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Surgical treatment of pathological loss of lumbar lordosis (flatback) in patients with normal sagittal vertical axis achieves similar clinical improvement as surgical treatment of elevated sagittal vertical axis

Clinical article

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Object. Increased sagittal vertical axis (SVA) correlates strongly with pain and disability for adults with spinal deformity. A subset of patients with sagittal spinopelvic malalignment (SSM) have flatback deformity (pelvic incidence–lumbar lordosis [PI-LL] mismatch > 10°) but remain sagittally compensated with normal SVA. Few data exist for SSM patients with flatback deformity and normal SVA. The authors' objective was to compare baseline disability and treatment outcomes for patients with compensated (SVA < 5 cm and PI-LL mismatch > 10°) and decompensated (SVA > 5 cm) SSM.

Methods. The study was a multicenter, prospective analysis of adults with spinal deformity who consecutively underwent surgical treatment for SSM. Inclusion criteria included age older than 18 years, presence of adult spinal deformity with SSM, plan for surgical treatment, and minimum 1-year follow-up data. Patients with SSM were divided into 2 groups: those with compensated SSM (SVA < 5 cm and PI-LL mismatch > 10°) and those with decompensated SSM (SVA ≥ 5 cm). Baseline and 1-year follow-up radiographic and health-related quality of life (HRQOL) outcomes included Oswestry Disability Index, Short Form–36 scores, and Scoliosis Research Society–22 scores. Percentages of patients achieving minimal clinically important difference (MCID) were also assessed.

Results. A total of 125 patients (27 compensated and 98 decompensated) met inclusion criteria. Compared with patients in the compensated group, patients in the decompensated group were older (62.9 vs 55.1 years; $p = 0.004$) and had less scoliosis (43° vs 54°; $p = 0.002$), greater SVA (12.0 cm vs 1.7 cm; $p < 0.001$), greater PI-LL mismatch (26° vs 20°; $p = 0.013$), and poorer HRQOL scores (Oswestry Disability Index, Short Form-36 physical component score, Scoliosis Research Society-22 total; $p \leq 0.016$). Although these baseline HRQOL differences between the groups reached statistical significance, only the mean difference in Short Form–36 physical component score reached threshold for MCID. Compared with baseline assessment, at 1 year after surgery improvement was noted for patients in both groups for mean SVA (compensated –1.1 cm, decompensated +4.8 cm; $p \leq 0.009$), mean PI-LL mismatch (compensated 6°, decompensated 5°; $p < 0.001$), and all HRQOL measures assessed ($p \leq 0.005$). No significant differences were found between the compensated and decompensated groups in the magnitude of HRQOL score improvement or in the percentages of patients achieving MCID for each of the outcome measures assessed.

Conclusions. Decompensated SSM patients with elevated SVA experience significant disability; however, the amount of disability in compensated SSM patients with flatback deformity caused by PI-LL mismatch but normal SVA is underappreciated. Surgical correction of SSM demonstrated similar radiographic and HRQOL score improvements for patients in both groups. Evaluation of SSM should extend beyond measuring SVA. Among patients with concordant pain and disability, PI-LL mismatch must be evaluated for SSM patients and can be considered a primary indication for surgery.
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Key Words • **adult** • **deformity** • **flatback** • **lumbar lordosis** • **outcome** • **pelvic parameter** • **sagittal imbalance** • **spine** • **surgery** • **lumbar**

Adults with spinal deformity characteristically experience disability and pain.[5,32,33,38–42] Several studies have demonstrated that one of the key drivers

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

Abbreviations used in this paper: HRQOL = health-related quality of life; MCID = minimal clinically important difference; PI-LL = pelvic incidence–lumbar lordosis; SF-36 = Short Form–36; SSM = sagittal spinopelvic malalignment; SRS-22 = Scoliosis Research Society–22; SVA = sagittal vertical axis.

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of pain and disability in this population is sagittal spinal malalignment.[1,3,4,7,11–13,15,18,19,22,26,27,29,40] Glassman et al. were among the first to demonstrate a clear correlation between sagittal spinal malalignment (sagittal vertical axis [SVA]) and health-related quality of life (HRQOL).[12,13] This correlation has been confirmed in subsequent studies, including that of Lafage et al.[18]

Although the role of SVA has been established, more recently it has become clear that global alignment is not fully accounted for by SVA alone.[1] The role of the pelvis as a key regulator of spinal alignment and as a source of compensation has led to an expanded view of sagittal alignment.[10,18,20,21] The term "sagittal spinopelvic alignment" captures not only assessment of SVA but also key pelvic parameters, including pelvic incidence, pelvic tilt, and sacral slope (Fig. 1). Pelvic incidence is a fixed parameter that reflects the morphology of the sacrum and pelvis in each person and has been suggested to be a primary determinant of the amount of lumbar lordosis required for harmonious spinal alignment.[25,31] In contrast, pelvic tilt is a compensatory parameter that reflects the degree of pelvic retroversion. Persons with positive sagittal malalignment may compensate to varying degrees through retroversion of the pelvis, thereby increasing the pelvic tilt and decreasing the sacral slope. Although pelvic retroversion can help offset and partially mask positive sagittal malalignment, the use of this compensatory measure has been shown to also correlate with increased disability and pain.[18]

A recent study by Schwab et al. assessed correlations between radiographic parameters (coronal and sagittal) and HRQOL scores among 492 adults with spinal deformity.[27] Of all radiographic parameters assessed, the 3 that most strongly correlated with HRQOL scores were the mismatch between pelvic incidence and lumbar lordosis (PI-LL), SVA, and pelvic tilt. This study further established the clinical effects of sagittal spinopelvic malalignment (SSM) on HRQOL and established thresholds of disability for these radiographic parameters.

Flatback deformity (PI-LL mismatch > 10°) is often accompanied by decompensation in sagittal alignment (SVA > 5 cm). However, a subset of patients with SSM have flatback deformity but remain sagittally compensated with normal SVA (Fig. 2). Few data exist for this subset of patients, including whether surgical treatment might offer improvement in HRQOL. Our objective in the study reported here was to compare baseline disability and treatment outcomes for patients with compensated (SVA < 5 cm and PI-LL mismatch > 10°) and decompensated (SVA > 5 cm) SSM.

Methods

Patient Population

This multicenter prospective assessment of adults with spinal deformity was collected through the International Spine Study Group, whose members are based at 11 sites across the United States. At each site, patients were enrolled through an institutional review board–approved protocol. Inclusion criteria for the study group database are age older than 18 years and at least one of the following measures of spinal deformity: scoliosis Cobb angle 20° or greater, SVA 5 cm or greater, pelvic tilt 25° or greater, and thoracic kyphosis 60° or greater. Additional criteria for inclusion in the study reported here were baseline images demonstrating either SVA greater than 5 cm or SVA less than 5 cm in combination with a PI-LL mismatch of more

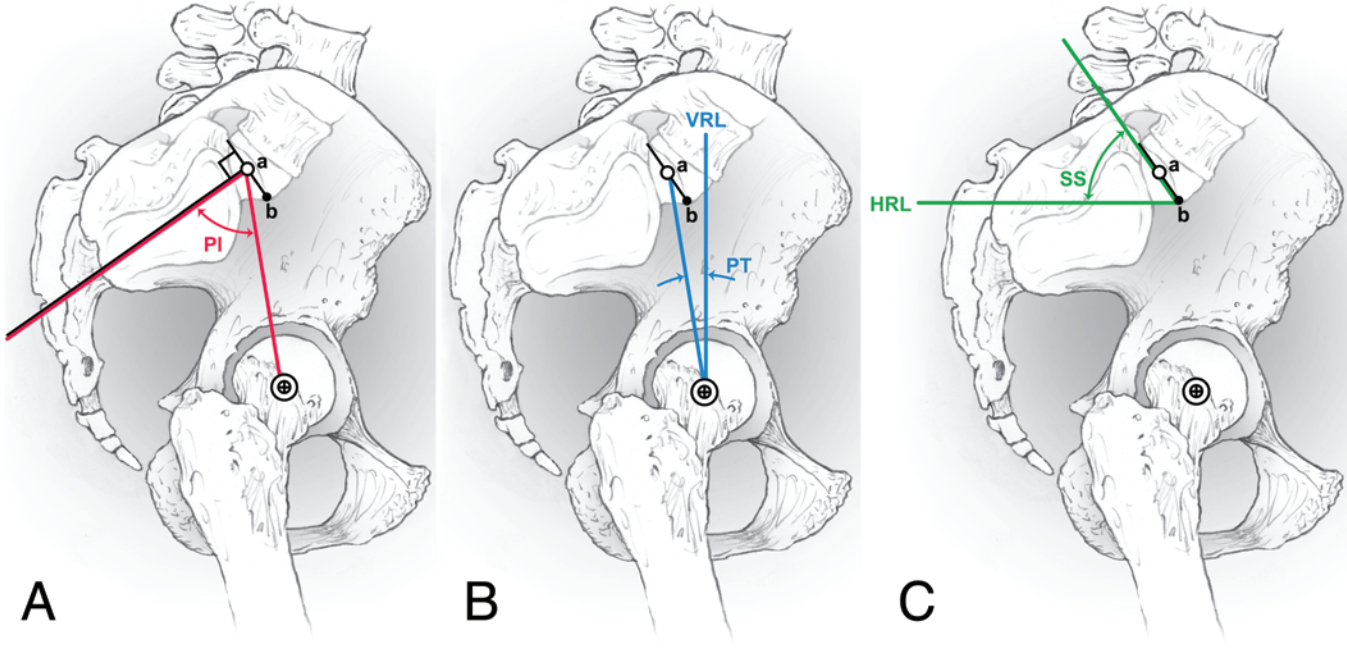

Fig. 1. Pelvic radiographic parameters. **A:** Diagram showing the measurements of PI. **B:** Diagram showing the measurements of pelvic tilt (PT). **C:** Diagram showing the measurements of sacral slope (SS). Note that PI = PT + SS. a = center of sacral endplate; b = anterior superior point of sacral endplate. HRL = horizontal reference line; VRL = vertical reference line. Copyright Kenneth X. Probst. Published with permission from Xavier Studio.

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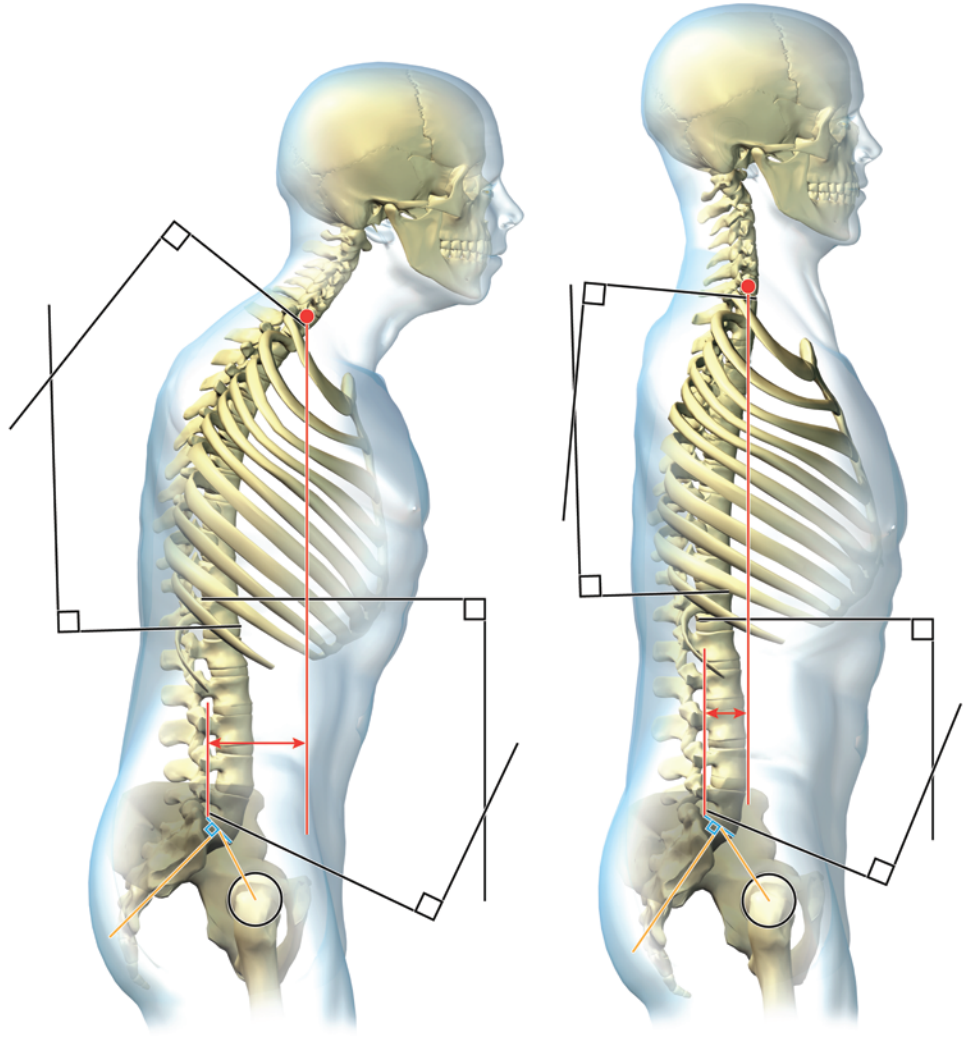

Fig. 2. Decompensated **(left)** and compensated **(right)** SSM. In patients with decompensated SSM, the global sagittal alignment (SVA) is abnormally high (> 5 cm). In contrast, in patients with compensated SSM, the SVA is not abnormal, but the magnitude of the PI-LL mismatch is abnormally high (> 10°). Copyright Kenneth X. Probst. Published with permission from Xavier Studio.

than 10°, documentation of surgical treatment, and data for a minimum of 1 year of follow-up.

Data Collection and Radiographic Assessment

Data collection at baseline and at 1 year after surgical treatment included standardized HRQOL questionnaires and clinical, demographic, and radiographic information. Basic demographic and clinical information included patient age, sex, body mass index, and Charlson Comorbidity Index.[9] In addition, a basic numeric rating scale score ranging from 0 to 10 for back and leg pain was collected; 0 represented no pain and 10 reflected the most unbearable pain.

Standardized HRQOL measures used were the Oswestry Disability Index, Short Form–36 (SF-36) scores, and Scoliosis Research Society–22 (SRS-22) scores. Two standard summary scores were calculated on the basis of the SF-36: the physical component score and the mental component score. The SRS-22 provides a summary score and multiple subdomains, including activity, pain, appearance, mental, and satisfaction.

Full-length free-standing anteroposterior and lateral spine radiographs (36-in cassette) at baseline and 1-year follow-up were analyzed by using validated Spineview software[8,23] (Surgiview). All radiographic measurements were performed at a central location (New York University) according to standard techniques; radiographic measures were coronal Cobb angle, thoracic kyphosis (T4–T12; Cobb angle between the superior end plate of T-4 and inferior end plate of T12), LL (Cobb angle between the superior endplate of T-12 and the superior endplate of S-1), SVA (C-7 plumb line relative to S-1), pelvic tilt, and PI-LL mismatch (Fig. 1).

Data and Statistical Analyses

Mean and standard deviation were used to describe continuous variables, and frequency analyses were used for categorical variables. Changes in outcome measures between baseline and 1-year follow-up were evaluated by using a paired t-test analysis, and group comparison was performed by using an unpaired t-test analysis. According

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to inclusion criteria, all patients had SSM. Patients were stratified into 1 of 2 groups, compensated or decompensated, on the basis of radiographic parameters present at initial examination. The compensated group was composed of patients with an SVA less than 5 cm but with a PI-LL mismatch greater than 10°, and the decompensated group was composed of patients with an SVA greater than 5 cm. Demographic, clinical, radiographic, and HRQOL measures were compared within and between these groups at baseline and at 1-year follow-up. The groups were also compared with regard to the percentages of patients who reached thresholds of improvement based on the minimal clinically important difference (MCID; Table 1) at 1-year follow-up after surgical treatment (S. Berven, V. Deviren, D. Polly, et al., presented at the International Meeting on Advanced Spine Techniques, Banff, Canada, July 7–9, 2005). MCID reference values for this population are not available for the SF-36 mental component score, SRS-22 total score, or SRS-22 satisfaction score.

Results

Baseline Findings

From a total of 353 adult patients with operative spinal deformity enrolled in the prospective database, 125 patients (100 women and 25 men) met our inclusion criteria; average age was 61.3 years (± 12.7 years). Of these patients, 27 were in the compensated group (SVA < 5 cm and PI-LL mismatch > 10°) and 98 were in the decompensated group (SVA > 5 cm). Representative cases are shown in Figs. 3 and 4. Baseline demographic and clinical data are summarized and compared in Table 2. Compared with patients in the compensated group, those in the decompensated group were older (62.9 vs 55.1 years, p = 0.004); nonsignificant trends were found toward a higher proportion of men (p = 0.063), greater body mass index (p = 0.097), higher Charlson Comorbidity Index (p = 0.083), and more back pain at baseline (p = 0.060) (Table 2).

A total of 44 (35.2%) patients had a history of thoracolumbar fusion: 35.7% of compensated patients and 33.3% of decompensated patients (p = 1.00). The mean number of previously fused levels did not differ significantly between the compensated and decompensated groups (6.1 vs 6.7, respectively; p = 0.69). Overall, only 8 patients had undergone previous fusions at levels between T2 and T9; of these, 4 (4.1%) patients were in the compensated group and 4 (14.8%) were in the decompensated group (p = 0.066).

Baseline radiographic measures are summarized in Table 3. Compared with results for patients in the decompensated group, for patients in the compensated group mean magnitude of maximum coronal Cobb angle was greater (53.5° vs 43.3°, p = 0.002), thoracic kyphosis was less (17.2° vs 30.7°, p < 0.001), SVA was lower (1.7 cm vs 12.0 cm, p < 0.001), pelvic tilt was similar (25.7° vs 27.8°, p = 0.56), and PI-LL mismatch was less (20.1° vs 26.3°, p = 0.013).

Baseline HRQOL scores are summarized in Table 4. Compared with results for patients in the compensated group, for patients in the decompensated group mean scores on multiple measures of HRQOL were significantly poorer: Oswestry Disability Index (48.1 vs 37.0, p = 0.010), SF-36 physical component score (29.6 vs 35.7, p = 0.004), SRS-22 total score (2.6 vs 3.0, p = 0.016), SRS-22 pain domain (2.3 vs 2.7, p = 0.017), and SRS-22 appearance domain (2.3 vs 2.6, p = 0.046). Notably, although these differences reached statistical significance, only the mean difference in SF-36 physical component score reached MCID threshold (Tables 1 and 4).

Changes Between Measures at Baseline and at 1 Year

For patients in both groups, all radiographic measures assessed (coronal Cobb angle, thoracic kyphosis, SVA, pelvic tilt, and PI-LL mismatch) improved significantly from baseline to 1-year follow-up after surgery (Table 3). At 1-year follow-up, compared with the compensated group, patients in the decompensated group continued to have greater mean thoracic kyphosis (40.9° vs 26.9°, p < 0.001) and greater mean SVA (4.8 cm vs –1.1 cm, p < 0.001). Also at 1-year follow-up, no significant differences between patient groups were found for mean maximum coronal Cobb angle (p = 0.57), pelvic tilt (p = 0.40), or PI-LL mismatch (p = 0.99) (Table 3).

For patients in both groups, each HRQOL measure applied in the study demonstrated significant improvement from baseline to 1-year follow-up (Table 4). The magnitudes of these improvements exceeded MCID thresholds, except for 2 measures in which the mean improvement approached MCID. Specifically, the mean improvement in Oswestry Disability Index for the compensated group was 14.3 points (MCID = 15 points), and the mean improvement in SRS-22 mental domain for the decompensated group was 0.3 points (MCID = 0.42 points) (Tables 1 and 4). Notably, at 1-year follow-up, the following scores remained poorer for patients in the decompensated group: Oswestry Disability Index (32.2 vs 22.7, p = 0.031), SF-36 physical component score (37.2 vs 44.2, p = 0.003), SF-36 mental component score (48.6 vs 56.0, p = 0.002), and SRS-22 total score (3.5 vs 3.9, p = 0.032) (Table 4).

From baseline to 1-year follow-up after surgery, patients in the compensated and decompensated groups demonstrated remarkably similar mean point improvements for each of the HRQOL measures applied (Table 5). None of the differences in mean point improvements

TABLE 1: Summary of MCID values applied in the study*

SF-36 PCS	ODI	SRS-22 Pain	SRS-22 Appearance	SRS-22 Activity	SRS-22 Mental
+5.2	−15	+0.587	+0.8	+0.375	+0.42

* Data from S. Berven, V. Deviren, D. Polly et al., presented at the International Meeting on Advanced Spine Techniques, Banff, Canada, July 7–9, 2005. ODI = Oswestry Disability Index.

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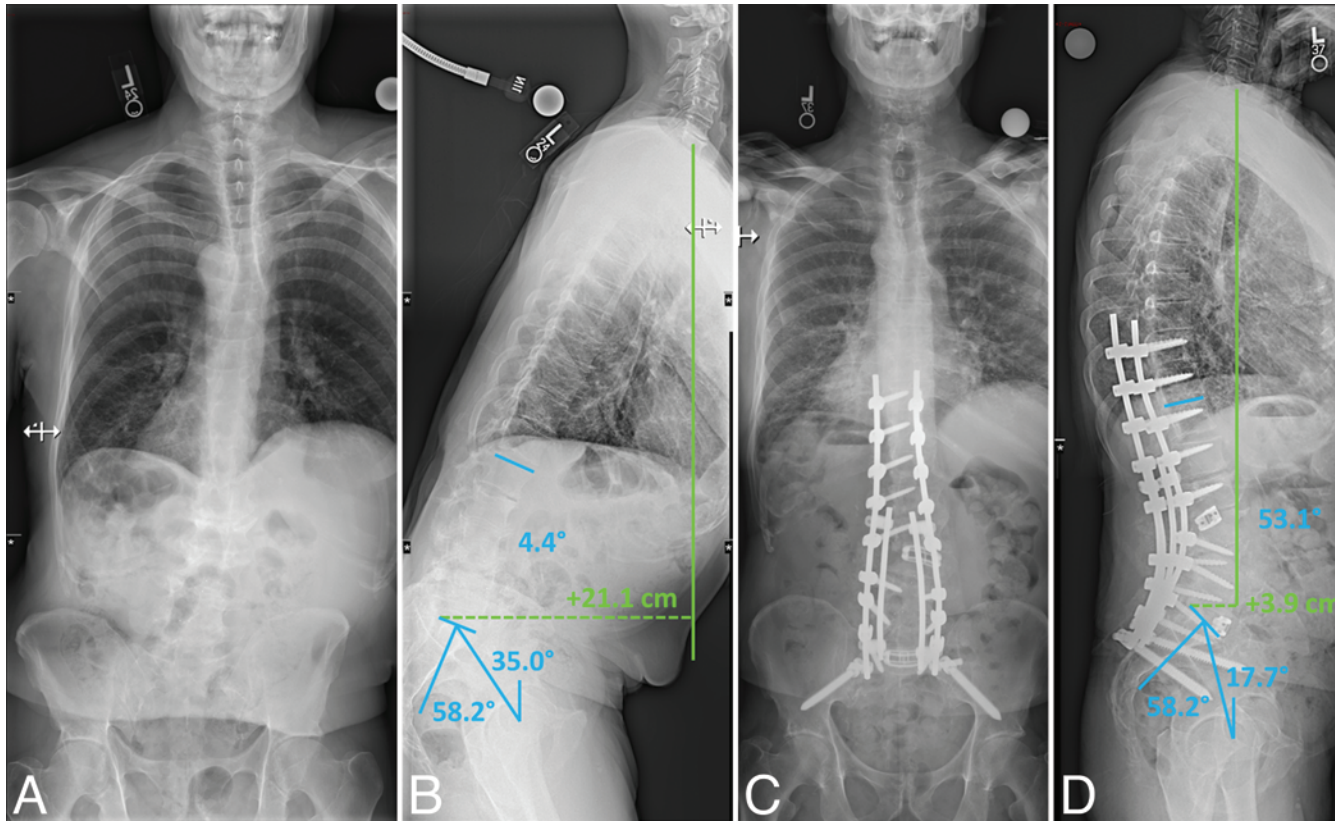

Fig. 3. Representative patient with decompensated SSM, including preoperative anteroposterior **(A)** and lateral **(B)** and postoperative anteroposterior **(C)** and lateral **(D)** full-length standing radiographs. The preoperative SVA is 21.1 cm, reflecting significant positive sagittal malalignment. Other preoperative measures were lumbar lordosis of 4.4°, PI of 58.2°, pelvic tilt of 35.0°, and PI-LL mismatch of 53.8°. Postoperative measures were SVA of 3.9 cm, lumbar lordosis of 53.1°, PI of 58.2°, pelvic tilt of 17.7°, and PI-LL mismatch of 5.1°.

between the 2 groups even approached MCID or statistical significance (Tables 1 and 5). The percentages of patients achieving MCID for each HRQOL measure were also remarkably similar between the groups, and none of the differences in percentages between the 2 groups reached statistical significance (Table 5).

Discussion

It has been well established that abnormally elevated SVA correlates with pain and disability in adults with spinal deformity, and attention has been rightfully directed toward assessing this parameter in the clinical setting.[1,3,7,11–13,15,16,20,22,25–27,30,40] This condition is a recognized primary indication for surgical treatment. Many reports have clearly documented that surgical correction of symptomatic sagittal spinal malalignment has the potential to result in improved HRQOL. However, in a subset of patients, pathological loss of lumbar lordosis occurs despite normal SVA. These patients, who exhibit a form of compensated flatback syndrome, have not been well studied, and their sagittal alignment may be erroneously considered normal on the basis of assessment of the SVA alone. However, recent studies have clearly shown that PI-

TABLE 2: Baseline demographic and clinical parameters for 125 adults with SSM*

Parameter	Decompensated (n = 98)	Compensated (n = 27)	p Value
mean age, in yrs (SD)	62.9 (12.4)	55.1 (12.1)	**0.004**
sex, % female	76	93	0.063
mean body mass index (SD)	28.6 (5.1)	26.6 (5.9)	0.097
mean Charlson Comorbidity Index (SD)	1.6 (1.7)	1.1 (1.2)	0.083
mean pain score (range 0–10) (SD)			
back pain	7.7 (2.0)	6.8 (2.4)	0.060
leg pain	4.6 (3.2)	4.6 (3.6)	0.97

* Patients were stratified into 2 groups: decompensated (SVA > 5 cm) and compensated (SVA < 5 cm with PI-LL mismatch > 10°). Boldface indicates statistical significance.

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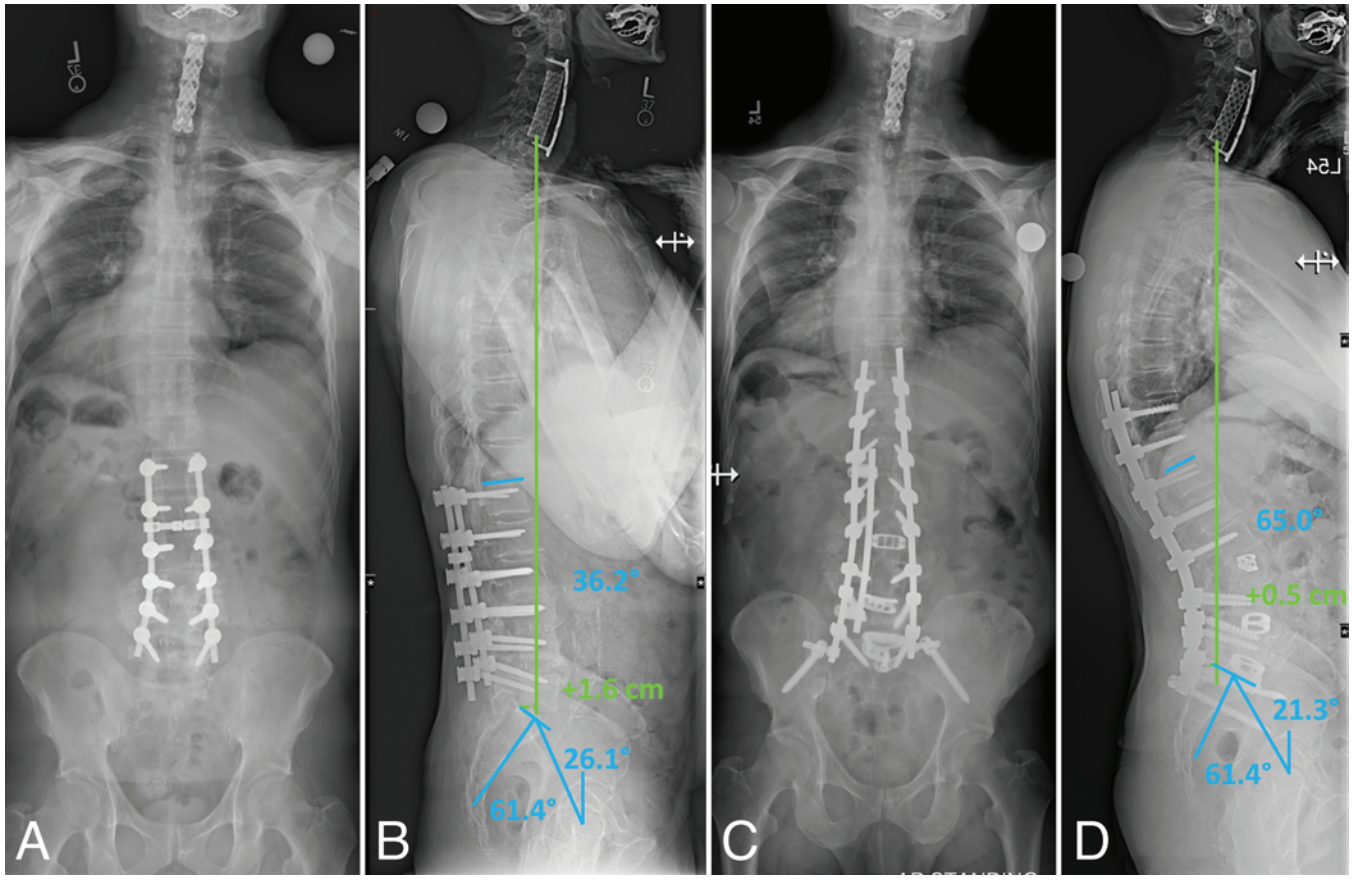

Fig. 4. Representative patient with compensated SSM, including preoperative (this study) anteroposterior **(A)** and lateral **(B)** and postoperative anteroposterior **(C)** and lateral **(D)** full-length standing radiographs. The preoperative SVA is 1.6 cm, a value within normal range for global spinal alignment. Other preoperative measures were lumbar lordosis of 36.2°, PI of 61.4°, pelvic tilt of 26.1°, and PI-LL mismatch of 25.2°. Postoperative measures were SVA of 0.5 cm, lumbar lordosis of 65.0°, PI of 61.4°, pelvic tilt of 21.3°, and PI-LL mismatch of −3.6°.

LL mismatch is among the key radiographic parameters associated with pain and disability among adults with spinal deformity.[1,17,18,21,25,27,31,34,43] The study reported here demonstrated that patients with compensated flatback syndrome can have significant pain and disability at baseline and that surgical correction can lead to similar radiographic and HRQOL improvements for these patients as for those with pathologically elevated SVA. Collectively, these findings demonstrate that evaluation of sagittal spinal alignment should extend beyond measuring SVA and that PI-LL mismatch among patients with concordant pain and disability can be considered a primary indication for surgery with the potential for significant improvement of HRQOL.

It remains unclear why decompensation of the SVA develops in some patients with SSM but a normal (compensated) SVA is maintained by others.[2] It is possible that patients in these 2 groups represent different points on a continuum of sagittal spinopelvic alignment pathology in which compensation reflects an earlier stage. In support of this hypothesis, the mean age of patients in the decompensated group was significantly lower than that of patients in the compensated group. In addition, the severity of PI-LL mismatch was greater among patients in the decompensated group than among those in the compensated groups.

Alternatively, it is possible that the magnitude of thoracic kyphosis might affect whether a patient with SSM will maintain a compensated SVA. In the study reported here, magnitude of thoracic kyphosis was significantly greater for patients in the decompensated group than for those in the compensated group. Increased thoracic kyphosis might favor an increased SVA in the setting of deformity, but a relatively flat thoracic spine might help to mask or even compensate for pathologic loss of lumbar lordosis. Notably, patients in the compensated and decompensated groups did not differ significantly in the proportion with a history of previous thoracolumbar fusion or in the number of previously fused levels. Despite a nonsignificant trend toward a greater proportion of compensated patients having a history of fusion that included levels between T2 and T9, the overall number of patients with such fusions was relatively small. Collectively, these findings suggest that a history of thoracic fusion is not a primary explanation as to why some patients are able to remain compensated.

Of note, patients in both groups demonstrated evidence of compensatory pelvic retroversion, and mean pelvic tilt at baseline and at follow-up did not differ significantly between the groups. Thus, it does not seem that patients in the compensated group maintain a normal SVA

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TABLE 3: Comparison of baseline and 1-year follow-up (after surgical correction) radiographic measures for 125 adults with SSM*

Radiographic Parameter	Decompensated (n = 98)†	Compensated (n = 27)†	p Value
mean max coronal Cobb angle (°)			
baseline	43.3 (17.2)	53.5 (17.0)	**0.002**
1 yr after surgical treatment	24.9 (15.5)	27.0 (17.0)	0.57
p value	**<0.001**	**0.005**	—
mean thoracic kyphosis at T4–T12 (°)			
baseline	30.7 (18.1)	17.2 (9.5)	**<0.001**
1 yr after surgical treatment	40.9 (15.4)	26.9 (12.4)	**<0.001**
p value	**<0.001**	**<0.001**	—
mean C7–S1 SVA (cm)			
baseline	12.0 (5.6)	1.7 (2.8)	**<0.001**
1 yr after surgical treatment	4.8 (5.2)	−1.1 (5.3)	**<0.001**
p value	**<0.001**	**0.009**	—
mean pelvic tilt (°)			
baseline	27.8 (11.8)	25.7 (7.1)	0.56
1 yr after surgical treatment	22.6 (11.6)	22.5 (8.6)	0.40
p value	**<0.001**	**0.034**	—
mean PI-LL mismatch (°)			
baseline	26.3 (19.0)	20.1 (6.0)	**0.013**
1 yr after surgical treatment	5.4 (14.8)	5.5 (11.8)	**0.99**
p value	**<0.001**	**<0.001**	—

* Patients were stratified into 2 groups: decompensated (SVA > 5 cm) and compensated (SVA < 5 cm with PI-LL mismatch > 10°). Significant improvement for each radiographic measure from baseline to 1-year follow-up is demonstrated for both groups. Boldface indicates statistical significance. — = not applicable.

† Standard deviation values are presented parenthetically.

through a relatively greater degree of pelvic retroversion than do patients in the decompensated group.

The changes in mean score from baseline to follow-up across multiple standardized measures of HRQOL were remarkably similar between the compensated and decompensated groups. The similarities in standard deviations for these means between groups for each HRQOL measure also suggest similar degrees of variation in scores between the groups (Table 5). The percentages of patients in the compensated and decompensated groups reaching MCID for each outcome measure did not significantly differ, suggesting that surgical treatment for patients in either group can offer significant clinical improvement.

When contemplating surgical treatment for adult patients with spinal deformity, one should recognize the high rates of complications associated with these often complex procedures, especially among elderly patients.[24,28,35–37,41] Smith et al. recently reviewed the literature regarding complication rates for deformity surgery in adults and reported rates as high as 96%.[33] In a risk-benefit assessment of spinal deformity surgery in adults, Smith et al. noted that the associated complication rates increased more than 4-fold from younger patients (25–44 years of age; 17% complication rate) to elderly patients (65–85 years of age; 71% complication rate).[41]

Although the analyses were based on prospectively collected data, the primary limitation of the study reported here is its retrospective design. In addition, although follow-up at 1 year after surgery should be sufficient for assessing the potential benefits,[14] it is possible that longer-term follow-up could demonstrate differences in HRQOL measures between the groups that were not appreciated in our analysis. Previous reports have documented longer-term follow-up for surgical treatment of deformity in adults, including the indications and treatments described in our study, although these previous studies do not specifically stratify the radiographic indications as was done in our study.[5–7,33,34,38,39,41–43] In addition, Glassman et al. reported that among 283 adults surgically treated for spinal deformity, for most patients, standardized outcome measures had stabilized by the 1-year follow-up; these outcomes remained relatively unchanged at the 2-year follow-up.[14] Bridwell et al. further demonstrated that outcomes at 3–5 years after surgery for spinal deformity in adults remained relatively unchanged from outcomes at 2 years after surgery.[5] These data suggest that a plateau time exists, beyond which the outcome measures remain relatively stable. Because previous studies have already documented longer-term outcomes for similar nonstratified groups of surgically treated adult patients with deformity and because previous studies suggest a relative stabilization of outcome measures at approximately 1 year after surgery, we thus believe that using 1-year outcomes to compare the 2 groups assessed in our study is reasonable.

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TABLE 4: Comparison of HRQOL parameters at baseline and 1-year follow-up after surgery for 125 adults with SSM*

Parameter	Decompensated (n = 98)†	Compensated (n = 27)†	p Value‡
Oswestry Disability Index			
baseline	48.1 (17.7)	37.0 (18.2)	**0.010**
1 yr after surgical treatment	32.2 (19.9)	22.7 (18.8)	**0.031**
p value	**<0.001**	**<0.001**	—
SF-36 physical component score			
baseline	29.6 (9.0)	35.7 (7.6)	**0.004**
1 yr after surgical treatment	37.2 (9.9)	44.2 (10.0)	**0.003**
p value	**<0.001**	**0.001**	—
SF-36 mental component score			
baseline	43.4 (14.1)	47.3 (15.2)	0.27
1 yr after surgical treatment	48.6 (14.3)	56.0 (8.9)	**0.002**
p value	**0.001**	**0.007**	—
SRS-22 total score			
baseline	2.6 (0.7)	3.0 (0.6)	**0.016**
1 yr after surgical treatment	3.5 (0.8)	3.9 (0.7)	**0.032**
p value	**<0.001**	**<0.001**	—
SRS-22 activity domain			
baseline	2.7 (0.9)	3.0 (0.8)	0.064
1 yr after surgical treatment	3.3 (1.0)	3.6 (0.9)	0.11
p value	**<0.001**	**<0.001**	—
SRS-22 pain domain			
baseline	2.3 (0.8)	2.7 (0.8)	**0.017**
1 yr after surgical treatment	3.2 (1.0)	3.6 (1.0)	0.098
p value	**<0.001**	**<0.001**	—
SRS-22 appearance domain			
baseline	2.3 (0.8)	2.6 (0.7)	**0.046**
1 yr after surgical treatment	3.5 (0.9)	3.9 (0.8)	0.051
p value	**<0.001**	**<0.001**	—
SRS-22 mental domain			
baseline	3.3 (1.0)	3.7 (1.0)	0.069
1 yr after surgical treatment	3.6 (1.1)	4.2 (0.7)	**0.003**
p value	**<0.001**	**0.005**	—
SRS-22 satisfaction domain			
baseline	2.6 (1.1)	2.8 (1.1)	0.50
1 yr after surgical treatment	4.2 (1.0)	4.3 (0.9)	0.52
p value	**<0.001**	**<0.001**	—

* Patients were stratified into 2 groups: decompensated (SVA > 5 cm) and compensated (SVA < 5 cm with PI-LL mismatch > 10°). Significant improvement for each outcome measure from baseline to 1-year follow-up is demonstrated for both groups. Boldface indicates statistical significance; — indicates not applicable.

† Standard deviation values are presented parenthetically .

‡ p values derived from paired t-tests.

Strengths of our study include the contribution of cases from multiple spinal deformity centers, which adds to the generalizability of the findings. In addition, multiple standardized measures of HRQOL were determined at baseline and at follow-up to assess changes across a broad spectrum of outcome domains. Furthermore, to minimize variation in measurement technique, we performed all radiographic measures at a single center where image analysis experience was substantial.

Conclusions

Significant disability occurs in decompensated SSM patients with elevated SVA; however, the amount of disability in compensated SSM patients with flatback deformity resulting from PI-LL mismatch but normal SVA is underappreciated. Surgical correction of SSM for patients in compensated and decompensated groups demonstrated similar radiographic and HRQOL improvements among

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TABLE 5: Change in HRQOL measures and percentage of patients reaching MCID from baseline to 1-year follow-up after surgical treatment in 125 adults with SSM*

Parameter	Decompensated (n = 98)	Compensated (n = 27)	p Value
change in score, 1 yr – baseline (SD)			
Oswestry Disability Index	−16.0 (15.7)	−14.3 (15.7)	0.64
SF-36 physical component score	7.7 (10.9)	8.5 (10.5)	0.73
SF-36 mental component score	5.2 (12.4)	8.7 (14.4)	0.24
SRS-22 total score	0.9 (0.6)	0.9 (0.6)	0.84
activity domain	0.6 (0.8)	0.6 (0.7)	0.88
pain domain	1.0 (0.9)	1.0 (0.9)	0.88
appearance domain	1.3 (1.0)	1.3 (0.8)	0.90
mental domain	0.4 (0.8)	0.5 (0.9)	0.39
satisfaction domain	1.6 (1.2)	1.6 (1.6)	0.99
percentage reaching MCID at 1 yr			
Oswestry Disability Index	54	52	0.87
SF-36 physical component score	41	54	0.42
SRS-22			
activity domain	56	74	0.15
pain domain	63	63	0.98
appearance domain	67	78	0.28
mental domain	26	37	0.49

* Patients were stratified into 2 groups: decompensated (SVA > 5 cm) and compensated (SVA < 5 cm with PI-LL mismatch > 10°). No significant differences were observed between the 2 groups with regard to magnitude of point change in outcome measures or percentages of patients who achieved MCID for each outcome measure.

patients in both groups. Evaluation of SSM should extend beyond measuring SVA. PI-LL mismatch must be evaluated for SSM patients and can be considered a primary surgical indication among patients with concordant pain and disability.

Disclosure

Dr. Shaffrey is a consultant for Biomet, Globus, Medtronic, and Stryker; a patent holder in Biomet and Medtronic, from which he also receives royalties. Dr. Ames is a consultant for DePuy, Medtronic, and Stryker; owns stock in Visualase, Doctors Research Group, and Baxano Surgery; he is a patent holder in Fish & Richardson, P.C.; and he receives royalties from Aesculap and Lanx. Dr. Smith is a consultant for Biomet, Globus, DePuy, and Medtronic; he receives clinical or research support for study described (includes equipment or material) from DePuy, International Spine Study Group Foundation, and DePuy. Dr. Deviren is a consultant for NuVasive, Guidepointe, and Stryker. Dr. Hart receives royalties from Seaspine and DePuy; is a consultant for DePuy, Medtronic, and Eli Lilly; owns stock in Spine Connect; receives support of non-study-related clinical or research effort from Medtronic, DePuy Spine, Synthes, and Orthopaedic Research and Education Foundation; is a patent holder in Oregon Health & Science University; and on the Speakers Bureau for DePuy and Medtronic. Dr. Burton is a consultant for DePuy Spine; receives royalties from DePuy Spine; and is a member of the University of Kansas Physicians, Inc. Dr. Gupta receives royalties from DePuy; has ownership in Proctor and Gamble, Pioneer, Johnson and Johnson, and Pfizer; is a consultant for DePuy, Medtronic, and Osteotech; and he is the treasurer (unpaid) of FOSA. Dr. Bess is a consultant for DePuy/Synthes, Medtronic, K2M, and Alphatec; he receives clinical or research support for the study described (includes equipment or material) from DePuy/Synthes. Dr. Mundis is a consultant for NuVasive and K2M; he receives clinical or research support for the study described (includes equipment or material) from International Spine Study Group Foundation; he receives support of non-study-related clinical or research effort from NuVasive and Orthopaedic Research and Education Foundation; and he receives royalties from NuVasive and K2M. Dr. Klineberg receives honoraria/grant funding from DePuy, Stryker, AOSpine, and Orthopaedic Research and Education Foundation. Dr. Protopsaltis is a consultant for Globus and is on the Speakers Bureau of K2M.

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