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DIAGNOSTICS

Dynamic Changes of the Pelvis and Spine Are Key to Predicting Postoperative Sagittal Alignment After Pedicle Subtraction Osteotomy

A Critical Analysis of Preoperative Planning Techniques

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Study Design. Retrospective, radiographical analysis of mathematical formulas used to predict sagittal vertical axis (SVA) after pedicle subtraction osteotomy (PSO).

Objective. Evaluate the ability of different formulas to predict SVA after PSO.

Summary of Background Data. Failure to achieve optimal spinal alignment after spinal fusion correlates with poor outcomes. Numerous mathematical models have been proposed to aid preoperative PSO planning and predict postoperative SVA. Pelvic parameters have been shown to impact spinal alignment; however, many preoperative planning models fail to evaluate these. Compensatory changes within unfused spinal segments have also been shown to impact SVA. Predictive formulas that do not evaluate pelvic parameters and unfused spinal segments may erroneously guide PSO surgery. A formula that integrates pelvic tilt (PT) and spinal compensatory changes to predict optimal SVA has been previously proposed.

Methods. Comparative analysis of 5 mathematical models used to predict optimal postoperative SVA ($<$5 cm) after PSO was performed using a multicenter PSO database.

Results. Radiographs of 147 patients, mean age 52 years (SD = 15 yr), who received 147 PSOs (42 thoracic and 105 lumbar) were evaluated. Mean preoperative and postoperative SVA was 108 mm (SD = 95 mm) and 30 mm (SD = 60 mm; $P < 0.001$), respectively. Each mathematical formula provided unique prediction for postoperative SA (Pearson $R^2 < 0.15$). Formulas that neglected pelvic alignment poorly predicted final SVA and poorly correlated with optimal SVA. Formulas that evaluated pelvic morphology (pelvic incidence) had improved SVA prediction. The Lafage formulas, which incorporate PT and spinal compensatory changes, had the best SVA prediction ($P < 0.05$) and best correlation with optimal SVA ($R^2 = 0.75$).

Conclusion. Preoperative planning for PSO is essential to optimize postoperative spinal alignment. Mathematical models that do not consider pelvic parameters and changes in unfused spinal segments poorly predict optimal postoperative alignment and may predispose to poor clinical outcomes. The Lafage formulas, which incorporated PT and spinal compensatory changes, best predicted optimal SVA.

Key words: osteotomy, pedicle subtraction osteotomy, prediction formula, spinopelvic alignment, sagittal vertical axis. **Spine 2012;37:845–853**

Restoration of sagittal alignment (SA) is fundamental to spinal deformity surgery. Sagittal malalignment has been shown to correlate with pain, disability, and poor health-related quality of life (HRQOL).[1–11] Pedicle subtraction osteotomy (PSO) is an established surgical technique used to restore SA and improve HRQOL among adult spinal deformity (ASD) patients with positive sagittal spinal malalignment.[1,5,12–14]

Although the ideal posture and its impact on HRQOL have not been fully defined, several studies have provided significant insight. Glassman *et al*[3,4] established that global SA (sagittal vertical axis [SVA]) correlates with HRQOL, and more recently Lafage *et al*[7] confirmed this correlation and established pelvic tilt (PT) as a second parameter with strong correlation with HRQOL. Furthermore, Lafage *et al* recently established the thresholds for key radiographical parameters

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on the basis of their correlation with HRQOL measures,[15] and these values are the basis of a new classification of ASD.[16]

Preoperative surgical planning is essential to determine whether PSO can effectively restore SA. To assist in the preoperative planning for PSO, several mathematical prediction formulas have been proposed to estimate SA after PSO.[17–22] Some prediction formulas simply estimate the amount of lumbar lordosis (LL) necessary to restore SA, whereas others use trigonometric modeling to determine the amount of angular resection necessary at the osteotomy site to normalize the SVA.[18,19,22,23]

Several authors have recently hypothesized that SVA measures alone do not provide a complete picture of the pathology leading to sagittal malalignment.[23–25] The contribution of pelvic alignment to SA has been increasingly emphasized, and the concept of global spinopelvic alignment has been reported to provide a more complete picture of the physiologic mechanisms used to maintain upright posture.[8,26–28] Consequently, the need to integrate pelvic measurements into SVA prediction formulas has also been emphasized.[20,21] Pelvic measurements include pelvic incidence (PI), which is a fixed morphologic parameter and 2 dynamic parameters that reflect volitional position of the pelvis to maintain upright posture (PT and sacral slope [SS]). For example, pelvic retroversion is a compensatory mechanism used to maintain upright posture in the setting of forward sagittal malalignment, which results in an increased PT and a decreased SS. Increased PT has been shown to correlate with poor HRQOL.[7] PT has also been reported to normalize in conjunction with improved SVA after lumbar PSO.[29] Therefore, if PT is not evaluated, the amount of spinopelvic malalignment may be underestimated. Accordingly, preoperative PSO planning formulas that do not evaluate PT may underestimate the amount of sagittal spinopelvic malalignment present and may lead to incomplete correction after PSO.

Another mechanism producing sagittal malalignment after spinal fusion is alignment changes within the remaining unfused spinal segments. Several reports have indicated that increased kyphosis in the unfused regions of the thoracic spine negatively affects SA after lumbar PSO, especially when proximal fusion levels terminate within the thoracolumbar junction.[13,30–32] Consequently, proximal and distal fusion levels must also be considered when predicting postoperative SA after spinal fusion.

In an attempt to improve the accuracy of predicting SA after PSO, Lafage *et al*[33,34] developed 2 mathematical formulas. These formulas integrate PT values and attempt to account for alignment changes in the unfused spine. Preliminary results validating the use of the formulas demonstrated a 76% positive predictive value for predicting a successful single-level lumbar PSO (postoperative SVA $\leq$ 50 mm and PT $\leq$ 25°) and 98% negative predictive value for predicting an unsuccessful single-level lumbar PSO (postoperative SVA $>$ 50 mm or PT $>$ 25°).[35] Because of the critical nature of restoring SA after PSO, a comparative analysis of the mathematical formulas currently used for preoperative PSO planning is warranted. The purpose of this study was to evaluate the accuracy of 5 mathematical formulas developed to predict SA after PSO. We hypothesized that the formulas that integrate pelvic measures and account for dynamic changes in the pelvis and unfused spine would have the best accuracy in predicting optimal postoperative SA.

MATERIALS AND METHODS

This study was a multicenter retrospective analysis of patients with ASD treated with single-level PSO for positive sagittal malalignment. Data were from 8 centers across the United States. The institutional review board approval was obtained by each site. Inclusion criteria were patients with ASD older than 21 years with preoperative and at least 6-month postoperative full-length 36-inch anteroposterior and sagittal radiographs. Patients with underlying neurological or neuromuscular conditions were excluded. Patients were also excluded if multilevel PSO was performed or if the femoral heads were not visible on any of the sagittal radiographs.

Radiographical Analysis

Patients were instructed to assume a free-standing posture, with elbows flexed at approximately 45° and fingertips on the clavicles.[36,37] Films were digitized using a Vidar scanner (Vidar Systems Corp, Herndon, VA) with 75-dpi resolution and 12 gray levels and assessed using Spineview (Surgiview, Paris, France).[38,39] Spinal measurements (Figure 1) included thoracic kyphosis (TK; Cobb angle superior endplate of T5 to inferior endplate of T12), thoracolumbar kyphosis (Cobb angle superior endplate of T10 to inferior endplate of L2), LL (Cobb angle superior endplate of T12 to superior endplate of S1), maximal kyphosis (Max TK), maximal LL (Max LL), and SVA (distance C7 plumbline to posterior superior corner sacrum). Pelvic measurements included PT (angle between the vertical and the line through the midpoint of the sacral plate to axis of femoral heads), SS (angle between the horizontal and the superior S1 endplate), and PI (angle between the perpendicular to the superior S1 endplate at its midpoint and the line connecting this point to the center of the femoral heads; Figure 2). PSO degree of resection was defined as the change of the angle formed by the lower vertebral endplate of the cephalic adjacent vertebra and the upper vertebral endplate of the caudal adjacent vertebra (PSO angle; Figure 3).

Analysis of Predictive Mathematical Formulas

Five mathematical formulas that have been previously reported to predict SA after PSO were evaluated (Table 1).[18–22,40] Schematic representation of these formulas is shown in Figure 4. Formulas 1 to 5 were created to predict good *versus* poor postoperative SA. Formulas 2 and 5 were also designed to predict actual postoperative SVA. Therefore, the mathematical formulas were evaluated in terms of (1) the ability of the formula to predict good postoperative alignment (SVA $<$ 5 cm), (2) ability of the formula to predict poor postoperative alignment (SVA $\geq$ 5 cm), and (3) accuracy in predicting actual SVA and the standard error of measure for SVA prediction (examples shown in Figures 5 and 6).

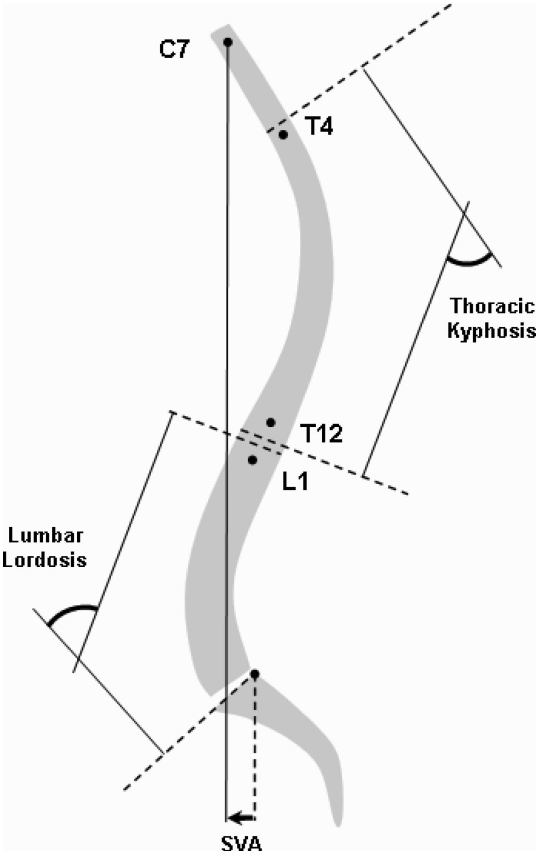


Figure 1. Sagittal spinal radiological parameters: Thoracic kyphosis, lumbar lordosis, and sagittal vertical axis (SVA).

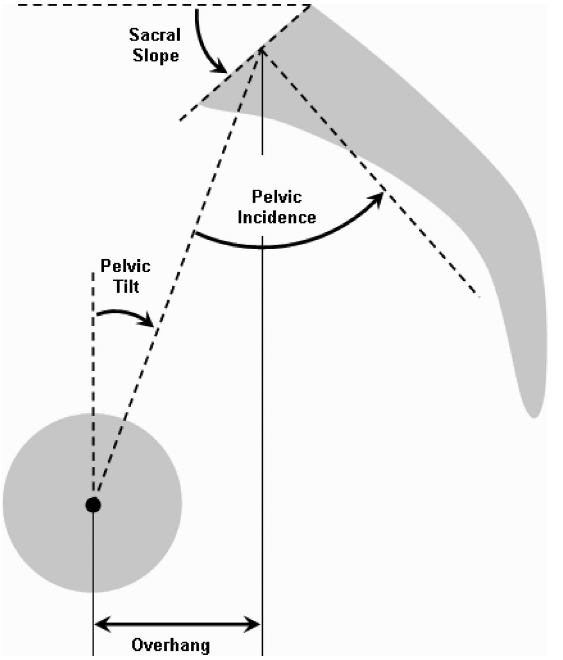


Figure 2. Pelvic radiographical parameters: sacral slope, pelvic incidence, and pelvic tilt.

Statistical Analysis

Data were analyzed using SPSS (SPSS, Chicago, IL). Preoperative radiographical measures and surgical correction of sagittal curvatures were input into all formulas to predict the likelihood of achieving good or poor alignment. Actual postoperative alignment was analyzed and classified as good (SVA < 5 cm) or poor (SVA ≥ 5 cm). The ability of each formula to accurately predict postoperative SVA was analyzed using the chi-square method. Both false-positive and false-negative results were assigned a value of 0 for the binary comparison with the χ^2 method, whereas true-negative or true-positive results were assigned a value of 1. The numbers of false-negative and false-positive results were compared with the numbers of true-negative and true-positive results for each predictive formula (significance at $P < 0.05$).

The Spearman rho was used to calculate correlation between the predicted classification and actual classification of postoperative SVA (good/poor). Correlation significance was calculated using the 2-tailed Student *t* test with significance set at $P < 0.05$. The mean error between predicted and actual postoperative SVA was also calculated for formulas 2 and 5.

RESULTS

Demographic and Operative Data

Between 2006 and 2009, 147 patients who underwent PSO procedures (42 thoracic and 105 lumbar) were available for analysis. Mean age at the time of surgery was 52 years (SD = 15 years). The mean number of levels fused was 12.6 (SD = 3.8 levels). Mean preoperative and postoperative SVA were 10.8 cm (SD = 9.5 cm) and 3 cm, respectively (SD = 6 cm; $P < 0.001$). Forty-seven patients (32%) had postoperative SVA ≥ 5 cm.

Mathematical Formula Analysis

Each of the 5 mathematical formulas evaluated provided unique prediction for postoperative spinal alignment (Pearson $R^2 \leq 0.15$). Analysis of the accuracy for each mathematical formula to predict good *versus* poor SVA demonstrated that the formulas that included regional sagittal spinal curvatures (TK and LL) but neglected morphologic and dynamic pelvic

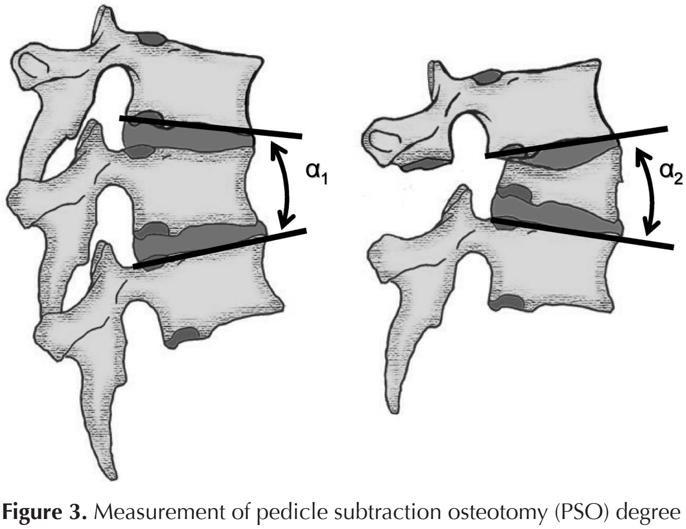


Figure 3. Measurement of pedicle subtraction osteotomy (PSO) degree of resection (PSO angle), defined as $\alpha_2 - \alpha_1$.

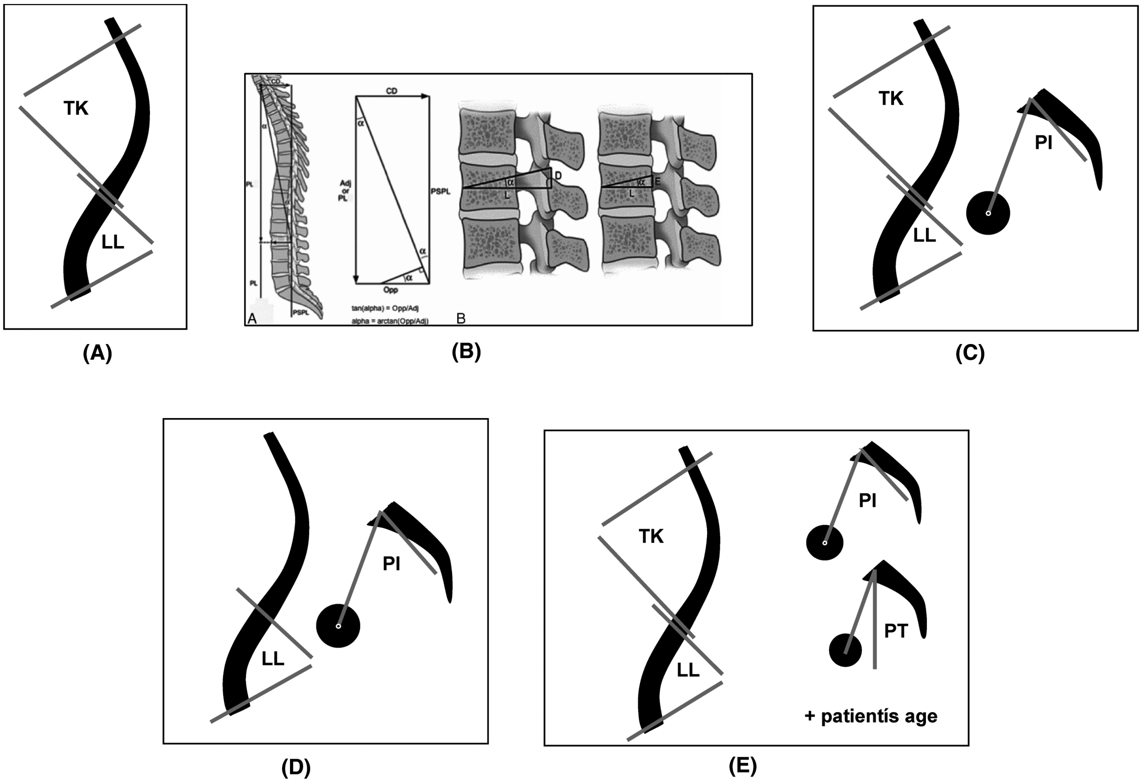


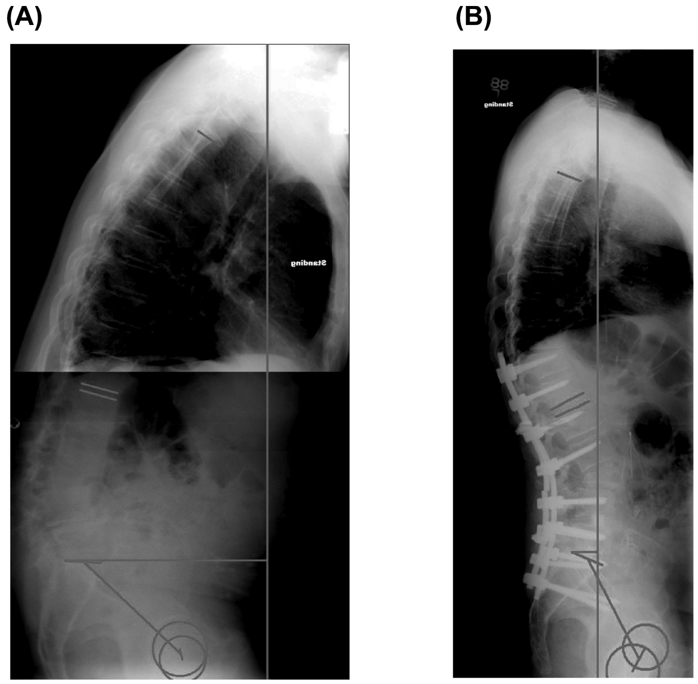
Figure 4. Diagrams depicting the measurements included in each of the 5 mathematic formulas evaluated. Formulas 1 through 5 were reported by (**A**) Kim *et al,*[18] criteria for good alignment = $LL \geq TK + 20$; (**B**) Ondra *et al,*[19] trigonometric formula to estimate the amount of PSO resection PSO angle = atan (y/z); (**C**) Rose *et al,*[20] criteria for good alignment $LL + PI + TK \leq 45$; (**D**) Schwab *et al,*[21] criteria for good alignment $LL > PI - 10$; and (**E**) Lafage *et al,*[33,34] estimation of postoperative SVA respectively. TK indicates thoracic kyphosis, LL, lumbar lordosis; PI, pelvic incidence; PSO, pedicle subtraction osteotomy; and PT, pelvic tilt.

parameters (formulas 1 and 2) showed moderate accuracy in predicting good postoperative SVA and showed moderate total SVA prediction accuracy (accurate prediction of good and poor SVA; Table 1). Formulas that included or incorporated regional sagittal spinal curvatures and morphologic pelvic parameters (PI) but did not evaluate dynamic pelvic parameters (PT) and did not evaluate alignment changes in unfused spine segments (formulas 3 and 4) demonstrated poor to moderate accuracy in predicting poor SVA and moderate total prediction accuracy (Table 1). The formula that incorporated measures of regional sagittal spinal curvatures, morphologic and dynamic pelvic parameters (PI and PT), and also evaluated alignment changes in unfused spinal segments (formula 5) demonstrated the best total prediction accuracy (89%, $P < 0.05$) and demonstrated the best correlation with predicted *versus* actual good *versus* poor postoperative SVA (Spearman coefficient = 0.75, $P < 0.05$; Table 1). Evaluation of the mean error between predicted and actual SVA demonstrated that formula 2 had a significantly greater mean error in SVA prediction than formula 5 (11.1 cm *vs.* 3 cm, $P < 0.05$).

DISCUSSION

PSO is an effective technique to restore SA. This study demonstrates that many of the formulas designed to aid preoperative PSO planning poorly predict optimal SA after single-level PSO and may predispose to incomplete correction and residual postoperative sagittal spinal malalignment.

The value of preoperative planning for spinal osteotomy procedures was initially reported by Ondra *et al.*[19,22,23,40] Ondra et al used trigonometric formulas to predict SVA based on the spinal level and angle of the osteotomy resection. The accuracy of this approach was validated in 15 patients with ASD undergoing lumbar PSO.[19] Average preoperative SVA was 11.2 cm, and average postoperative SVA was 0.4 cm. Fourteen of 15 patients had final SVA < 5 cm. The average predicted correction at the osteotomy site and the actual correction achieved were both 26°. The authors did not indicate preoperative or postoperative LL, TK, or pelvic parameters, and the final SVA predicted by the planned PSO was not indicated. Despite the high degree of correlation between the predicted and actual degrees of correction at the PSO site, the value of Ondra's trigonometric method is somewhat limited because final SVA is not actually predicted. Instead the formulas are based upon aligning the SVA with the PSVL (vertical line that extends cephalad from the posterior superior corner of the sacrum). If the data reported by Ondra *et al* are evaluated in terms of the accuracy of the formula to align the SVA to the PSVL, the standard deviation of the postoperative SVA values is approximately 3.3 cm.[19] This large standard deviation may place patients with larger sagittal deformities at risk for undercorrection after PSO. These speculations



(C)

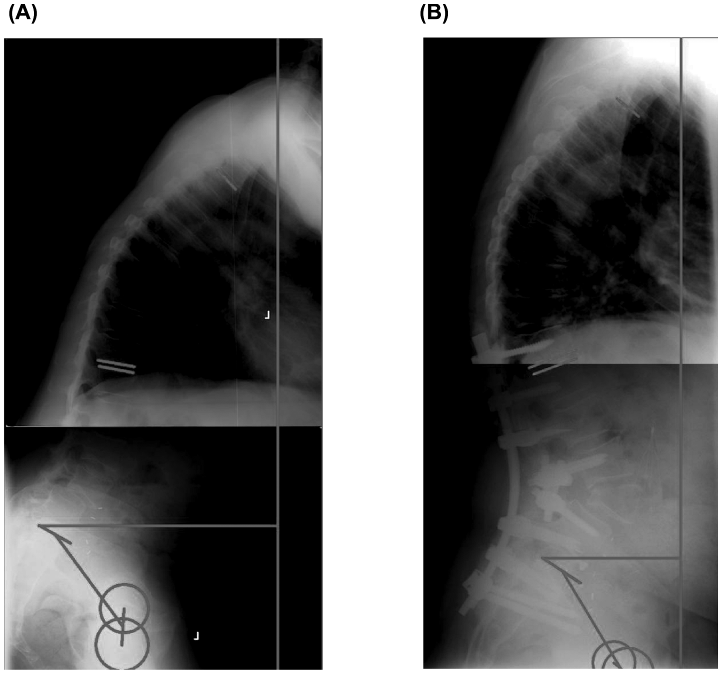
Radiographical measurements				Predicted Postoperative Alignment				
Parameter	Preop	Postop	Postop SVA	Formula 1	Formula 2	Formula 3 *	Formula 4	Formula 5 **
LL (°)	14	40	**Good**	**Bad** LL = 40 and therefore is smaller than TK + 20° (60°)	**Bad** Predicted SVA = −105 mm with a PSO resection of 41° at L3	**Good** TK + PI + LL = 45° (≤45°)	**Good** LL = 40° and therefore is larger than PI−10° (35°)	**Good** Predicted SVA = 9 mm
TK (°)	20	40						
PI (°)	45	45						
PT (°)	45	26						
SVA (mm)	197	32						
Age (yr)	58	59						

Figure 5. Preoperative and postoperative radiographical imaging and the calculated predictions of postoperative alignment of a patient with good postoperative SVA (<5 cm) after PSO. (**A**) Preoperative radiograph. (**B**) Postoperative radiograph. (**C**) Radiographical measurements and postoperative alignment prediction results for formulas 1 to 5. Formulas 3, 4, and 5 predicted good SVA. Formula 5 provided a reasonable prediction of the postoperative sagittal vertical axis (9 cm), compared with the actual (3.2 cm). Formula 2 predicted a postoperative SVA-105 cm. *Lumbar lordosis represented as a negative number. **Thoracic kyphosis represented as a negative number. LL indicates lumbar lordosis; TK, thoracic kyphosis; PI, pelvic incidence; PT, pelvic tilt; SVA, sagittal vertical axis.

are consistent with our findings, because we found that the Ondra formula demonstrated a large error for SVA prediction (11.1 cm) and had only moderate correlation with predicted postoperative SVA (Spearman coefficient = 0.54).

Another concerning aspect of Ondra's trigonometric technique is its accuracy in predicting good postoperative alignment (SVA < 5 cm; 59% accuracy). One possible reason for the inaccuracies of the trigonometric formula is that it models the spine as if it were a rigid unit. However, a number of dynamic changes occur within the pelvis and unfused spinal segments after PSO that alter SA. PT has been shown to decrease after PSO, allowing relaxation of pelvic compensatory mechanisms, creating a new postoperative spinopelvic alignment.[29,35] High PT is a risk factor for incomplete correction and residual sagittal plane deformity after PSO.[35,41] The trigonometric formula was likely able to accurately predict poor SA because it requires an osteotomy that is large enough to align the C7 plumb line with the PSVL. However, the inaccuracy that we found when using the trigonometric method to predict good postoperative alignment and the associated wide margin of error when predicting SVA may be due to postoperative alignment changes that occur within the pelvis that are unaccounted for when using this calculation. Similarly, it is possible that the 2 patients in the series by Ondra *et al*[19] with a residual postoperative SVA > 4.5 cm not only had large positive sagittal malalignment that was not amendable to a single-level PSO, but may have had high PT that was unaccounted for and incompletely corrected by the planned PSO.

Another commonly used method for preoperative PSO planning is to estimate the amount of LL needed to restore lumbar SA and then perform the PSO accordingly to generate the desired amount of LL. Kim *et al*[18] recommended that the sagittal Cobb angle difference between LL and TK be a minimum of 20° and proposed the formula LL ≥ TK + 20°



(C)

Radiographical measurements				Predicted Postoperative Alignment				
Parameter	Preop	Postop	Postop SVA	Formula 1	Formula 2	Formula 3 *	Formula 4	Formula 5 **
LL (°)	20	52	**Bad**	**Bad** LL = 52 and therefore is smaller than TK + 20° (85°)	**Good** Predicted SVA = 21 mm with a PSO resection of 32° at L4	**Bad** TK + PI + LL = 77° (>45°)	**Bad** LL = 52 and therefore is smaller than PI −10°(54°)	**Bad** Predicted SVA = 95.8 mm
TK (°)	39	65						
PI (°)	64	64						
PT (°)	36	31						
SVA (mm)	248	121						
Age (yr)	69	70						

Figure 6. Preoperative and postoperative radiographical imaging and the calculated predictions of postoperative alignment of a patient with poor postoperative SVA $\geq$ 5 cm after PSO. (**A**) Preoperative radiograph. (**B**) Postoperative radiograph. (**C**) Radiographical measurements and postoperative alignment prediction results for formulas 1 to 5. Formula 2 failed to predict poor postoperative sagittal alignment and erroneously predicted a good postoperative SVA of 2.1 cm compared to the actual poor SVA (12.1 cm). Formula 5 provided a reasonable prediction of the postoperative SVA (9.58 cm), compared with the actual SVA (12.1 cm). *Lumbar lordosis represented as a negative number. **Thoracic kyphosis represented as a negative number. LL indicates lumbar lordosis; TK, thoracic kyphosis; PI, pelvic incidence; PT, pelvic tilt; SVA, sagittal vertical axis.

to achieve optimal postoperative SA. However, the authors indicated that they were unable to predict the amount of LL needed if the fusion stopped in the lower thoracic spine because of the "unpredictable nature of how the spine will change above" the fusion. We found that their formula was able to accurately predict poor SVA (87% accuracy), but had difficulty predicting good SVA (51% accuracy). Again, we think that this discrepancy exists because the spine is modeled as a rigid object and pelvic parameters are not measured. Rose *et al*[20] subsequently refined this formula by integrating PI. Using the formula $PI + LL + TK \leq 45°$, the authors demonstrated a 91% sensitivity for predicting ideal SA in 40 ASD patients treated with PSO. This formula represents a greater level of sophistication compared with the Ondra and Kim[19] formulas, because pelvic alignment is integrated into the equation. However, PI is a morphologic measure and does not provide insight into the amount of pelvic retroversion used to maintain an upright posture. From our analysis, the Kim[18] formula was able to accurately predict a good SVA because patients with a low PT also had low PI; therefore, larger correction was not needed and these patients were at lower risk for incomplete correction. Conversely, patients with high PI likely had high PT and were therefore at higher risk for incomplete sagittal correction, as reflected by the inaccuracy in poor SVA prediction (28% accuracy).

Recently, Schwab *et al*[21] noted that, because pelvic parameters are modified by changes in spinal contour, a predictive model for postoperative SA must include the relationship between spinal alignment and pelvic position. The authors indicated that among patients with loss of LL, the amount of LL needed for a given PI can be estimated using the formula $LL = PI + 9° (\pm 9)$.[21] However, the authors also noted that this calculation was applicable only for patients with decreased LL but otherwise "reasonable spinal contour," and

TABLE 1. Accuracy of Mathematical Formulas to Predict Good and Poor Postoperative Sagittal Alignment After Single-Level PSO

Mathematical Formula	Author	Accuracy Prediction Good Postoperative SVA (% Correct)	Accuracy Prediction Poor Postoperative SVA (% Correct)	Total Prediction Accuracy (Good and Poor Postoperative SVA; % Correct)	Prediction Accuracy (Good and Poor Postoperative SVA; Spearman Coefficient)	Mean Error SVA Prediction (mm)
(1) $LL \geq TK + 20°$	Kim *et al*[18]	51	87	63	0.37	NA
(2) PSO angle = atan (*y*/*z*)	Ondra *et al*[19]	59	98	72	0.54	111
(3) $LL + PI + TK \leq 45°$	Rose *et al*[20]	97	28	74	0.37	NA
(4) $LL \geq PI - 10°$	Schwab *et al*[21]	78	79	78	0.55	NA
(5) $SVA = -52.87 + 5.90\,(PI) - 5.13\,(LL_{max}) - 4.45\,(PT) - 2.09\,(TK_{max}) + 0.57\,(age)$	Lafage *et al*[33,34]	98	70	89*	0.75*	30

LL indicates lumbar lordosis; TK, thoracic kyphosis; PI, pelvic incidence; LL_{max}, maximum lumbar lordosis; TK_{max}, maximum thoracic kyphosis; TL, T10-L1 kyphosis; NA, not applicable.

$^*P < 0.05$.

further indicated that for patients with thoracic hyper- or hypokyphosis, other methods would be needed to calculate optimal spinal alignment. Although this formula provided more consistent results than the previously evaluated formulas, demonstrating relatively good ability to predict good SVA (78% accuracy) and poor SVA (79% accuracy), as well as moderate correlation with postoperative SVA prediction (Spearman coefficient = 0.55), it did not include a prediction of realignment of unfused spinal segments.

In an attempt to overcome the inaccuracies of the existing preoperative planning techniques, Lafage *et al*[33,34] developed 2 formulas to predict SA resulting from a single-level PSO. Preoperative variables (PI, Max LL, Max TK, and age) are used to calculate the predicted postoperative PT and SVA. In our analysis, the Lafage formulas accurately predicted both poor and good SVA correction (70% and 98% accuracy, respectively), demonstrated good correlation for SVA prediction (Spearman coefficient = 0.75), and had the greatest actual SVA prediction accuracy (89%) with a small margin of error (3 cm). The improved accuracy of the Lafage formulas likely stems from evaluation of the regional spinal sagittal curvatures and evaluation of the morphologic (PI) and dynamic measures (PT) in the pelvis. PT has increasingly been recognized as a critical measure of pelvic and spinal alignment and plays an important role in SA after lumbar PSO.[7,10,21,35,41] Other causes of sagittal malalignment after spinal reconstruction are alignment changes within unfused spinal segments. Several reports have indicated that the unfused spinal segments cephalad and caudal to the PSO do not move in line with the fused spinal segments. Instead, the unfused spinal segments move independently and adopt a new position that is often counter to the direction of the fused spinal segments.[42,43] The Lafage formulas attempt to integrate the potential for dynamic changes in the unfused spine by integrating age into the calculation, because age is a risk factor for increased TK after lumbar PSO.[33,34,42]

Limitations to this study include the retrospective application of the mathematical prediction formulas. The ideal evaluation would be a prospective analysis of PSO procedures based solely upon the preoperative planning model. However, challenges for such a study design include the large number of patients needed and the ethical concerns of performing the PSO based solely on preoperative planning without integrating intraoperative clinical and radiographical data to optimize postoperative alignment. A general limitation of the formulas in this article is the lack of full accounting for the positions of the lower extremities (knees and ankles) and the head.[44] In addition, although the formulas do take into account the location of the center of rotation of the hip joint, they do not account for the position of the hip joint as to neutral, flexion, or extension.[44] Another limitation of this study is the use of age as a surrogate value for alignment changes in the unfused spine. However, to our knowledge, no models currently exist that predict spinal alignment changes within unfused spinal segments and the positional status of the lower extremity joints.[42] Further research is needed in this area to enhance the accuracy in SA prediction.

CONCLUSION

Dynamic changes that occur in the pelvis and unfused spinal segments after spinal reconstruction must be considered during preoperative planning for PSO procedures. PT is a critical measure of SA. The majority of reported preoperative planning formulas that predict SVA after PSO do not account for PT and do not incorporate expected changes in the unfused spine. As a result, these formulas may introduce inaccuracy in the preoperative planning process and may thus mislead the surgical team, predisposing to residual deformity after PSO. The reported formulas by Lafage *et al* demonstrated the greatest accuracy in predicting postoperative SVA after PSO surgery.[15] A general limitation of the formulas in this article is the lack of full accounting for the positions of the lower extremities (knees and ankles) and the head. In addition, although the formulas do take into account the location of the center of rotation of the hip joint, they do not account for the position of the hip joint as to neutral, flexion, or extension. Further research is needed is this area, and prospective clinical studies may enhance the predictive power of the planning formulas presented here.

➢ Key Points

- ☐ Preoperative planning aids spinal reconstruction.
- ☐ PT and compensatory changes in the unfused spine have been shown to impact SVA after PSO procedures.
- ☐ Mathematical formulas used to predict SVA after PSO that do not integrate pelvic alignment and compensatory changes in unfused spinal segments poorly predict optimal SVA.
- ☐ Formulas that incorporate PT and compensatory changes in the unfused spine most accurately predict SVA after PSO.

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