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DEFORMITY

Defining Spino-Pelvic Alignment Thresholds

Should Operative Goals in Adult Spinal Deformity Surgery Account for Age?

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Study Design. Retrospective review of prospective, multicenter database.

Objective. The aim of the study was to determine age-specific spino-pelvic parameters, to extrapolate age-specific Oswestry Disability Index (ODI) values from published Short Form (SF)-36 Physical Component Score (PCS) data, and to propose age-specific realignment thresholds for adult spinal deformity (ASD).

Summary of Background Data. The Scoliosis Research Society-Schwab classification offers a framework for defining alignment in patients with ASD. Although age-specific changes in spinal alignment and patient-reported outcomes have been established in the literature, their relationship in the setting of ASD operative realignment has not been reported.

Methods. ASD patients who received operative or nonoperative treatment were consecutively enrolled. Patients were stratified by age, consistent with published US-normative values (Norms) of the SF-36 PCS (<35, 35–44, 45–54, 55–64, 65–74, >75 y old). At baseline, relationships between between radiographic spino-pelvic parameters (lumbar-pelvic mismatch [PI-LL], pelvic tilt [PT], sagittal vertical axis [SVA], and T1 pelvic angle [TPA]), age, and PCS were established using linear regression analysis; normative PCS values were then used to establish age-specific targets. Correlation analysis with ODI and PCS was used to determine age-specific ideal alignment.

Results. Baseline analysis included 773 patients (53.7 y old, 54% operative, 83% female). There was a strong correlation between ODI and PCS ($r = 0.814$, $P < 0.001$), allowing for the extrapolation of US-normative ODI by age group. Linear regression analysis (all with $r > 0.510$, $P < 0.001$) combined with US-normative PCS values demonstrated that ideal spino-pelvic values increased with age, ranging from PT = 10.9 degrees, PI−LL = −10.5 degrees, and SVA = 4.1 mm for patients under 35 years to PT = 28.5 degrees, PI−LL = 16.7 degrees, and SVA = 78.1 mm for patients over 75 years. Clinically, older patients had greater compensation, more degenerative loss of lordosis, and were more pitched forward.

Conclusion. This study demonstrated that sagittal spino-pelvic alignment varies with age. Thus, operative realignment targets should account for age, with younger patients requiring more rigorous alignment objectives.

Key words: adult spinal deformity, age, age-specific, elderly, Health-Related Quality of Life, Oswestry Disability Index, realignment, sagittal alignment, sagittal balance, sagittal malalignment, SF-36, spino-pelvic alignment, threshold.

Level of Evidence: 3

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Sagittal plane assessment has become crucial in the setting of adult spinal deformity (ASD) treatment. Over the past 30 years, numerous studies have highlighted the correlation between radiographic parameters and Health-Related Quality of Life (HRQOL) outcomes.[1–4] This emphasis has helped define precise objectives for sagittal malalignment correction. The Scoliosis Research Society (SRS)-Schwab classification characterizes sagittal alignment in ASD with 3 parameters: (1) regional deformity represented by the mismatch (PI−LL) between the L1-S1 lumbar lordosis (LL) and the pelvic incidence (PI),

(2) compensatory mechanism represented by the pelvic tilt (PT), and (3) global alignment measured by the sagittal vertical axis (SVA).[5] More recently, Protopsaltis *et al* proposed another parameter, the T1 pelvic angle (TPA), which quantifies the severity of global alignment while avoiding calibration and patient position issues.[6]

These parameters are easy to use with computer-assisted measurements[7] and widely used around the world, offering a framework to characterize alignment in ASD patients. With the growth of the aging population and increases in their functional demands,[8] surgical corrections for spinal deformity are increasing, with more aggressive spinal osteotomies[9] and long fusions.[10] Precise preoperative planning with the use of established formulas is critical to help guide realignment targets or thresholds.[11]

Preoperative planning, however, cannot and should not be performed without understanding the nature of the patient's deformity and the associated compensatory mechanisms. In both healthy volunteers and ASD patients, gravity is a major driver of age-related changes in spino-pelvic alignment.[12] Degenerative loss of lordosis moves the spine forward; as a result, compensatory mechanisms such as pelvic retroversion and knee flexion lead to posterior pelvic shift.[12] These changes occur in an attempt to maintain an erect posture and limit muscle energy expenditure and biomechanical loads on intervertebral segments.[13] Failure of this compensation cascade leads to deformity, global malalignment, and disability.[14]

In addition, age-related changes occur in every part of the musculoskeletal system as well as in the neuro-sensorial system. Aging is a degenerative process associated with muscle atrophy. As demonstrated by imaging, electrophysiological, and histological studies, these changes impact muscle size, cross-sectional area, and fiber type; they are associated with decreases in neurogenic motor functioning units.[15–18] In addition, studies have shown that arthritis and the associated cartilage changes are also subject to change with age.[19] Finally, neuro-sensorial and postural control are impaired by aging, and may include progressive visual, vestibular, and somatosensory deficiencies.[20] Therefore, sagittal realignment should take the entirety of these age-related dynamic generative changes into account.

In line with these age-related changes, HRQOL scores significantly decline with age due to the emergence of chronic disease or comorbidities. Previous work has demonstrated that the symptoms of scoliosis vary with age, and accordingly, Baldus *et al*[21] proposed an age–sex normative data set of SRS-30 scores among generational categories. These findings were consistent with previous published normative data on other HRQOL scores such as the Short Form (SF)-36 physical component score (PCS) and mental component score (MCS).[22]

There are many benefits to the SF-36 questionnaire, including the ability to compare results with normative data based on age and sex. This instrument, however, cannot be easily translated into a comparable result; instead, it requires sophisticated algorithms and calculations. As a result, the Oswestry Disability Index (ODI) has emerged as a commonly used clinical outcome instrument,[23] as it is shorter in length and can be more easily scored and interpreted by the clinician in the office. Yet, despite the prevalence and utility of the ODI, there are no published data on age-adjusted or age-specific values or changes for this instrument. Thus, despite the fact that age is taken into account in both evaluation and treatment of patients of ASD, there is no clinically efficacious tool that can assess patient-reported outcomes in an age-specific manner.

Therefore, the purpose of this study was to investigate preoperative spino-pelvic alignment and HRQOL outcomes (including the ODI) to determine age-specific values for sagittal parameters, such as PT, PI minus LL (PI−LL), SVA, and TPA. Finally, this study aimed to determine age-specific realignment targets in ASD patients.

MATERIALS AND METHODS

Study Design

This study is a multicenter, retrospective analysis of prospectively collected data from ASD patients conducted through the International Spine Study Group, a collaboration of spine surgeons from 11 sites across the United States. Institutional Review Board approval was obtained at each site for the patient enrollment and data collection protocols. Patients were enrolled into an operative or nonoperative branch according to the informed consent process between the patient and the surgeon. Inclusion criteria for enrollment were age greater than 18 years and a radiographic diagnosis of ASD defined by at least one of the following: coronal Cobb angle at least 20 degrees, SVA at least 5 cm, PT at least 25 degrees, and/or thoracic kyphosis (TK) at least 60 degrees. Exclusion criteria for the database include spinal deformity secondary to neuromuscular, syndromic, autoimmune, infectious, tumor, or posttraumatic conditions.

Data Collection

Demographic data included patient age, sex, body mass index, Charlson Comorbidity Index, and history of prior spine surgery. All subjects had 36-inch standing scoliosis radiographs for which the patients were free of any external support, such as walkers or hanging bars. Radiographic measurements were performed at a central location using a dedicated and validated software (ENSAM Laboratory of Biomechanics, Paris, France).[24] Radiographic parameters used to characterize lumbar and thoraco-lumbar deformity are shown in Figure 1, and included LL, PI, PI−LL, PT, SVA, LL minus TK (LL−TK), and TPA.

HRQOL outcome assessment tools included the ODI and SF-36 questionnaires. The ODI assesses the physical limitations imposed by lower back pain and is scored on a scale of 0 to 100, in which higher scores correspond to greater disability.[23] The SF-36 is divided into 2 standard summary scores: the PCS and the MCS. Each component score uses a

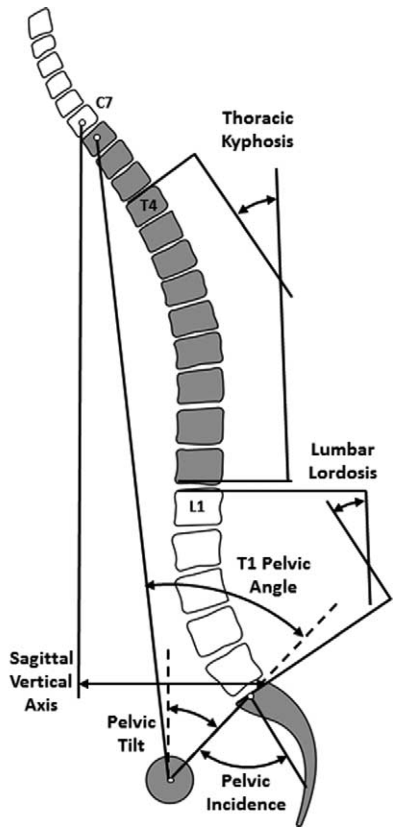


Figure 1. Sagittal spino-pelvic radiographic parameters included PI, PT, LL, TPA, T4–T12 TK, and SVA. PI indicates pelvic incidence; PT, pelvic tilt; LL, lumbar lordosis; TPA, T1 pelvic angle; TK, thoracic kyphosis; SVA, sagittal vertical axis.

scale from 0 to 100, in which higher values indicate the best outcomes.[22]

Age-Specific Alignment Thresholds

Using the entire population's baseline data, linear regression analysis allowed for calculation of ODI US-norms from the SF-36 PCS US-norms. Once this relationship was established, multilinear regressions were performed using age and HRQOL as independent parameters and radiographic parameters (PI−LL, PT, LL−TK, SVA, and TPA) as dependent parameters. Subsequently, ODI US-norm values were used to establish age-specific values of alignment. As the complexity of these formulas renders their application difficult in the clinical setting, a set of simplified formulas were developed. Finally, using these regressions, values for radiographic parameters were used to calculate ODI values corresponding to moderate disability (ODI = 20) and severe disability (ODI = 40).[23] All data were statistically analyzed using SPSS (SPSS Inc. Version 20.0; Armonk, NY: IBM Corp).

RESULTS

Patient Population

A total of 773 patients were included in the baseline analysis, with mean age 53.7 years (SD = 16.4) and 83% female. Among these patients, 54% were in the operative cohort. Baseline radiographic parameters are shown in Table 1. There was substantial variability in radiographic spino-pelvic parameters and HRQOL scores, as illustrated by the standard deviation and range between minimum and maximum values (Table 1).

Identification of Age-Specific ODI

There was a strong correlation between ODI and PCS ($r = 0.814$, $P < 0.001$). Linear regression modeling allowed identification of ODI values that corresponded to PCS US-norms[25] based on the following equation: $ODI = 87.705 - 1.456 * PCS$, $r^2 = 0.663$. As shown in Table 2, the ODI US-norm increased from 9.5 in the general population under 35 years of age to 32.5 in the general population over 74 years of age.

Age-Specific Alignment Threshold

In the regression analysis, all radiographic parameters strongly correlated with HRQOL and age ($P < 0.001$). All formulas yielded correlation coefficients greater than 0.5. The simplified, clinically applicable versions of these formulas are shown in Appendix 1, http://links.lww.com/BRS/B31.

The original formulas identified radiographic values corresponding to the ODI US-norms (Table 3) and PCS US-norms (Table 4). As shown in Tables 3 and 4, radiographic spino-pelvic alignment values increased with age. For example, the PT ranged from 11 degrees in patients younger than 35 years old to 39 degrees in patients over 74 years old.

Using the same formulas, values corresponding to a moderate disability (ODI = 20) and severe disability

TABLE 1. Description of Radiographic Parameters and Patient-Reported Outcomes at Baseline

Parameters – (unit)	Abbreviation	Mean	SD	Min	Max
Pelvic incidence minus lumbar lordosis - (°)	PI−LL	10.1	20.4	−47.0	86.0
Pelvic tilt - (°)	PT	21.5	11.2	−13.0	68.0
Lumbar lordosis minus thoracic kyphosis - (°)	LL−TK	8.4	18.5	−46.0	70.0
Sagittal vertical axis - (mm)	SVA	41.1	70.2	−120.0	326.0
T1 pelvic angle - (°)	TPA	18.8	13.6	−9.0	69.0
Oswestry Disability Index	ODI	34.07	20	0	92
SF-36, physical component score	PCS	36.9	11	10.04	64.8

TABLE 2. Conversion of PCS US-Norms to ODI US-Norms Using the Linear Regression Between ODI and PCS

	Age Group, y					
	<35	35–44	45–54	55–64	65–74	≥74
PCS	53.72	52.15	49.64	45.9	43.33	37.89
ODI	9.49	11.77	15.43	20.87	24.62	32.54

Both ODI and SF-36 PCS were reported on scales of 0 to 100. For ODI, higher values indicate higher disability; for SF-36, higher values indicate better health status.

TABLE 3. Radiographic Thresholds Based on Age-Specific ODI US-Norms

Age Group	% in Database	Mean Age in Database	ODI US-Norm*	PT	PI−LL	LL−TK	SVA	TPA
<35	17.7	26.2	9.49	11.1	−11.3	29.2	−29.1	4.4
35–44	8.8	40.7	11.77	15.5	−6.2	21.9	−4.0	10.0
45–54	19.9	51.2	15.43	18.9	−1.7	16.4	16.5	14.5
55–64	28.0	60.5	20.87	22.1	3.3	11.1	37.0	18.8
65–74	19.5	69.7	24.62	25.2	7.5	6.1	55.6	22.8
≥74	6.2	79.6	32.54	28.8	13.7	0.2	79.9	27.8

*value extrapolated using the PCS US-norm.

TABLE 4. Radiographic Thresholds Based on Age-Specific SF-36 PCS US-Norms

Age Group	% in Database	Mean Age in Database	PCS US-Norm	PT	PI−LL	LL−TK	SVA	TPA
<35	17.7	26.2	53.72	10.8	−9.7	29.8	−31.9	4.0
35–44	8.8	40.7	52.15	15.2	−3.0	22.3	−7.0	9.6
45–54	19.9	51.2	49.64	18.6	2.6	16.5	13.6	14.1
55–64	28.0	60.5	45.9	21.9	8.3	11.1	34.6	18.5
65–74	19.5	69.7	43.33	24.9	13.4	5.9	53.4	22.5
≥74	6.2	79.6	37.89	28.7	20.2	−0.2	78.6	27.7

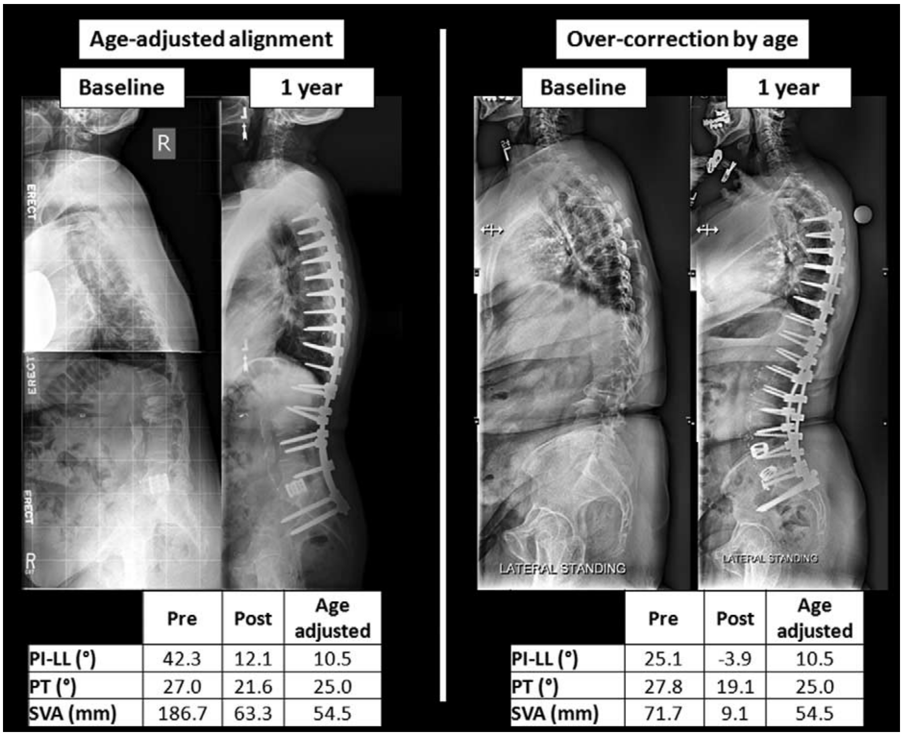
(ODI = 40) were computed and reported in Table 5. For a given HRQOL score, older patients had more severe deformity than younger patients.

DISCUSSION

The current sagittal modifiers of the SRS-Schwab classification are fixed. Although these criteria provide good clinical assessment in the representative majority of ASD patients (*i.e.*, those between 50 and 60 years old), they seem be limited in the elderly and/or the young population.[26] As research in the field of spine surgery has progressed, one of the modern goals is to develop a "tailor-made" approach[26] to fit each individual's specific needs and characteristics, such as age. The objective of this study was to define precise,

TABLE 5. Radiographic Thresholds Corresponding to an ODI of 20 (Left) and 40 (Right)

Age Group	Moderate Disability (ODI = 20)					Severe Disability (ODI = 40)				
	PT	PI−LL	LL−TK	SVA	TPA	PT	PI−LL	LL−TK	SVA	TPA
<35	11.3	−6.8	27.6	−17.4	6.2	13.2	1.8	24.5	5	9.8
35–44	15.1	−2.7	20.7	5.2	11.5	17	5.9	17.6	27.6	15
45–54	17.8	0.2	15.7	21.6	15.3	19.7	8.8	12.6	44	18.8
55–64	20.2	2.9	11.3	36.1	18.7	22.2	11.5	8.2	58.5	22.2
65–74	22.6	5.5	6.9	50.4	22	24.6	14.1	3.8	72.8	25.5
≥75	25.2	8.3	2.1	65.8	25.6	27.1	16.9	−1.0	88.2	29.1



	Pre	Post	Age adjusted
PI-LL (°)	42.3	12.1	10.5
PT (°)	27.0	21.6	25.0
SVA (mm)	186.7	63.3	54.5

	Pre	Post	Age adjusted
PI-LL (°)	25.1	-3.9	10.5
PT (°)	27.8	19.1	25.0
SVA (mm)	71.7	9.1	54.5

Figure 2. Case example (baseline and 1-y postoperatively) of 2 patients with nearly identical ages (65–66 y old), type of surgery (iliac fixation, cages, length of fusion), and age-adjusted alignment ideals. The patient on the left was surgically realigned to a sagittal alignment that was similar to age adjusted ideals. The patient on the right was overcorrected past the thresholds dictated by these age-based thresholds. PI-LL indicates pelvic incidence minus lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis.

age-specific objectives for sagittal spino-pelvic realignment in the setting of ASD.

ODI Extrapolation

This study demonstrated a strong correlation between SF-36 PCS and ODI. As a result, normative age-adjusted ODI values were able to be extrapolated using SF-36 PCS normative values established in the United States and across the world by the International Quality of Life Assessment project.[27] This close relationship between ODI and PCS has been observed in prior studies.[28,29] Normative values of ODI were previously published by Fairbank and Pynsent[23] and Tonosu *et al*.[30] In the first study, the authors compiled ODI scores from control groups using several descriptive and comparative series, and found an average score of 10.19 for the normative ODI (range 2.2–12). The second study is the only known work to define normative ODI scores by age. The authors estimated the normative ODI score by adjusting the data based on the age distribution in Japan, and then estimated the cutoff ODI score that separated individuals without low back pain from subjects with low back pain and disability.

There are discrepancies between this study's extrapolation of ODI US-normative values and the previously published values. Two reasons could explain this phenomenon. First, methodology; the Japanese team performed a direct Internet survey on healthy individuals and those with low back pain. Instead, this study mathematically extrapolated ODI values from PCS-normative values using a linear regression obtained from the correlation of ODI and PCS in our ASD population. Based on a review of the existing literature, no such direct survey on ODI score in a Western population has been published. Second, the anatomical, physiological, and cultural differences that exist among continents may cause discrepancies in the results, despite cross-cultural adaptation of the translation of the questionnaire.[31] Furthermore, the aim of this study was not to establish ODI normative values. Rather, this study intended to provide age-adjusted objectives of acceptable and achievable quality of life scores for ASD patients after correction surgery. In a study of degenerative scoliosis patients, Mac-Thiong *et al*[14] found a positive correlation between ODI and age ($r = 0.52$, $P < 0.001$), highlighting the fact that age had a significant impact on HRQOL outcomes in ASD. The present study's findings are also consistent with previous work suggesting that symptoms associated with scoliosis or ASD vary with age.[21]

Age-Specific Alignment Thresholds

This study used regression models to generate radiographic parameters (PT, PI−LL, SVA, and TPA) based on age-specific HRQOL outcomes (ODI, SF-36). These values increased with age, emphasizing the fact that spinal alignment and degenerative spinal pathologies, along with most other anatomical and physiological processes, are age-related progressions (Figure 2).

Several studies have previously described the process of the normal and pathologic aging spine and its relation to spino-pelvic alignment.[32] Studies using force plate technology not only validated Dubousset's concept of the "conus of economy,"[33] but also established specific correlations between age and spino-pelvic parameters in both normal and pathologic populations.[12,34] Although normative alignment in healthy individuals has been studied,[35] this certainly does not mean that each patient must be realigned exactly to the standards of healthy patients, or even others with similar deformity. It is unreasonable to assume the surgeon can make the degenerated, deformed spine as good as new. ASD is a chronic pathologic disease, and complex realignment surgery should be considered a form of treatment for pain, disability, and severe malalignment, rather than an outright cure.

This study provided age-adjusted, realistically achievable alignment objectives that correlated with satisfactory patient-reported outcomes. The goal of surgical correction for ASD is to find an ideal range of alignment that correlates to the least amount of disability. This study determined that for a given ODI value, even smaller values that correspond to only moderate disability, older patients were more likely to have an element of sagittal malalignment, based on the classic spino-pelvic parameters. Thus, it can be concluded that elderly patients do not need to be held to as rigorous alignment objectives. In these patients, it may be natural to have a modest increase in anterior shift and pelvic retroversion. The exact reason for this is still unknown. It is, however, important to understand alignment in the greater context of posture and balance. Bony alignment is the only factor that spine surgeons can surgically correct; thus, it receives most of the attention in scientific literature. The concept of balance is, however, multifactorial, and includes neuro-sensorial modulation, soft tissue response to gravity, and bony alignment.[36] Therefore, the mechanisms for these age-related changes in alignment are also likely to be due to a variety of neurological, musculoskeletal, and other factors, and deserve additional research.

Limitations and Future Works

This study has several limitations. First, the population is heterogeneous: both operative and nonoperative patients with any kind of ASD were included, creating a selection bias. In addition, the question remains in terms of strategies of alignment. One option is to strictly use the patient's age at surgery to calculate alignment targets. An alternative is to consider the evolution of the disease and choose a target that reflects the ideal alignment for an age older than the patient (*e.g.*, the patient's age plus 5 years). Finally, it is important to remember that this study describes one aspect of the evaluation and surgical planning for patients. By no means does this study advocate complex realignment surgeries to strict age-adjusted thresholds for every patient. Many patients with sagittal malalignment in addition to severe radiculopathy and stenosis may actually benefit more from decompression and stabilization procedures rather than complex fusions and osteotomies. Ultimately, comprehensive evaluation, multimodality radiologic evaluation, and clear understanding of the patient's functional limitations and goals are the key determinant of surgery.

Alignment targets for surgical realignment should take in account the patient's age-adjusted alignment during the preoperative planning. Younger patients require a more rigorous alignment than older patients to reach age-specific ideal alignment.

➢ Key Points

- ❑ Although quantitative targets for ideal sagittal alignment exist, no study has incorporated age into sagittal realignment thresholds.
- ❑ Age-specific ODI values can be extrapolated from US-normative values for the SF-36.
- ❑ Ideal spino-pelvic alignment values that corresponded to patient-reported outcomes increased with age, with older patients having substantially greater baseline deformity.
- ❑ Evaluation and operative treatment of adult spinal deformity should incorporate age.

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