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ORIGINAL ARTICLE

Do Current Recommendations for Upper Instrumented Vertebra Predict Shoulder Imbalance? An Attempted Validation of Level Selection for Adolescent Idiopathic Scoliosis

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Abstract *Background:* Shoulder balance for adolescent idiopathic scoliosis (AIS) patients is associated with patient satisfaction and self-image. However, few validated systems exist for selecting the upper instrumented vertebra (UIV) post-surgical shoulder balance. *Questions/Purposes:* The purpose is to examine the existing UIV selection criteria and correlate with post-surgical shoulder balance in AIS patients. *Methods:* Patients who underwent spinal fusion at age 10–18 years for AIS over a 6-year period were reviewed. All patients with a minimum of 1-year radiographic follow-up were included. Imbalance was determined to be radiographic shoulder height |RSH|≥15 mm at latest follow-up. Three UIV selection methods were considered: Lenke, Ilharreborde, and Trobisch. A recommended UIV was determined using each method from pre-surgical radiographs. The recommended UIV for each method was compared to the actual UIV instrumented for all three methods; concordance between these levels was defined as "Correct" UIV selection, and discordance was defined as "Incorrect" selection. *Results:* One hundred seventy-one patients were included with 2.3±1.1 year follow-up. For all methods, "Correct" UIV selection resulted in more shoulder imbalance than "Incorrect" UIV selection. Overall shoulder imbalance incidence was improved from 31.0% (53/171) to 15.2% (26/171). New shoulder imbalance incidence for patients with previously level shoulders was 8.8%. *Conclusions:* We could not identify a set of UIV selection criteria that accurately predicted post-surgical shoulder balance. Further validated measures are needed in this area. The complexity of proximal thoracic curve correction is underscored in a case example, where shoulder imbalance occurred despite "Correct" UIV selection by all methods.

Keywords shoulder balance · validation of expert opinion · adolescent idiopathic scoliosis · deformity correction · radiographic shoulder height · T1 tilt · upper instrumented vertebra · level selection · proximal thoracic curve correction

Level of Evidence: IV

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Introduction

Radiographic shoulder balance has been associated with patient satisfaction and self-image [1, 2, 7, 19, 26]. To achieve postoperative shoulder balance, appreciation of proximal thoracic (PT) curve morphology and behavior is critical in preoperative planning. For the majority of adolescent idiopathic scoliosis (AIS) cases, a right main thoracic (MT) curve is present, and a compensatory PT curve (if present) is to the patient's left [8]. One of the main determinants of post-surgical shoulder balance is the selection of the upper instrumented vertebra (UIV). Level selection criteria have evolved and paralleled changes in instrumentation systems. Criteria from King [13] were developed in an era of Harrington rod instrumentation, supplanted by Lenke with the advent of Cotrel-Dubousset systems (multi-level hooks and dual rods), which have been maintained with current pedicle screw constructs [19].

There are many systems of fusion level recommendations as well as radiographic and clinical predictors of shoulder imbalance; however, there are few studies that have validated any correlations between the two. Shoulder imbalance has been defined by a variety of methods, relying on

bony landmarks and ratios, soft tissue prominence, and clinical measurements; however, there is no widely accepted standard classification. Most systems measuring the vertical height of an anatomic landmark accept a clinically relevant imbalance as 15 mm; however, some classifications define imbalance as a height difference as little as 10 mm [10, 20]. At our institution, radiographs are routinely collimated to include only the spine as to avoid unnecessary radiation exposure. As such, most standard radiographs do not include the coracoid processes, acromia, or soft tissue shadows produced by the trapezius. For this reason, we have found radiographic shoulder height (RSH) [3] to be the most consistently visible measurement, as it requires only 10 cm of visible medial clavicle. We have found angular measurements involving the medial clavicle to be highly variable, with poor reproducibility and inter-observer reliability. We were therefore unable to utilize clavicular tilt angle difference or the newly described clavicle chest cage angle difference [30].

Appropriate surgical planning regarding the UIV should consider operative time, blood loss, upper extensor muscle dissection and denervation, and scar visibility on the lower neck [15]. For these reasons, routine fusion to T1 or T2 is not recommended given the increased morbidity [15].

We have completed a literature review of UIV selection with regard to shoulder balance since the original classification system and level selection by Lenke in 1994 and found only separate descriptions of UIV selection as it relates to shoulder balance.

Lenke recommends inclusion of the PT curve based on push-prone radiographs, rotation, translation, and pre-surgical shoulder elevation. Ilharreborde [11] subsequently described a system for evaluation of Lenke 1 and 2 curves based on PT Cobb angles for both PA and bending radiographs, T1 tilt, and pre-surgical shoulder balance. A table was devised for inclusion of the curve to T1, partial inclusion to T2 or T3, or no inclusion (T4 or below). A recent review from Trobisch [29] uses only curve type and pre-surgical shoulder balance to create a simplified algorithm for UIV selection.

Several authors have pointed out that the radiographic parameters for shoulder imbalance do not correlate perfectly with clinical appearance or patient satisfaction and self-image [22, 25]. Nonetheless, we feel that a retrospective analysis for shoulder balance is a powerful means of validating current recommendation algorithms for level selection. In a survey of Scoliosis Research Society members [17], an average of five different UIV levels was chosen for each case of AIS that was presented. We feel that in an area where considerable heterogeneity exists in expert opinion there is a room for improvement in our treatment algorithms.

The primary purpose of this research is to validate an existing algorithm for UIV selection with regard to shoulder balance or investigate a novel method if a superior one exists. Our secondary research questions were (1) Does posterior spinal fusion improve overall shoulder balance for AIS patients? (2) What is the incidence of post-surgical shoulder imbalance for all patients with modern (pedicle screw) instrumentation? and (3) What is the incidence of new shoulder imbalance (imbalance in patients with pre-surgical level shoulders)?

Patients and Methods

Institutional review board (IRB) approval was obtained prior to the initiation of this study. All patients who underwent spinal fusion from July 2007 to October 2012 at our institution were reviewed. Inclusion criteria for the study were primary diagnosis of AIS, age 10–18 years at the time of surgery, availability of digital pre-surgical bending PA radiographs as well as pre- and post-surgical PA (or AP), and lateral radiographs of the entire spine.

All radiologic studies were performed and digitized at our institution with standard 36-inch plates, calibrated with a 2.5 cm magnification marker placed on the patient's neck.

All radiographs were assessed by an orthopedic surgery resident physician (BTB) for adequacy using the original Lenke criteria [17] and verified to have complete visible C7 to S1 vertebrae, and that pelvic obliquity (if present) was corrected to less than 2 cm. For purposes of RSH measurement, we required that the medial 10 cm of each clavicle was visible on all radiographs.

RSH has been described in multiple ways [10, 20]. We believe the most reliably available measurement is made comparing the difference in the cephalad border of the clavicles at a point drawn 10 cm from the center of the manubrium [20]. All other variables, including coronal T1 tilt, rotation, and Cobb angle (bending and PA), were measured according to their original descriptions. In the Trobisch method, clavicle angle is used to describe shoulder height; for this measurement, we used RSH for reasons mentioned previously. Shoulder imbalance was defined as $|RSH| \geq 15$ mm, whereas $|RSH| < 15$ mm was defined as balanced. Pre-surgical and latest follow-up radiographs were measured at different time points at least 1 week apart in random order by a senior orthopedic surgery resident physician (BTB). The UIV was recorded for all patients, based on operative report and confirmed by radiographic reports, when available. Disagreement was settled by further inspection or consultation with another senior orthopedic surgery resident physician (GDS) or attending orthopedic surgeon (MEC).

Based on these measurements, a recommended UIV was determined for each methodology for every patient. The

Table 1 Lenke criteria for inclusion of the PT curve in fusion

Inclusion of PT Curve for:
PT Cobb>30°
Rotation≥Grade 1
PT apical translation≥1 cm
Preoperative left shoulder elevation
T1 tilt toward PT concavity
PT/MT transitional vertebra at T6 or below
Left shoulder elevation with push-prone radiograph

Table 2 Ilharreborde recommendations, where α and β represent Cobb angles of the bending radiograph toward the convexity of the PT and MT curves, respectively

	T1 Tilt and RSH to the left	T1 Tilt and shoulder balance in opposite directions	T1 tilt and RSH to the right
α-(β/2)<15°	T4 or below	T2 or T3	T1 or T2
α-(β/2)>15°	T2 or T3	T1 or T2	T1 or T2

recommended UIV for each method was then compared to the actual UIV instrumented. A "Correct" level was one that was in agreement with each method's recommendation, and an "Incorrect" level was one that differed.

Three methods of UIV selection with regard to shoulder balance were found after a review of the literature: Lenke [18], Ilharreborde [11], and Trobisch [29]. Appropriate radiographic measurements of pre-surgical radiographs were taken, and a recommended UIV was determined for each methodology for every patient. The recommended UIV for each method was then compared to the actual UIV instrumented. Rates of shoulder imbalance were calculated for all patients, and rates of shoulder imbalance were calculated for fusions that followed the recommendations of the three aforementioned methods. Post-surgical shoulder imbalance was determined to be |RSH|≥15 mm at latest radiographic follow-up. Several additional methods were investigated, but could not be applied to all patients, as appropriate anatomic landmarks could not be visualized.

Statistical analysis for all comparisons was performed using chi-square test for categorical variables (proportions of "Correct" and "Incorrect" shoulder imbalance outcomes) with statistical significance defined as α=0.05. A student's *t* test was performed for all continuous variables (absolute RSH comparison pre- and post-surgically), with statistical significance defined as α=0.05.

Description of Recommendations

Lenke recommends inclusion of the PT curve for Cobb angle greater than 30° that does not correct to below 20°, ≥ Grade 1 rotation [21], apical translation ≥1 cm, left shoulder elevation, T1 tilt toward the PT concavity, or when the PT/MT transitional vertebra lies at T6 or below. Fusion to T2 is recommended if left shoulder elevation occurs on push-prone radiograph. These are summarized in Table 1.

Ilharreborde [11] subsequently described a system for evaluation of Lenke 1 and 2 curves based on PT Cobb angles for both PA and bending radiographs, T1 tilt, and pre-surgical shoulder balance. A table was devised for inclusion of the curve to T1, partial inclusion to T2 or T3, or no inclusion (T4 or below). In our patient sample, there were only two patients fused to T1. For the sake of creating comparable and meaningful groups, the Ilharreborde method's recommendation of fusion to T1 was also considered to be "Correct" if the actual fusion was to T2. These recommendations are summarized below in Table 2.

A recent review from Trobisch [29] uses curve type and pre-surgical shoulder balance only to create a simplified algorithm for UIV selection. For Lenke curve types 1, 3, or 6, the recommended UIV is to T2 for left shoulder elevation, T3 for level shoulders, and T4 (or below) for left shoulder elevation. Fusion to T2 is recommended for all Lenke curve types 2 or 4. Fusion to the upper end vertebra (EV) of the thoracolumbar/lumbar curve is recommended in Lenke curve type 5. The amount of "shoulder elevation" is not defined in the original description; for the purposes of this study, "elevation" was considered to be |RSH|≥15 mm, while "level shoulders" was considered to be |RSH|<15 mm. These recommendations are summarized below in Table 3.

Table 3 Trobisch recommendations for UIV based on Lenke curve type

Lenke curve type(s)	UIV selection
1, 3, or 6	T2 for preoperative left shoulder elevation T3 for level shoulders T4 for preoperative right shoulder elevation
2 or 4	T2
5	Upper EV of thoracolumbar/lumbar curve

Table 4 Patient demographics

Patient demographics	
Male	42
Female	129
Age	14.7±1.8 years
Latest follow-up	2.3±1.1 years

Results

Two hundred sixty-three consecutive AIS patients were reviewed. One hundred seventy-one patients were included at an average 2.3±1.1 year follow-up. Using RSH, all patients could be evaluated for shoulder balance. Patient demographics, Lenke curve types, and UIV selections are presented in Tables 4, 5, and 6.

There was no clearly superior methodology for our cohort of patients. Using the Lenke method, correct UIV selection resulted in shoulder imbalance in 16.0% of patients; incorrect UIV selection resulted in shoulder imbalance in 14.6% of patients. Using the Ilharreborde method, correct UIV selection resulted in shoulder imbalance in

Table 5 Patient selection by Lenke curve type

	Lumbar modifier			
Lenke curve type	A	B	C	Total
1	36	21	34	91
2	21	9	6	36
3	2	0	2	4
4	0	0	3	3
5	0	0	24	24
6	0	0	13	13
Total	59	30	82	

Table 6 UIV selection for all included subjects

UIV selection	
UIV	Number
T1	2
T2	48
T3	48
T4	55
T5	7
T6	2
T7	0
T8	0
T9	1
T10	5
T11	3

14.9% of patients (16.4% of Lenke 1 and 2 only); incorrect UIV selection resulted in shoulder imbalance in 15.4% of patients (13.9% of Lenke 1 and 2 only). Using the Trobisch method, correct UIV selection resulted in shoulder imbalance in 21.9% of patients; incorrect UIV selection resulted in shoulder imbalance in 10.2% of patients. These data are summarized in Table 8 and graph 1.

In our cohort, posterior spinal fusion resulted in a decreased overall incidence of shoulder imbalance, from a 31.0% pre-surgical incidence to a 15.2% post-surgical incidence (p=0.0008). Overall, absolute RSH was decreased from 10.6±7.9 mm to 7.9±6.2 mm (p=0.0007); the overall absolute T1 tilt remained unchanged at 5°. There was an 8.8% incidence of new shoulder imbalance. These findings are presented in Tables 7 and 8.

Case Example

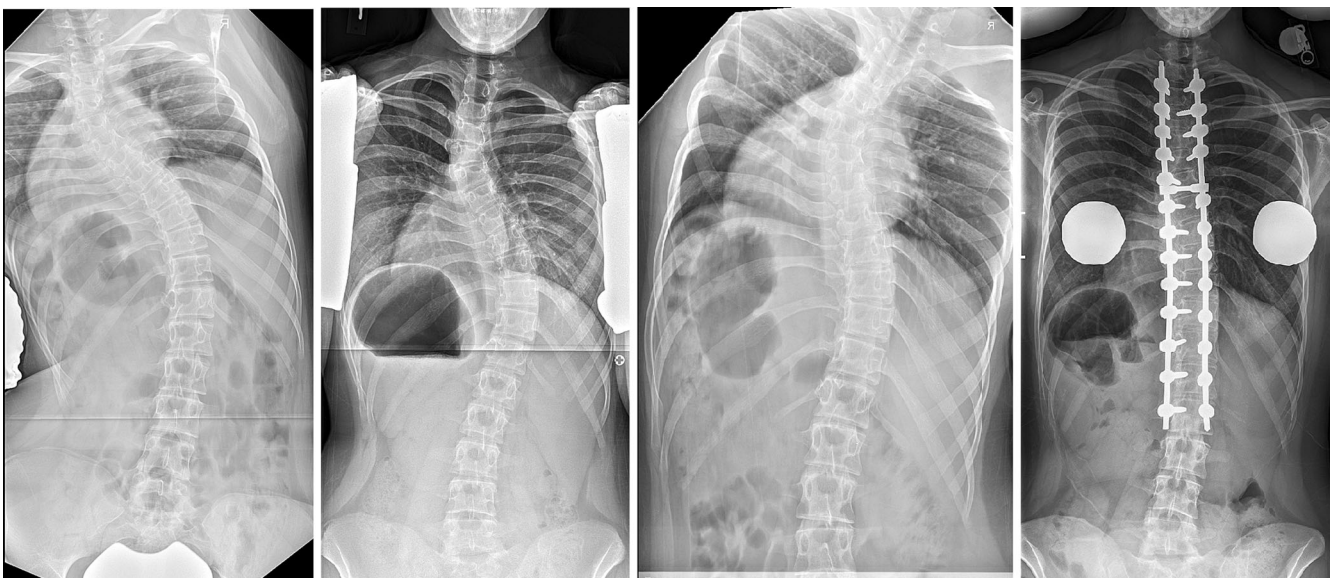
As an example of our methodology, we present a female diagnosed with AIS who underwent PSF T2-L2 with pedicle screw instrumentation at the age of 12 years and 9 months. Her curve was a Lenke 2A (PT; T2–6 45° (44°), MT; T7–12 51° (20°)). Pre-surgically, her left shoulder was elevated (−22.0 mm) and remained elevated at 4.6-year follow-up (−23.1 mm).

All of the methods described would recommend fusion to T2 for this patient. For the Lenke method, this is based on the degree of the PT curve (45°>30°). For the Ilharreborde method, α-(β/2)≡44–(20/2)=34°>15°, and so recommended fusion is T2 or T3. The Trobisch method would recommend fusion to T2 for all Lenke type 2 curves. Despite a "correct" fusion to T2 for this patient based on all methodologies, this patient developed a significant shoulder imbalance, as shown in Fig. 1.

Discussion

Shoulder balance is an established predictor of post-surgical satisfaction and self-image in AIS patients, and the selection of the UIV as part of the fusion construct is an important determinant of shoulder balance. The results of this retrospective analysis, however, show that published methods for UIV selection are not effective at reducing the incidence of post-surgical shoulder imbalance.

This study is not without limitation. After a review of radiographic markers for shoulder balance, several methods have been validated for accuracy in this area [3, 9, 10, 22, 25, 27, 30]. However, we found the only reproducible methods to be T1 tilt, RSH, and clavicle angle. Several components of asymmetry have been discussed, both posterior-anterior [31] and medial-lateral [22], and RSH is most likely a reflection of both the anterior and medial components of overall balance. Medial balance has been shown to have a greater correlation with clinical balance [22]. RSH has also been shown to have excellent inter-observer reliability. Prior descriptions have used 10 mm as a cutoff for imbalance in a reproducibility study [10], or a



Graph 1. Incidence of shoulder imbalance by UIV selection method. *Unlike the original recommendation, this method applied to all subjects, regardless of curve type.

Table 7 Pre- and postoperative radiographic parameters and overall incidence of shoulder imbalance

	Preoperative	Postoperative	*p* value
RSH	10.6±7.9 cm	7.9±6.2 cm	*0.0007*
T1 tilt	5.0±3.4°	5.0±3.7°	0.99
Balanced	118	145	*0.0008*
Unbalanced	53	26	
% Unbalanced	31.0%	15.2%	
Newly unbalanced		15	

step-wise grading of minimal (10–20 mm), moderate (20–30 mm), or significant imbalance (>30 mm) [14, 20]. For the purpose of this study, 15 mm (a "moderate" value by prior description) was defined as shoulder imbalance before data collection.

We found clavicle angle to be of very limited utility, particularly because the unique morphology of the clavicle made inter-observer reliability poor in our patient sample. We found that the coronal T1 tilt did not change after surgery for these patients. Additionally, we did not find T1 tilt to be an independent predictor of pre- or post-surgical shoulder imbalance, similar to prior findings [14, 16]. There is speculation that residual T1 tilt may be a source of long-term neck pain [14]; however, this is unsubstantiated. In an institutional effort to limit radiation for the patient, we have excluded any radiographic parameters that are lateral to or including the coracoid process. Clinical measurements may ultimately have a more meaningful representation of patient self-image [25]. These measurements are not available in a retrospective manner.

Overall, we have demonstrated that shoulder imbalance can be decreased with surgical correction of AIS. Prior reports have estimated post-surgical shoulder imbalance to be between 7 and 31% [3, 16], consistent with this series. This is largely dependent on the method used, and so it is difficult to compare our values to historical controls. For this reason, we chose a moderate value for imbalance for a meaningful conclusion.

Table 8 Incidence of shoulder imbalance by UIV selection method

	Postoperative shoulder balance		
UIV Selection	Balanced	Unbalanced	% Unbalanced
	Lenke Method		
"Correct"	63	12	16.0%
"Incorrect"	82	14	14.6%
	*Ilharreborde method**		
"Correct"	55	10	15.4%
"Incorrect"	90	16	15.1%
	Ilharreborde method–Lenke 1/2 only		
"Correct"	44	9	17.0%
"Incorrect"	64	10	13.5%
	Trobisch method		
"Correct"	61	18	22.8%
"Incorrect"	84	8	8.7%

*Unlike the original recommendation, this method applied to all subjects, regardless of curve type

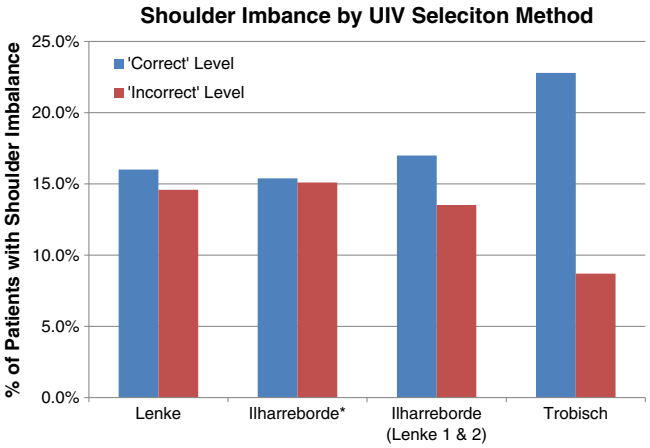


Fig. 1. Pre- and post-surgical radiographs of a patient who developed shoulder imbalance despite "correct" UIV selection.

In this cohort, the incidence of new shoulder imbalance was 8.8%. We were unable to find a prior value for new shoulder imbalance, and we cannot comment on this from a historical perspective. Overall, we feel that this value is somewhat higher than expected. However, given the sensitivity of our methodology, this could be approaching the standard error for this measurement. This was not available from prior studies, and a comparison to healthy controls was not performed for this study.

The concept of UIV selection should include additional clinical and radiographic concerns. Proximal junctional kyphosis (PJK), adding-on and residual curve progression are all concerns in selection of UIV; motion preservation is less of a concern as the thoracic spine is inherently more rigid due to attachments of the ribs and sternum. The incidence of post-surgical PJK was found to be 27%, although the UIV was not found to have any relation [12]. Preservation of intervertebral elements and various instrumentation techniques may reduce biomechanical forces across the upper thoracic spine [4]. Neither these techniques nor PJK appear to have a correlation with shoulder imbalance [23]. Open triradiate cartilage as a surrogate for skeletal immaturity is a risk factor for adding-on of the proximal curve [28], although the effect it has on shoulder balance is unclear.

Because of the multitude of operative variables affecting balance and persistence of shoulder imbalance even with the advent of modern techniques, intraoperative imaging may be of some importance. Computer-aided guidance, automated reconstruction, and three-dimensional imaging of both surface and bony geometry may assist in future determination of level selection and overall balance [5, 6, 24]. To date, there is no study that correlates overall post-surgical balance and advanced intraoperative imaging for AIS.

Overall, UIV selection does not appear to be an independently reliable predictor of shoulder balance at intermediate follow-up. UIV selection appears to be one variable of many in the ultimate shoulder balance for patients treated with PSF for AIS. There are many additional operative variables: handling of adjacent soft tissues, spinous processes, interspinous ligaments, instrumentation type, compression and distraction, concomitant sagittal correction, and radius

of curvature for the proximal rods. In the post-surgical period, trunk balance, neck pain, posture, and positioning for radiographs also affect overall shoulder balance. The complexity of PT curve correction is underscored in our case example, where the shoulder imbalance was overcorrected from a modern all pedicle screw construct. The treating surgeon should be aware that although recommendations exist for UIV selection, there are additional technical and radiographic variables that should be considered.

Disclosures

Conflict of Interest: Benjamin T. Bjerke, MD, MS, Zoe B. Cheung, MS, Grant D. Shifflett, MD, Sravisht Iyer, MD, Peter B. Derman, MD, MBA, and Matthew E. Cunningham, MD, PhD have declared that they have no conflict of interest.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Informed Consent: Informed consent was obtained from all patients for being included in the study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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