PI-LL mismatch and SVA significantly decreased, there were no significant changes in PT. However, SVA correction was suboptimal in the LowPT group, with a postoperative SVA corresponding to the intermediate grade of the SRS-Schwab sagittal modifiers (i.e., $45 < SVA < 90$ mm) [6].

Within the LowPT group, 33 % of these patients experienced an increase of PT of greater than 5° at 1-year follow-up. It is possible that the gain in LL could facilitate increased capacity for pelvic retroversion in these patients.

### Compensatory mechanisms

The lack of pelvic compensation associated with positive sagittal malalignment is a challenging issue because it calls for the clinician to recognize underlying mechanisms to achieve the best therapeutic strategy. Reasons for limited capacity for pelvic retroversion for these patients require further investigation [14].

Hip pathology is one of the potential causes for the lack of pelvic compensation. Relationships between hip and spine have been previously demonstrated [28]. While limited range of pelvic tilt between standing and sitting position has been observed as a factor of hip dislocation [29, 30], one could assume that a hip stiffness that limits the extension of the coxofemoral joint could lead to limitation in pelvic retroversion. Sariali and Weng observed that patients with hip osteoarthritis had lower pelvic tilt than asymptomatic adults (with similar PI) [31, 32].

Other hypotheses to explain limited pelvic retroversion include neurologic etiologies involving the neuro-sensorial system and proprioception [33, 34]. Some authors described patients with Parkinson's disease with uncompensated high SVA (SVA >5 cm and PT <20°) who had greater PD severity than compensated PD patients (SVA <5 cm and high PT) [33]. In Lamartina-Berjano study, pelvic kyphosis group was defined as sagittal malalignment without compensatory pelvic retroversion which is frequently observed in Parkinson patient [35]. These data suggest that neuromuscular disease may compromise the capacity for PT compensation.

Soft tissue degeneration (i.e., muscles and ligaments) is another hypothesis. Lee appreciated the role of muscle quality in failure of surgical correction with respect to gait: inability to maintain pelvic retroversion in ambulation was identified as a marker for failure to correct sagittal malalignment irrespective of degree of preoperative deformity [36].

These hypotheses suggest that multidisciplinary evaluation of these patients should be considered before pursuing spinal intervention that attempts to address spinal alignment.

## Limitations

We appreciate several limitations in conducting this study. First, as expected in the ASD population, patients with small pelvic retroversion are relatively uncommon. Second, we did not assess the difference between actual PT and an expected PT given a degree of sagittal deformity and whether there is a threshold in which lack of compensation results in surgical failure. Third, alternative methods could be used to stratify patients that may better capture global deformity (SVA, T1SPi) based on surgeon preference.

## Conclusion

In this study, 3CO was demonstrated to be an effective technique to correct sagittal malalignment. The LowPT group had high disability, even when matched a group with similar global deformities. Significant postoperative changes were not observed in ODI score. Moreover, 33 % of LowPT patients experienced increases in PT with only partial improvement in SVA. Further work is necessary to determine optimal realignment approaches for this unusual subset of patients with anterior malalignment without pelvic compensation. Finally, the differences highlighted between low and highPT patients may lead to future multidisciplinary investigations. Pathophysiologic mechanisms responsible for limited pelvic retroversion need to be further investigated utilizing full body imaging along with soft tissue and dynamic analyses.

**Acknowledgments** Grant support received by the International Study Group Foundation from Depuy Spine. IRB approval was granted for this study at all participating sites.

**Conflict of interest** None.

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