Spontaneous improvement of cervical alignment after correction of global sagittal balance following pedicle subtraction osteotomy

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Clinical article

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Object. Sagittal spinopelvic malalignment is a significant cause of pain and disability in patients with adult spinal deformity. Surgical correction of spinopelvic malalignment can result in compensatory changes in spinal alignment outside of the fused spinal segments. These compensatory changes, termed reciprocal changes, have been defined for thoracic and lumbar regions but not for the cervical spine. The object of this study was to evaluate postoperative reciprocal changes within the cervical spine following lumbar pedicle subtraction osteotomy (PSO).

Methods. This was a multicenter retrospective radiographic analysis of patients from International Spine Study Group centers. Inclusion criteria were as follows: adults (> 18 years old) with spinal deformity treated using lumbar PSO, a preoperative C7–S1 plumb line greater than 5 cm, and availability of pre- and postoperative full-length standing radiographs.

Results. Seventy-five patients (60 women, mean age 59 years) were included. The lumbar PSO significantly improved sagittal alignment, including the C7–S1 plumb line, C7–T12 inclination, and pelvic tilt ($p < 0.001$). After lumbar PSO, reciprocal changes were seen to occur in C2–7 cervical lordosis (from 30.8° to 21.6°, $p < 0.001$), C2–7 plumb line (from 27.0 mm to 22.9 mm), and T-1 slope (from –38.9° to –30.4°, $p < 0.001$). Ideal correction of sagittal malalignment (postoperative sagittal vertical alignment < 50 mm) was associated with the greatest relaxation of cervical hyperlordosis (–12.4° vs –5.7°, $p = 0.037$). A change in cervical lordosis correlated with changes in T-1 slope ($r = -0.621$, $p < 0.001$), C7–T12 inclination ($r = 0.418$, $p < 0.001$), T12–S1 angle ($r = -0.339$, $p = 0.005$), and C7–S1 plumb line ($r = 0.289$, $p = 0.018$). Radiographic parameters that correlated with changes in cervical lordosis on multivariate linear regression analysis included change in T-1 slope and change in C2–7 plumb line ($r^2 = 0.53$, $p < 0.001$).

Conclusions. Adults with positive sagittal spinopelvic malalignment compensate with abnormally increased cervical lordosis in an effort to maintain horizontal gaze. Surgical correction of sagittal malalignment results in improvement of the abnormal cervical hyperlordosis through reciprocal changes.
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Key Words • **cervical spine** • **deformity** • **lordosis** • **pedicle subtraction osteotomy** • **sagittal alignment**

Positive sagittal malalignment (defined as anterior deviation of the C-7 plumb line > 5 cm from the posterior superior corner of S-1) is recognized as a cause of pain and disability in cases of ASD.[8,20,28,30,31] Poor sagittal alignment has been shown to require increased energy expenditure, and multiple compensatory measures have been described, including knee flexion, pelvic retroversion, and thoracic hypokyphosis.[20,30,31] Surgical correction of positive sagittal malalignment has been correlated with significant improvement in health-related quality of life measures.[8,31]

Although most improvement in sagittal alignment

Abbreviations used in this paper: ASD = adult spinal deformity; ISSG = International Spine Study Group; LL = lumbar lordosis; PI = pelvic incidence; PSO = pedicle subtraction osteotomy; PT = pelvic tilt; SS = sacral slope; SVA = sagittal vertical alignment; TK = thoracic kyphosis.

This article contains some figures that are displayed in color online but in black-and-white in the print edition.

after spinal deformity surgery occurs within the instrumented and fused spinal segments, there is increasing appreciation of the changes in spinopelvic alignment that occur outside the fused spinal segments. These alignment changes have been termed "reciprocal changes" and have been reported for the thoracic and lumbar regions, as well as the pelvis. Klineberg et al.[15] recently reported that a thoracic osteotomy with limited fusion for correction of kyphosis results in a spontaneous reciprocal decrease in lordosis within the unfused lumbar spine. Conversely, Klineberg et al. reported that a lumbar osteotomy with restoration of LL also generates a spontaneous increase in kyphosis within the unfused thoracic spine. Reciprocal changes in pelvic alignment, specifically relaxation of pelvic retroversion and normalization of the PT, have also been reported.[23,24]

Reciprocal changes in sagittal spinal alignment after correction of spinal deformity may have substantial consequences, including increased susceptibility to junctional degeneration and failure, alteration of final sagittal alignment, and a negative impact on health-related quality of life scores. Lafage et al.[18] reported that reciprocal changes in TK following lumbar PSO can negatively impact sagittal alignment, potentially countering the improvement in alignment for which lumbar PSO is typically performed. These findings underscore the importance of appreciating global spinal alignment and of recognizing the need to account for potential alignment changes occurring outside the fused segments when contemplating spinal deformity correction.

Radiographic measures of thoracic, lumbar, and pelvic alignment have been defined in healthy volunteers and in patients with deformity; however, there remains relatively limited understanding of these measures for the cervical spine. A recent study by Blondel et al.[1] provided assessment of cervical alignment and its relationship to spinopelvic alignment in asymptomatic adults in standing posture. These authors noted that to achieve anatomical spinopelvic harmony, a larger PI requires a larger LL, which necessitates increased TK, which in turn is correlated with an increased cervical lordosis. They also noted that cervical lordosis tends to increase significantly with age.

Measures of cervical alignment have been linked to clinical outcome. Villavicencio et al.[35] reported significantly greater improvement in the 36-Item Short Form Health Survey and Neck Disability Index scores in patients whose sagittal alignment was maintained or improved after anterior cervical discectomy and fusion. In addition, Tang et al.[34] recently reported that positive cervical sagittal alignment negatively impacts outcomes in patients after posterior cervical fusion procedures.

In the present study, we hypothesized that patients with ASD with positive sagittal malalignment partially compensate with increased cervical lordosis to maintain horizontal gaze. In addition, we hypothesized that surgical correction of this positive sagittal malalignment would generate a reciprocal change in cervical alignment that results in a relaxation of the compensatory cervical hyperlordosis. In the present study we sought to address these hypotheses in an effort to improve the global understanding of sagittal interactions and compensatory mechanisms as an aid to patient evaluation and surgical planning.

Methods

Patient Selection

This study was conducted through the ISSG, a multicenter group consisting of 11 sites at which complex ASD surgery is commonly performed. This is a multicenter retrospective radiographic analysis of patients treated with lumbar PSO at ISSG centers. Institutional review board approval was obtained at each study site prior to enrollment of patients and prior to initiation of the present study.

Consecutive cases meeting the following inclusion criteria were included for analysis: adults (> 18 years) who were surgically treated for ASD with treatment including lumbar PSO, preoperative global positive sagittal malalignment (C-7 plumb line relative to S-1 [C7–S1 plumb line] > 5 cm), and availability of pre- and postoperative full-length anteroposterior and lateral standing radiographs that included visualization from C-2 through S-1 and visualization of the femoral heads. Patients with ankylosing spondylitis or spinal deformity resulting from neuromuscular conditions, tumor, or infection were excluded from analysis.

Radiological Measurements

Preoperative and postoperative full-length radiographs were obtained using a standard protocol.[1,29] Postoperative full-length radiographs were obtained between 3 and 6 months after surgery. Patients were instructed to adopt a comfortable standing posture with their arms positioned at approximately 45° of forward shoulder flexion and their fingertips placed on the midclavicle region. Radiographic measurements were performed using validated software[6,26] (Spineview, Surgiview) designed for assessment of coronal and sagittal spinal measurements, including pelvic parameters.

Measurements for the study included the following: C2–3 angle, C2–7 cervical lordosis measured using the Cobb method, T2–12 TK, T1–S1 LL, PT, PI, SS, C7–S1 plumb line, C-2 plumb line relative to S-1 (C2–S1 plumb line), C-2 plumb line relative to C-7 (C2–7 plumb line), T-1 spinopelvic inclination, PI − LL (reflects the mismatch between PI and LL), and T-1 slope[16] (angle between the superior endplate of T-1 and the horizontal). Regional spinal inclinations were calculated by determining the angle between a line connecting the centers of the inclusive vertebral bodies and a vertical reference line. Measured regional inclinations included the following: C3–7, C7–T12, and T12–S1. Focal sagittal correction achieved at the PSO site was assessed using the Cobb angle between the inferior endplate of the vertebra above the PSO level and the superior endplate of the vertebra below the PSO level, as previously described.[22,24]

Statistical Analysis

All statistical analyses were performed using SPSS (version 19.0, IBM SPSS, Inc.). Summary statistics were calculated for demographic, surgical, and radiographic parameters. Paired samples t-tests were used to compare pre- and postoperative radiographic measurements. Correlations between clinical, surgical, and radiographic parameters were performed using the Pearson correlation coefficient. Linear regression analyses were used to evaluate for independent associations among the radiographic parameters assessed. Linear regression analyses were performed to identify parameters independently associated with cervical lordosis. The following 3 stepwise models were generated: 1) preoperative C2–7 lordosis as the dependent variable and all other preoperative radiographic measures assessed as the independent variables; 2) postoperative C2–7 lordosis as the dependent variable and all other postoperative radiographic measures assessed as the independent variables; and 3) change in C2–7 lordosis as the dependent variable and all other changes in radiographic measures assessed as the independent variables. Statistical analyses were 2-sided, and $p < 0.05$ was considered statistically significant.

Results

Demographic and Operative Data

Seventy-five patients (60 women and 15 men) with a mean age of 59 ± 10 years (range 37–77 years) were analyzed in this study. Procedures were primary in 24 patients (32%) and revision in 51 patients (68%). Surgical treatment in all patients included a single-level lumbar PSO, with distribution of levels L-1, L-2, L-3, L-4, and L-5 of 8 (11%), 12 (16%), 38 (51%), 16 (21%), and 1 (1%), respectively. The mean PSO wedge resection was 23.1° ± 10.2°, and the mean number of posterior spinal levels fused was 12 ± 3.7. The uppermost instrumented vertebra was at T-6 or above in 38 patients (51%) (most commonly T-4), and it was at T-7 or below in 37 patients (49%) (most commonly T-10). The uppermost instrumented vertebra in all cases was in the thoracic spine. Instrumentation extended to the pelvis in 56 patients (75%), to the sacrum in 10 (13%), and to L-3, L-4, or L-5 in 9 patients (12%).

Preoperative to Postoperative Changes in Radiographic Parameters

Radiographic measures of sagittal spinal alignment improved significantly after deformity correction (Table 1 and Figs. 1 and 2). Significant improvements were identified in global measures of sagittal alignment, including C2–S1 plumb line, C7–S1 plumb line, and T-1 spinopelvic inclination ($p < 0.001$). Pelvic parameters, including PT and SS, also demonstrated significant improvement ($p < 0.001$), reflective of relaxation of pelvic compensatory measures following improvement in sagittal alignment.

Measures of thoracolumbar regional sagittal alignment also demonstrated significant improvement after surgery, including TK, LL, C7–T12 inclination, and T12–S1 inclination ($p < 0.001$). Changes in cervical alignment were also demonstrated, including relaxation of cervical lordosis ($p < 0.001$) and reduction of the C2–7 plumb line ($p = 0.033$). No significant changes were identified in the C2–3 angle ($p = 0.34$) or C3–7 inclination ($p = 0.37$).

TABLE 1: Preoperative and postoperative radiographic spinopelvic alignment parameters in 75 adults with spinal deformity treated with lumbar PSO

Radiographic Parameter	Mean ± SD		p Value*
	Preop	Postop	
C2–3 angle (°)	4.4 ± 4.6	3.7 ± 4.2	0.34
C2–7 angle (°)	30.8 ± 11.7	21.6 ± 14.5	**<0.001**
C2–7 plumb line (mm)	27.0 ± 21.5	22.9 ± 16.8	**0.033**
T-1 slope (°)	–38.9 ± 11.3	–30.4 ± 11.2	**<0.001**
T2–12 angle (°)	–35.7 ± 20.2	–48.0 ± 16.2	**<0.001**
T12–S1 angle (°)	17.4 ± 19.0	49.3 ± 15.1	**<0.001**
C2–S1 plumb line (mm)	189.2 ± 59.7	73.4 ± 56.6	**<0.001**
C7–S1 plumb line (mm)	163.8 ± 56.1	51.8 ± 52.8	**<0.001**
T-1 spinopelvic inclination (°)	5.5 ± 5.2	–2.9 ± 5.2	**<0.001**
C3–7 inclination (°)	19.9 ± 18.9	18.1 ± 20.7	0.37
C7–T12 inclination (°)	28.8 ± 18.1	9.5 ± 8.3	**<0.001**
T12–S1 inclination (°)	1.3 ± 13.4	–4.7 ± 9.6	**<0.001**
PT (°)	32.5 ± 8.8	23.9 ± 8.7	**<0.001**
SS (°)	24.5 ± 11.9	33.6 ± 9.7	**<0.001**

* Probability values from paired samples t-tests. Significant p values ($p < 0.05$) are shown in boldface type.

Correlations of Clinical, Surgical, and Radiographic Parameters With Changes in Cervical Lordosis

Following the lumbar PSO procedure, the mean cervical lordosis reduced significantly (from 30.8° to 21.6°, $p < 0.001$). The change in cervical lordosis did not correlate with demographic or surgical parameters, including patient age, number of thoracolumbar spinal levels fused, level of the PSO, or angle of the PSO bone resection ($p > 0.05$; Table 2). The mean change in C2–7 lordosis did not differ significantly between women (–8.9° ± 14.2°) and men (–10.4° ± 9.8°) ($p = 0.36$). The change in cervical lordosis did correlate with changes in multiple radiographic parameters; the strongest correlations were with change in T-1 slope ($r = –0.621$, $p < 0.001$), change in C7–T12 inclination ($r = 0.418$, $p < 0.001$), and change in LL (T12–S1) ($r = –0.339$, $p = 0.005$) (Table 2). Change in cervical lordosis also demonstrated significant correlation with changes in the C2–3 angle, C2–S1 plumb line, C7–S1 plumb line, and T-1 spinopelvic inclination (Table 2). A moderate correlation was identified between the preoperative C2–7 lordosis and the change in C2–7 lordosis (postoperative – preoperative) (Pearson $r = –0.33$, $p = 0.006$). Patients with normal or near-normal C2–7 lordosis (< 20°) prior to surgery did not demonstrate a significant change in cervical lordosis at follow-up ($p = 0.33$); however, there were only 8 patients in this group. In contrast, patients with preoperative C2–7 lordosis of 21°–30° or greater than 30° had significant improvement in cervical lordosis at follow-up ($p = 0.001$ and $p < 0.001$, respectively).

Reciprocal changes for patients who achieved satis-

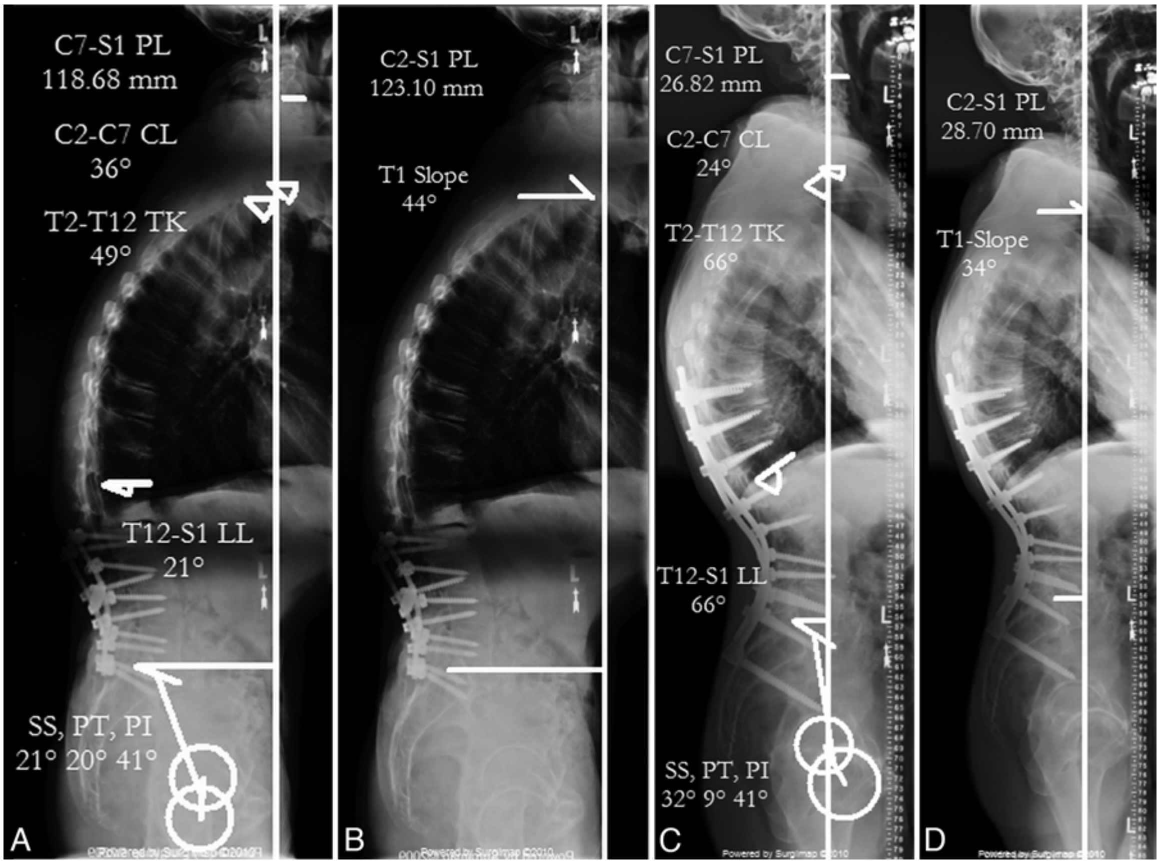

Fig. 1. Case example. Preoperative **(A and B)** and postoperative **(C and D)** sagittal radiographs showing measurement markup. Note the decrease in cervical lordosis following lumbar PSO. CL = cervical lordosis; PL = plumb line.

factory sagittal spinopelvic alignment (C7–S1 plumb line < 50 mm, PT < 25°, and an LL within 10° of the PI)[31] versus those who did not were assessed. The mean change in cervical lordosis was significantly greater for patients who met the C7–S1 plumb line threshold ($p = 0.037$), but it was not significantly different based on whether patients met the PT or PI − LL alignment thresholds (Table 3).

Regression Analysis

The best-fit model on linear regression analysis for preoperative C2–7 lordosis included the following 3 variables: T-1 slope, C2–7 plumb line, and C2–3 angle ($r^2 = 0.56$, $p < 0.001$). The best-fit model for postoperative C2–7 lordosis included the same 3 variables: T-1 slope, C2–7 plumb line, and C2–3 angle ($r^2 = 0.66$, $p < 0.001$). The best-fit model for change in C2–7 lordosis included change in T-1 slope and change in C2–7 plumb line ($r^2 = 0.53$, $p < 0.001$; Table 4). In all 3 of these linear regression models, inclusion of the C2–7 plumb line parameter into the best-fit model was dependent on inclusion of the T-1 slope. In addition, there was no direct correlation between C2–7 lordosis and C2–7 plumb line preoperatively ($r = 0.130$, $p = 0.27$), postoperatively ($r = 0.167$, $p = 0.18$), or as a change from pre- to postoperatively ($r = 0.030$, $p = 0.81$). These findings suggest an interaction between the T-1 slope and the C2–7 plumb line in setting the C2–7 lordosis.

Discussion

Over the last decade, there has been an increasing appreciation of the critical role of anatomical sagittal spinopelvic alignment in the maintenance of an economic posture.[1,8,18–21,23,24,27,29–31,34,35] Disruption of this alignment can compromise the ability to stand upright and ambulate and can profoundly impact quality of life.[8,31] Improved spinal instrumentation and development of specialized osteotomy techniques, such as the PSO, have enabled surgical correction of positive sagittal malalignment.[2–4,7,22] However, it has been increasingly recognized that sagittal spinopelvic alignment is a complex chain of correlations from the pelvis to occiput and that changes in one region of the spine, such as with instrumented fusion for deformity correction, can result in reciprocal changes in other spinopelvic regions, with potential alignment consequences.[15,18,23] These reciprocal changes have been described for the thoracolumbar spine and pelvis but have not been previously defined for the cervical spine.

In the present study we hypothesized that adults with positive sagittal malalignment would compensate with abnormally increased cervical lordosis in an effort to maintain horizontal gaze and that correction of the sagittal malalignment would result in correction of the cervical hyperlordosis through reciprocal changes. Based on assessment of the radiographic measures in this retrospective series of 75 adults with positive sagittal mal-

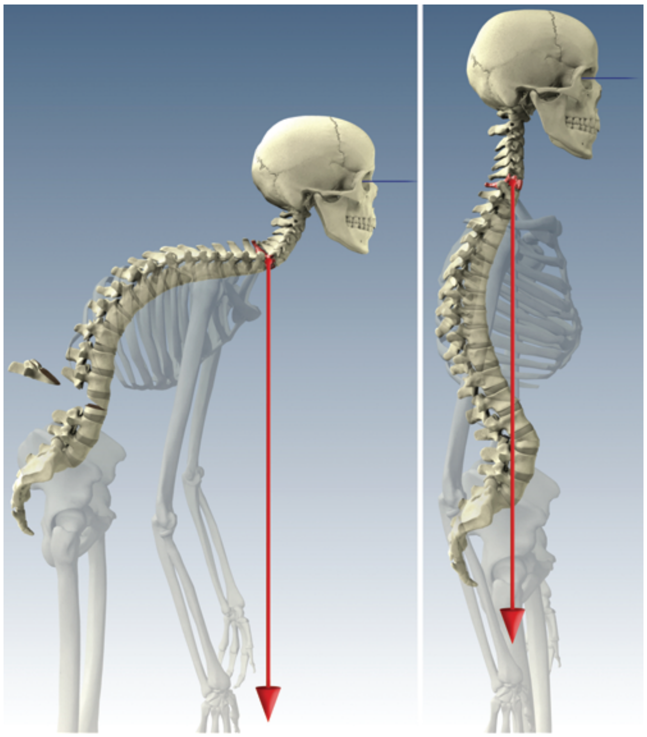

Fig. 2. Diagrammatic demonstration of the changes in sagittal spinopelvic alignment that occur after lumbar PSO. **Left:** Depiction of significant positive sagittal malalignment, increased cervical lordosis to maintain horizontal gaze, and a lumbar wedge symbolizing the bone removal for a lumbar PSO. **Right:** Depiction of corrected sagittal alignment and decrease of cervical lordosis following closure of a lumbar PSO. Printed with permission from Kenneth Xavier Probst.

alignment treated surgically with a lumbar PSO, both of these hypotheses proved to be correct.

A remarkably broad range of normal values for cervical lordosis has been previously reported.[9–14,17,25,33,35] These variations likely reflect a number of factors, including differing measurement techniques and lack of discrimination of patients based on symptoms or pathology. In addition, many previous studies did not distinguish measures of cervical lordosis based on patient age, and recent studies have demonstrated that cervical lordosis significantly increases with age.[1,5,9]

Blondel et al.[1] recently assessed 55 asymptomatic volunteers and reported mean C2–7 lordosis measures of 9.4°, 6.6°, and 22.2° for individuals 20–39 years, 40–59 years, and 60 years or older, respectively. Using these age groups and normal values from asymptomatic volunteers, the mean cervical lordosis that would be expected for the patients with significant positive sagittal malalignment in the present study would be 14.4° ± 7.8°. However, the observed mean preoperative cervical lordosis was 30.8°, more than twice the expected value, consistent with the presence of abnormal hyperlordosis. Notably, to overcome potential variations in the measurement techniques, Blondel et al.[1] used standardized imaging software specifically designed for spinal deformity assessment (Spineview, Surgiview). The radiographic measurements obtained in the present study were the same as those obtained by Blondel et al., who used the same software and technique in their study.

TABLE 2: Correlations of clinical, surgical, and radiographic parameters with changes in cervical lordosis (C2–7 angle) for 75 adults with spinal deformity treated with lumbar PSO

		Correlation w/ ΔC2–7 Angle (postop – preop)	
Radiographic Parameter	Mean ± SD	Pearson Correlation Coefficient	p Value*
patient age (yrs)	58.6 ± 10.2	0.153	0.24
no. of levels fused	12.0 ± 3.7	0.054	0.66
PSO level	L-3 ± 0.9	–0.136	0.27
PSO resection (°)	–23.1 ± 10.2	0.132	0.29
ΔC2–3 angle (°)	–0.68 ± 5.8	**0.257**	**0.036**
ΔC2–7 plumb line (mm)	–4.1 ± 15.4	0.030	0.81
ΔT-1 slope (°)	8.5 ± 10.6	**–0.621**	**<0.001**
ΔT2–12 angle (°)	–12.3 ± 13.9	–0.213	0.084
ΔT12–S1 angle (°)	31.9 ± 15.3	**–0.339**	**0.005**
ΔC2–S1 plumb line (mm)	–115.8 ± 60.9	**0.277**	**0.023**
ΔC7–S1 plumb line (mm)	–111.9 ± 55.0	**0.289**	**0.018**
ΔT-1 spinopelvic inclination	–8.3 ± 4.9	**0.276**	**0.033**
ΔC3–7 inclination (°)	–1.8 ± 16.8	0.129	0.30
ΔC7–T12 inclination (°)	–19.3 ± 18.2	**0.418**	**<0.001**
ΔT12–S1 inclination (°)	–6.0 ± 9.8	–0.036	0.77
ΔPT (°)	–8.6 ± 8.3	0.157	0.23
ΔSS (°)	9.1 ± 8.6	–0.221	0.073

* Significant p values and corresponding correlation coefficients are shown in boldface type.

After surgical treatment with PSO, the 75 patients in the present study demonstrated improvements in sagittal alignment that would be expected based on prior reports, including reduced C2–S1 and C7–S1 plumb lines, decreased T-1 spinopelvic inclination, decreased PT, and increased SS. Thoracic (C7–T12) and lumbar (T12–S1)

TABLE 3: Comparison of changes in cervical lordosis (C2–7 angle) for 75 adults with spinal deformity treated with lumbar PSO based on achievement of ideal sagittal alignment thresholds

	Mean ΔC2–7 Angle ± SD		
Parameter (postop threshold)	Threshold Not Achieved	Threshold Achieved	p Value*
C7–S1 plumb line in mm (<50 mm)	–5.7 ± 13.8	–12.4 ± 12.2	**0.037**
PT in ° (<25°)	–8.6 ± 14.3	–9.5 ± 12.8	0.80
mismatch btwn LL & PI in ° (w/in 10°)	–9.0 ± 14.7	–9.1 ± 12.7	0.98

* The significant p value is shown in boldface type.

TABLE 4: Assessment of radiographic factors associated with preoperative, postoperative, and changes between pre- and postoperative measures of cervical lordosis (C2–7 angle) based on linear regression analysis

Measure	Standardized Coefficient (Beta)	95% CI	p Value
preop*			
T-1 slope	–0.958	–1.268 to –0.771	<0.001
C2–7 plumb line	–0.600	–0.458 to –0.202	<0.001
C2–3 angle	0.253	0.238 to 1.116	<0.001
constant	–2.224	–9.965 to 5.518	0.57
postop†			
T-1 slope	–0.996	–1.580 to –1.045	<0.001
C2–7 plumb line	–0.601	–0.702 to –0.327	<0.001
C2–3 angle	0.251	0.253 to 1.438	<0.001
constant	–9.978	–16.696 to –3.260	0.004
change btwn pre- & postop‡			
ΔT-1 slope	–0.900	–1.559 to –0.929	<0.001
ΔC2–7 plumb line	–0.483	–0.669 to –0.240	<0.001
constant	–1.011	–4.236 to 2.214	0.53

* r^2 for model = 0.56.
† r^2 for model = 0.66.
‡ r^2 for model = 0.53.

measures of inclination relative to the vertical also improved significantly. These findings reflect favorable changes in the sagittal alignment achieved after surgery.

There was also a significant increase in TK following surgery and reciprocal reduction in the T-1 slope, relaxation of cervical hyperlordosis, and modest, but significant, improvement in the C2–7 plumb line. The mean postoperative C2–7 lordosis was 21.6°, substantially closer than the preoperative measure to the mean expected value of 14.4° predicted based on the study by Blondel et al.[1]

The magnitude of C2–7 lordosis correction after PSO did not correlate with patient age, number of levels fused, spinal level of the PSO, or angle of the PSO wedge resection. The magnitude of cervical lordosis correction did correlate with changes in several radiographic measures, including global measures of improved sagittal alignment, such as the C2–S1 and C7–S1 plumb lines and the T-1 spinopelvic inclination. This supports the conclusion that cervical lordosis is changing in response to an improvement in the global sagittal alignment after PSO. However, the radiographic parameters with changes that had the strongest correlations with changes in cervical lordosis were those closest to the cervical region, specifically the T-1 slope and the thoracic (C7–T12) inclination. This is consistent with the study of Blondel et al.[1] that demonstrated a chain of correlations in normal sagittal spinopelvic alignment, with the strongest correlations between adjacent regions.

Best-fit linear regression models to predict preoperative and postoperative cervical lordosis incorporated the same radiographic parameters for each model: T-1 slope, C2–7 plumb line, and C2–3 angle. Changes in the T-1 slope and C2–7 plumb line were the only radiographic changes incorporated in the best-fit linear regression model to predict changes in cervical lordosis after PSO. Collectively, these findings suggest fundamental roles for the T-1 slope and C2–7 plumb line in setting the cervical lordosis and in transmitting changes in the global sagittal alignment to the cervical region. Furthermore, since changes in the C2–7 plumb line had no evidence of correlation with changes in the cervical lordosis on univariate analysis and since inclusion of the C2–7 plumb line into the best-fit models was dependent on inclusion of the T-1 slope, there likely exists an interaction between the T-1 slope and the C2–7 plumb line in setting the cervical lordosis. This is consistent with prior reports that have suggested an association of T-1 slope with global sagittal alignment and with cervical lordosis.[1,16]

The full meaning behind the T-1 slope and C2–7 plumb line parameters will likely not be understood without further study. It is possible that the relationship between the T-1 slope and cervical lordosis is comparable to the relationship between the PI and the LL. Patients with a greater PI require a greater LL to achieve appropriate alignment. Previous reports have suggested that the mismatch between the PI and the LL should be no more than 10° and that mismatches that exceed this limit can be a significant source of disability and pain.[32] The T-1 superior endplate is the base of the cervical spine and may help to determine the degree of lordosis required of the cervical spine. The magnitude of the T-1 slope is exaggerated in patients with significant positive sagittal malalignment, which in turn increases the degree of cervical lordosis necessary to maintain horizontal gaze. The C2–7 plumb line is more complex and likely reflects an interaction among the SVA, the T-1 slope, and the degree to which hyperlordosis is present in the cervical spine to maintain horizontal gaze.

Potential strengths of the present study include the relatively large number of patients, the multicenter design, and the standardized approach used for radiographic measurements. The primary limitations of the present study are the retrospective design and relatively short clinical follow-up. In addition, clinical outcomes measures specifically designed to assess for symptoms related to the cervical region, such as a numeric rating scale score for neck pain, the Neck Disability Index, and the Nurick questionnaire, were not collected.

The significant findings of the present report suggest that future study is warranted to investigate the possible impact of compensatory cervical hyperlordosis in the setting of positive sagittal malalignment. These possible impacts may include pain and disability directly related to the cervical region due to muscle fatigue and abnormal loading of the facets, as well as accelerated degenerative changes.

Conclusions

Sagittal spinopelvic malalignment is a recognized cause of significant pain and disability in adults with spinal deformity. The present study demonstrates that adults with spinal deformity that includes positive sagittal malalignment compensate with abnormally increased cervical lordosis in an effort to maintain horizontal gaze and that correction of the sagittal malalignment following PSO results in correction of the abnormal cervical hyperlordosis through reciprocal changes. Patients who achieved full correction of positive sagittal malalignment had the greatest relaxation of cervical hyperlordosis. Key radiographic parameters that correlated with changes in cervical lordosis on linear regression analysis included change in the T-1 slope and change in the C2–7 plumb line.

Disclosure

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