J Neurosurg Spine 16:539–546, 2012

Sagittal realignment failures following pedicle subtraction osteotomy surgery: are we doing enough?

Clinical article

Frank J. Schwab, M.D.,[1] Ashish Patel, M.D.,[1] Christopher I. Shaffrey, M.D.,[2] Justin S. Smith, M.D., Ph.D.,[2] Jean-Pierre Farcy, M.D.,[1] Oheneba Boachie-Adjei, M.D.,[3] Richard A. Hostin, M.D.,[4] Robert A. Hart, M.D.,[5] Behrooz A. Akbarnia, M.D.,[6] Douglas C. Burton, M.D.,[7] Shay Bess, M.D.,[8] and Virginie Lafage, Ph.D.[1]

[1]Department of Orthopedic Surgery, NYU Hospital for Joint Diseases, New York, New York; [2]Department of Neurological Surgery, University of Virginia Health System, Charlottesville, Virginia; [3]Department of Orthopedic Surgery, Hospital for Special Surgery, New York, New York; [4]Orthopedic Surgery, Baylor Scoliosis Center, Plano, Texas; [5]Department of Orthopedic Surgery, Oregon Health & Science University, Portland, Oregon; [6]Orthopedic Surgery, San Diego Center for Spinal Disorders, La Jolla, California; [7]Department of Orthopedic Surgery, University of Kansas Medical Center, Kansas City, Kansas; and [8]Orthopedic Surgery, Rocky Mountain Scoliosis and Spine, Denver, Colorado

Object. Pedicle subtraction osteotomy (PSO) is a surgical procedure that is frequently performed on patients with sagittal spinopelvic malalignment. Although it allows for substantial spinopelvic realignment, suboptimal realignment outcomes have been reported in up to 33% of patients. The authors' objective in the present study was to identify differences in radiographic profiles and surgical procedures between patients achieving successful versus failed spinopelvic realignment following PSO.

Methods. This study is a multicenter retrospective consecutive PSO case series. The authors evaluated 99 cases involving patients who underwent PSO for sagittal spinopelvic malalignment. Because precise cutoffs of acceptable residual postoperative sagittal vertical axis (SVA) values have not been well defined, comparisons were focused between patient groups with a postoperative SVA that could be clearly considered either a success or a failure. Only cases in which the patients had a postoperative SVA of less than 50 mm (successful PSO realignment) or more than 100 mm (failed PSO realignment) were included in the analysis. Radiographic measures and PSO parameters were compared between successful and failed PSO realignments.

Results. Seventy-nine patients met the inclusion criteria. Successful realignment was achieved in 61 patients (77%), while realignment failed in 18 (23%). Patients with failed realignment had larger preoperative SVA (mean 217.9 vs 106.7 mm, $p < 0.01$), larger pelvic tilt (mean 36.9° vs 30.7°, $p < 0.01$), larger pelvic incidence (mean 64.2° vs 53.7°, $p < 0.01$), and greater lumbar lordosis–pelvic incidence mismatch (–47.1° vs –30.9°, $p < 0.01$) compared with those in whom realignment was successful. Failed and successful realignments were similar regarding the vertebral level of the PSO, the median size of wedge resection 22.0° (interquartile range 16.5°–28.5°), and the numerical changes in pre- and postoperative spinopelvic parameters ($p > 0.05$).

Conclusions. Patients with failed PSO realignments had significantly larger preoperative spinopelvic deformity than patients in whom realignment was successful. Despite their apparent need for greater correction, the patients in the failed realignment group only received the same amount of correction as those in the successfully realigned patients. A single-level standard PSO may not achieve optimal outcome in patients with high preoperative spinopelvic sagittal malalignment. Patients with large spinopelvic deformities should receive larger osteotomies or additional corrective procedures beyond PSOs to avoid undercorrection.

(http://thejns.org/doi/abs/10.3171/2012.2.SPINE11120)

Key Words • pedicle subtraction osteotomy • sagittal realignment • adult spinal deformity • sagittal vertical axis • sagittal balance • degenerative spinal disease

Adult spinal deformity is a complex musculoskeletal pathology with varied clinical presentations. Recent reports have demonstrated that pain and disability resulting from ASD are strongly associated with sagittal spinopelvic malalignment.[13,21,29] Common etiologies for sagittal spinopelvic malalignment include

Abbreviations used in this paper: ASD = adult spinal deformity; BMI = body mass index; IQR = interquartile range; LL = lumbar lordosis; PI = pelvic incidence; PSO = pedicle subtraction osteotomy; PT = pelvic tilt; SS = sacral slope; SVA = sagittal vertical axis; TK = thoracic kyphosis; TL-Kypho = thoracolumbar kyphosis.

degenerative conditions, iatrogenic or postoperative flatback, and posttraumatic conditions.[3,10,27,30] Surgery for spinopelvic malalignment can provide a more ergonomic standing posture, resulting in improved function and reduced pain.[6] Several spinal osteotomy techniques have been described for sagittal plane correction,[4,8,11] including PSO.

Pedicle subtraction osteotomy may offer substantial spinopelvic realignment with application at a single level.[2,4,7,15,18,25,26,34] However, PSOs do not always ensure optimal realignment, and radiographic failures have been reported. In a retrospective radiographic analysis,[18] an optimal SVA (< 80 mm) was not achieved in 4 of 35 patients who underwent PSO surgery. Patients with SVA greater than 80 mm had significantly worse outcomes than patients with postoperative SVA of less than 80 mm. Similarly, in a recent radiographic analysis, 13 of 40 patients did not achieve an "ideal sagittal balance" (SVA < 50 mm) following PSO.[28] Pedicle subtraction osteotomy realignment failures do occur, but limited information exists about the differences in radiographic profiles between a successful versus a failed PSO outcome.

The objective of this investigation was to identify differences in radiographic parameters between patients treated with PSO in whom spinopelvic realignment was successful and those in whom it failed. Specifically, the study aims to answer the following questions: 1) are there differences between the 2 groups of patients regarding their preoperative and postoperative spinopelvic deformity, and 2) are patients in these 2 outcome categories treated with different PSO techniques. Based upon these findings, improved strategies can be developed to avoid realignment failures and to increase the likelihood of obtaining a successful spinopelvic realignment following PSO surgery.

Methods

Study Sample

This study is a multicenter retrospective consecutive PSO case series. Institutional review board approval was obtained at each participating site. Briefly, 8 centers contributed consecutive PSO cases to a central database. A total of 99 cases with complete radiographic records were available. Radiographs were acquired early after surgery (less than 6 months) to evaluate the results of surgery without taking into account further changes and potential loss of correction.

Although the severity of disability and pain have been shown to correlate with increasing positive SVA, precise cutoffs of acceptable residual postoperative SVA have not been well defined.[13] For example, a residual positive SVA of more than 50 mm has been suggested as failed sagittal realignment in some reports,[28] while other reports suggest a threshold of 80 mm.[18] Therefore, we chose to focus our comparisons between patient groups with a postoperative SVA that could clearly qualify the realignment as a success or a failure and to exclude the cases with an intermediate postoperative SVA. Thus, for the present study successful spinal realignment was defined by a postoperative SVA of less than 50 mm, and failed spinal realignment was defined by a postoperative SVA of more than 100 mm. Patients with a postoperative SVA of 50–100 mm were excluded from this analysis.

Data Collection

Patient demographic data and radiographs were collected at the time of patient enrollment into the PSO database. Radiographic analysis focused on the following sagittal parameters: 1) PSO wedge resection—the change in vertebral angulation at the osteotomy site (the preoperative vs postoperative difference in angulation from the endplates above and below the osteotomy site); 2) sagittal vertical axis (SVA)—the linear distance in millimeters from the C-7 plumbline to the posterosuperior corner of S-1; 3) thoracic kyphosis (TK)—the Cobb angle from T-4 to T-12; 4) thoracolumbar kyphosis (TL-Kypho)—the Cobb angle from T-10 to L-1; 5) lumbar lordosis (LL)—the Cobb angle from L-1 to S-1; 6) pelvic incidence (PI)—the angle between the perpendicular to the sacral endplate at its midpoint and the line connecting this point to the axis of the femoral heads; 7) pelvic tilt (PT)—the angle between the vertical and the line through the midpoint of the sacral endplate to the axis of the femoral heads; 8) sacral slope (SS)—the angle between the horizontal and the sacral endplate; and 9) lumbar lordosis–pelvic incidence relationship (LL-PI)—lumbar lordosis minus pelvic incidence (Fig. 1). Data regarding the proximal and distal instrumentation level were also collected.

Statistical Analysis

The normality of the data was evaluated using the Shapiro-Wilk test. Descriptive statistics, including means, medians, interquartile values (25th and 75th percentiles), and 95% confidence intervals, were used to summarize each radiographic parameter. Differences in radiographic parameters between successful and failed spinal realignment patients were compared using unpaired Student t-tests.

Results

Patient Sample

From the original database of 99 cases, 20 cases were excluded from the database because they had a postoperative SVA between 50 and 100 mm, leaving 79 cases available for analysis. No differences in demographic variables were found between patients retained for further analysis and those not retained. Of the 79 retained cases, spinal realignment had been successful in 61 (postoperative SVA < 50 mm) and had failed in 18 (postoperative SVA > 100 mm). Patients in the successful realignment group were younger than those in the failed realignment group (mean age 51.8 ± 11 years vs 63.1 ± 10.2 years, respectively, $p < 0.01$), and the successful realignment group had a lower BMI than the failed realignment group (mean 25.0 ± 4.5 kg/m^2 vs 28.1 ± 6.1 kg/m^2, respectively, $p = 0.01$). The distribution for the age and the BMI in terms of median and IQR is presented in Fig. 2 for both groups.

Surgical Technique

The median PSO wedge resection was 22.0° (IQR

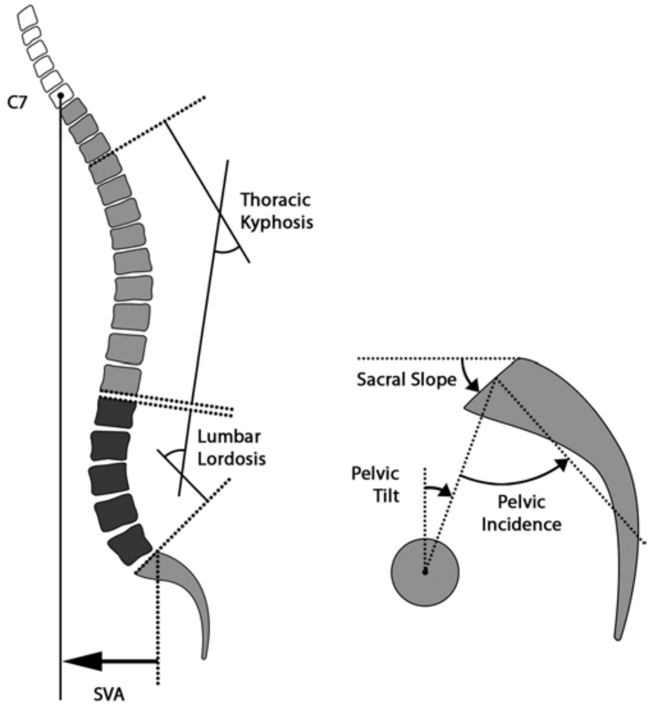

Fig. 1. Radiographic parameters included in the analysis.

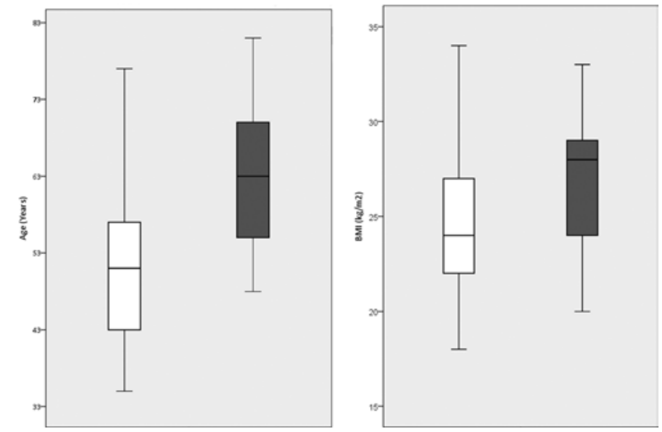

Fig. 2. Differences in age **(left)** and BMI **(right)** between the successful and failed realignment groups (*white* and *dark gray* boxes, respectively). The boxplots show the IQR (25%–75%), with *whiskers* indicating the 5%–95% range. The *horizontal bars* indicate median values.

16.5°–28.5°) in the entire study group. This reflects a standard degree of resection based upon previously reported data.[22] No significant association was found between the angle of PSO wedge resection achieved and the vertebral level at which the PSO was performed, $p = 0.927$ (Fig. 3). The median proximal fusion level was T-7 (IQR T4–10), and the distal level was the pelvis in all but 12 patients (10 fused to S-1, 2 fused to L-5). There was no difference in proximal and distal fusion levels between groups.

Sagittal Vertical Axis

The successful realignment group had a substantially lower mean preoperative SVA than the failed realignment group (106.7 ± 67.7 mm vs 217.9 ± 54.4 mm, respectively, $p < 0.01$). The successful group also had a substantially lower postoperative SVA than the failed group (8.0 ± 29 mm vs 136.2 ± 34.5 mm, respectively, $p < 0.01$). The distribution in terms of median and IQR is presented in the Fig. 4 for both groups. The median SVA correction was 86.5 mm (IQR 54.5–134.5 mm) in the entire study group. No difference was found in amount of SVA correction (pre- vs postoperative numerical difference) between the successful and failed realignment groups (98.7 ± 64.3 mm vs 81 ± 56 mm, respectively, $p = 0.31$).

Pelvic Tilt

The successful realignment group had a substantially lower mean preoperative PT than the failed realignment group (30.7° ± 11.4° vs 36.9° ± 10.9°, respectively, $p < 0.01$). The successful group also had a substantially lower mean postoperative PT than the failed group (21.3° ± 9.8° vs 29.3° ± 13.7°, respectively, $p < 0.01$). The distribution in terms of median and IQR is presented in Fig. 5 for both groups. The median PT correction was 7.5° (IQR 3.3°–13.3°) in the entire study group. No difference was found in mean PT correction between the successful and failed realignment groups (9.4° ± 8.9° vs 7.5° ± 10.5°, respectively, $p = 0.44$).

Lumbar Lordosis

The median LL correction was 29.2° (IQR 15.5°–40.1°) in the entire study group. No differences were found between successful versus failed PSO realignment groups in mean preoperative LL (22.8° ± 17.4° vs 17.1° ± 19.9°, respectively, $p = 0.24$), change in LL (29.4° ± 17.7° vs 27.6° ± 15.5°, respectively, $p = 0.69$), or postoperative LL (52.1° ± 14.7° vs 44.6° ± 14.1°, respectively, $p = 0.06$). The distribution in terms of median and IQR is presented in Fig. 6 for both groups

Pelvic Incidence

The median preoperative PI was 55.5° (IQR 47.9°–65.3°) in the entire study group. The successful group had a substantially lower mean preoperative PI than the failed group (53.7° ± 13.2° vs 64.2° ± 12.7°, respectively, $p < 0.01$). The distribution in terms of median and IQR is presented in Fig. 7 for both groups. As expected, there was virtually no change in PI values from preoperative to postoperative measurements (successful realignment group: 0.0° ± 5°; failed realignment group: 0.6° ± 1.5°).

Lumbar Lordosis–Pelvic Incidence Relationship

The LL-PI relationship is recognized as an indicator of appropriate patient-specific lumbar alignment.[24] A postoperative LL = PI ± 9 is considered a pragmatic method during spinopelvic realignment procedures.[31] The patients in the successful realignment group patients had a lower LL-PI mismatch at both preoperative and postoperative assessment, but the amount of change in LL-PI mismatch was not significantly different between the 2 groups. The successful realignment group had a substantially lower preoperative LL-PI mismatch than the failed realignment group (–30.9° ± 17.7° vs –47.1° ± 15.4°, re-

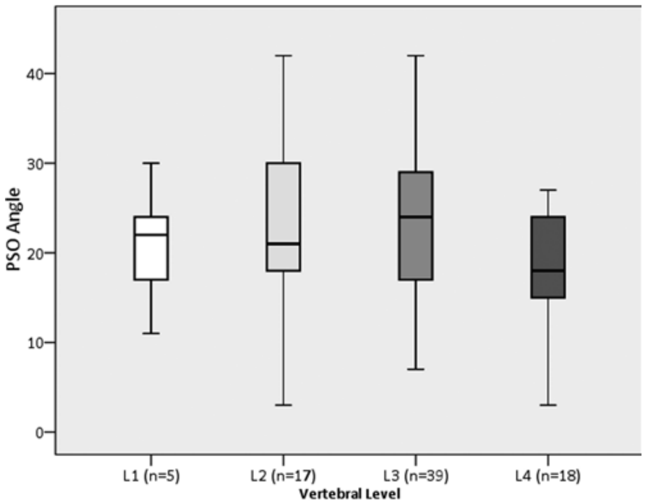

Fig. 3. Pedicle subtraction osteotomy degree of wedge resection by vertebral level. No significant association was found between the vertebral level at which the PSO was performed and the angle of PSO wedge resection.

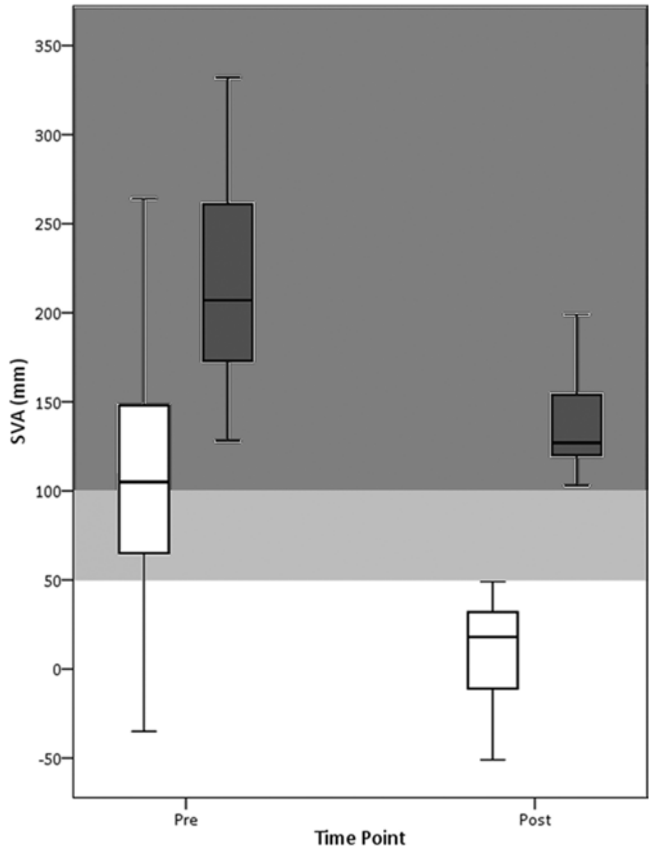

Fig. 4. Sagittal vertical axis. Preoperative (Pre) and postoperative (Post) SVA differences between the successful and failed realignment groups. *White zone* indicates optimal SVA, *light gray zone* intermediate SVA (neither optimal nor poor), *dark gray zone* poor SVA.

spectively, $p < 0.01$). The successful realignment group also had a substantially lower postoperative LL-PI mismatch than the failed realignment group (–1.6° ± 12.2° vs –20.2° ± 16°, respectively, $p < 0.01$). No significant difference was found with respect to LL-PI correction between the successful and failed realignment groups (29.3° ± 17.6° vs 27.0° ± 15.3°, respectively, p = 0.61). The distribution in terms of median and IQR is presented in Fig. 8 for both groups.

Other Radiographic Parameters

The median TK change was 5.9° (IQR –1.5° to 16.1°) in the entire study group. No differences were found between the successful vs failed PSO realignment groups for mean preoperative TK (29.8° ± 19.7° vs 31.0° ± 13.4°, p = 0.81), change in TK (5.9° ± 13.1° vs 11.0° ± 10.2°, respectively, p = 0.13), or postoperative TK (35.7° ± 16.9° vs 42.0° ± 12.9°, respectively, p = 0.15).

The median TL-Kypho change was 0.6° (IQR –6.1° to 5.1°) in the entire study group. No differences were found between the successful versus failed PSO realignment groups for mean preoperative TL-Kypho (8.7° ± 15.1° vs 10.3° ± 12.9°, respectively, p = 0.70), change in TL-Kypho (1.1° ± 11.2° vs 0.5° ± 11.2°, respectively, p = 0.84), or postoperative TL-Kypho (7.6° ± 10.1° vs 9.7° ± 9.9°, p = 0.43).

The median SS change was 8.1° (IQR 4.2°–13.6°) in the entire study group. No differences were found in comparison of the successful versus failed PSO realignment groups with respect to mean preoperative SS (23.0° ± 11.1° vs 27.3° ± 13.7°, respectively, p = 0.17), change in SS (9.5° ± 9° vs 8.1° ± 10.1°, respectively, p = 0.59), or postoperative SS (32.4° ± 10.6° vs 35.5° ± 11.3°, respectively, p = 0.30).

Discussion

Sagittal spinopelvic malalignment is a major cause of pain and loss of function associated with ASD.[1,13,21] Surgical restoration of optimal sagittal alignment is indicated for symptomatic patients and has demonstrated superior clinical and radiographic outcomes compared with nonoperative management.[5,32] Previous studies have shown that realignment of SVA and PT is critical to optimize clinical outcomes.[21] High SVA correlates with pain, loss of function, and poor health-related quality of life scores, and it is also a risk factor for pseudarthrosis,[19] adjacent segment degeneration, and junctional kyphosis following spine surgery.[20] Optimal sagittal realignment centers the patient's head over his or her pelvis, restores level gaze, and creates ergonomically efficient standing and walking alignment.[17] According to Jackson and Hales,[16] normative values identified for these radiographic spinopelvic parameters indicate that the SVA should be less than 50 mm. While clinical outcomes were not included in the present study, several studies have shown a high correlation between increased SVA and greater disability.[12,13,21,29] Single-level PSO is effective for spinopelvic sagittal realignment, but failures have been reported.[18,28] Failure to attain optimal sagittal alignment following PSO may result in continued pain and disability and necessitate challenging revision surgery.[14]

The current investigation revealed several key radiographic differences between successful and failed PSO realignment groups. The failed realignment group had significantly greater preoperative SVA, PT, and PI than

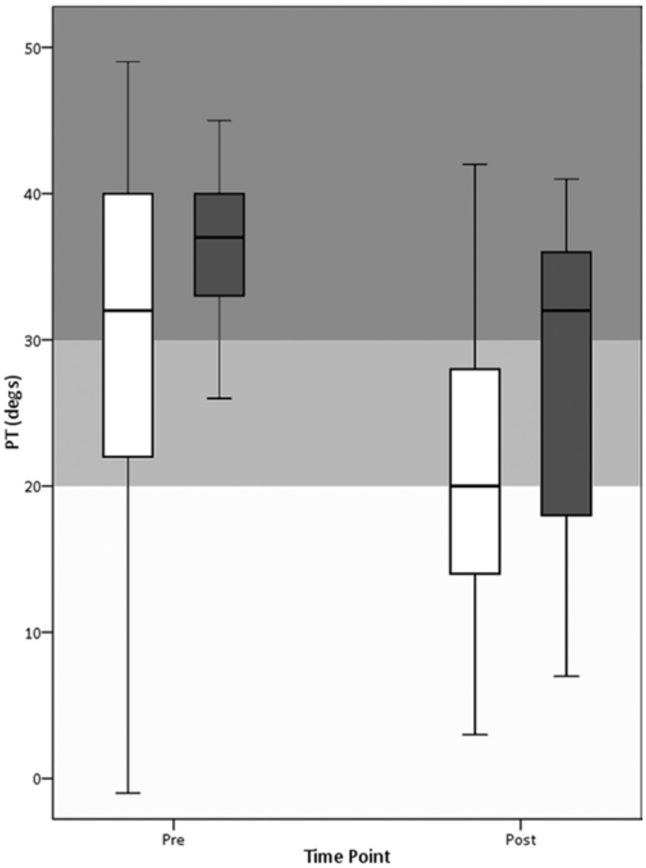

Fig. 5. Pelvic tilt. Preoperative and postoperative PT differences between the successful and failed realignment groups. *White zone* indicates optimal PT, *light gray zone* intermediate PT (neither optimal nor poor), *dark gray zone* poor PT. Degs = degrees.

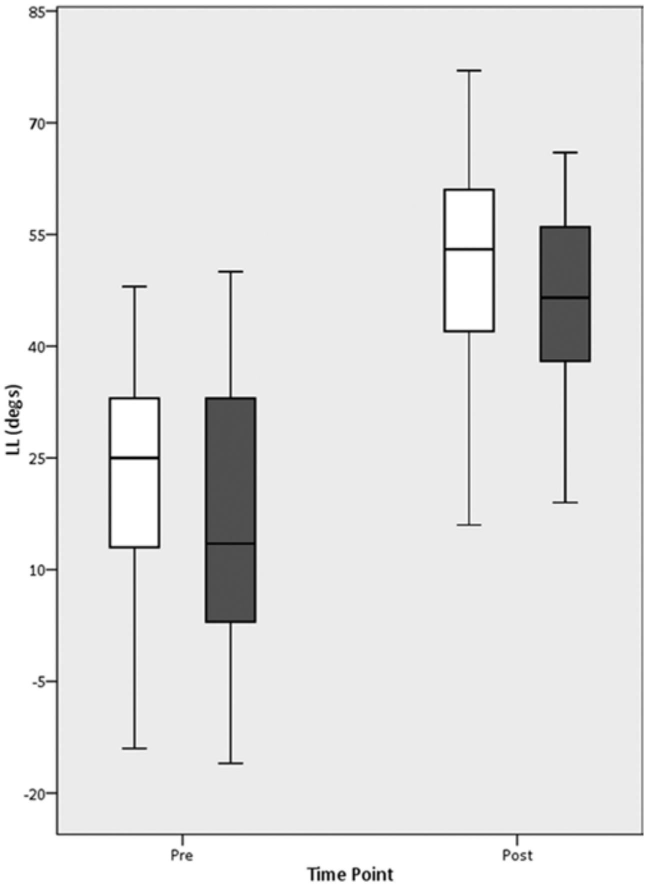

Fig. 6. Lumbar lordosis. Preoperative and postoperative LL differences between the successful and failed realignment groups.

patients in whom realignment was successful. Although the LL was similar in both groups, the LL-PI relationship was significantly worse in the patients with failed realignment. Collectively, these parameters suggest that the patients with failed realignment had greater preoperative spinopelvic malalignment than the successfully realigned patients. Consequently, they required a larger realignment procedure than was actually provided to obtain a successful outcome. Despite the need for a larger procedure, patients in the failed realignment group received the same surgical intervention as those in the successful realignment group, leading to similar numerical changes in SVA, PT, and LL-PI mismatch. Thus, these patients did not receive sufficient correction and remained malaligned. Yang and Ondra[33] have offered a trigonometric formula that suggests that the same degree of resection will have a larger impact on sagittal correction if applied at a lower vertebra. While mathematically valid and easy to use, this formula does not account for the rotation of the pelvis (pelvic retroversion) that acts as a compensatory mechanism for sagittal alignment and leads to an apparently low SVA. Results from a previous investigation demonstrated that a more caudal osteotomy would increase the likelihood of correcting pelvic retroversion but would not provide increased SVA correction.[22]

The findings of the present study are clinically important; the failed realignments were not due to technical errors or an unforeseen event. In both groups, the amount of focal and global correction that was achieved was consistent with the amount that is anticipated from a single-level standard PSO. Unfortunately, the correction applied in the failed realignment group was insufficient to achieve necessary realignment. In hindsight, on the basis of our study results, it was predictable before surgery that the amount of correction would be insufficient. While a standard PSO is undoubtedly an extensive and technically demanding procedure, the correction provided might not be enough for patients with severe deformity, and additional or alternative techniques that are more extensive must be considered to obtain a successful outcome. In patients with substantial preoperative deformity, additional methods of deformity correction should be considered. These could include a PSO with multilevel Smith-Peterson osteotomies, vertebral column resection, extended PSO (that is, taking the cephalad or caudal disc and closing the wedge onto the adjacent vertebral body endplate), or even PSO at more than 1 level.

The rate of failed realignment calls attention to the need for improvements in preoperative planning for patients with ASD. It appears necessary to apply more patient-specific approaches to spinal realignment procedures, to increase the likelihood of obtaining an optimal outcome. Adult patients with anterior truncal inclination

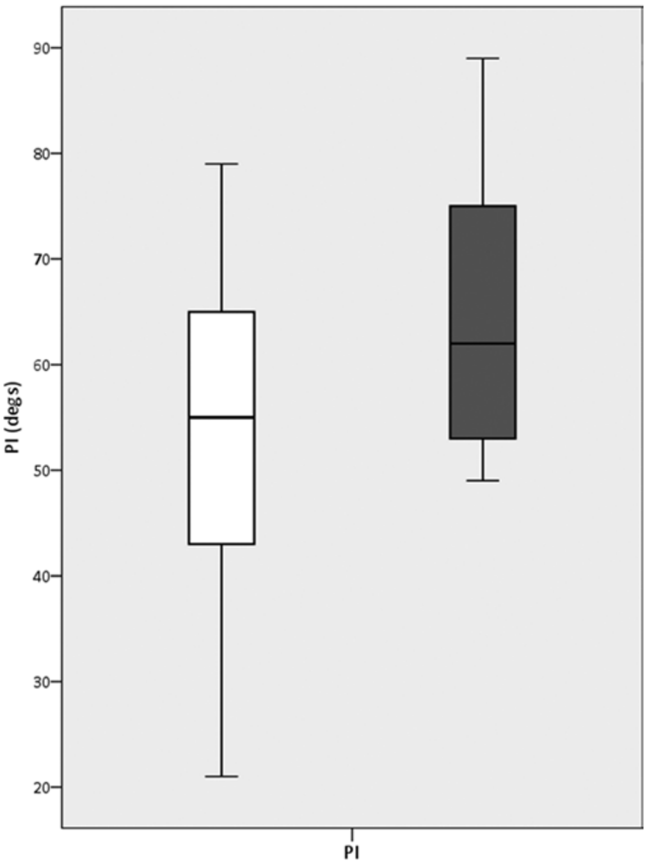

Fig. 7. Pelvic incidence. Preoperative PI differences between the successful and failed realignment groups.

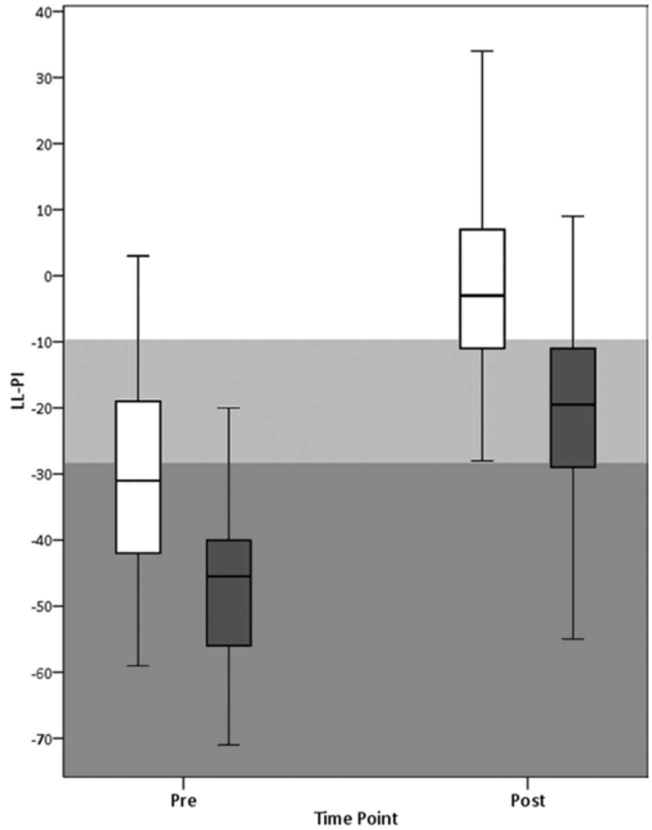

Fig. 8. Lumbar lordosis–pelvic incidence relationship. Preoperative and postoperative LL-PI differences between the successful and failed realignment groups. The *white zone* indicates optimal LL-PI, the *light gray zone* intermediate LL-PI (neither optimal nor poor), the *dark gray zone* poor LL-PI.

typically present with a triad of spinopelvic malalignment, including a high SVA (or T1-sagittal pelvic inclination), high PT, and a LL-PI mismatch from degenerative or iatrogenic loss of lordosis.[30] Anterior displacement of the C-7 plumbline (increasing SVA) results in abnormal effort to maintain a standing position,[9] loss of horizontal gaze, and activation of compensatory mechanisms (pelvic retroversion, hip and knee flexion) to maintain physiological function. For each patient, SVA, PT, and LL-PI mismatch present with variable severity depending on the specific malalignment present and the patient's ability to compensate through the spine, pelvis, and lower extremities. Preoperative SVA, PT, and LL-PI should be quantified for all ASD patients to understand the specific spinopelvic deformity. Approximately 30° has been reported as the goal for PSO resection.[28] However, this approach is not patient-specific and may result in over- or undercorrection. Osteotomy planning tools may be used to approximate the osteotomy. Additionally, standing balance formulas can be used to estimate realignment strategies.[23] A simple formula, LL = PI ± 9, may be used to estimate appropriate lordosis induction. In the present study, both groups had a substantial preoperative LL-PI mismatch, but the successfully realigned group achieved approximately LL = PI, while the unsuccessfully realigned patients still had a substantial residual mismatch of a mean 20° (that is, LL = PI–20). Use of these formulas during preoperative planning for the failure group could have predicted some of the failed outcomes and led to an alternative corrective approach.

Significant differences in patient variables were also observed between the 2 groups. Patients in the failed realignment group were older and had a higher BMI than the patients in the successfully realigned group. Logistic regression analysis revealed that preoperative SVA, change in lordosis, and younger age were significant predictors of a successful radiographic outcome. Our findings suggest that realignment procedures are more likely to fail in older patients than in younger patients. Pedicle subtraction osteotomy realignment procedures do result in large amounts of blood loss and carry a significant risk of complications.[6] It may be that older patients are not being operated on as vigorously as younger patients due to the concern of an increased risk of complications. Older patients may have more rigid deformities than younger ones, possibly resulting in less postoperative correction for the same operative resection. Patients with a higher BMI may also obtain less correction due to mechanical strain on the spine and implants. The impact of age and BMI on success rate following PSO warrants further investigation.

Conclusions

Our findings indicate that failure to achieve optimal sagittal spinopelvic alignment following PSO is due to applying an inadequate amount of correction in more severely deformed cases. The failed realignment group had a similar amount of deformity correction following single-level PSO as the successfully realigned patients. Because of a greater preoperative malalignment, patients in the failed realignment group still had residual postoperative deformity. A single-level standard PSO will not achieve adequate realignment in patients with high preoperative SVA or high LL-PI mismatch. Osteotomy simulation or mathematical formulas may help to predict residual deformity and lead to improvements in patient-specific surgical planning to achieve higher postoperative success rates.

Disclosure

The International Spine Study Group (ISSG) is funded through research grant support from DePuy Spine. Dr. Shaffrey is a consultant for DePuy Spine and Biomet, receives fellowship support from Medtronic and AO North America, and has received support for non–study related clinical or research efforts from the NIH, Department of Defense, AO North America, and the Neurosurgery Research and Education Foundation of the AANS. Dr. Smith reports that he is a consultant for Medtronic, Biomet, and Axial Biotech, and has received research study group support from DePuy Spine and Medtronic. Dr Hart is a consultant for DePuy Spine, owns stock in SpineConnect, is a patent holder with SeaSpine, and is a member of the speakers' bureau and/or has received honoraria from DePuy Spine, Synthes, and Kyphon; and has received support for non–study related clinical or research efforts from DePuy Spine, Medtronic, the Orthopaedic Research and Education Foundation, and Synthes. Dr. Schwab received clinical or research support for the study described from DePuy Spine. Dr. Burton is a consultant for and patent holder with DePuy Spine and received study support from the company. Dr. Akbarnia owns stock in Nuvasive and is a consultant for and has received research support from K2M, DePuy Spine, and NuVasive. Dr. Bess is a consultant for DePuy Spine, AlloSource, and Pioneer Spine and has received clinical or research support for the study described from DePuy Spine.

Author contributions to the study and manuscript preparation include the following. Conception and design: all authors. Acquisition of data: Lafage, Schwab, Patel, Shaffrey, Farcy, Boachie-Adjei, Hostin, Hart, Akbarnia, Burton, Bess. Analysis and interpretation of data: Lafage, Schwab, Smith, Burton, Bess. Drafting the article: Lafage, Schwab, Patel. Critically revising the article: Schwab, Patel, Shaffrey, Smith, Farcy, Boachie-Adjei, Hostin, Hart, Akbarnia, Burton, Bess. Statistical analysis: Lafage, Patel. Administrative/technical/material support: Schwab. Study supervision: Schwab.

Acknowledgment

The authors would like to thank Michael Hanna, Ph.D. (Mercury Medical Research & Writing), for providing feedback on the study and mentoring Dr. Patel on the writing of the manuscript.

References

1. Baldus C, Bridwell KH, Harrast J, Edwards C II, Glassman S, Horton W, et al: Age-gender matched comparison of SRS instrument scores between adult deformity and normal adults: are all SRS domains disease specific? **Spine (Phila Pa 1976) 33:**2214–2218, 2008
2. Boachie-Adjei O, Ferguson JA, Pigeon RG, Peskin MR: Transpedicular lumbar wedge resection osteotomy for fixed sagittal imbalance: surgical technique and early results. **Spine (Phila Pa 1976) 31:**485–492, 2006
3. Bradford DS, Tribus CB: Current concepts and management of patients with fixed decompensated spinal deformity. **Clin Orthop Relat Res (306):**64–72, 1994
4. Bridwell KH: Decision making regarding Smith-Petersen vs. pedicle subtraction osteotomy vs. vertebral column resection for spinal deformity. **Spine (Phila Pa 1976) 31 (19 Suppl):** S171–S178, 2006
5. Bridwell KH, Glassman S, Horton W, Shaffrey C, Schwab F, Zebala LP, et al: Does treatment (nonoperative and operative) improve the two-year quality of life in patients with adult symptomatic lumbar scoliosis: a prospective multicenter evidence-based medicine study. **Spine (Phila Pa 1976) 34:**2171–2178, 2009
6. Bridwell KH, Lewis SJ, Edwards C, Lenke LG, Iffrig TM, Berra A, et al: Complications and outcomes of pedicle subtraction osteotomies for fixed sagittal imbalance. **Spine (Phila Pa 1976) 28:**2093–2101, 2003
7. Bridwell KH, Lewis SJ, Rinella A, Lenke LG, Baldus C, Blanke K: Pedicle subtraction osteotomy for the treatment of fixed sagittal imbalance. Surgical technique. **J Bone Joint Surg Am 86-A (Suppl 1):**44–50, 2004
8. Cho KJ, Bridwell KH, Lenke LG, Berra A, Baldus C: Comparison of Smith-Petersen versus pedicle subtraction osteotomy for the correction of fixed sagittal imbalance. **Spine (Phila Pa 1976) 30:**2030–2038, 2005
9. Dubousset J: Three-dimensional analysis of the scoliotic deformity, in Weinstein SL (ed): **The Pediatric Spine: Principles and Practice.** New York: Raven Press, 1994, pp 479–496
10. Farcy JP, Schwab FJ: Management of flatback and related kyphotic decompensation syndromes. **Spine (Phila Pa 1976) 22:**2452–2457, 1997
11. Gill JB, Levin A, Burd T, Longley M: Corrective osteotomies in spine surgery. **J Bone Joint Surg Am 90:**2509–2520, 2008
12. Glassman SD, Berven S, Bridwell K, Horton W, Dimar JR: Correlation of radiographic parameters and clinical symptoms in adult scoliosis. **Spine 30:**682–688, 2005
13. Glassman SD, Bridwell K, Dimar JR, Horton W, Berven S, Schwab F: The impact of positive sagittal balance in adult spinal deformity. **Spine (Phila Pa 1976) 30:**2024–2029, 2005
14. Gottfried ON, Daubs MD, Patel AA, Dailey AT, Brodke DS: Spinopelvic parameters in postfusion flatback deformity patients. **Spine J 9:**639–647, 2009
15. Ikenaga M, Shikata J, Takemoto M, Tanaka C: Clinical outcomes and complications after pedicle subtraction osteotomy for correction of thoracolumbar kyphosis. **J Neurosurg Spine 6:**330–336, 2007
16. Jackson RP, Hales C: Congruent spinopelvic alignment on standing lateral radiographs of adult volunteers. **Spine 25:** 2808–2815, 2000
17. Kim KT, Suk KS, Cho YJ, Hong GP, Park BJ: Clinical outcome results of pedicle subtraction osteotomy in ankylosing spondylitis with kyphotic deformity. **Spine (Phila Pa 1976) 27:**612–618, 2002
18. Kim YJ, Bridwell KH, Lenke LG, Cheh G, Baldus C: Results of lumbar pedicle subtraction osteotomies for fixed sagittal imbalance: a minimum 5-year follow-up study. **Spine (Phila Pa 1976) 32:**2189–2197, 2007
19. Kim YJ, Bridwell KH, Lenke LG, Rhim S, Cheh G: Pseudarthrosis in long adult spinal deformity instrumentation and fusion to the sacrum: prevalence and risk factor analysis of 144 cases. **Spine (Phila Pa 1976) 31:**2329–2336, 2006
20. Kumar MN, Baklanov A, Chopin D: Correlation between sagittal plane changes and adjacent segment degeneration following lumbar spine fusion. **Eur Spine J 10:**314–319, 2001
21. Lafage V, Schwab F, Patel A, Hawkinson N, Farcy JP: Pelvic tilt and truncal inclination: two key radiographic parameters in the setting of adults with spinal deformity. **Spine (Phila Pa 1976) 34:**E599–E606, 2009

22. Lafage V, Schwab F, Vira S, Hart R, Burton D, Smith JS, et al: Does vertebral level of pedicle subtraction osteotomy correlate with degree of spinopelvic parameter correction? Clinical article. **J Neurosurg Spine 14:**184–191, 2011
23. Lafage V, Schwab F, Vira S, Patel A, Ungar B, Farcy JP: Spino-pelvic parameters following surgery can be predicted: a preliminary formula and validation of standing alignment. **Spine (Phila Pa 1976):**1037–1045, 2011
24. Legaye J, Duval-Beaupère G, Hecquet J, Marty C: Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. **Eur Spine J 7:**99–103, 1998
25. Mummaneni PV, Dhall SS, Ondra SL, Mummaneni VP, Berven S: Pedicle subtraction osteotomy. **Neurosurgery 63 (3 Suppl):**171–176, 2008
26. Murrey DB, Brigham CD, Kiebzak GM, Finger F, Chewning SJ: Transpedicular decompression and pedicle subtraction osteotomy (eggshell procedure): a retrospective review of 59 patients. **Spine (Phila Pa 1976) 27:**2338–2345, 2002
27. Potter BK, Lenke LG, Kuklo TR: Prevention and management of iatrogenic flatback deformity. **J Bone Joint Surg Am 86-A:**1793–1808, 2004
28. Rose PS, Bridwell KH, Lenke LG, Cronen GA, Mulconrey DS, Buchowski JM, et al: Role of pelvic incidence, thoracic kyphosis, and patient factors on sagittal plane correction following pedicle subtraction osteotomy. **Spine (Phila Pa 1976) 34:**785–791, 2009
29. Schwab F, Farcy JP, Bridwell K, Berven S, Glassman S, Harrast J, et al: A clinical impact classification of scoliosis in the adult. **Spine (Phila Pa 1976) 31:**2109–2114, 2006
30. Schwab F, Lafage V, Patel A, Farcy JP: Sagittal plane considerations and the pelvis in the adult patient. **Spine (Phila Pa 1976) 34:**1828–1833, 2009
31. Schwab F, Patel A, Ungar B, Farcy JP, Lafage V: Adult spinal deformity-postoperative standing imbalance: how much can you tolerate? An overview of key parameters in assessing alignment and planning corrective surgery. **Spine (Phila Pa 1976) 35:**2224–2231, 2010
32. Smith JS, Shaffrey CI, Berven S, Glassman S, Hamill C, Horton W, et al: Improvement of back pain with operative and nonoperative treatment in adults with scoliosis. **Neurosurgery 65:**86–94, 2009
33. Yang BP, Ondra SL: A method for calculating the exact angle required during pedicle subtraction osteotomy for fixed sagittal deformity: comparison with the trigonometric method. **Neurosurgery 59 (4 Suppl 2):**ONS458–ONS463, 2006
34. Yang BP, Ondra SL, Chen LA, Jung HS, Koski TR, Salehi SA: Clinical and radiographic outcomes of thoracic and lumbar pedicle subtraction osteotomy for fixed sagittal imbalance. **J Neurosurg Spine 5:**9–17, 2006

Manuscript submitted February 14, 2011.
Accepted February 23, 2012.
Please include this information when citing this paper: published online March 30, 2012; DOI: 10.3171/2012.2.SPINE11120.
Address correspondence to: Virginie Lafage, Ph.D., 380 2nd Avenue, Suite 1001, New York, New York 10010. email: virginie.lafage@gmail.com.