Spine

SPINE Volume 38, Number 13, pp E803–E812

DEFORMITY

Radiographical Spinopelvic Parameters and Disability in the Setting of Adult Spinal Deformity

A Prospective Multicenter Analysis

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Study Design. Prospective multicenter study evaluating operative (OP) *versus* nonoperative (NONOP) treatment for adult spinal deformity (ASD).

Objective. Evaluate correlations between spinopelvic parameters and health-related quality of life (HRQOL) scores in patients with ASD.

Summary of Background Data. Sagittal spinal deformity is commonly defined by an increased sagittal vertical axis (SVA); however, SVA alone may underestimate the severity of the deformity. Spinopelvic parameters provide a more complete assessment of the sagittal plane but only limited data are available that correlate spinopelvic parameters with disability.

Methods. Baseline demographic, radiographical, and HRQOL data were obtained for all patients enrolled in a multicenter consecutive database. Inclusion criteria were: age more than 18 years and radiographical diagnosis of ASD. Radiographical evaluation was conducted on the frontal and lateral planes and HRQOL questionnaires (Oswestry Disability Index [ODI], Scoliosis Research Society-22r and Short Form [SF]-12) were completed. Radiographical parameters demonstrating highest correlation with HRQOL values were evaluated to determine thresholds predictive of ODI more than 40.

Results. Four hundred ninety-two consecutive patients with ASD (mean age, 51.9 yr) were enrolled. Patients from the OP group (n = 178) were older (55 *vs*. 50.1 yr, $P < 0.05$), had greater SVA (5.5 *vs*. 1.7 cm, $P < 0.05$), greater pelvic tilt (PT; 22° *vs*. 11°, $P < 0.05$), and greater pelvic incidence/lumbar lordosis PI/LL mismatch (PI-LL; 12.2 *vs*. 4.3; $P < 0.05$) than NONOP group (n = 314). OP group demonstrated greater disability on all HRQOL measures compared with NONOP group (ODI = 41.4 *vs*. 23.9, $P < 0.05$; Scoliosis Research Society score total = 2.9 *vs*. 3.5, $P < 0.05$). Pearson analysis demonstrated that among all parameters, PT, SVA, and PI-LL correlated most strongly with disability for both OP and NONOP groups ($P < 0.001$). Linear regression models demonstrated threshold radiographical spinopelvic parameters for ODI more than 40 to be: PT 22° or more ($r = 0.38$), SVA 47 mm or more ($r = 0.47$), PI − LL 11° or more ($r = 0.45$).

Conclusion. ASD is a disabling condition. Prospective analysis of consecutively enrolled patients with ASD demonstrated that PT and PI-LL combined with SVA can predict patient disability and provide a guide for patient assessment for appropriate therapeutic decision making. Threshold values for severe disability (ODI > 40) included: PT 22° or more, SVA 47 mm or more, and PI − LL 11° or more.

Key words: adult spinal deformity, health related quality of life, disability, prediction, sagittal alignment, patient assessment, radiographical parameters, surgery, conservative care, prospective analysis.

Spine 2013;38:E803–E812

Within the field of spinal disorders, adult spinal deformity (ASD) remains one of the most controversial topics. ASD presents a significant health care issue due to its growing incidence in an aging Western population. Some reports have noted the prevalence of ASD to be as high as 60% in the older population.[1] For many

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Acknowledgment date: October 4, 2011. First revision date: April 22, 2012. Second revision date: August 23, 2012. Third revision date: March 2, 2013. Acceptance date: March 4, 2013.

The manuscript submitted does not contain information about medical device(s)/drug(s).

Depuy Synthes Spine grant funds were received to support this work.

Relevant financial activities outside the submitted work: consultancy, grants pending, royalties, payment for lectures, payment for expert testimony, grants pending, stock/stock options, travel/accommodations/meeting expenses, patents, support for travel, payment for development of educational presentations, and fees for participation in review activities.

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DOI: 10.1097/BRS.0b013e318292b7b9

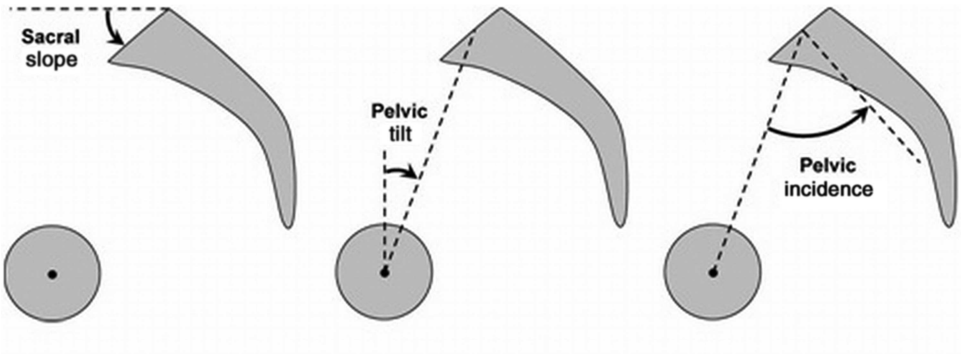

Figure 1. Schematic representation of the pelvic parameters: pelvic incidence is defined as the angle between the perpendicular to the sacral plate at its midpoint and the line connecting this point to the femoral head axis. This is a morphological parameter of primary importance commonly used to define some spinopelvic morphotypes or alignments. Pelvic tilt is defined by the angle between the vertical and the line through the midpoint of the sacral plate to femoral heads axis; sacral slope is defined as the angle between the horizontal and the sacral plate.

years, the diagnosis and treatment of ASD was based upon coronal plane radiographical analysis using Cobb angle measurements. However, recent research has shown that sagittal spinopelvic alignment among patients with ASD plays a critical role in pain and disability and is a primary determinant of health related quality of life (HRQOL) measures.[2–6]

Although truncal alignment has been studied and its clinical relevance established in the setting of ASD, the interest in pelvic parameters is more recent. Since their initial description,[7,8] the key pelvic parameters tied to spinal sagittal alignment have been established as pelvic incidence (PI), pelvic tilt (PT), and sacral slope (Figure 1, Table 1), inter-related by the equation as follows.

$$\mathrm{PI} = \mathrm{PT} + \text{sacral slope (SS)}.$$

Using these parameters, it is possible to predict theoretical values of regional sagittal parameters such as lumbar lordosis (LL) and thoracic kyphosis.[9,10] More recently, Lafage *et al*[11] have reported high correlations between pelvic retroversion (measured by the PT) and sagittal vertical axis (SVA) with HRQOL scores, underscoring the role of sagittal spinopelvic parameters as the main drivers of disability for patients with ASD. Accordingly, using retrospectively collected HRQOL and radiographical data, Schwab *et al*[12] have proposed threshold values of sagittal spinopelvic alignment that should be achieved with spinal reconstructive procedures to obtain satisfactory outcomes in terms of HRQOL.

The objective of this study was to establish the clinical relevance of radiographical deformity parameters when

TABLE 1. Normative Values of Radiographical Sagittal Key Parameters*

	Normative Values and References					
Parameter	Schwab 2006[29]	Berthonnaud 2005[30]	Vialle 2005[31]	Legaye 1998[32]	Boulay 2006[33]	Roussouly 2006[34]
No. subjects	75	160	300	49	149	153
Age	49.3 yr (18–80)	25.7 ± 5.5 yr (20–70)	35 yr (20–70)	24.0 ± 5.8 yr (19–50)	30.8 ± 6.0 yr (19–50)	27 yr (18–48)
M:F ratio	0.56	0.95	0.63	0.56	0.52	0.52
SVA	−20 ± 30	…	…	…	…	35.2 ± 19.4 (−18.1 to 80.8)
T1-SPI	…	…	−1.4 ± 2.7 (−9.2 to 7.1)	…	…	…
TK (T4–12)	41 ± 12	47.5 ± 4.8 (22.5–70.3)	40.6 ± 10.0 (0–69)	≈43.0 ± 13.0	53.8 ± 10.1 (33.2–83.5)	46.3 ± 9.5 (23.0–65.9)
LL (L1-S1)	60 ± 12	42.7 ± 5.4 (16–71.9)	60.2 ± 10.3 (30–89)	≈60.0 ± 10.0	66.4 ± 9.5 (44.8–87.2)	61.2 ± 9.4 (39.9–83.7)
PI	52 ± 10	51 ± 5.3 (33.7–83.7)	54.7 ± 10.6 (33–82)	≈52.0 ± 10.0	53.1 ± 9.0 (33.7–77.5)	50.6 ± 10.2 (27.9–82.8)
PT	15 ± 7	12.1 ± 3 .2 (−5.1 to 30.5)	13.2 ± 6.1 (−4.5 to 27)	≈11.0 ± 5.5	12.0 ± 6.4 (−2 to 30)	11.1 ± 5.9 (−2.8 to 23.7)
SS	30 ± 9	39.7 ± 4.1 (21.2–65.9)	41.2 ± 8.4 (17–63)	≈40.0 ± 8.5	41.2 ± 7.0 (0.6–19.7)	39.6 ± 7.6 (17.5–63.4)

*Reprinted, with permission, Schwab et al.[12]

M incidates male; F, female; SVA, sagittal vertical axis; T1-SPI, T1 spinopelvic inclination; TK, thoracic kyphosis; PI, incidence; LL, lumbar lordosis; PT, pelvic tilt; SS, sacral slope.

TABLE 2. Baseline HRQOL Scores (Mean ± Standard Deviation) for the Entire Population and by Group. Comparison Between NONOP and OP Groups Were Evaluated Using an Unpaired *t* test. Maximal Potential Scores are 100 for ODI and SF-12 MCS/PCS and 5 for SRS Scale

	All	NONOP Group	OP Group	Difference and *P*	
Age	51.9 ± 16.8	50.1 ± 16.9	55.0 ± 16.1	−4.9	0.002
ODI	30.2 ± 20.1	23.9 ± 17.2	41.4 ± 20.1	−17.5	<0.001
SRS	3.3 ± 0.7	3.5 ± .7	2.9 ± .7	0.7	<0.001
SF-12/PCS	50.1 ± 10.8	53.0 ± 9.7	44.8 ± 10.6	8.2	<0.001
SF-12/MCS	29.1 ± 11.9	26.3 ± 10.9	34.3 ± 11.8	−8.1	<0.001

HRQOL indicates health related quality of life; MCS, mental component score; ODI, Oswestry Disability Index; PCS, physical component score; SF, Short Form; SRS, Scoliosis Research Society.

correlated to HRQOL scores to predict disability preoperatively in a consecutive, multicentered series of patients with ASD. This study focused on pelvic and spinal measures, collectively termed spinopelvic parameters.

MATERIALS AND METHODS

Study Design

Prospective analysis of consecutive series of patients with ASD enrolled in a multicenter prospective study (11 sites and 15 physicians across the United States) evaluating operative (OP group) and nonoperative (NONOP group) treatments for ASD. Of note, decision to operate or to treat conservatively each patient was made by the surgeon, based on his own clinical and radiographical criteria, without knowledge of the study results. Institutional review board approval was obtained at each participating site.

Inclusion Criteria and Data Collection

All subjects have been enrolled in the database following institutional review board approval at each site. Inclusion criteria were age greater than 18 years and a radiographical diagnosis of ASD defined by at least 1 of the following parameters: Cobb angle more than 20°, SVA more than 5 cm, PT more than 25°, or TK more than 60°. Exclusion criteria included patients with inflammatory arthritis, tumors, or neuromuscular diseases.

Evaluation Criteria

For each patient, baseline full-length standing anteroposterior and lateral spine radiographs (36″ cassette) were available as well as completed Oswestry Disability Index (ODI), Scoliosis Research Society-22, and Short Form (SF)-36 questionnaires. Each baseline radiograph was analyzed using a dedicated and validated software[13,14] (Spineview, Surgiview, Paris). Coronal radiographical parameters consisted in Cobb Angles (upper thoracic, thoracic, thoracolumbar, and lumbar), maximal Cobb angle, pelvic obliquity, leg length discrepancy, and coronal imbalance. Sagittal radiographical parameters consisted in TK (T2–T12, T4–T12, and maximal), LL (L1–S1, and Maximal), thoracolumbar alignment (T10–L2), T1 and T9 spinopelvic inclinations, pelvic parameters (sacral slope, PT, and PI), SVA, and PI minus LL.

TABLE 3. Breakdown of ODI Scores by Domain for the OP and NONOP Groups

	NONOP Group	OP Group	Difference and *P*	
Social life	**1.04 ± 1.21**	**2.28 ± 1.51**	**1.25**	**<0.001**
Walking	0.93 ± 1.23	2.14 ± 1.48	1.21	<0.001
Standing	1.69 ± 1.38	2.76 ± 1.37	1.08	<0.001
Employment/homemaking	1.05 ± 1.19	1.99 ± 1.54	0.94	<0.001
Traveling	0.84 ± .93	1.71 ± 1.42	0.87	<0.001
Lifting	2.01 ± 1.50	2.77 ± 1.48	0.76	<0.001
Pain	1.68 ± 1.45	2.37 ± 1.43	0.69	<0.001
Sleeping	0.77 ± 0.97	1.43 ± 1.36	0.67	<0.001
Sitting	1.19 ± 1.07	1.80 ± 1.13	0.61	<0.001
Personal are	0.39 ± 0.73	0.92 ± 1.15	0.53	<0.001

OP indicates operative.

TABLE 4. Breakdown of SRS Scores by Domain for the OP and NONOP Groups

	NONOP Group	OP Group	Difference and *P*	
Activity	**3.82 ± 0.83**	**3.01 ± 0.95**	**−0.81**	**<0.001**
Appearance	3.28 ± 0.76	2.50 ± 0.77	−0.78	<0.001
Pain	3.32 ± 0.95	2.56 ± 0.90	−0.76	<0.001
Satisfaction	3.21 ± 0.99	2.74 ± 1.06	−0.47	<0.001
Mental heath	3.82 ± 0.78	3.43 ± 0.89	−0.38	<0.001

OP indicates operative.

Statistical Analysis

Baseline comparison of the groups (OP and NONOP) was performed using unpaired *t* tests to investigate differences between OP and nonoperative patients. Correlations between radiographical parameters and HRQOL scores were performed using Pearson Coefficient on the entire database and by group (OP and NONOP) to evaluate which parameters had the strongest correlation with disability. On the basis of this analysis, the 3 most clinically relevant radiographical parameters were retained and multilinear regression analysis was conducted to establish radiographical thresholds predicting disability. For all statistical analysis, the level of significance was set at $P < 0.05$.

RESULTS

Demographic Data

Between October 2008 and December 2010, 492 consecutive patients with ASD (70 males and 422 females) with a mean age of 51.9 years (SD, 16.8; range, 18–85 yr) were enrolled across the participating sites. Among this population, 178 patients were included in the OP group and 314 in the nonoperative group (NONOP). Patients enrolled in the OP group were significantly older (55 ± 16 *vs*. 50.1 ± 16.9 yr, P = 0.02) than patients from the NONOP group.

The analysis of radiographical features revealed that 38% of the patients were included in the database for coronal deformity only, 10% for sagittal deformity only, and 52% for combined deformity.

HRQOL Scores

Comparison of clinical scores (Table 2) demonstrated that patients in the OP group exhibited greater baseline disability on all HRQOL measures compared with patients in the NONOP group. The same difference was observed based on Scoliosis Research Society score and ODI subdomains (Tables 3, 4). Subgroup analysis based on ODI revealed that 102 patients out of 178 from the OP group had an ODI 40 or more and 254 patients out of the 314 from the NONOP group had an ODI less than 40.

Correlations Between Radiographical Parameters and Disability Scores

Results from the correlation analysis between radiographical parameters (coronal and sagittal) and HRQOL (Table 5)

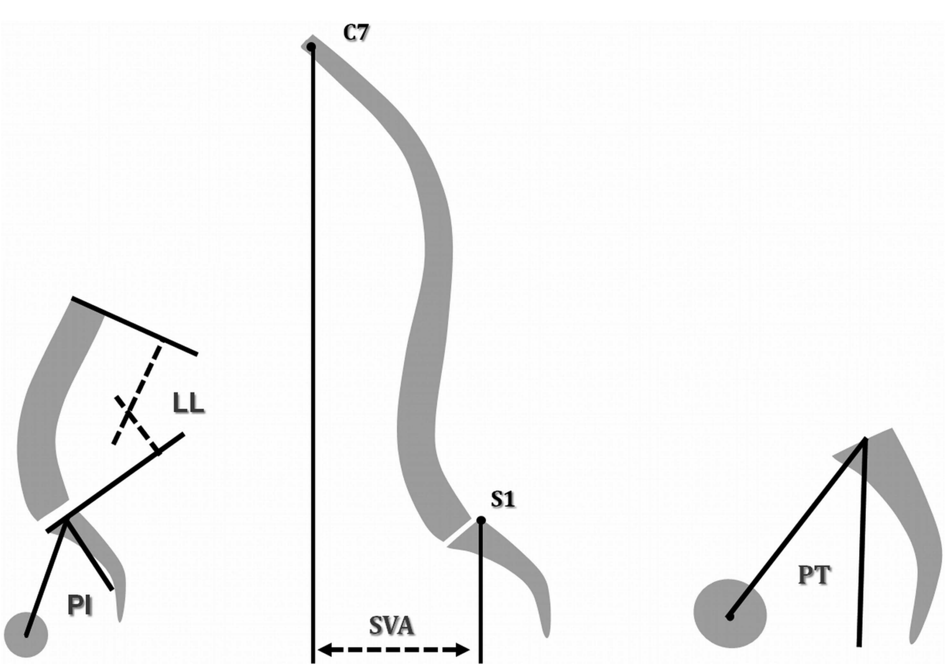

Figure 2. Schematic representation of the 3 radiographical parameters the most highly correlated with clinical outcomes in the setting of patients with ASD. The PI-LL assesses the offset between PI and LL. This parameter evaluates the flattening of the lumbar spine in relation to the patient pelvic morphology. The SVA assess the linear offset of C7 in regard to the posterosuperior corner of S1; this parameter quantifies the global sagittal malalignment. The PT assesses the degree of pelvic retroversion. In other terms, this parameter permits to quantify the compensatory mechanism used by the patient to maintain an erected posture. PI indicates pelvic incidence; LL, lumbar lordosis; SVA, sagittal vertical axis; PT, pelvic tilt; ASD, adult spinal deformity.

TABLE 5. Correlation Between All the Radiographical Parameters (Coronal and Sagittal Planes) and HRQOL Scores

	ODI		SRS		PCS		MCS	
Cobb angle thoracic	...	...	...	...	...	...	...	...
Cobb angle thoracolumbar	...	...	0.198	*	...	...	0.239	*
Cobb angle lumbosacral	...	...	...	...	...	...	...	...
Cobb angle maximal	−0.201	†	0.128	*	0.160	†	...	...
Pelvic obliquity	−0.170	†	0.175	†	0.113	*	0.175	†
Leg length discrepancy	0.188	†	−0.150	†	−0.209	†	...	...
Coronal imbalance	0.180	†	−0.147	*	−0.199	†	...	...
Kyphosis T2–T12	0.176	†	−0.183	†	−0.219	†	−0.136	*
Kyphosis T4–T12	0.145	*	−0.139	*	−0.177	†	−0.106	*
Kyphosis maximal	...	...	...	...	...	...	...	...
Lordosis L1–S1	−0.410	†	0.371	†	0.434	†	0.213	†
Lordosis maximal	−0.356	†	0.314	†	0.394	†	0.184	†
Thoracolumbar alignment T10–L2	−0.137	*	...	...	0.128	*	...	...
T1 spinopelvic inclination	0.375	†	−0.277	†	−0.345	†	−0.120	*
T9 spinopelvic inclination	0.141	*	...	...	−0.142	*	...	...
Sagittal vertical axis	0.469	†	−0.356	†	−0.426	†	−0.146	*
Pelvic incidence	0.092	*	...	...	...	...	...	...
Pelvic tilt	0.381	†	−0.318	†	−0.391	†	−0.115	*
Sacral slope	−0.279	†	0.266	†	0.297	†	0.155	†
Pelvic incidence−lumbar lordosis	−0.450	†	0.377	†	0.467	†	0.166	†

*$P < 0.05$; †$P < 0.001$.

HRQOL indicates health related quality of life; MCS, mental component score; ODI, Oswestry Disability Index; PCS, physical component score; SRS, Scoliosis Research Society.

revealed that the most clinically relevant and strongly correlated radiographical parameters were PT, SVA, and PI-LL (Figure 2). These correlations were observed across the entire study population (based on ODI, correlations were 0.381, 0.469, and −0.45 for PT, SVA, and PI-LL, respectively, $P < 0.001$), as well as within each group (Table 6). Of note, stronger correlations were found for patients within the OP group than for patients within the NONOP group.

Radiographical Parameters

Comparison of the 3 most relevant parameters (PT, SVA, PI-LL) between the OP group and the NONOP group revealed that the OP patients had greater sagittal spinopelvic malalignment than the NONOP patients as defined by SVA (55 ± 80 mm *vs.* 17 ± 55 mm, $P = 0.001$), PT (22 ± 12° *vs.* 19 ± 11°, $P < 0.001$) and PI minus LL (12 ± 22° *vs.* 4.3 ± 18°, $P < 0.001$) for OP *versus* NONOP, respectively. The correlation analysis demonstrated PI-LL was significantly correlated with PT ($r = 0.844$, $P < 0.001$) and SVA ($r = 0.685$, $P < 0.001$).

Linear Regression

Linear regression models to predict ODI score were built on the basis of the 3 most relevant parameters (PT, SVA, and PI-LL) independently, and the following equations were obtained:

–ODI = 0.2106 × PT + 13.719, with $r^2 = 0.1415$.
–ODI = 1.5563 × SVA − 16.293, with $r^2 = 0.2172$.
–ODI = 0.4379 × PI − LL − 6.0827, with $r^2 = 0.2027$.

These equations were then used to establish thresholds of radiographical parameters predictor of severe disability, defined by an ODI more than 40,[15,16] leading to the following values: PT = 22°, SVA = 47 mm, and PI − LL = 11°. Other values of radiographical parameters based on the established linear relationships with ODI are summarized in Table 7.

Of note, when considering the 3 parameters all together to predict the ODI using a multilinear regression analysis with a stepwise condition, the following equation was obtained with an r^2 of 0.24:

TABLE 6. Correlation Between the 3 Key Radiographical Parameters and HRQOL Scores on the Entire Set of Patients for Each Group (All With $P < 0.001$)

Group	Score	PT	SVA	PI − LL
All	ODI	0.381	0.469	−0.45
	SRS	−0.318	−0.356	−0.377
	PCS	−0.385	−0.404	−0.453
OP	ODI	0.377	0.458	0.425
	SRS	−0.411	−0.357	−0.416
	PCS	−0.471	−0.377	−0.501
NONOP	ODI	0.338	0.36	0.402
	SRS	−0.204	−0.215	−0.27
	PCS	−0.281	−0.316	−0.354

HRQOL indicates health related quality of life; MCS, mental component score; OP, operative; ODI, Oswestry Disability Index; PCS, physical component score; SRS, Scoliosis Research Society; PI, pelvic incidence; LL, lumbar lordosis; SVA, sagittal vertical axis; PT, pelvic tilt.

$$\text{ODI} = 0.089 \times \text{SVA} + 0.253 \times \text{PI} - \text{LL} + 25.332.$$

The standardized coefficients were 0.298 for the SVA and 0.246 for the PI-LL, demonstrating an equal importance of these parameters in the prediction of ODI.

Treatment Distribution *Versus* Radiographical Thresholds

The analysis of treatment distribution demonstrated that patients with radiographical parameters below the established thresholds were more likely to receive conservative treatment (Figure 3) than surgical care (Figure 4). Analysis by parameters revealed lower surgical rates for patients with SVA less than 47 mm (29% *vs*. 71%, $P < 0.001$); with PT below 22° (31% *vs*. 69%, $P = 0.004$) or with PI-LL below 11° (29.3% *vs*. 70.7%, $P < 0.001$). Analysis of the number of radiographical parameters above the defined thresholds (Table 8) demonstrated that 52.7% of NONOP patients had zero parameter above thresholds (*vs*. 38.3% for OP patients), while 31.1% of OP patients had 3 parameters above thresholds (*vs*. 15.2% for NONOP patients). These distributions were significantly different among groups (χ^2, $P < 0.001$).

Clinical Relevance

In light of the correlations found between the PI-LL and the 2 other parameters, a further analysis was carried out to establish the likelihood of meeting SVA and PT thresholds based for patients with PI-LL below or above 11°. As illustrated in Figures 5 and 6, patients with a PI-LL mismatch (*i.e.*, PI-LL > 11°) were more likely to have a pelvic retroversion (80.6% had PT > 22°, while 19.4% had PT < 22°, $P < 0.001$) or to have a global malalignment (64.4% had SVA > 47 mm, while 35.6% had SVA < 47 mm, $P < 0.001$).

Result from the relative risk analysis revealed that patients with PI-LL mismatch compared with patients with PI-LL harmony had 4.2-fold greater risk of pelvic retroversion, 10.9-fold greater risk of positive sagittal malalignment (SVA), and 3.9-fold greater risk of severe disability.

DISCUSSION

Previous reports have suggested that up to 60% of the elderly population demonstrates evidence of spinal deformity.[1] As demographic trends in many developed countries shift toward a substantially older population, the prevalence of ASD is likely to continue to increase to unprecedented levels. Fortunately, many of those remain asymptomatic or are treatable with nonoperative measures. However, a substantial number of patients, due to their pain and disability, will seek more aggressive treatments, including surgical correction of deformity.[17] Several outcomes-related studies have established that surgical management for carefully selected patients offers superior outcomes compared with nonoperative care in terms of back pain, leg pain, and quality of life.[18–24] However, management of these conditions remains difficult in terms of establishing objective surgical indications as well as selecting optimal corrective approaches. In contrast to adolescent idiopathic scoliosis, in which the key surgical objective is typically to address cosmetic deformity, in adults with spinal deformity, the surgical objectives are typically to address disability and pain. Thus, effective surgical treatment of ASD not only requires a clear understanding of the factors that generate disability and pain, but also defined objectives for approaches to address these factors.

This study defines key radiographical parameters that are drivers of disability among patients with ASD and establishes thresholds for severe disability for these parameters based on a prospective multicenter evaluation. The 3 radiographical parameters having the strongest correlations with disability and quality of life are all sagittal measurements, including SVA, PT, and the mismatch between the LL and the PI. These

TABLE 7. ODI Values and Associated Thresholds of Spinopelvic Parameters

ODI	0	10	20	30	40	50	60	70	80	90	100
PT (°)	13.7	15.8	17.9	20	22.1	24.2	26.4	28.5	30.6	32.7	34.8
SVA (mm)	−16.3	−0.7	14.8	30.4	45.9	61.5	77.1	92.6	108.2	123.8	139.3
PI − LL (°)	−6.1	−1.7	2.7	7.1	11.4	15.8	20.2	24.6	28.9	33.3	37.7

ODI indicates Oswestry Disability Index; PI, pelvic incidence; LL, lumbar lordosis; SVA, sagittal vertical axis; PT, pelvic tilt.

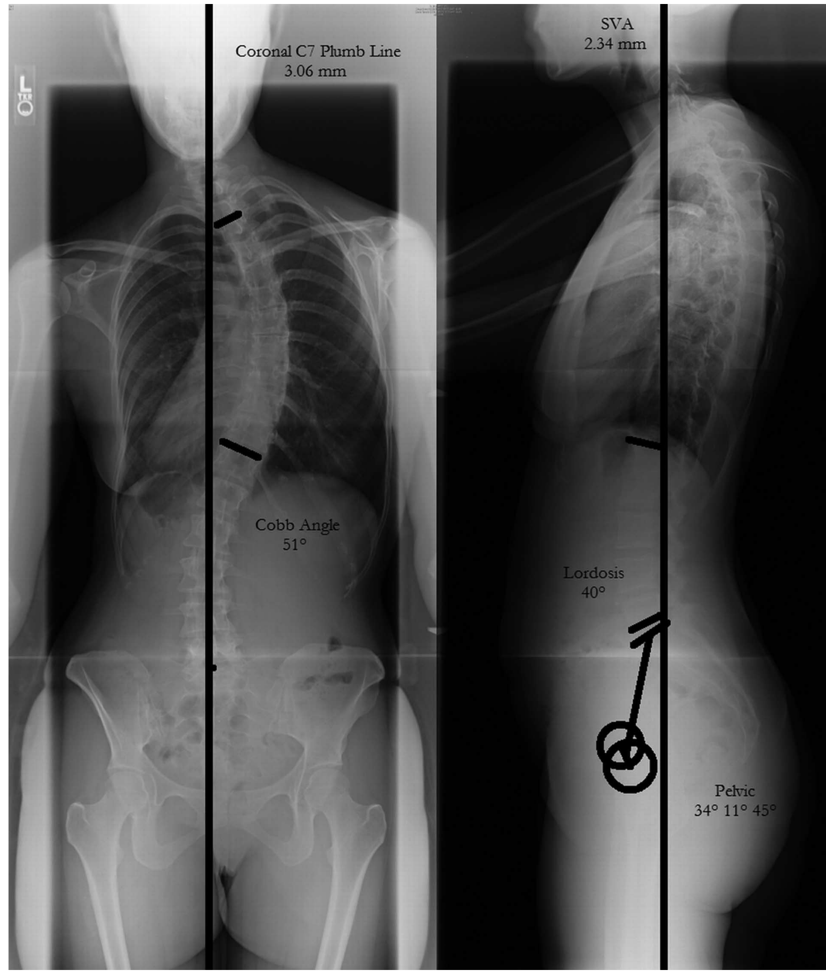

Figure 3. Patient with thoracic deformity enrolled in the NONOP group. Baseline sagittal parameters are below thresholds (PT = 11°, SVA = 2 mm, PI − LL = 5°). PI indicates pelvic incidence; LL, lumbar lordosis; SVA, sagittal vertical axis; PT, pelvic tilt.

correlations were evident in both operatively and nonoperatively treated patients with ASD, and in both populations, the mismatch between the LL and PI had the strongest direct correlation with disability and poor quality of life. Analyses also clearly demonstrated the clinical relevance of these thresholds because patients with ASD with 1 or more radiographical parameters exceeding the key threshold values were significantly more likely to seek OP treatment, compared with nonoperative treatment. Collectively, these data emphasize the critical importance of sagittal spinopelvic alignment and provide objective radiographical thresholds of disability, as well as radiographical objectives for surgical correction. It is important to note though that this study does not attempt to outline ideal treatment approaches (surgical *vs*. nonoperative). Treatment decisions are based upon a complex interplay beyond radiographical parameters and HRQOL measures, also taking into account patient expectations, fears, biases, and risk factors.

Although the coronal Cobb angle may be the most readily recognized radiographical parameter and has historically received the most attention in adult deformity, multiple studies have established the greater impact of sagittal spinopelvic alignment parameters on disability and quality of life.[4,18,25] This shift in emphasis on the sagittal plane gained substantial momentum following the landmark report of Glassman *et al*[4] that demonstrated the fundamental relationship between sagittal alignment and HRQOL. Subsequently, Lafage *et al*[11,26] and Schwab *et al*[10,12] reported that the radiographical parameters that most highly correlate with HRQOL scores in patients with ASD are all based on the sagittal plane and included SVA, T1 sagittal tilt, and PT. However, prior to this study, these findings had not been confirmed on the basis of prospective, multicenter data.

In addition to defining the key radiographical parameters that drive disability in ASD, this study also establishes thresholds of severe disability for these parameters, as defined by an ODI score of more than 40.[5,7] Our results are consistent with previous realignment objectives reported by Schwab *et al*.[12] that include SVA less than 50 mm, PT less than 25°, and LL proportional to the PI. Understanding these thresholds can help in distinguishing radiographical factors that drive the transition from nonoperative to OP treatment because patients in this study were significantly and progressively more likely to seek OP treatment as the number of radiographical parameters that exceeded the disability thresholds increased. In addition, the thresholds for severe disability for the key radiographical parameters defined in this study provide valuable radiographical objectives for surgical planning that aims to maximize improvement of disability.

Interestingly, despite significant baseline differences between the OP and NONOP groups, our results showed

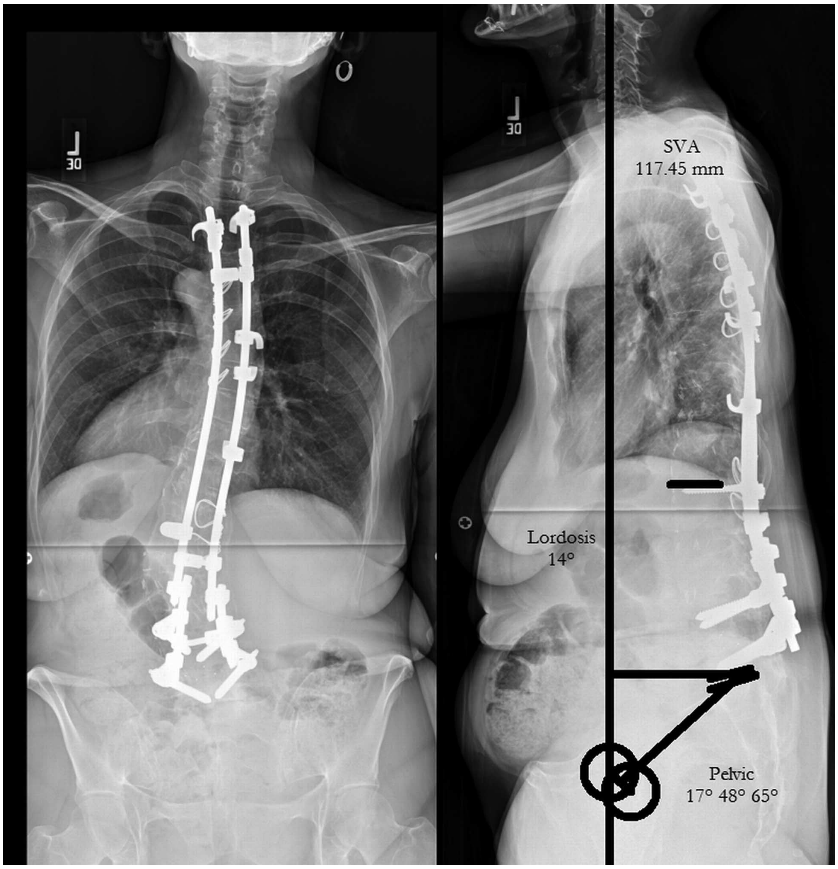

Figure 4. Patient with a previous surgery and sagittal malalignment enrolled in the OP group. Baseline sagittal parameters are above thresholds (PT = 48°, SVA = 117 mm, PI − LL = 51°). PI indicates pelvic incidence; LL, lumbar lordosis; SVA, sagittal vertical axis; PT, pelvic tilt.

that the most significant and clinically relevant radiographical parameters, with regard to HRQOL scores, were the same in both groups: SVA, PT, and, PI-LL mismatch, underscoring the importance of the sagittal plane as the main driver of disability in the setting of ASD. Highest correlations were found in the OP group (and especially for PI-LL) compared with the NONOP group, likely due to the fact that surgical patients presented with more severe radiographical deformities and a wider range of disabilities. The lower correlations established within the NONOP group reinforce the decision tree model in the setting of patients with ASD, where radiographical parameters do not play as major of a role for patients with low/moderate disability or pain.

In a recent report, Fu *et al*[27] retrospectively analyzed standardized measures of health status and disability in patients with ASD to identify drivers for surgical treatment. As in this study, they found significant baseline differences between OP and nonoperative groups in terms of HRQOL scores (ODI, Scoliosis Research Society-30, and SF-12), but in contrast to this study, they did not identify differences in terms of age

TABLE 8. Distribution of Radiographical Measurements Above the Defined Thresholds (PT, SVA, and PI−LL) Among the 2 Groups (NONOP and OP). These Distributions Were Significantly Different Between the 2 Groups (χ^2, $P < 0.001$)

			Groups		
			NONOP	OP	Total
Numbers of radiographical measurements above the defined thresholds (PT, SVA, and PI − LL)	0	% within group	52.7%	38.3%	47.5%
	1	% within group	17.6%	12.0%	15.6%
	2	% within group	14.5%	18.6%	16.0%
	3	% within group	15.2%	31.1%	21.0%
Total			100.0%	100.0%	100.0%

PI indicates pelvic incidence; LL, lumbar lordosis; SVA, sagittal vertical axis; PT, pelvic tilt; OP, operative.

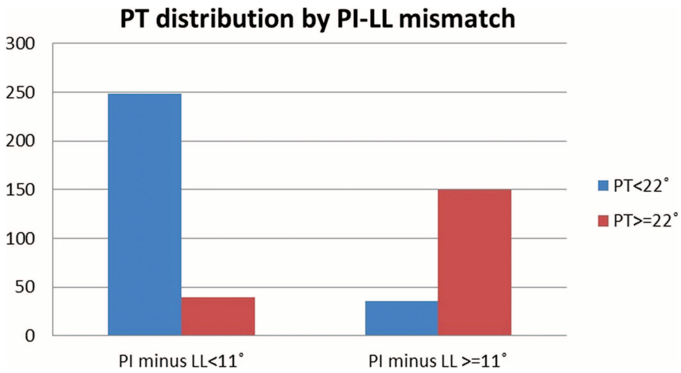

Figure 5. PT distribution (< or ≥ 22°) in the population according to the PI − LL mismatch (< or ≥11°). PI indicates pelvic incidence; LL, lumbar lordosis; PT, pelvic tilt.

and major radiographical parameters. This may reflect differences in patient populations, because that of Fu *et al*[27] consisted solely of elderly patients with degenerative scoliosis. Similar observations have also been reported by Li *et al*[18] in a retrospective study, in which the OP group had significantly greater SVA compared with the nonoperative group (105 mm *vs*. 59 mm, $P = 0.001$).

Of the 3 key radiographical drivers of disability defined in this study, the mismatch between the PI and LL not only had the strongest correlation with clinical outcomes measures, but also had strong correlations with the other 2 key parameters: SVA and PT. Mismatch between the PI and LL reflects an inadequate amount of LL, which is an intrinsic part of the deformity and can be directly addressed through surgical treatment, often through osteotomies.[28] The other 2 key parameters, SVA and PT, are not intrinsic components of the deformity, but rather are consequences of the deformity. Thus, of the 3 key radiographical parameters defined in this study, only the mismatch between PI and LL can be directly addressed with surgical treatment. Collectively, these findings indicate that restoration of the balance between PI and LL should be a primary objective in the surgical management of ASD because it can be expected to lead to concurrent corrections of PT and SVA.

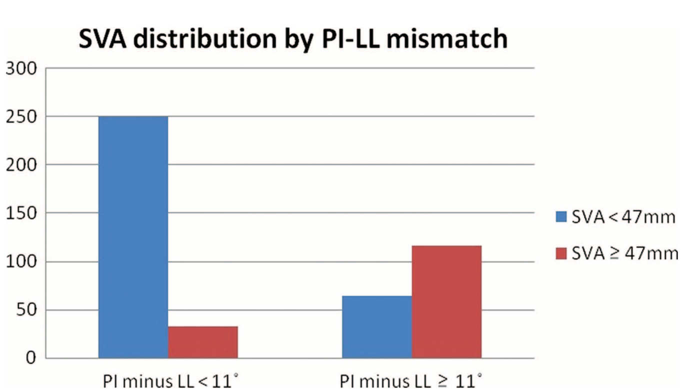

Figure 6. SVA distribution (< or ≥ 47 mm) in the population according to the PI−LL mismatch (< or ≥11°). PI indicates pelvic incidence; LL, lumbar lordosis; SVA, sagittal vertical axis.

CONCLUSION

Results from this study demonstrate that the sagittal plane is the main driver of disability in patients with ASD and indicate that among the sagittal radiographical parameters, SVA, PT, and PI-LL mismatch are the key factors that impact disability. Defining radiographical thresholds that correlate with disability offers a quantitative method for assessing disability in addition to self-reported function. With regard to treatment, the outlined radiographical criteria can help guide appropriate therapeutic decision making and preoperative planning. Long-term follow-up of OP and nonoperative patients will be necessary to evaluate changes in HRQOL scores that may occur over time and thus help refine optimal treatment thresholds and likelihood of satisfaction after correction of symptomatic ASD. Furthermore, developing predictive models of outcome may be expanded to include patient-specific expectations, risk factors, and fears to lay a groundwork for clinically useful treatment pathways.

➢ Key Points

- ❑ Sagittal spinal malalignment analysis needs inclusion of spinopelvic parameters for complete assessment.
- ❑ Results of a prospective multicenter study evaluating OP *vs*. nonoperative (NONOP) treatment for ASD revealed that SVA, PT, and PI-LL were the parameters the most strongly correlated with disability for both OP and NONOP patients.
- ❑ Linear regression models were used to establish thresholds of radiographical spinopelvic parameters predictive of ODI more than 40: PT 22° or more ($r = 0.38$), SVA 47 mm or more ($r = 0.47$), PI − LL 11° or more ($r = 0.45$).
- ❑ These spinopelvic parameters (PT, PI-LL, and SVA) predict patient disability and provide a guide for patient assessment.

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