Shoulder Balance and Scoliosis: The Unresolved Issue

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ABSTRACT

Background Data: The main indication of surgery in patients with AIS is better function and cosmesis. Shoulder balance should be considered amongst cosmetic parameters that are strongly associated with patient satisfaction after surgery in patients with AIS. Proper correction of the main and proximal thoracic curves in conjunction with horizontalization of upper instrumented vertebra (UIV) is supposed to promote shoulder balance. In other words, better correction of radiological parameters should promote clinical shoulder balance; however, this is not always observed.

Purpose: Determining which of the following radiological measures correlate significantly with postoperative clinical shoulder balance: T1 tilt, UIV tilt, clavicle rib intersection angle, and degree of proximal thoracic curve correction.

Study Design: Retrospective clinical case cohort study.

Patients and Methods: The study included 20 patients of AIS operated for correction by pedicle screw instrumentation. There were 13 females and 7 males. The mean age at the time of surgery was 14±2.4 years with a range from 11 to 18 years. Mean preoperative Cobb angle of the major curve was 76.1±21.7° corrected to a mean postoperative Cobb 28.2±14.2°. Correction percentage of the major curve was 63.1±14.2%. The data obtained from high resolution back view photographs (to assess clinical shoulder balance) and whole spine X-ray films taken within the first year of follow-up period (to assess radiological measures related to shoulder balance) were retrospectively evaluated. Outcome measures: clinical shoulder balance was correlated with 4 radiological parameters, namely, proximal thoracic curve correction percentage, T1 tilt, UIV tilt, and clavicle-rib intersection angle. Measurements were done by Surgimap software version 2.2.12 (Nemaris, Inc.,US, https://www.surgimap.com).

Results: A weak positive correlation was found between postoperative shoulder balance and UIV tilt (r)=0.242, P=0.305, and a very weak negative correlation was found between postoperative shoulder balance and proximal thoracic curve correction percentage (r)=-0.027, P=0.910. A moderate positive correlation but statistically nonsignificant was found between postoperative shoulder balance and T1 tilt (r)=0.440, P=0.052, and a statistically significant positive correlation was found between shoulder balance and clavicle-rib intersection angle (r)=0.567, P=0.009.

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Conclusion: Horizontal UIV combined with proper correction of the main and proximal thoracic curves does not necessarily promote clinical shoulder balance. However, a moderate positive correlation exists between T1 tilt and shoulder balance, and a significant positive correlation exists between clavicle rib intersection angle and clinical shoulder balance. How to control those parameters remains unclear.

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Keywords: shoulder balance; AIS scoliosis; spinal instrumentation; pedicle screw fixation

INTRODUCTION

The main goal of surgical treatment in adolescent idiopathic scoliosis (AIS) is to improve function and cosmesis. This could be achieved via 3D maximum permanent correction of the deformity in order to halt curve progression, while leaving as many mobile segments as possible in the lumbosacral spine, in addition to balance the trunk. Recommendations have been developed from King et al. in 1983 to Lenke et al. in 2001 to facilitate selecting the curves and the vertebral levels to be included in the fusion mass. Distally, surgeons focus on selecting levels that optimally correct the deformity and result in maximum lumbar flexibility. Proximally, the primary concern is to select the level that will achieve maximum deformity correction and fulfill well-balanced shoulders. Lenke’s classification recommended fusion of the structural proximal thoracic curve.

The correction of the main thoracic curve while leaving a structural upper thoracic curve may lead to postoperative clinical shoulder imbalance. Others suggested instrumenting the upper thoracic curve according to the clavicular angle, the patient’s preoperative shoulder balance, or T1 tilt. In spite of these suggestions, authors found a discrepancy between radiographic and clinical shoulder balance; as in many cases, correction of radiological parameters related to shoulder balance may not guarantee well-balanced shoulders.

In this study, we present the results of correlation between radiographic shoulder balance and clinical shoulder balance.

PATIENTS AND METHODS

At Alexandria main university hospitals, 20 patients who had adolescent idiopathic scoliosis had one stage or staged posterior surgery for correction of their deformities using modern instrumentation. These included 13 females and 7 males. The mean age at the time of the operation was 14±2.4 years with a range from 11 to 18 years. Patients included in the study were only patients with adolescent idiopathic scoliosis of different Lenke types except Type V and who were followed up for one year or more. Cases of congenital kyphoscoliosis and other causes of secondary scoliosis were excluded from the study.

All patients had high resolution posterior photographs (by high resolution cameras, within 2 meters from the patient, including head, neck, trunk, and proximal lower limbs, JPEG image) and whole spine X-ray films taken preoperatively and within one year postoperatively. All the measurements were done using surgimap® software version 2.2.12. (Nemaris, Inc., US, https://www.surgimap.com). By convention, when the right shoulder is elevated, it received positive values and left shoulder elevation received negative values; also, this was applied to all other radiological parameters except percentage of proximal thoracic curve correction. Clinical shoulder balance was defined as the angle from one acromion to the other as referenced from the horizontal line (Figure 1). T1 tilt was defined as the angle between a line parallel to the upper end plate of T1 and the horizontal line (Figure 2). UIV tilt was defined as the angle between a line parallel to the upper end plate of the upper instrumented vertebra and the horizontal line (Figure 3). Clavicle rib intersection angle was
defined as the angle between 2 lines: the first line is drawn between the intersection points of the superior border of the clavicle and the first ribs on each side and the second line is the horizontal (Figure 4). Cobb method was used to measure major structural and proximal thoracic curves (Figure 5).

Statistical Analysis

Statistical analysis was conducted to find a correlation between clinical and radiological shoulder balance (T1 tilt, UIV tilt, clavicle rib intersection angle, and proximal thoracic curve correction %). Data were fed to the computer and analyzed using IBM SPSS software package version 20.0 (Armonk, NY, IBM Corp). The Kolmogorov-Smirnov, Shapiro, and D’agstino tests were used to verify the normality of distribution of variables; Spearman’s coefficient $r$ was used to correlate between quantitative variables. Correlation is an effect size and the strength of the correlation is described using the absolute value of $r$. Significance of the obtained results was judged at the 5% level.

RESULTS

The study included 20 patients, 13 females and 7 males. The mean age at the time of surgery was 14±2.4 years with a range from 11 to 18 years. The main thoracic curve was the major structural curve in all cases except one case (Table 1). Various types of Lenke classification were included except for Lenke 5, where we had 6 patients categorized as Lenke 1, 1 patient as Lenke 2, 5 patients as Lenke 3, 7 patients as Lenke 4, and 1 patient as Lenke 6. Mean preoperative Cobb angle of the major curve was 76.1±21.7 (range 50.0–125°) corrected to a mean postoperative Cobb 28.2±14.2 (range 10-65°). Average correction percentage of the major curve was 63±14.2 (range 23.5–84.8%) (Figure 6). Mean preoperative proximal thoracic curve Cobb was 28.2±13.6 (range 2.0 – 51.0 °) that was corrected to a mean of 14.2±8.6 (range 0.8-28.8°) (49.4±19.0 % correction rate). D3 was the most common UIV in 50% of cases followed by D2. Choice of UIV level was dependent upon two factors, namely, preoperative shoulder status and the structural characteristics of the proximal thoracic curve (structural proximal thoracic curve usually was included in the fusion mass). A weak positive correlation was found between postoperative shoulder balance and UIV tilt (the angle between a line parallel to the upper end plate of the upper instrumented vertebra and the horizontal line) ($r$)=0.242, $P=0.305$; also, a very weak negative correlation was found between postoperative shoulder balance and proximal thoracic curve correction % ($r$)=-0.027, $P=0.910$. A moderate but statistically nonsignificant positive correlation was found between postoperative shoulder balance and T1 tilt (the angle between a line parallel to the upper end plate of T1 and the horizontal line) ($r$)=0.440, $P=0.052$, and a statistically significant positive correlation was found between shoulder balance and clavicle rib intersection angle (the angle between 2 lines: the first line is drawn between the intersection points of the superior border of the clavicle and the first ribs on each side and the second line is the horizontal) ($r$)=0.567, $P=0.009$ (Table 2, Figure 7-10).
**Table 1.** Patients' demographic and radiological characteristics within one year of follow-up.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age</th>
<th>Lenke type</th>
<th>MC Preop Cobb</th>
<th>MC Postop Cobb</th>
<th>Postop shoulder balance</th>
<th>UIV level</th>
<th>UIV tilt</th>
<th>T1 tilt</th>
<th>CRIA</th>
<th>PTC correction %</th>
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<td>D3</td>
<td>8.3</td>
<td>4.5</td>
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<td>3A+</td>
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<td>D3</td>
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<td>D2</td>
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<td>3.7</td>
<td>0.8</td>
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<td>3BN</td>
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<td>D4</td>
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<td>20</td>
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<td>D2</td>
<td>7.1</td>
<td>5.4</td>
<td>6.8</td>
<td>57.62</td>
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</table>

MC: major curve; CRIA: clavicle rib intersection angle; PTC: proximal thoracic curve.

**Table 2.** Correlation of postop shoulder balance with UIV tilt, T1 tilt, clavicle rib intersection angle, and proximal thoracic curve correction % within one year of follow up (N=20).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Postop shoulder balance</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>$r_s$</td>
</tr>
<tr>
<td>UIV tilt</td>
<td>0.242</td>
</tr>
<tr>
<td>T1 tilt</td>
<td>0.440</td>
</tr>
<tr>
<td>Clavicle rib intersection angle</td>
<td>0.567*</td>
</tr>
<tr>
<td>Percentage of correction (PTC)</td>
<td>-0.027</td>
</tr>
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</table>

$r_s$: Spearman’s coefficient (strength of correlation).

*: Statistically significant at $P \leq 0.05$.

**Figure 1.** Clinical shoulder balance was defined as the angle from one acromion to the other as referenced from horizontal line.

**Figure 2.** T1 tilt was defined as the angle between a line parallel to the upper end plate of T1 and the horizontal line.
Figure 3. UIV tilt was defined as the angle between a line parallel to the upper end plate of the upper instrumented vertebra and the horizontal line.

Figure 4. Clavicle rib intersection angle was defined as the angle between 2 lines, the first line is drawn between the intersection point of the superior border of the clavicle and the first ribs on each side and the second line is the horizontal.

Figure 5. Cobb method was used to measure major structural and proximal thoracic curves.

Figure 6. Average correction percentage of the major curve was 63% within one year of follow-up.

Figure 7. Correlation between one-year postop shoulder balance and T1 tilt (N=20).

Figure 8. Correlation between one-year postop shoulder balance and UIV tilt (N=20).
Figure 9. Correlation between postop shoulder balance and percentage of correction (proximal thoracic curve, PTC) (N=20).

Figure 10. Correlation between one-year postop shoulder balance and clavicle rib intersection angle (N=20).

Figure 11. (A) 15-year-old female patient with AIS presented with elevated Rt shoulder. (B) Posteroanterior X-ray showing double major curve with major structural curve Cobb angle of 85 degrees and C lumbar modifier. (C) Lateral view X-ray showing thoracic hyperkyphosis. (D) One-year postop X-ray with satisfactory radiological correction. (E) One-year postop lateral X-ray showing sagittal balance. (F) One-year postop shoulder balance showing well-balanced shoulders with slightly elevated Lt shoulder. (G) One-year postop X-ray focusing on three radiological parameters. UIV is not horizontal although the patient has a well-balanced shoulder. T1 tilt and clavicle rib intersection angle are more correlated with clinical shoulder balance.
DISCUSSION

Shoulder balance is an essential cosmetic factor to be considered when planning a surgery to correct any scoliotic deformity. Factors that contribute to the clinical aspects of shoulder balance are not completely understood. In addition, shoulder balance can be divided into ‘medial’ and ‘lateral’. Medial shoulder balance is correlated with the T1 tilt, trapezial prominence, and neck tilt. Lateral shoulder balance (also called clinical shoulder balance) correlates with RSH (radiographic shoulder height difference), CHD (coracoids height difference), CRID (clavicle rib intersection difference), and CA (clavicular angle). Evaluation of shoulder balance by radiological parameters is typically met with tremendous challenges due to generally less than moderate correlation between radiological and clinical parameters. The anatomy of the shoulder enables us to comprehend this discrepancy. The spine and the shoulder are not attached to each other directly. Alternatively, there is a direct contact between the spine and the ribs, which then loosely connect with the scapula. Lee CS et al. have conducted a narrative review in order to assess the problems related to the selection of fusion levels in patients with adolescent idiopathic scoliosis and have found that postoperative shoulder imbalance is one of the major controversial issues facing spine surgeons when planning to correct spine deformities, with a weak correlation between clinical and radiological views. Furthermore, there are no guidelines considering surgical techniques, fusion levels, and other risk factors related to postoperative shoulder imbalance.

In this study, we have investigated four different radiological parameters in relation to clinical shoulder balance, namely, UIV tilt, T1 tilt, clavicle rib intersection angle, and proximal thoracic curve correction %. Many UIV selection systems had been proposed by many authors in an attempt to obtain well-balanced shoulders. Nevertheless, all of these UIV selecting systems do not guarantee postoperative well-balanced shoulders. Likewise, leveling the upper thoracic spine does not mean well-balanced shoulders postoperatively. Consistent with the literature, we had found a weak positive correlation between UIV tilt and clinical shoulder balance (r=0.242, P=0.305).

Postoperative shoulder balance is one of the factors that influence extending the fusion up to the upper thoracic region with subsequent inclusion of the proximal thoracic curve within the fusion construct. The Lenke classification recommended the inclusion of structural proximal thoracic curve within the region of fusion. Li M et al. believe that fusing a main thoracic curve while leaving a structural upper thoracic curve unfused may lead to shoulder imbalance. Kuklo TR et al. and Qiu XS et al. have proposed correcting the upper thoracic curve according to clavicular angle, T1 tilt, or the patient’s preoperative shoulder level. However, a very weak negative correlation was found between proximal thoracic curve correction % and postoperative shoulder balance (r=-0.027, P=0.910).

Bago et al. and Ilharreborde B et al. believe that the T1 tilt has the poorest correlation with shoulder balance when compared to other radiographic parameters. Amir D et al. found that trapezial prominence was affected by leveling T1 and by upper thoracic curve correction. Sarwahi et al. conducted a retrospective case-controlled study on 195 AIS patients followed up to a minimum of one year aiming to assess the factors responsible for well-balanced shoulders and found that T1 tilt is one of the predictors of well-balanced shoulders. Despite being statistically nonsignificant, our findings have revealed a moderate positive correlation between T1 tilt and shoulder balance (r=0.440, P=0.052).

Clavicle rib intersection angle in this study is a modification of the clavicle-rib cage intersection distance described by Bago et al. and modified to be an angle rather than a distance for more consistency and accuracy, as angles could be standardized for comparison and not affected by the size of X-ray films from different centers. Bago et al. have proved a strong relationship between clavicle-rib cage intersection distance and shoulder balance. Qiu XS et al. have found that clavicle-rib
intersection distance had the highest correlation coefficient on correlation between cosmetic parameters and radiological parameters related to shoulder balance. Clavicle-rib intersection angle was also described in the literature by Yang et al.,\textsuperscript{25} as an angle rather than a distance and they have found a statistically significant correlation between clavicle rib intersection angle and clinical shoulder balance. Our results were consistent with Bago et al.,\textsuperscript{3} Qiu XS et al.,\textsuperscript{18} and Yang et al.,\textsuperscript{25} as we have found a statistically significant correlation between clavicle rib intersection angle and clinical shoulder balance \((r=0.567, P=0.009)\) (Case Illustration Figure 11 A-G).

The study of different radiological factors that may affect postoperative shoulder balance in this study had failed to find a strong correlation between three different factors of radiological shoulder balance and cosmetic shoulder balance with subsequent patient satisfaction. The controversial nature of postoperative shoulder balance and its correlation with radiological findings warrants further studies.

The main limitations of this study are the relatively small number of patients and the diversity of curve patterns included; however, future studies including larger number of patients and targeting specific curve patterns could be performed.

**CONCLUSION**

Leveling the upper thoracic spine (horizontal UIV) combined with proper correction of the main and proximal thoracic curves has a weak impact on postoperative clinical shoulder balance. However, a moderate correlation exists between T1 tilt and postoperative shoulder balance, and a significant correlation exists between clavicle rib intersection angle and clinical shoulder balance. How to control those parameters remains unclear. Further evaluation of a larger sample size is needed.

**REFERENCES**


الملخص العربي

توافق الكتف واعوجاج العضد الفقري، القضية التي لم تحل

البيانات الخلفية: يعتبر توافق الكتف من المؤشرات الرئيسية للدقة المرضي بعد التصحيح الجراحي لمرضي اعوجاج العضد الفقري المجهول السبب الدقيق. ومن المفترض أن تصحيح اعوجاج الكتف يさまد من الملاحظات الصدرية الرئيسية والدائمة. حيث تبدأ في بناء الفقرة العلوية، ويتبعها توافق الكتف. بعبارة أخرى، تصحيح المعالجات الإشعاعية يعزز توافق الكتف السريع، مع ذلك، هذا لا يلاحظ دائما.

الغرض: لتحديد أي من المعالجات الإشعاعية التالية ترتبط بشكل كبير مع توافق الكتف السريع، مثل الفقرة العلوية، الفقرة العلوية المثبتة، زاوية تقاطع الترقو، و أبعاد الترف من القفص الصدري و مدى تصليح منحنى الصدر.

تصميم الدراسة: تحليل البيانات عن طريق التقسيم المثلى لبيانات التأكد من البيانات التي تم الحصول عليها من 20 حالة مرض

باوعوجاج العمود الفقري المجهول السبب الدقيق، الذين تم استخدام العمود الفقري بهم باستخدام الطرق الحديثة.

المريض والفرق: تحليل البيانات عن طريق التقسيم المثلى لبيانات التأكد من البيانات التي تم الحصول عليها من الصور الفوتوغرافية عالية الدقة، والأفلام الإشعاعية للمريض، والتي تم عملها في غضون السنة الأولى بعد العملية الجراحية. وشملت الدراسة 20 حالة مرض باوعوجاج العمود الفقري المجهول السبب الدقيق، الذين تم استخدام العمود الفقري بهم باستخدام الطرق الحديثة.

النتائج: تم العثور على ارتباط ضعيف بين توافق الكتف وكلا من: ميل الفقرة العلوية المثبتة ومدي تصليح منحنى الصدر الدائم، ودقة التأكد على ارتباط متوسط بين توافق الكتف ومدي الترف في الفقرة المثبتة. و هناك ارتباط ذو أهمية إحصائية بين توافق الكتف وزاوية تقاطع الترف من القفص الصدري.

الاستنتاج: جعل الفقرة العلوية المثبتة في وضع أفقي (جنبا إلى جنب مع التصحيح السليم للمنحنيات الصدرية الرئيسية والدائمة)، لا تعزز بالضرورة توافق الكتف. ومع ذلك هناك ارتباط أكبر بين كلا من: ميل الفقرة الظهرية الأولى وزاوية تقاطع الترف من القفص الصدري والتوافق الكتف السريع.