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The Amount of Relative Curve Correction Is More Important Than Upper Instrumented Vertebra Selection for Ensuring Postoperative Shoulder Balance in Lenke Type 1 and Type 2 Adolescent Idiopathic Scoliosis

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Study Design. Retrospective review of a prospectively collected multicenter database.
Objective. To assess how "overcorrection" of the main thoracic curve without control of the proximal curve increases the risk for shoulder imbalance in Lenke type 1 Adolescent Idiopathic Scoliosis (AIS).
Summary of Background Data. Postop shoulder imbalance is a common complication following AIS surgery. It is thought that a more cephalad upper-instrumented vertebra (UIV) decreases the risk of shoulder imbalance in Lenke type 1 and 2 curves; however, this has not been proven.

Methods. Thirteen surgeons reviewed preop and 5-year postop clinical photos and PA radiographs of patients from a large multicenter database with Lenke type 1 and 2 AIS curves who were corrected with pedicle screw/rod constructs. Predictors of postop shoulder imbalance were identified by univariate analysis; multivariate analysis was done using the classification and regression tree method to identify independent drivers of shoulder imbalance.
Results. One hundred forty-five patients were reviewed. The UIV was T3–T5 in 87% of patients, with 8.9% instrumented up to T1 or T2. Fifty-two (36%) had shoulder imbalance at 5 years. On classification and regression tree analysis when the proximal thoracic (PT) Cobb angle was corrected more than 52%, 80% of the patients had balanced shoulders. Similarly, when the PT curve was corrected less than 52% and the main thoracic (MT) curve was corrected less than 54%, 87% were balanced. However, when the PT curve was corrected less than 52%, and the MT curve was corrected more than 54%, only 41% of patients had balanced shoulders ($P = 0.05$). This relationship was maintained regardless of the UIV level.
Conclusion. In Lenke type 1 and 2 AIS curves, significant correction of the main thoracic curve (>54%) with simultaneous "under-correction" (<52%) of the upper thoracic curve resulted in shoulder height imbalance in 59% of patients, regardless of the UIV. This suggests the PT curve must be carefully scrutinized in order to optimize shoulder balance, especially when larger correction of the MT curve is performed.
Key words: AIS, curve correction, deformity, Lenke type 1 curves, Lenke type 2 curves, scoliosis, shoulder balance, shoulder imbalance, surgery, upper instrumented vertebra.
Level of Evidence: 2
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S houlder height imbalance is a significant potential complication following surgical correction for patients with Lenke type 1 and type 2 adolescent idiopathic

scoliosis (AIS) that can result in poor cosmetic result, patient dissatisfaction, and in some cases require reoperation.[1] Strategies for selecting fusion levels when correcting idiopathic scoliosis have been widely studied and have changed substantially with the evolution of spinal column instrumentation. Modern pedicle screw and rod constructs allow surgeons to achieve significant curve corrections, however if only the main thoracic curve is corrected without regard to the proximal curve, shoulder height imbalance may result. Several techniques have been described for mitigating postoperative shoulder imbalance; however, this complication remains prevalent in idiopathic scoliosis patients, reported in up to 25% or more of cases.[1] In this study we seek to analyze the impact of the amount of correction of both the main thoracic (MT) and proximal thoracic (PT) curves in relationship to each other, and to describe a simple strategy for decreasing the risk of shoulder height imbalance.

Selection of the upper-instrumented vertebra (UIV) has been proclaimed as a key element in protecting against postoperative shoulder imbalance, with surgeons advocating instrumenting the PT curve when correction of the MT curve would worsen any existing imbalance.[2,3] Many authors emphasize that UIV selection in Lenke 1 and 2 curves is the key to mitigating shoulder imbalance, and most suggest including a more proximal UIV (typically T2 or T3) when patients with right-sided Lenke 1 and 2 curves have a high left shoulder at baseline.[2,4] In 2008, Ilharreborde *et al* reported their technique for UIV selection in which they consider the rigidity of the PT curve, T1 and shoulder tilt, and the anticipated effect of correcting the MT curve. Other authors have also recommended that more proximal fusion levels should be included when the left shoulder is high preoperatively.[4–6]

In these prior works, the recommendations for mitigating shoulder imbalance most often center on which proximal vertebra to include in the fusion. There is generally little discussion around the correction maneuvers in the PT curve, and even less focus on the amount of PT curve correction relative to the amount of MT curve correction. To our knowledge there are no studies that analyze the interplay between the amount of correction of the MT curve and the amount of correction of the PT curve and how these relative correction amounts contribute to shoulder balance after surgical correction. In the clinical experience of the senior author, careful attention to the preoperative shoulder balance, PT curve flexibility, and relative amount of correction of both the MT and PT curves (whether instrumented or spontaneous) is critical to preventing shoulder imbalance postoperatively. Thus, in this study we investigated the hypothesis that significant correction of the main thoracic curve with simultaneous relative "under-correction" of the proximal thoracic curve will lead to postoperative shoulder height imbalance in the majority of Lenke Type 1 and 2 AIS cases.

MATERIALS AND METHODS

Surgeon Reviewers

Thirteen independent spine surgeons reviewed preoperative and 5-year postoperative clinical photos and PA full-length standing radiographs of the spine of patients from a large multicenter database. Participating surgeons scored anterior clinical photographs, posterior clinical photographs, and PA radiographs each as either: 1) Left shoulder high, 2) right shoulder high, 3) shoulders equal, or 4) unable to discern. All surgeon answers were recorded in an electronic survey format. Inter- and intraobserver reliability calculations were made for each method of assessing shoulder balance using Fleiss kappa calculations. For the purpose of analysis, the simple majority was used to determine a given patient's shoulder balance. When there was no clear majority, the answer given by the senior author (and most senior surgeon on the panel) was used as the gold standard.

Patients

All deidentified patient radiographs and clinical photos were provided by a multicenter research study group database. This database was queried for patients with Lenke type 1 or type 2 AIS and a minimum of 5-year follow-up. Patients were included if they had either a Lenke type 1 or type 2 adolescent idiopathic scoliosis, with a PT Cobb angle greater than 20° and an MT Cobb angle of greater than 40°, and underwent posterior surgical correction with use of pedicle screw/rod constructs. There were no specific inclusion/exclusion criteria for Risser signs or rotation grades. Patients in which thoracic hooks were utilized were only included if the majority of thoracic fixation was with pedicle screw instrumentation. Cases of congenital, neuromuscular, or Lenke type 3–6 scoliosis were excluded from this analysis.

Statistics

Predictors of postoperative shoulder imbalance were identified by univariate analysis; multivariate analysis was done using the classification and regression tree method to identify independent drivers of shoulder imbalance. Fleiss kappa statistics were used to assess inter- and intraobserver reliability for each of the methods used for the assessment of shoulder balance.

RESULTS

One hundred forty-five patients with average age of 14.6 years met the inclusion criteria and were reviewed. The UIV was T3-T5 in 87% of patients, with 8.9% instrumented up to T1 or T2, and 3.4% of UIVs at T6-T7 (Table 1). The interobserver reliability of each method for assessing shoulder balance (k = Fleiss kappa) both pre- and postoperatively showed fair agreement across all 13 reviewing surgeons for each method: anterior clinical photos (k = 0.20), posterior clinical photos (k = 0.30), and PA X-ray (k = 0.31). The intraobserver reliability was more consistent, with anterior clinical photos showing the highest intraobserver reliability (k = 0.68) and PA X-rays showing moderate intraobserver agreement (0.59). Given that anterior clinical photos had the highest intraobserver reliability and because it has been shown that patient perception of shoulder balance does not strongly correlate with radiographic measures, the anterior

TABLE 1. Patient and Surgical Characteristics	
N	145
Female	113
Age at surgery	14.6
Upper instrumented vertebra	
T1	1 (0.7%)
T2	12 (8.3%)
T3	33 (22.8%)
T4	71 (49%)
T5	23 (15.9%)
T6	4 (2.8%)
T7	1 (0.7%)
Postoperative shoulder balance	
Balanced	93 (64%)
Right high	4 (3%)
Left high	48 (33%)

clinical photograph was used as the standard for the remaining calculations.[7,8]

Fifty-two of the 145 patients (36%) had shoulder imbalance at 5 years as determined by anterior clinical photographs with 33% of left shoulders being high, and 3% with the right shoulder high. On classification and regression tree analysis: when the PT Cobb angle was corrected more than 52%, 80% of the patients had balanced shoulders. Similarly, when the PT curve was corrected less than 52% and the MT curve was corrected less than 54%, 87% were balanced. However, when the PT curve was corrected less than 52%, and the MT curve was corrected more than 54%, only 41% of patients had balanced shoulders ($P = 0.05$) (Figure 1). Importantly, this relationship was maintained regardless of the UIV level. There was no difference in the amount of proximal thoracic correction (percentage) whether the UIV was T1–2, T3–3, or distal to T4 ($P = 0.32$). In addition, there were no significant differences in patients falling into one correction "category" *versus* another based on the UIV (Table 2).

DISCUSSION

In this study of Lenke type 1 and 2 adolescent idiopathic scoliosis patients we demonstrate that relative "under-correction" of the proximal thoracic curve (less than 52% Cobb angle correction) with significant correction of the main thoracic curve (greater than 54% Cobb angle correction) led to postoperative shoulder height imbalance in nearly 60% of patients, independent of the upper instrumented vertebra level. Conversely, when the PT curve is corrected by more than 52%, shoulder height imbalance was seen in only 20% of cases. Additionally, when the PT curve was corrected less than 52% with simultaneous "under-correction" of the MT curve (less than 54%), imbalance was seen in 13% of patients. These relationships were seen independent of the level chosen as the UIV. These findings suggest that the amounts of correction of the main thoracic and proximal thoracic curves relative to each other

are paramount in achieving symmetric shoulder height postoperatively. In other words, if the proximal thoracic curve is not corrected (either via instrumented correction or spontaneously) there is a significant increase in the incidence of shoulder imbalance postoperatively. To our knowledge this is the first study analyzing the amount of correction of both the main thoracic and proximal thoracic curves relative to each other and how these relative corrections may contribute to postoperative shoulder height imbalance.

Numerous prior works have touted the importance of selecting the appropriate UIV level for achieving symmetric shoulder heights following scoliosis correction.[2–4,7,9] Most surgeons recommend including a more proximal UIV when the patient is at higher risk for shoulder imbalance; typically when the left shoulder is high at baseline, or more simply when correction of the main thoracic curve is predicted to worsen shoulder height asymmetry with correction. Errico *et al* have published recommendations to include T2 as the UIV when the left shoulder is high, T3 if shoulders are level, and T4 if the left shoulder is down for the typical right-thoracic Lenke 1 curves.[4] Ilharreborde *et al*[3] also propose a similar algorithm to determine the UIV; considering the flexibility of the PT and MT curves as well as how correction of the MT is predicted to impact shoulder heights. These important studies, along with others, have highlighted the importance of controlling the proximal curve by instrumenting a more cranial UIV when the patient is at greater risk for shoulder imbalance. However, in most of these studies the level of instrumentation is primarily emphasized as the key determinant of shoulder imbalance; with relatively little discussion of the corrective maneuvers needed to achieve shoulder symmetry, *i.e.*, compression across the convexity and distraction across the concavity. In addition, there has been little discussion of the relative amount of correction of the MT and PT curves with respect to each other; which in the present study is highlighted as a key element in achieving equal shoulder heights.

We believe the findings of the present study suggest that a more proximal UIV alone may be inadequate to prevent shoulder imbalance; rather, both a more proximal UIV and careful attention to the relative PT curve correction are critical. With the modern use of thoracic pedicle screw and rod constructs, surgeons now have the ability to achieve a high level of control of the spine during corrective maneuvers. Coupled with posterior column osteotomy techniques, the use of pedicle screw and rod constructs essentially allows the surgeon to easily manipulate the spine in the typical young adolescent patient. This ability to manipulate the spine allows surgeons to significantly correct main thoracic curves. However, as we have shown, if the PT curve is not also considered with this correction the result can be significant shoulder asymmetry. By instrumenting the PT curve and choosing a more proximal UIV, the surgeon achieves control of the PT curve and can thus avoid pushing the left shoulder high as the MT curve is corrected. Importantly, the results of the present study highlight that simply instrumenting a more proximal level does not itself reduce the odds of
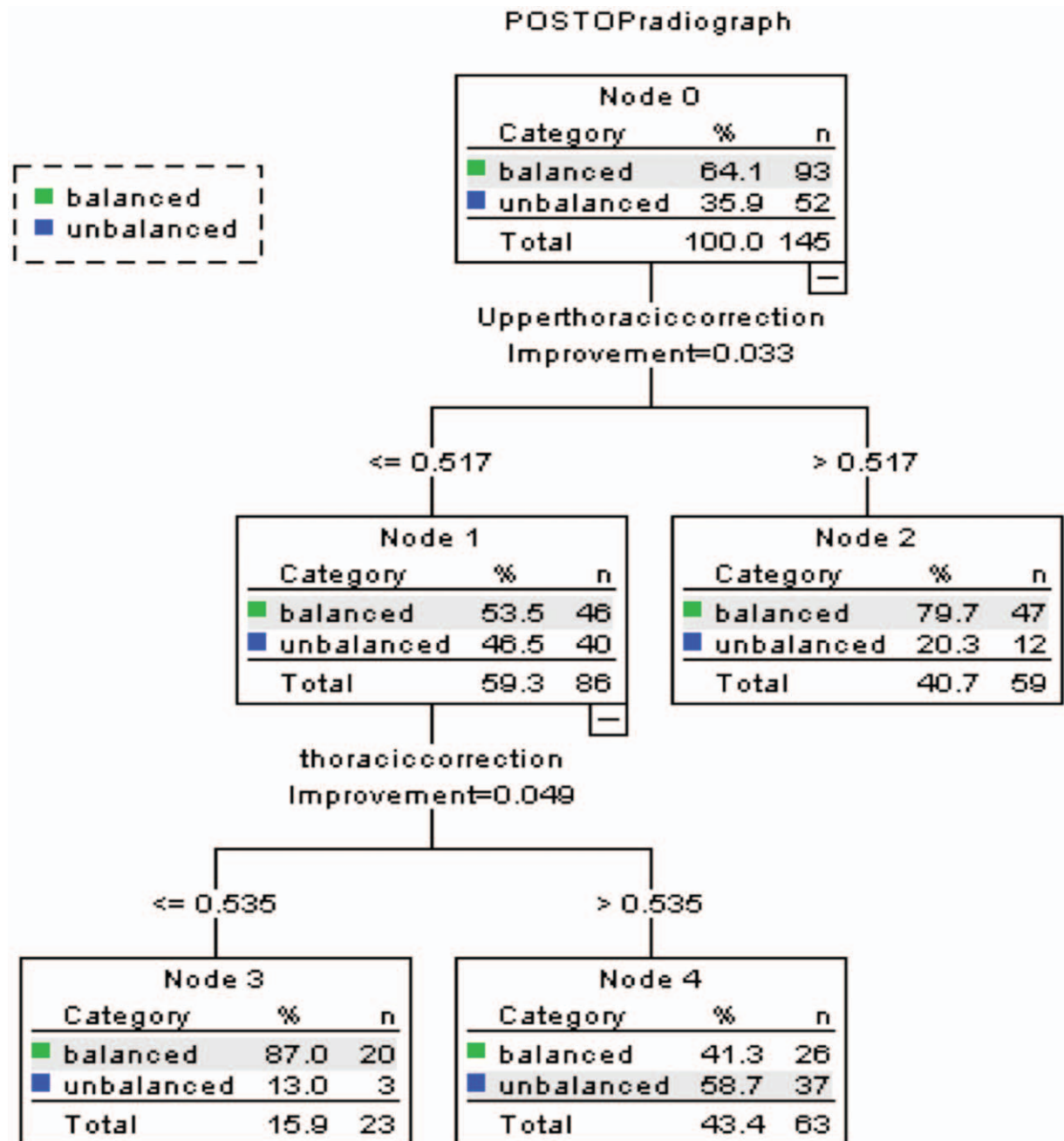
Figure 1. Classification and regression tree (CART) analysis for predicting shoulder imbalance.

postoperative shoulder imbalance. Rather, achieving appropriate correction of the PT curve in relation to the amount of correction obtained in the MT curve is critical.

When the MT curve is corrected significantly (greater than 54% as our results show), the PT curve must also be corrected to "compensate" for this MT correction. This can be achieved through compression across the convexity and distraction through the concavity of the PT curve. Thus with a more proximal UIV, the surgeon has the ability to perform such compression/distraction maneuvers of the PT curve following correction of the MT curve. In order to avoid pushing the left shoulder high with MT correction, we advocate the following maneuvers.

In agreement with Errico and others, in general we recommend instrumenting to T2 if the left shoulder is high preoperatively, T3 if the shoulders are balance, and T4 if the left shoulder is down in a right-thoracic Lenke Type 1 or 2 AIS patient.

Compression across the convexity and distraction across the concavity of the PT curve should be done in order to mitigate shoulder imbalance. Importantly, the surgeon must consider the sagittal plane when deciding which side of the PT curve to address first. In general, compression across thoracic pedicle screws will decrease kyphosis across the compressed segments, while distraction will increase kyphosis. In the majority of AIS cases there is relative thoracic

TABLE 2. Upper Thoracic Correction					
Dependent Variable: Upper Thoracic Correction					
UIV	Mean Correction	Std. Dev.	N		*P*
T1-2	39.6%	0.258	13		0.321
T3-4	46.3%	0.223	104		
Distal to T4	40.2%	0.222	28		
Total	44.5%	0.226	145		
Correction Categories					
		UIV			**Total**	
		T1−2	T3−4	Distal to T4		*P*
>52% Upper thoracic correction	Count	4	44	11	59	0.824
	%	6.80%	74.60%	18.60%	100.00%	
<=52% Upper T Correction, <=54% thoracic correction	Count	2	15	6	23	
	%	8.70%	65.20%	26.10%	100.00%	
<52% Upper T Correction, >54% thoracic correction	Count	7	45	11	63	
	%	11.10%	71.40%	17.50%	100.00%	
Total	Count	13	104	28	145	
	%	9.00%	71.70%	19.30%	100.00%	

hypokyphosis. Thus, when more thoracic kyphosis is needed, we suggest starting with distraction across the concavity of the PT curve. This will build more kyphosis into the correction while still allowing for "pushing" the right shoulder up and the left shoulder down to maintain balance. After distraction across the concavity, compression should be performed across the convexity to further bring the left shoulder down and maintain balance. This can be done with the side of the concavity "locked" so that kyphosis is maintained.

Surgeons must consider these corrective maneuvers if thoracic transverse process (TP) hooks are to be used in place of pedicle screws. For example, on the convexity of the curve the proximal thoracic TP hook must be placed on the cranial TP with the hook aimed caudally, while the caudal hook must be placed on the caudal edge of the TP and aimed cranially to allow the surgeon to compress across these levels. One benefit of pedicle screw instrumentation is that such constraints are avoided. Figure 2A and B shows two specific cases that nicely illustrate these concepts, with the patient in Figure 2A showing shoulder imbalance despite instrumentation to T2 and the patient in Figure 2B showing shoulder balance with correction of both the main and proximal thoracic curves.

The results of this study do not indicate that the surgeon must achieve full instrumented control of the proximal thoracic curve in all cases. Indeed, Lenke et al have shown that the flexible PT curve will consistently correct spontaneously with MT instrumentation in Lenke type 1 cases.[10] Rather, the results of the present study indicate only that relative correction of the PT curve is important but does not discriminate whether the PT correction is achieved spontaneously or deliberately via instrumentation. We believe by assessing the outcomes at 5 years postoperatively all the spontaneous correction of the PT curve would most likely have occurred by that point. Thus, those left with residual shoulder imbalance may have been better served with deliberate correction of the PT curve with instrumentation and corrective maneuvers. Another potential limitation of this study is highlighted in the study by Smith et al,[7] in which they showed that patient perceptions of shoulder height do not always correlate with clinical assessments. In this study the assessment of shoulder asymmetry was based purely on clinical photograph and radiographic assessment by surgeons; patient perceptions of shoulder balance were not considered. It has also been shown that shoulder asymmetry can exist both medially due to T1 tilt elevating the first rib as well as laterally as seen with clavicle height differences.[11,12]

We did not discriminate between these two features of shoulder imbalance. Additionally, T1 tilt may be concordant or discordant with shoulder height, complicating the assessment and required treatment.[13]
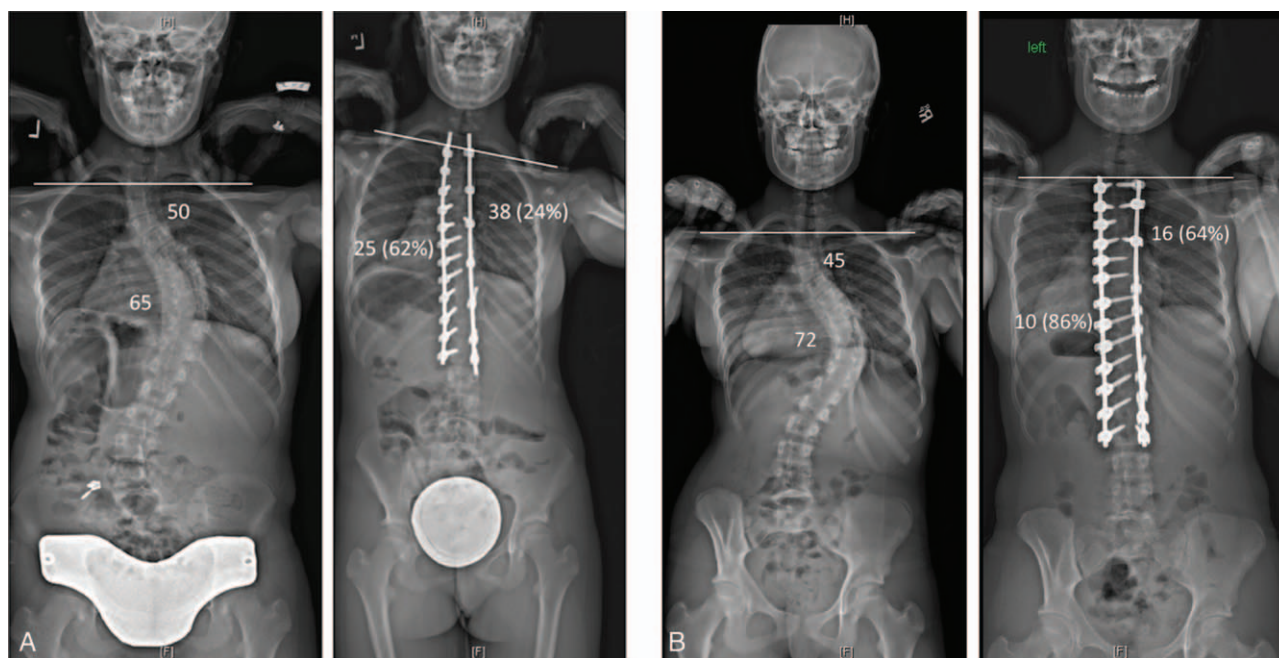
Figure 2. (**A**) This patient was instrumented up to T2; however, the proximal curve was under-corrected relative to the main curve, resulting in shoulder height imbalance postoperatively. (**B**) This Lenke Type 2 AIS patient was instrumented to T2. The proximal curve was addressed with distraction across the PT concavity to both correct the coronal plane and increase kyphosis. Compression of the convexity was then performed, resulting in balanced shoulders.

CONCLUSION

In Lenke type 1 and type 2 AIS curves, significant correction of the main thoracic curve (>54%) with simultaneous "under-correction" (<52%) of the upper thoracic curve resulted in shoulder height imbalance in 59% of patients, regardless of the UIV. These findings suggest the correction of the PT curve relative to the amount of correction of the MT curve has a greater impact on postop shoulder balance than does the UIV selection. However, maximizing PT curve correction may well require a proximal UIV, but the corrective measures must also be applied to the PT curve to obtain/maintain optimal shoulder balance. Therefore, the PT curve must be carefully scrutinized in order to optimize shoulder balance both from the standpoint of UIV selection as well as correction maneuvers, especially when larger correction of the MT curve is planned.

> ## ➤ Key Points

- ❑ Postop shoulder imbalance is a common complication following AIS surgery.
- ❑ In Lenke type 1 and 2 AIS curves, significant correction of the main thoracic curve (>54%) with simultaneous "under-correction" (<52%) of the upper thoracic curve resulted in shoulder height imbalance in 59% of patients, regardless of the UIV.
- ❑ The proximal thoracic curve must be carefully scrutinized in order to optimize shoulder balance, especially when larger correction of the main thoracic curve is performed.

References

1. Smyrnis PN, Sekouris N, Papadopoulos G. Surgical assessment of the proximal thoracic curve in adolescent idiopathic scoliosis. *Eur Spine J* 2009;18:522–30.
2. Suk SI, Kim WJ, Lee CS, et al. Indications of proximal thoracic curve fusion in thoracic adolescent idiopathic scoliosis: recognition and treatment of double thoracic curve pattern in adolescent idiopathic scoliosis treated with segmental instrumentation. *Spine (Phila Pa 1976)* 2000;25:2342–9.
3. Ilharreborde B, Even J, Lefevre Y, et al. How to determine the upper level of instrumentation in Lenke types 1 and 2 adolescent idiopathic scoliosis: a prospective study of 132 patients. *J Pediatr Orthop* 2008;28:733–9.
4. Trobisch PD, Ducoffe AR, Lonner BS, et al. Choosing fusion levels in adolescent idiopathic scoliosis. *J Am Acad Orthop Surg* 2013;21:519–28.
5. Chang DG, Kim JH, Kim SS, et al. How to improve shoulder balance in the surgical correction of double thoracic adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)* 2014;39:E1359–67.
6. Cao K, Watanabe K, Hosogane N, et al. Association of postoperative shoulder balance with adding-on in Lenke Type II adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)* 2014;39: E705–12.
7. Smith PL, Donaldson S, Hedden D, et al. Parents' and patients' perceptions of postoperative appearance in adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)* 2006;31:2367–74.
8. Yang S, Feuchtbaum E, Werner BC, et al. Does anterior shoulder balance in adolescent idiopathic scoliosis correlate with posterior shoulder balance clinically and radiographically?. *Eur Spine J* 2012;21:1978–83.
9. Kuklo TR, Lenke LG, Graham EJ, et al. Correlation of radiographic, clinical, and patient assessment of shoulder balance following fusion versus nonfusion of the proximal thoracic curve in adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)* 2002;27:2013–20.
10. Kuklo TR, Lenke LG, Won DS, et al. Spontaneous proximal thoracic curve correction after isolated fusion of the main thoracic curve in adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)* 2001;26:1966–75.

11. Ono T, Bastrom TP, Newton PO. Defining 2 components of shoulder imbalance: clavicle tilt and trapezial prominence. *Spine (Phila Pa 1976)* 2012;37:E1511–6.

12. Qiu XS, Ma WW, Li WG, et al. Discrepancy between radiographic shoulder balance and cosmetic shoulder balance in adolescent idiopathic scoliosis patients with double thoracic curve. *Eur Spine J* 2009;18:45–51.

13. Menon KV, Tahasildar N, Pillay HM, et al. Patterns of shoulder imbalance in adolescent idiopathic scoliosis: a retrospective observational study. *J Spinal Disord Tech* 2014;27:401–8.