SPINE Volume 30, Number 6, pp 682–688
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Correlation of Radiographic Parameters and Clinical Symptoms in Adult Scoliosis

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Study Design. This study is a retrospective review of the initial enrollment data from a prospective multicentered study of adult spinal deformity.

Objectives. The purpose of this study is to correlate radiographic measures of deformity with patient-based outcome measures in adult scoliosis.

Summary of Background Data. Prior studies of adult scoliosis have attempted to correlate radiographic appearance and clinical symptoms, but it has proven difficult to predict health status based on radiographic measures of deformity alone. The ability to correlate radiographic measures of deformity with symptoms would be useful for decision-making and surgical planning.

Methods. The study correlates radiographic measures of deformity with scores on the Short Form-12, Scoliosis Research Society-29, and Oswestry profiles. Radiographic evaluation was performed according to an established positioning protocol for anteroposterior and lateral 36-inch standing radiographs. Radiographic parameters studied were curve type, curve location, curve magnitude, coronal balance, sagittal balance, apical rotation, and rotatory subluxation.

Results. The 298 patients studied include 172 with no prior surgery and 126 who had undergone prior spine fusion. Positive sagittal balance was the most reliable predictor of clinical symptoms in both patient groups. Thoracolumbar and lumbar curves generated less favorable scores than thoracic curves in both patient groups. Significant coronal imbalance of greater than 4 cm was associated with deterioration in pain and function scores for unoperated patients but not in patients with previous surgery.

Conclusions. This study suggests that restoration of a more normal sagittal balance is the critical goal for any reconstructive spine surgery. The study suggests that magnitude of coronal deformity and extent of coronal correction are less critical parameters.

Key words: adult scoliosis, radiographic measures, outcome measures, sagittal balance. **Spine 2005;30:682–688**

Scoliosis in the adult is a disorder that involves a convergence of deformity and degenerative disease in the spine. Patients with significant adult scoliosis may be relatively asymptomatic or severely disabled by their deformity. Although adult scoliosis is reasonably common, the unique and complex pattern of each deformity makes a reproducible assessment of adult scoliosis difficult. Measurement of the effect of spinal deformity on physical function, pain, mental health, and self-image may be quantified using standardized self-assessment measures including the Short Form-36 (SF-36) and the Scoliosis Research Society-29 (SRS-29). The extent to which spinal deformity actually changes these quality of life measures as compared to an unaffected population has been variably reported and remains an important controversy.[1–11]

Prior studies of adult scoliosis have attempted to correlate radiographic appearance and clinical symptoms,[12–15] but the effect of spinal deformity on overall health status is variable and has proven difficult to predict based on radiographic measures of deformity alone. The ability to correlate radiographic measures of spinal deformity with patient symptoms and health status would be useful for decision-making and surgical planning by the physician caring for patients with spinal deformity.

The current study uses a database that is composed of radiographic measures and patient self-assessment data from multiple centers and permits a more statistically powerful investigation of the relationship between radiographic measures and clinical health status. The purpose of this study is to correlate radiographic measures of deformity with patient-based quality of life and health status assessments in adult scoliosis. The study hypotheses are: 1) major curve location, rotatory subluxation, coronal shift, apical vertebral rotation, and positive sagittal balance will correlate with increased pain and decreased function and self-image; and 2) curve magnitude will not correlate with pain or function.

Materials and Methods

We reviewed the initial enrollment data from a prospective multicenter study of adult spinal deformity. Study inclusion criteria (Table 1) include patients over 18 years of age with scoliosis greater than 30° or other significant spinal deformity including primary deformity in the sagittal plane. The study also includes patients who have undergone previous surgical treatment of spinal deformity and who are greater than 12 months from the time of their index procedure. This study makes no attempt to specifically evaluate the index procedure.

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Acknowledgment date: November 3, 2003. First revision date: March 19, 2004. Acceptance date: April 19, 2004.
The manuscript submitted does not contain information about medical device(s)/drug(s).
Corporate/Industry funds were received to support this work. One or more of the author(s) has/have received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this manuscript, *e.g.*, honoraria, gifts, consultancies, royalties, stocks, stock options, or decision-making position.
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Table 1. Inclusion Criteria for Prospective Database

Patients only need to meet 1:
- All scoliosis curves, idiopathic or degenerative, over 30° by Cobb measurement
- Sagittal imbalance greater than 5 cm
- Coronal imbalance greater than 5 cm
- Thoracic kyphosis greater than 60° (T3 or T5–T12)
- Lumbar lordosis less than 30° with scoliosis equal to or greater than 15°
- Thoracolumbar kyphosis (T12 or T10–L2) greater than 20° (lumbar lordosis is to be measured from the top of T12 to the superior endplate of S1)
- Lumbar kyphosis (equal to or greater than 3 levels) greater than 10°
- Documented progression (10° in the coronal plane/10° in the sagittal plane/3 mm of listhesis); any of the 3
- Patient with previous deformity surgery who is 12 mo or more postop

All patients were enrolled in 2002. The baseline assessment consisted of standard demographics including age, gender, smoking status, and history of prior spine surgery. Radiographic evaluation was performed according to an established positioning protocol[16] for anteroposterior (AP) and lateral 36-inch standing radiographs. Patient self-assessment measures of health status collected were the SRS-29, SF-12, and Oswestry Disability Index (ODI) profiles.

Radiographic measures of deformity were recorded based on a standardized manual of measurement techniques. Coronal plane parameters included major and minor curve location, curve magnitude by Cobb angle, and coronal imbalance by plumb line deviation. Apical rotation was assessed by the Pedriolle technique and lateral listhesis by magnitude of offset. Sagittal plane measures included global and segmental kyphosis by Cobb angle and C7 plumb line for global sagittal balance (Figures 1 and 2).

The data were analyzed to investigate the relationship between radiographic measures of deformity and clinical health status. The radiographic parameters studied were curve type, curve location, curve magnitude, coronal balance, sagittal balance, apical rotation, and rotatory subluxation. Curves were segregated by type as single major or double major and by location as thoracic, thoracolumbar, lumbar, or other. Curve magnitude was analyzed in a linear fashion and also in groups of less than 40°, 40° to 60°, and greater than 60°. Coronal balance was categorized as less than 4 cm shift or greater than 4 cm shift. Sagittal balance was divided as negative or neutral/positive based on plumb line measurement. Rotatory subluxation was classified as present or absent.

Overall and domain specific responses within the health status measures were then compared based on variation within

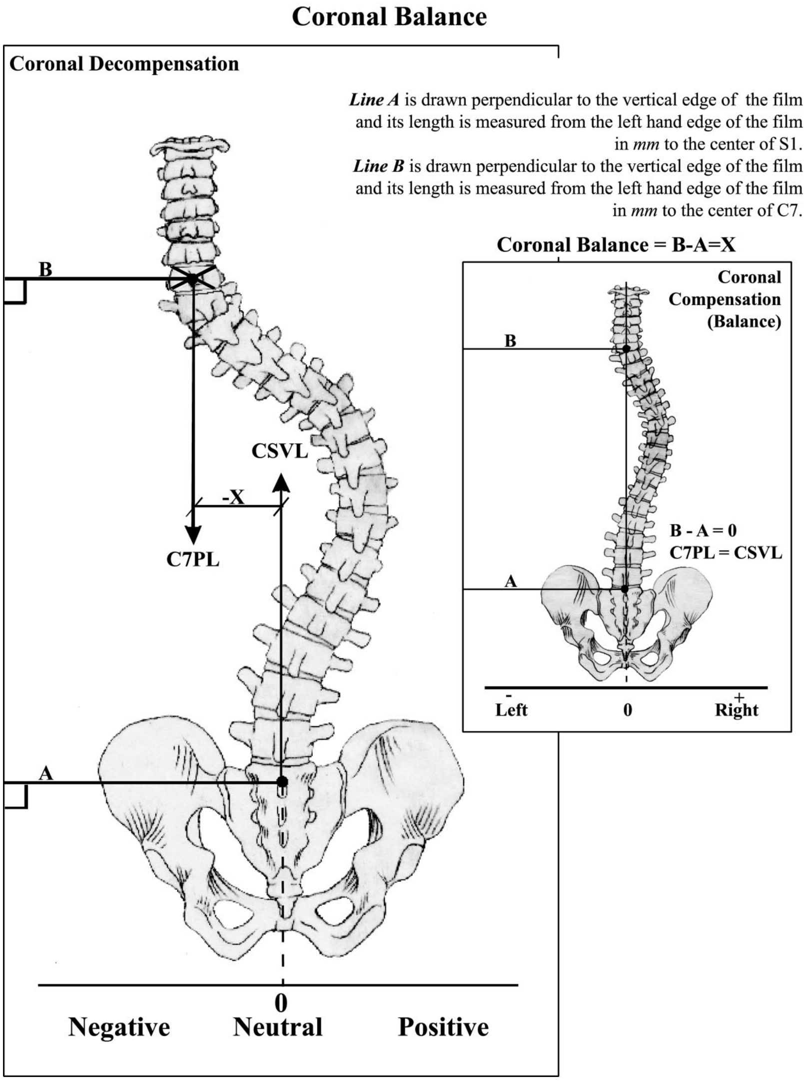

Figure 1. Measurement technique for coronal balance.

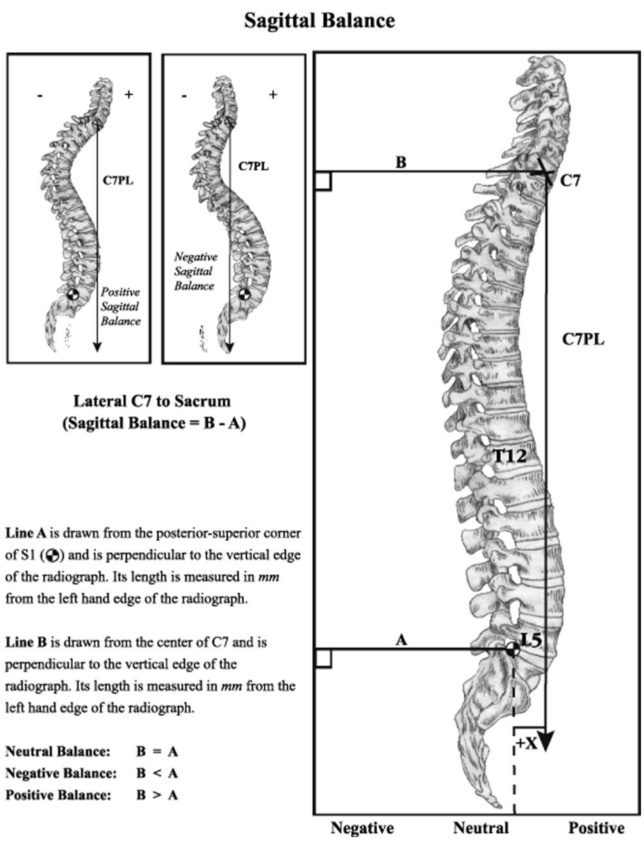

Figure 2. Measurement technique for sagittal balance.

these radiographic indexes. Statistical analysis was performed. We used linear regression and calculation of Spearman correlation coefficients to measure the relationship between continuous variables, and we used Student's t test to measure significance in the relationship between dichotomous predictor and continuous outcome variables.

■ Results

The 298 patients studied include 172 with no prior surgery and 126 who had undergone prior spine fusion. Mean age was 48 (range 18–87) years in the no prior surgery group and 51 (range 20–81) years in the prior surgery group. Both groups were 84% female. The no prior surgery group included 11% cigarette smokers *versus* 9% in the prior surgery group (Table 2).

Among the patients without prior surgery, the major curve was thoracic in 44 patients, thoracolumbar in 47 patients, and lumbar in 41 patients. Twenty-nine patients had a primary curve location reported as cervicothoracic, high thoracic, or lumbosacral. Eleven patients had a primary kyphosis, and no associated scoliosis >30°. Curve magnitude was mean 54° (range 30–124) for thoracic curves, mean 51° (range 30–110) for thoracolumbar curves, and mean 45° (range 30–75°) for lumbar curves.

Table 2. Demographic Characteristic of the Study Cohort

Characteristic	No Previous Surgery	Prior Surgery	Total
No.	176	126	302
Age (yrs)	48 (18–87)	51 (20–81)	49 (18–87)
Gender (% female)	84	85	
Smokers (%)	9	11	10

Table 3. Curve Location *versus* Outcome Measures in Patients Without Prior Surgery

Curve location	Thoracic	Other	P Value
N	44	128	
Pain	Less pain		
SRS-22	3.5	3.1	0.01
SF-12	71	58	0.03
ODI	17	26	0.01
Function	Better function		
SRS-22	3.9	3.5	0.01
SF-12	70	55	0.03
Self-image			
SRS-22	3.4	3.3	0.38
Social Function			
SF-12	83	76	0.16
Vitality			
SF-12	53	50	0.49

SRS = Scoliosis Research Society; SF-12 = Short Form-12; ODI = Oswestry Disability Index.

In the group with prior surgery, the primary residual curve location was thoracic in 45 patients, thoracolumbar in 20 patients, lumbar in 28 patients, and any other location in 33 patients. Curve magnitude was mean 52° (range 21–96) for thoracic curve, mean 45° (range 17–87) for thoracolumbar curves, and mean 42° (range 20–83) for lumbar curves.

No Prior Surgery

Analysis of the patients without prior surgery demonstrated no statistical differences in health status measures based on curve magnitude, apical rotation, or comparison between single and double major curves. Comparison based on curve location revealed more favorable scores for thoracic curves *versus* thoracolumbar or lumbar curves [SRS-22 pain ($P = 0.01$) and function ($P = 0.01$), SF-12 bodily pain ($P = 0.03$), and physical function ($P = 0.03$), and ODI ($P = 0.01$)] (Table 3). There were no statistically significant differences when curve location was divided into more limited subgroups.

The most significant findings for patients with no prior surgery were noted in the assessment of coronal and sagittal balance. Patients with coronal shift greater than 4 cm reported poorer function based on the SRS-22 ($P = 0.03$) and greater pain on the SF-12 ($P = 0.05$) and ODI ($P = 0.05$) compared to patients with a coronal shift less than 4 cm (Table 4). Patients with positive sagittal balance measured from C7 to the posterior margin of the sacrum had the most significant compromise in health status when compared to patients who were in neutral balance or negative global sagittal balance. Patients with positive sagittal balance reported greater pain (SRS-22, $P = 0.01$; SF-12, $P = 0.00$; ODI, $P = 0.00$), diminished physical function (SRS-22, $P = 0.00$; SF-12, $P = 0.00$), poorer self image (SRS-22, $P = 0.03$), and social function (SF-12, $P = 0.02$) (Table 5).

Table 4. Curve Location *versus* Outcome Measures in Patients With Prior Surgery

Curve Location	Thoracic	Thoracolumbar	Lumbar	Other	*P* Value
N	45	20	28	33	
Pain				More pain	
SRS-22	3.2	3.0	3.2	2.6	0.04
SF-12	58	50	54	38	0.06
ODI	26	33	29	38	0.04
Function	Better function			Worse function	
SRS-22	3.5	3.2	3.4	2.7	0.00
SF-12	49	30	38	23	0.02
Self-image				Worse self-image	
SRS-22	3.4	3.0	3.3	2.7	0.00
Social Function					
SF-12	76	75	76	60	0.09
Vitality					
SF-12	49	45	45	42	0.66

SRS = Scoliosis Research Society; SF-12 = Short Form-12; ODI = Oswestry Disability Index.

Prior Surgery

For patients with prior spinal fusion surgery, clinical health status measures were not influenced by curve magnitude, single *versus* double major curve type, rotatory subluxation, or coronal balance. Analysis based on curve location revealed less pain (ODI, $P = 0.03$), better function (SRS-22, $P = 0.01$ and SF-12, $P = 0.01$), and better self-image (SRS-22, $P = 0.02$) for thoracic curves *versus* all other curve locations (Table 6). The poorest self-reported scores were for "other" curve locations such as high thoracic or fractional lumbosacral curves. These patients had lower SRS-22 scores for pain ($P = 0.04$), function ($P = 0.00$), and self-image ($P = 0.00$) and greater pain based on ODI score ($P = 0.04$).

Comparison of patients with positive *versus* negative sagittal balance demonstrated markedly impaired health status measures for patients with positive sagittal balance. Poorer outcomes were noted in pain, function, and self-image domains of the SRS-22 ($P = 0.00$), as well as bodily pain, physical function, vitality ($P = 0.00$), and social function ($P = 0.02$) on the SF-12. Greater pain was also reported on the ODI scale ($P = 0.00$) (Table 5).

Age is an independent predictor variable for pain and function in this study. Controlling for age, we found that positive sagittal balance remained the radiographic parameter most significant in predicting pain, limited function, and compromise of self-image in adults with scoliosis.

■ Discussion

Previous studies have been unable to demonstrate a significant predictive value for any radiographic parameter with respect to health status of the patient. Jackson *et al* demonstrated a moderate correlation between apical vertebral rotation and pain and a poor correlation of curve magnitude and sagittal plane measures with pain.[12] Using the SRS Questionnaire as a measure of health status, D'Andrea *et al* demonstrated a poor correlation between radiographic measures of deformity and clinical status in adolescents, and Deviren *et al* demonstrated a similar poor correlation in adults with spinal deformity.[13,14] Using a visual analogue scale to measure pain, Schwab *et al* demonstrated a moderate correlation between radiographic measures including lumbar lordo-

Table 5. Sagittal Balance *versus* Outcome Measures

Sagittal C7 plumb line	In Patients Without Prior Surgery —	In Patients Without Prior Surgery 0/+	In Patients Without Prior Surgery *P* Value	In Patients With Prior Surgery —	In Patients With Prior Surgery 0/+	In Patients With Prior Surgery *P* Value
N	91	73		30	88	
Pain		More pain			More pain	
SRS-22	3.4	3.0	0.01	3.5	2.9	0.00
SF-12	70	51	0.00	71	45	0.00
ODI	19	28	0.00	19	35	0.00
Function		Worse function			Worse function	
SRS-22	3.8	3.3	0.00	3.7	3.1	0.00
SF-12	69	46	0.00	57	31	0.00
Self-image		Worse self-images			Worse self-images	
SRS-22	3.4	3.2	0.03	3.5	3.0	0.00
Social Function		Poorer social function			Poorer social function	
SF-12	82	71	0.02	83	68	0.02
Vitality					Less vitality	
SF-12	54	48	0.14	58	42	0.00

SRS = Scoliosis Research Society; SF-12 = Short Form-12; ODI = Oswestry Disability Index.

Table 6. Coronal Balance *versus* Outcome Measures in Patients Without Prior Surgery

Coronal plumb line	0–40 mm shift	>40 mm shift	*P* Value
N	158	12	
Pain		More pain	
SRS-22	3.2	3.0	0.36
SF-12	63	44	0.05
ODI	23	34	0.05
Function		Worse function	
SRS-22	3.6	3.1	0.03
SF-12	60	36	0.06
Self-image			
SRS-22	3.3	3.0	0.17
Social Function			
SF-12	78	71	0.42
Vitality			
SF-12	50	54	0.66

SRS = Scoliosis Research Society; SF-12 = Short Form-12; ODI = Oswestry Disability Index.

sis, thoracolumbar kyphosis, and endplate obliquity with pain (r values all < = 0.5) and poor correlation of overall sagittal balance and curve magnitude with pain.[15] These previous studies have been limited by sample sizes of less than 101 patients and may not have had adequate statistical power to demonstrate correlations and differences in a group as diverse and with the variance of clinical presentation as that seen in adults with spinal deformity.

Although adult spinal deformity has become an increasing component of many spine surgery practices, the role of radiographic measures in predicting the clinical status of the patient is not well characterized. Standing AP and lateral 36-inch radiographs are the basic evaluation tool for the adolescent or adult with spinal deformity, yet the utility of radiographic measures as a process variable in predicting health status has not been reliably demonstrated in the past literature. A definition of the relationship between radiographic measures and clinical health status is important to the physician caring for patients with spinal disorders, especially in helping to direct surgical planning and strategies for deformity correction.

This study demonstrates that sagittal balance is the most important and reliable radiographic predictor of clinical health status, as patients with positive sagittal imbalance reported worse self-assessment in pain, function, and self-image domains (Figure 3). The observation that global sagittal balance is a significant predictor of clinical status is consistent with the experience of Emami *et al*, who demonstrated that patients with positive sagittal imbalance after long fusions to the sacrum had increased pain compared to patients with negative global sagittal balance.[17]

Age has an important influence on the natural history of sagittal plane changes in the adult spine. Thoracic kyphosis increases with age, whereas lumbar lordosis decreases, leading to a net effect trending toward positive global sagittal balance with advancing age.[18–21] Diminished ability to use compensatory mechanisms such as hip extension and knee flexion may also contribute to the development of a more positive global spinal alignment

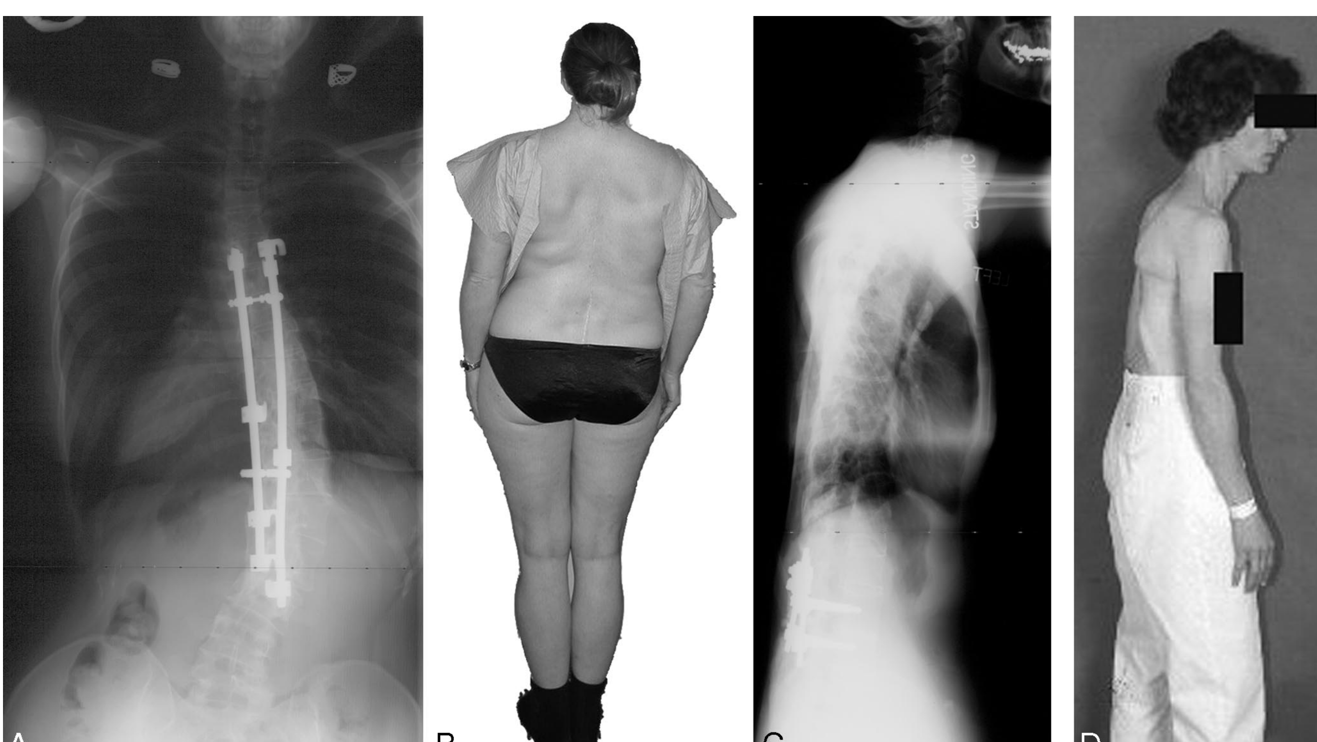

Figure 3. Examples of patients with coronal and sagittal imbalance. The patient with coronal imbalance (**A** and **B**) is asymptomatic, whereas the patient with sagittal imbalance (**C** and **D**) is symptomatic.

in older adults compared to adolescents.[22] This study demonstrated that age was an independent predictor of clinical health status, with older patients reporting worse scores for pain, function, and disability. After controlling for age, positive sagittal plane balance remained an important and significant predictor of clinical health status in patients with adult spinal deformity with or without prior surgery. Therefore, restoration of a more normal sagittal balance of the spine is an important goal for any reconstructive spine surgery.

Coronal imbalance of greater than 4 cm was associated with deterioration in pain and function scores for the unoperated patients but not in patients with previous surgery. This result suggests that correction of coronal balance to within 4 cm of neutral may not be as important a goal as restoration of appropriate sagittal balance. Other commonly used radiographic parameters including curve magnitude and curve type were unrelated to the magnitude of clinical symptoms. Therefore, the results of this study predict that greater correction of coronal curve magnitude is unlikely to result in a significantly better clinical outcome than a less complete correction.

For patients with or without previous surgery, thoracolumbar and lumbar curves generated less favorable scores than thoracic curves. This finding is consistent with the observation of Weinstein *et al*, who report that at 50 years follow-up, a population of adults with late-onset adolescent idiopathic scoliosis and predominantly thoracic curves had little functional compromise.[23] As with prior studies,[12–14] our findings substantiate the underlying concept that clinically significant symptoms result from a concurrence of deformity and lumbar degenerative disease. Therefore, we may expect significantly more disability in a population of adults with significant thoracolumbar and lumbar deformity associated with progressive lumbar degenerative disease.

This study demonstrated no correlation between pain complaints and the presence of rotatory subluxation. The literature is controversial with regard to the effect of lateral olisthesis or rotatory subluxation on clinical symptoms. Jackson *et al* found rotatory olisthesis more likely to be associated with radicular complaints, but "statistically unrelated to the occurrence of pain."[24] In contrast, Kostuik et al reported that "presence of a lateral and rotatory subluxation was invariably associated with pain."[25]

Another finding that contradicted our initial hypothesis was the observation that increased apical rotation and coronal imbalance was not correlated with measures of self-image. With regard to coronal imbalance, the subgroup with a significant coronal plane offset included only 11 patients and may have been too small to demonstrate a statistically significant difference. There was a trend toward poor self-image in patients with greater than 4 cm of coronal shift for both the groups with and without previous surgery ($P = 0.07$ in prior surgery group).

The primary strengths of this study are the large sample size, the consistent radiographic measurement technique, and the extent of patient-based quality of life data that was collected. The presence of consistent findings across multiple validated outcome tools obviously increases statistical confidence and thus the clinical relevance of the observations. A weakness of the study is the diversity of the study population, which dilutes the specificity of the data with regard to any single category of deformity. Ongoing patient enrollment should provide a sufficient data pool to assess more narrowly defined study groups in the future.

■ Key Points

- Positive sagittal balance predicts clinical symptoms in adult spinal deformity.
- Thoracolumbar and lumbar curves generate less favorable scores than thoracic curves.
- Significant coronal imbalance was associated with pain and dysfunction in unoperated patients only.

Acknowledgments

The authors thank John Harrast for his assistance in preparation of the data analysis and thank the Spinal Deformity Study Group for their support.

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