Correlation of Radiographic, Clinical, and Patient Assessment of Shoulder Balance Following Fusion Versus Nonfusion of the Proximal Thoracic Curve in Adolescent Idiopathic Scoliosis

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Study Design. Retrospective clinical, radiographic, and patient outcome review of surgically treated adolescent idiopathic scoliosis.

Objectives. To correlate radiographic and clinical features of shoulder balance and the proximal thoracic curve with patient satisfaction outcomes at a minimum 2-year follow-up.

Summary of Background Data. Traditionally, radiographic features of a structural proximal thoracic curve have been T1 tilt, proximal thoracic Cobb angle, and proximal thoracic side-bending Cobb; however, these do not always correlate with clinical shoulder balance.

Methods. A total of 112 patients (single surgeon) with adolescent idiopathic scoliosis and a proximal thoracic curve ≥20° (average 32°, range 20–78°) were evaluated in terms of shoulder balance and curve flexibility/correction. Four groups were analyzed: Group 1, posterior spinal fusion to T2 (proximal thoracic curve included, n = 24); Group 2, posterior spinal fusion to T3 (proximal thoracic curve partially included, n = 23); Group 3, posterior spinal fusion to T4 or T5 (proximal thoracic curve not included, n = 21); and Group 4, anterior spinal fusion to T4 or below (proximal thoracic not included, n = 44). Proximal thoracic, main thoracic, and thoracolumbar-lumbar upright coronal, side-bending, and sagittal Cobb measurements were assessed before surgery, 1 week after surgery, and at a minimum 2-year postoperative follow-up (average 3.8 years, range 2.0–7.6 years). In addition to T1 tilt, clavicle angle (intersection of a horizontal line and the tangential line connecting the highest two points of each clavicle), coracoid height difference, trapezius length (horizontal distance of the T2 pedicle to second rib–clavicle intersection), first rib–clavicle height difference (vertical distance of first rib apex to superior clavicle), and proximal thoracic, main thoracic, and thoracolumbar-lumbar apical vertical translation were determined. Shoulder asymmetry as measured by the radiographic soft tissue shadow was graded as balanced (<1 cm), slight (1–2 cm), moderate (2–3 cm), or significant (>3 cm). A postoperative patient questionnaire addressed shoulder balance and overall appearance at most recent follow-up.

Results. The four groups were found to be statistically equivalent in terms of preoperative proximal thoracic curve (P = 0.4146), proximal thoracic side-bending Cobb (P = 0.2199), main thoracic curve (P = 0.6999), and main thoracic side-bending curves (P = 0.7307). Radiographic: Preoperative proximal thoracic measurements correlating with postoperative shoulder balance (P < 0.05) included the clavicle angle (three of four groups with a trend toward statistical significance in the fourth group, P = 0.07) and coracoid height (two of four groups). No other measurement, including T1 tilt and proximal thoracic side-bending Cobb, correlated in more than one group. Proximal thoracic curve correction was greatest in Group 1 (posterior spinal fusion to T2; average 12°) and Group 4 (anterior spinal fusion to T4 or below; average 12°). Clinical: Shoulder balance improved in all four groups (range 0.38–1.00 grades). There was no difference in shoulder balance between groups (P = 0.2723). Patient assessment: All four groups also reported improvement in self-perceived shoulder balance (63% up to one grade, 37% over two-grade improvement), whereas no patient reported worsening of shoulder balance. There was no significant difference in patient outcomes between the four groups (P = 0.3654).

Conclusion. The clavicle angle, not T1 tilt, upright proximal thoracic, or side-bending proximal thoracic Cobb, provided the best preoperative radiographic prediction of postoperative shoulder balance. In each of the four groups, postoperative shoulder balance and clinical appearance also improved and correlated with patient postoperative assessments. [Key words: adolescent idiopathic scoliosis, proximal thoracic curve, spontaneous correction, patient outcome, clavicle angle] Spine 2002; 27:2013–2020

Inclusion of the proximal thoracic (PT) curve in the instrumented fusion of adolescent idiopathic scoliosis (AIS) is often a difficult clinical decision, especially when attempting to balance the shoulders. Most commonly, this decision has been based on experience with Harrington rod instrumentation for a King V double thoracic curve pattern, which considered an elevated left shoulder or first rib, relative stiffness of the upper curve, and a “positive T1 tilt” as indicators for fusion of the PT curve.5,8 Positive T1 tilt, characterized as elevation of the left upper corner of the first thoracic vertebra versus the right upper corner in a right main thoracic (MT) curve...
pattern, was considered indicative of a complete or full PT curve. Neutral or negative T1 tilt was considered indicative of a fractional curve.

Winter emphasized other criteria (trapezial fullness, left thoracic rib prominence, and left shoulder elevation) while describing special techniques with Cotrel-Dubousset (CD) instrumentation. Other authors have analyzed the upper (proximal) thoracic curve following posterior instrumented fusion with and without inclusion of the curve and noted spontaneous correction or minimal progression of the PT curve when it was not fused, or proximal kyphosis after posterior spinal fusion (PSF). Additionally, Lenke et al established specific radiographic criteria for including the PT curve in the instrumented fusion of AIS with CD instrumentation. They defined a structural PT curve as $>30^\circ$ that corrected to no better than $20^\circ$ on side bending. Most recently, Suk et al reported their indications for inclusion of the PT curve in posterior thoracic AIS fusions when using pedicle screws for correction.

The anterior approach has also gained popularity in the surgical treatment of AIS. Betz et al and Kaneda et al separately reported on the advantages of the anterior thoracic approach when treating certain thoracic curve patterns. Betz et al also noted the lack of coronal decompensation with the anterior technique. One of the key preoperative points with anterior spinal fusions includes careful evaluation of the structural nature of the PT curve. For instance, a true double thoracic curve pattern is believed to be a contraindication for an anteriorly instrumented fusion of the MT curve. More recent work has compared the spontaneous correction of the PT curve following anterior versus PSF.

However, the best radiographic predictor of postoperative shoulder balance following posterior or anterior spinal fusion has not yet been determined. Our purpose was to evaluate a group of AIS patients with a PT curve of $\geq 20^\circ$ (range 20–78°) treated with either a selective PSF (various levels) or anterior spinal fusion (ASF) of the MT region, to critically evaluate a variety of radiographic measurements to determine the best preoperative predictor of postoperative shoulder balance, and to compare these findings with patient satisfaction.

### Materials and Methods

A total of 112 consecutive patients from 1992 to 1998 with AIS (single surgeon) and a PT curve of $\geq 20^\circ$ (average 32°, range 20–78°) were evaluated in terms of shoulder balance, curve flexibility, and postoperative correction. Four groups were analyzed to determine if any differences existed because of the surgical approach or fused levels: Group 1, PSF to T2 (PT curve included, n = 24); Group 2, PSF to T3 (PT curve partially included, n = 23); Group 3, PSF to T4 or T5 (PT curve not included, n = 21); and Group 4, ASF to T5 or T6 (PT not included, n = 44). All cases in each group had the following characteristics: the diagnosis of AIS with a PT curve $\geq 20^\circ$, age 10–19 years when the operations were performed, and use of autogenous bone graft in the fusions, either from the ribs (in all anterior cases and in poste-
and T12–L2. Radiographic shoulder height (RSH) was also determined from the standing AP radiograph. This was defined as the graded height difference of soft tissue shadows directly superior to the acromioclavicular joints (Figure 2). This shadow is routinely visualized on a standard long cassette radiograph or occasionally with the assistance of a hot light. This shadow is routinely visualized on a standard long cassette radiograph directly superior to the acromioclavicular joints (Figure 2).

**Clinical Evaluation.** Interpretation of the RSH was confirmed clinically in all cases by the treating surgeon. Grade 0 was shoulders < 1 cm from the horizontal and was considered balanced; Grade 1 was ≥1 cm but ≤2 cm from the horizontal; Grade 2 was ≥2 cm but ≤3 cm from the horizontal; and Grade 3 was ≥3 cm from the horizontal. This mirrored the RSH and was assigned directionality with positive being left shoulder up and right shoulder down, similar to the T1 tilt and clavicle angle directionality.

**Patient Assessment/Outcome Questionnaire.** A patient outcome questionnaire was also completed to correlate patient satisfaction with the clinical and radiographic evaluations (Figure 3). This included five multiple-choice questions specifically addressing shoulder balance and overall appearance.

**Statistical Analysis.** Statistical analysis was performed for each dependent variable comparing the four groups. Analysis of variance was used to find differences between the groups, and pairwise comparisons were determined with the Tukey’s post hoc test. Statistical significance was set at \( P < 0.05 \).

### Results

**Evaluation Between Groups and Clinical Shoulder Balance**

For Group 1 (PSF to T2, PT curve included, \( n = 24 \)), the average age was 14.3 years (range 11–18 years), and the PT curve averaged 42° (range 26–78°) with correction to 28° (range 15–33°). The MT curve averaged 64° (range 45–109°) with correction to 32° (range 15–65°) (Table 1). For Group 2 (PSF to T3, PT curve partially included, \( n = 23 \)), the average age was 14.4 years (range 10–17 years), and the PT curve averaged 30° (range 20–47°) with correction to 21° (range 5–39°). The MT curve averaged 66° (range 46–95°) with correction to 34° (range 15–61°).

For Group 3 (PSF to T4 or T5, PT curve not included, \( n = 21 \)), the average age was 15.0 years (range 12–19 years), and the PT curve averaged 28° (range 20–49°) with spontaneous correction to 20° (range 10–47°). The MT curve averaged 62° (range 47–92°) with correction to 30° (range 13–55°). For Group 4 (ASF to T4 or below, PT curve not included, \( n = 44 \)), the average age was 15.4 years (range 10–19 years), and the PT curve averaged 28° (range 20–46°) with spontaneous correction to 16° (range 2–31°). The MT curve averaged 60° (range 42–90°) with correction to 29° (range 7–52°). There was no statistical difference between these groups, except for Group 1, which had a statistically significant larger PT curve (\( P = 0.0011 \)) as compared with the other groups. However, the purpose of the study was not to determine differences between the groups, rather radiographic predictors of postoperative shoulder balance.

As for the PT curve and PT SB radiographs, these preoperative measures did not correlate with postoperative shoulder balance for any of the four groups (Table 2).

Shoulder height was quantified according to the determined grade on standing evaluation. Grades were assigned a positive or negative value to correlate with T1 tilt and clavicle angle, where right shoulder down was considered positive. Absolute values were assigned to determine change in shoulder balance.

As previously noted, shoulder balance was quantified as significant imbalance between shoulder heights (>3 cm), moderate imbalance (2–3 cm), minimal imbalance (1–2 cm), or balanced (<1 cm side-to-side difference). Grades were assigned a positive or negative value to correlate with T1 tilt and clavicle angle, where right shoulder down was considered positive. Interpretation of the clinical shoulder balance was matched with the radiographic appearance in all cases by the treating surgeon.

Before surgery, the shoulder balance averaged -0.94 ± 1.15 grades, about 1–2 cm (Grade 1) side-to-side shoulder difference on average. The immediate postoperative shoulder balance was -0.19 ± 1.21 grades, and the latest follow-up was -0.12 ± 0.81 grades. This was used to correlate statistically to all other radiographic parameters.

**Radiographic Evaluation**

Numerous radiographic measurements were obtained before surgery, in the immediate postoperative period,
and at latest follow-up (minimum 2 years). Correlation of these parameters with shoulder balance, using Pearson correlation coefficients, is seen in Table 2. Significance was set at $P < 0.05$.

**T1 Tilt.** T1 tilt averaged $-0.71 \pm 7.55^\circ$ overall. There were 30 radiographs with positive T1 tilt (defined as $\geq 2^\circ$) on standing full-length radiographs. Of these, the right shoulder was considered up in 9 radiographs, slightly up in 11 radiographs, neutral in 8 radiographs, slightly down in 3 radiographs, and down in 1 radiograph. T1 tilt was neutral ($0 \pm 1^\circ$) in 39 radiographs with the right shoulder up in 11, slightly up in 8, neutral in 15, slightly down in 3, and down in 1 radiograph. T1

### Table 1. Preoperative and Postoperative Shoulder Balance

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Group 1 (n = 24)</th>
<th>Group 2 (n = 23)</th>
<th>Group 3 (n = 21)</th>
<th>Group 4 (n = 44)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average age (yrs)</td>
<td>14.3</td>
<td>14.4</td>
<td>15.0</td>
<td>15.4</td>
</tr>
<tr>
<td>PT curve (°)</td>
<td>42 (28–78)</td>
<td>30 (20–47)</td>
<td>28 (20–49)</td>
<td>28 (20–46)</td>
</tr>
<tr>
<td>PT curve latest follow-up (°)</td>
<td>28 (15–53)</td>
<td>21 (5–39)</td>
<td>20 (10–47)</td>
<td>16 (2–31)</td>
</tr>
<tr>
<td>MT curve (°)</td>
<td>64 (45–109)</td>
<td>66 (46–95)</td>
<td>62 (47–92)</td>
<td>60 (42–90)</td>
</tr>
<tr>
<td>MT curve latest follow-up (°)</td>
<td>32 (15–65)</td>
<td>34 (15–61)</td>
<td>30 (13–55)</td>
<td>29 (7–52)</td>
</tr>
<tr>
<td>TL-L curve (°)</td>
<td>32 (1–47)</td>
<td>45 (15–105)</td>
<td>49 (17–86)</td>
<td>38 (24–58)</td>
</tr>
<tr>
<td>TL-L curve latest follow-up (°)</td>
<td>12 (1–32)</td>
<td>19 (6–50)</td>
<td>22 (8–40)</td>
<td>20 (0–46)</td>
</tr>
</tbody>
</table>

Average preoperative and latest follow-up coronal Cobb measurements for each group. There was no statistical difference between groups, other than Group 1, which had a statistically significantly greater PT curve ($P = 0.0011$).

PT = proximal thoracic; MT = main thoracic; TL-L = thoracolumbar-lumbar.
tilt was negative in 43 radiographs, the most common finding. The right shoulder again was up in 26, slightly up in 10, neutral in 3, slightly down in 1, and down in 3. Evaluating T1 tilt by groups, only Group 4 (ASF to T4 or below, PT curve not included, n = 44) showed correlation between the T1 tilt and postoperative shoulder balance (P = 0.0089). Group 2 showed a trend toward statistical significance (P = 0.0599); however, Group 1 and Group 3 did not correlate (P = 0.8833, P = 0.7588).

Interestingly, nine patients were considered to have right shoulder elevation with a positive T1 tilt (Figure 4). Considering the entire cohort, T1 tilt did not correlate with postoperative shoulder balance (P = 0.7086, analysis of variance).

**Radiographic Shoulder Height.** Radiographic shoulder height was quantified according to the determined grade on standing AP radiographs. Grades were assigned a positive or negative value to correlate with T1 tilt and clavicle angle, where right shoulder down was considered positive. Preoperative radiographic shoulder balance/height averaged 1.22 ± 0.67 for all four groups combined, whereas the initial postoperative shoulder balance was 0.89 ± 0.78 (Table 3). On the latest follow-up, shoulder balance was 0.52 ± 0.57. There was no difference in shoulder balance between groups (P = 0.2723). Further, RSH correlated with postoperative shoulder balance in only Group 3 (P = 0.0036).

**Clavicle Angle.** The clavicle angle averaged −2.90 ± 3.79° (range −13° to +7°) before surgery, −0.31 ± 3.00° in the immediate postoperative period, and −0.09 ± 3.01° at the latest follow-up. Seventy-five radiographs had a negative clavicle angle (≥−2°), whereas 20 radiographs were considered neutral (0 ± 1°) and 17 radiographs positive (≥2°). Within the groups the clavicle angle correlated with postoperative shoulder balance for Group 1 (P = 0.0009), Group 2 (P = 0.0193), and Group 4 (P = 0.0007). This also approached statistical significance for Group 3 (P = 0.0716). A good example is shown in Figure 4.

**Coracoid Height.** Coracoid height was obtained on all 112 radiographs. Occasionally, a hot light was required to determine the exact location of the superior cortical margin. The average coracoid height was −8.98 ± 18.58 mm (range −57 mm to 38 mm). This improved to 1.36 ± 7.90 mm in the immediate postoperative period and −0.45 ± 10.81 mm at the latest follow-up. Coracoid height also correlated with postoperative shoulder balance in two of four groups: Group 1 (P = 0.0255) and Group 4 (P = 0.0001). This did not correlate with Group 2 (P = 0.1119) or Group 3 (P = 0.3912).

**Trapezius Length.** The trapezius length was also identifiable on all radiographs. This measurement averaged 48.29 ± 12.27 mm before surgery, 47.40 ± 10.64 mm in the immediate postoperative period, and 51.54 ± 13.50 mm at the latest follow-up. This did not correlate with postoperative shoulder balance in any group (Table 2).

**First Rib–Clavicle Height.** The rib–clavicle height was 37.66 ± 10.77 mm before surgery, 37.19 ± 11.83 mm in the immediate postoperative period, and 36.14 ± 9.81 at the latest follow-up. This correlated with postoperative shoulder balance in only one group (Group 3, P = 0.0036). The other three groups did not correlate.

**Patient Outcome Questionnaire**

Ninety-four of 112 (84%) postoperative questionnaires were returned. As to preoperative appearance, 13 patients thought that their left shoulder was elevated somewhat or a lot, 22 thought their left shoulder was slightly elevated, 24 thought that their shoulders were balanced, 30 thought their right shoulder was slightly elevated, and 5 thought their right shoulder was up somewhat or a lot. After surgery, 14 patients thought that their left shoulder was slightly elevated, and 8 patients thought that their right shoulder was slightly elevated. The great majority of patients (72 of 94, 76%) thought that their shoulders were clinically balanced. This correlated with the clinical evaluation (P = 0.0341).

Additionally, 78 of 94 patients (83%) thought that their body balance was either somewhat balanced or very well balanced. Three patients thought that they were still unbalanced, one of whom thought that she was primarily unbalanced at the hips.

Before surgery, 36 patients were unhappy with their appearance, and 30 were very unhappy. Eighteen patients had no opinion, and 12 were somewhat happy. After surgery, 34 patients were happy with their appearance, and 40 were very happy with their appearance (79% including both groups). Fifteen patients had no real opinion, and five patients were unhappy.

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**Table 2. Correlation of Various Radiographic Measurements to Shoulder Balance**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTC standing</td>
<td>0.7030</td>
<td>0.8465</td>
<td>0.3903</td>
<td>0.2978</td>
</tr>
<tr>
<td>PTC side bending</td>
<td>0.2411</td>
<td>0.6752</td>
<td>0.3295</td>
<td>0.2733</td>
</tr>
<tr>
<td>PTC AVT</td>
<td>0.7945</td>
<td>0.0472*</td>
<td>0.6400</td>
<td>0.0784</td>
</tr>
<tr>
<td>MTC standing</td>
<td>0.6329</td>
<td>0.0192*</td>
<td>0.2467</td>
<td>0.6761</td>
</tr>
<tr>
<td>MTC side bending</td>
<td>0.6759</td>
<td>0.0208*</td>
<td>0.4532</td>
<td>0.5850</td>
</tr>
<tr>
<td>MTC AVT</td>
<td>0.0615</td>
<td>0.2948</td>
<td>0.7294</td>
<td>0.0515</td>
</tr>
<tr>
<td>TL-L curve standing</td>
<td>0.7908</td>
<td>0.0081*</td>
<td>0.3513</td>
<td>0.3134</td>
</tr>
<tr>
<td>TL-L curve side bending</td>
<td>0.2117</td>
<td>0.0698</td>
<td>0.1470</td>
<td>0.1585</td>
</tr>
<tr>
<td>TL-L curve AVT</td>
<td>0.0656</td>
<td>0.0362*</td>
<td>0.6910</td>
<td>0.1151</td>
</tr>
<tr>
<td>T1 tilt</td>
<td>0.8833</td>
<td>0.0599</td>
<td>0.7588</td>
<td>0.0098*</td>
</tr>
<tr>
<td>Radiographic shoulder height</td>
<td>0.5075</td>
<td>0.3319</td>
<td>0.0038*</td>
<td>0.9481</td>
</tr>
<tr>
<td>Clavicle angle</td>
<td>0.0009*</td>
<td>0.0193*</td>
<td>0.0716</td>
<td>0.0007*</td>
</tr>
<tr>
<td>Coracoid height</td>
<td>0.0255*</td>
<td>0.1119</td>
<td>0.3912</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Trapezius area-length</td>
<td>0.2981</td>
<td>0.4075</td>
<td>0.1237</td>
<td>0.9481</td>
</tr>
<tr>
<td>First rib–clavicle height</td>
<td>0.5075</td>
<td>0.3319</td>
<td>0.0038*</td>
<td>0.4680</td>
</tr>
</tbody>
</table>

Correlation of various radiographic measurements with shoulder balance expressed as Pearson correlation coefficients with significance set at P < 0.05.

* Statistical significance.

PTC = proximal thoracic curve; AVT = apical vertical translation; MTC = main thoracic curve; TL-L = thoracolumbar-lumbar.

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Figure 4. **A–D**, Preoperative anteroposterior and lateral and side-bending radiographs of a girl 11 years, 10 months of age. **E** and **F**, Postoperative anteroposterior and lateral radiographs at the latest follow-up showing balanced shoulders.
Table 3. Preoperative and Postoperative Shoulder Balance

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preoperative</td>
<td>0.88</td>
<td>1.22</td>
<td>1.52</td>
<td>1.27</td>
</tr>
<tr>
<td>Immediate postoperative</td>
<td>0.75</td>
<td>1.09</td>
<td>0.76</td>
<td>0.93</td>
</tr>
<tr>
<td>&gt;2-year postoperative</td>
<td>0.50</td>
<td>0.52</td>
<td>0.52</td>
<td>0.54</td>
</tr>
<tr>
<td>Change</td>
<td>0.38</td>
<td>0.70</td>
<td>0.76</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Average preoperative radiographic shoulder height (RSH) in grades for each group with preoperative, immediate postoperative, and >2-year postoperative findings. Note the continued improvement of RSH from the immediate postoperative period until the latest follow-up.

Discussion

Recognition and proper treatment of the PT curve in AIS surgery is a primary factor in obtaining optimal clinical results. Radiographic criteria for determining when a PT curve is structural have been reported; nonetheless, the ultimate goal is good shoulder balance. The authors are not aware of any studies that have attempted to correlate postoperative shoulder balance with preoperative radiographic measurements with the purpose of aiding the surgeon with preoperative planning. Our purpose was to critically evaluate a variety of radiographic measurements to determine the best preoperative predictor of postoperative shoulder balance and to compare these findings with patient satisfaction.

Bago et al reported on four radiographic measures to estimate shoulder balance in scoliosis. However, this study was only an analysis of “indirect” radiographic measures of shoulder balance that “correlated” with another radiographic measurement (a line on the top margin of the acromion), which was considered to be the actual shoulder level by the authors. Further, it was not predictive of postoperative shoulder balance, and there was no clinical or patient satisfaction correlation. The only other radiographic study attempting to correlate clinical and radiographic deformity/appearance is a study of three-dimensional surface deformity of the trunk and the effect of changes in patient position. These authors noted that body position altered the magnitude of the surface deformity over the whole trunk and recommended the prone position because it offers the optimum association between three-dimensional shape and radiologic deformity. However, the widely accepted radiographic evaluation for scoliosis includes the standing full-length posteroanterior (or AP) and lateral radiographs, whereas three-dimensional imaging remains only experimental.

Other authors have attempted to analyze the upper thoracic curve in AIS and predict its postoperative behavior. Lee et al found that the PT curve was often more rigid than the MT curve and noted the difficulty in determining whether the proximal curve should be included in the fusion. They recommended limited fusion of the MT curve beyond the flexibility of the PT curve with resultant spinal imbalance, left proximal rib cage elevation, and shoulder imbalance. Other authors have reported correction with specific instrumentation systems or tried to define specific criteria for selective thoracic fusion. In addition, spontaneous correction of the PT curve has been reported after both ASF and PSF.

As for radiographic parameters, Ginsburg et al described the significance of T1 tilt and suggested that this correlated well with shoulder imbalance. In contradiction, Lee et al found that positive T1 tilt did not correlate with left shoulder elevation. They did not, however, attempt to predict postoperative shoulder balance.

Our study analyzed numerous radiographic parameters and correlated these parameters with postoperative shoulder balance. We found that the clavicle angle was the best predictor, reaching statistical significance in three of four surgical groups (Group 1, P = 0.0009; Group 2, P = 0.0193; Group 4, P = 0.007) while approaching statistical significance in the fourth group (Group 3, P = 0.0716). The next best predictor was coracoid height, which reached statistical significance in only two of four groups (Group 1, P = 0.0255; Group 4, P = 0.0001).

No other parameter in this study, including T1 tilt, trapezius length, first rib–clavicle height, and RSH, reached statistical significance in more than one group (Table 2). Further, the various radiographic measurements of the curve itself, including the PT curve, MT curve, TL-L curve, SB measurements, and apical vertebral translation of each portion of the curve did not correlate with postoperative shoulder balance. In evaluating the PT curve and PT SB Cobb measurements, neither of these parameters was statistically significant for any of the four groups.

Consequently, for patients with a negative clavicle angle (correlating with right shoulder elevation) fusion of the PT curve may not be necessary, despite a positive T1 tilt or even the presence of a structural PT curve, because correction of the main curve would elevate the left shoulder. For patients with a neutral clavicle angle, the shoulders are clinically balanced and are seldom changed with or without fusion of the PT curve. In the case of a positive clavicle angle (correlating with left shoulder elevation), fusion or at least partial fusion of the PT curve may be necessary to prevent further decompensation of shoulder balance as fusion of only the MT curve, assuming the common scenario of a right MT curve, would necessarily further elevate the left shoulder. This is similar to the recommendations of Lee et al for patients with right shoulder elevation. They recommended limiting the fusion on the lower curve despite positive T1 tilt because correction of the main curve (right thoracic curve) elevates the left shoulder, and the unfused PT curve corrects spontaneously.

This same principle can be applied when choosing an ASF. If the SB radiographs verify PT curve flexibility (<20° on SB radiographs), then selective MT curve in-
strumentation and fusion will elevate the left shoulder through convex compressive correction. Shoulder balance would correlate with clavicle angle; for example, negative clavicle angle indicating right shoulder elevation, thus leading to improved shoulder balance with the compressive correction. Further, the uninstrumented PT curve will spontaneously correct in an attempt to level the head and shoulders. 9

As for patient satisfaction, 76% of patients thought that their shoulders were clinically balanced, thus correlating with the clinical evaluation (P = 0.0341). Further, 74% of patients were either happy or very happy with their overall appearance.

The strengths of this study are that it is a large consecutive series of a single surgeon, independently analyzed by an unbiased second spine surgeon with significant data acquisition in terms of rigid radiographic analysis and statistical evaluation. Further, it is the first study that attempts to correlate preoperative radiographic parameters with postoperative clinical outcomes and patient satisfaction.

The weaknesses of the study are that it is retrospective in nature and that there was no preoperative clinical questionnaire. Further, operative approach/surgical treatment was not randomized. However, this is somewhat minimized by the large number of patients in each group, which permits extensive statistical comparisons.

■ Conclusion

The clavicle angle, not T1 tilt or proximal thoracic sidebending Cobb, as traditionally thought, provided the best preoperative radiographic prediction of postoperative shoulder balance. In four separate groups, postoperative shoulder balance and clinical appearance also improved and correlated with patient postoperative assessments. Future prospective studies will attempt to confirm the utility of using the clavicle angle as an important radiographic predictor of clinical shoulder balance.

■ Key Points

- The clavicle angle provided the best radiographic prediction of postoperative shoulder balance.
- T1 tilt did not correlate with postoperative shoulder balance.
- All four groups reported improvement in self-perceived shoulder balance.

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