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Distal adding-on in Lenke 1–2 adolescent idiopathic scoliosis: A focused analysis of the Lenke 1a subgroup

Lenke 1-2 adölesan idiyopatik skolyozda distal adding-on: Lenke 1a alt grubunun odaklanmış analizi

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ABSTRACT

Aim: Distal adding-on (DOA) is an important postoperative concern after thoracolumbar fusion in adolescent idiopathic scoliosis (AIS); however, its mechanical drivers, particularly the role of sagittal spinopelvic compensation, remain poorly understood.

Materials and Methods: We reviewed Lenke type 1 and 2 AIS patients with a minimum 2-year follow-up. To isolate biomechanical failure patterns and minimize confounding variables, a targeted, exploratory analysis was performed on the Lenke 1A subgroup (n=21). Firth penalized logistic regression was utilized as an exploratory method to identify preliminary "radiographic signals" rather than definitive associated factors, given the low-event nature of the cohort.

Results: We analyzed 72 patients and found that 6.9% (n=5) experienced distal adding-on (DOA). A preliminary analysis of the Lenke 1A subgroup (n=21) revealed a potential failure pattern: all 3 DOA events occurred when the lowest instrumented vertebra (LIV) was placed at the last touched vertebra (LTV) level. Conversely, extending the fusion beyond this point was associated with a reduced risk of this outcome (p=0.030). Additionally, we identified a potential 'warning sign': patients who developed DOA showed a more anteverted pelvic tilt after surgery compared to those who did not (-3.67° ± 12.50° vs. 8.39° ± 6.41°, p=0.016).

Conclusions: DOA remains a rare but relevant clinical challenge. Our exploratory findings suggest that the LTV may be an insufficient standalone landmark in Lenke 1A subtypes, and that pelvic anteversion may serve as a mechanical warning sign for potential junctional failure. These observations underscore the necessity of a more comprehensive, three-dimensional approach to LIV selection and require further prospective validation studies.

Keywords: Adolescent idiopathic scoliosis, distal adding-on, posterior fusion, lowest instrumented vertebra, spinopelvic parameters

ÖZ

Amaç: *Distal adding-on (DOA), adölesan idiyopatik skolyozda (AİS) torakolomber füzyon sonrası önemli bir postoperatif sorundur; ancak bunun mekanik belirleyicileri, özellikle sagital spinopelvik kompanzasyonun rolü, tam olarak anlaşılamamıştır.*

Gereç ve Yöntem: *En az 2 yıllık takibi olan Lenke tip 1 ve 2 AİS hastaları incelendi. Biyomekanik başarısızlık modellerini izole etmek ve karıştırıcı değişkenleri en aza indirmek amacıyla, Lenke 1A alt grubunda (n=21) hedefe yönelik, keşifsel bir analiz yapıldı. Kohorttaki düşük olay sayısı nedeniyle, kesin ilişkili faktörlerden ziyade öncü "radyografik sinyalleri" tanımlamak için keşifsel bir yöntem olarak Firth penalized logistik regresyon kullanıldı.*

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Bulgular: *72 hastayı analiz ettik ve %6,9'unda (n=5) distal adding-on (DOA) geliştiğini saptadık. Lenke 1A alt grubunun (n=21) ön analizi, potansiyel bir başarısızlık modelini ortaya koydu: 3 DOA olayının tamamı, en alt enstrümante vertebra (LIV) "last touched vertebra" (LTV- son temas eden vertebra) seviyesine yerleştirildiğinde gerçekleşti. Buna karşılık, füzyonu bu noktanın ötesine uzatmak, bu sonuç riskinin azalmasıyla ilişkiliydi (p=0,030). Ayrıca, potansiyel bir "uyarı işareti" belirledik: DOA gelişen hastalar, ameliyat sonrası dönemde, DOA gelişmeyenlere göre daha düşük pelvik tilt gösterdiler (-3,67° ± 12,50°'ye karşı 8,39° ± 6,41°, p=0,016).*

Sonuç: *DOA, nadir görülen ancak önemli bir klinik sorun olmaya devam etmektedir. Keşifsel bulgularımız, LTV'nin Lenke 1A alt tiplerinde tek başına yetersiz bir referans noktası olabileceğini ve pelvik anteversiyonun potansiyel başarısızlık için mekanik bir uyarı işareti görevi görebileceğini düşündürmektedir. Bu gözlemler, LIV seçiminde daha kapsamlı, üç boyutlu bir yaklaşıma duyulan ihtiyacı vurgulamakta ve ileriye dönük (prospektif) daha fazla doğrulama çalışması gerektirmektedir.*

Anahtar Sözcükler: *Adölesan idiyopatik skolyoz, distal adding-on, posteriyor füzyon, alt enstrümante vertebra*, spinoplevik parametreler

INTRODUCTION

Adolescent Idiopathic Scoliosis (AIS) surgery aims to achieve a balanced spinal correction while preserving as many motion segments as possible. In Lenke type 1 and 2 curves, the selection of the lowest instrumented vertebra (LIV) is a critical decision that balances curve stability against the preservation of lumbar mobility (1,2). Despite advancements in surgical techniques, distal adding-on (DOA) remains a persistent postoperative concern, leading to a loss of correction and potential clinical dissatisfaction.

Current clinical practice for LIV selection relies heavily on coronal plane landmarks, such as the last touched vertebra (LTV), stable vertebra (SV), or neutral vertebra (NV). Among these, the LTV has been widely utilized as a reference point (3). However, the occurrence of DOA in cases where the LIV was correctly selected suggests that coronal parameters alone may not provide a complete predictive profile for distal junctional stability. While skeletal maturity and curve morphology are known risk factors (4–6), the potential role of sagittal spinopelvic parameters as an associated factor for distal adding on remains an area of investigation.

The interaction between the fused thoracic spine and the mobile lumbar segments is complex. Although much of the literature has focused on curve morphology/flexibility, skeletal maturity, shoulder balance (7,8), it is unclear whether the baseline sagittal profile or early postoperative spinopelvic compensations, such as changes in pelvic tilt (PT), provide "radiographic signals" that precede or accompany the development of DOA. Specifically, whether certain sagittal phenotypes or postoperative sagittal shifts increase the frequency of failure in otherwise correctly selected fusion levels is not well established.

In this study, we aimed to evaluate the reliability of the LTV as a standalone criterion for LIV selection and to explore whether sagittal spinopelvic parameters are associated with DOA. To minimize confounding variables from significant lumbar compensatory curves, we performed a focused analysis on the Lenke 1A subgroup. This approach allows for a clearer observation of the distal junction's behavior and the potential associations of sagittal parameters in a simplified lumbar environment. Given the small sample size and low event rate, this study serves as a hypothesis-generating investigation designed to inform future, larger-scale prospective research.

MATERIAL and METHODS

A retrospective review was performed on 125 consecutive patients who underwent posterior-only spinal fusion for scoliosis at our institution between June 2020 and January 2024. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Başakşehir Cam and Sakura City Hospital Ethics Committee (KAEK/04.03.2026.146). The inclusion criteria were a diagnosis of adolescent idiopathic scoliosis (AIS), a Lenke type 1 or 2 curve patterns, and a minimum clinical and radiographic follow-up of 2 years.

Of the initial 125 patients, 53 were excluded: 52 patients did not meet the Lenke type 1 or 2 classification, and one patient was lost to follow-up. Ultimately, the final study cohort included 72 patients. The study was approved by the Institutional Ethics Committee, and the requirement for informed consent was waived due to the retrospective design.

All patients had standing long-cassette radiographs obtained preoperatively, on the first standing postoperative (“first erect”) radiograph, and at least 2-year follow-up. DOA was defined as an increase in Cobb angle of at least 5° and distalization of the end vertebra or a change in disc angulation of 5° or greater below the LIV from the first erect to the 2-year follow-up radiographs. Shoulder balance was evaluated on standing AP radiographs by measuring the Radiographic Shoulder Height (RSH), defined as the height difference between horizontal lines tangential to the superior soft tissue shadows of each shoulder. Balance was categorized into three severity grades: Balanced (RSH <1.0 cm), Mild Asymmetry (RSH 1.0–2.0 cm), and Marked Asymmetry (RSH >2.0 cm).

The LIV was selected according to the attending surgeon's discretion, considering coronal landmarks (center sacral vertical line [CSVL], stable/neutral vertebrae), skeletal maturity and curve characteristics. We determined last touched vertebra (LTV) on the basis of the CSVL and its relationship to the last lumbar vertebra that the line intersected (9). The LIV was categorized relative to the LTV as: proximal to LTV, at LTV, or distal to LTV.

All radiographic measurements were performed by the first author. Interobserver reliability for the main thoracic Cobb angle was assessed by comparison with independent measurements obtained by the second author (ICC = 0.954). In addition, sagittal spinopelvic measurements had been previously validated in the same patient cohort in a separate study, which reported excellent agreement for thoracic kyphosis (ICC = 0.970).

Statistical analyses were performed using R (v4.5.2). Recognizing the inherent limitations of our sample size and the low event rate, we intentionally avoided over-fitted multivariate models. Instead, Firth's penalized regression was employed to identify robust "signals" associated with DOA. A primary focus was placed on the Lenke 1A subgroup (n=21) to isolate the mechanical behavior of the distal junction, thereby reducing the confounding influence of significant preoperative lumbar modifier curves (Lenke B and C). A p-value < 0.05 was considered statistically significant for this hypothesis-generating analysis.

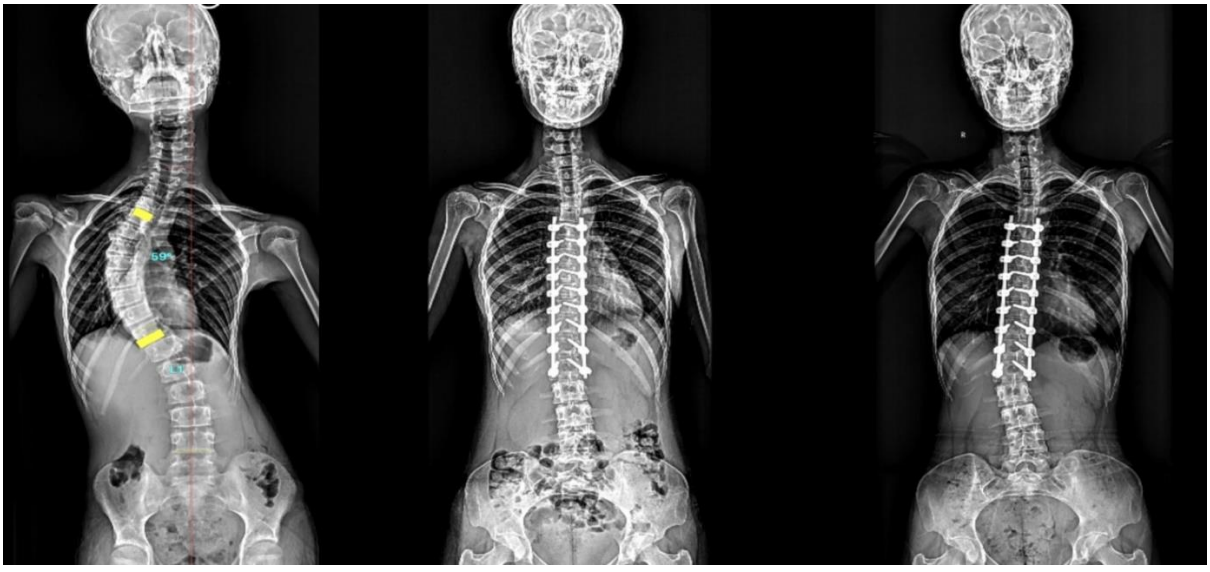

Figure-1. Representative preoperative (left), early postoperative (middle), and final follow-up (right) radiographs of a patient who developed DOA.

RESULTS

Demographic and Surgical Characteristics

A total of 72 patients were included in the study, categorized into the non-DOA group (n=67) and the DOA group (n=5). There were no statistically significant differences between the two groups in terms of demographic data (Table-1). The mean age was 14.45 ± 2.05 years in the non-DOA group and 15.20 ± 1.92 years in the DOA (p=0.407). Gender distribution was similar, with a predominance of female patients in both groups (76.1% vs 80.0%, p= 1.000).

Regarding surgical and clinical classifications, no significant differences were observed in Lenke types (p=0.312), lumbar modifiers (p=0.418), or Risser grades (p=0.625). Although the average surgery time was shorter in the DOA group (273.33 ± 77.68 min) compared to the non-DOA (336.79 ± 84.73 min), this difference did not reach statistical significance (p=0.235).

Radiographic Outcomes and LIV Selection

A targeted analysis of the Lenke 1A subgroup (n=21) revealed a critical failure pattern. Preoperatively, there were no significant differences in pelvic incidence, pelvic tilt, or thoracic kyphosis. However, in the first erect postoperative measurement, the DOA group exhibited a significantly lower, negative mean PT (-3.67° ± 12.50°) compared to the non-DOA group (8.39° ± 6.41°, p=0.016) (Table-2).

Analysis of other radiographic and clinical parameters, including preoperative curve magnitudes (PT, MT, and TL/L Cobb angles), percentage of surgical correction, and number of instrumented levels, showed no significant differences between the DOA and non-DOA groups (p > 0.05; Table-3). Furthermore, analysis of preoperative and postoperative shoulder balance revealed no statistically significant differences between the DOA and non-DOA groups. Additionally, skeletal surrogate markers such as bone mineral density (ROI-HU) and 25-OH Vitamin D levels were comparable between the two cohorts

Furthermore, LIV selection relative to the LTV demonstrated a correlation with failure (p=0.030) (Table-4). In the Firth penalized logistic regression evaluating LTV level as an associated factor of DOA, the model demonstrated promised discrimination (AUC = 0.889). Using “at the LTV” as the reference, ending the construct distal to the LTV was associated with a significantly lower odds of DOA (OR=0.056, 95% CI 0.0003–0.74; p=0.027), corresponding to an approximately 94.4% reduction in odds.

Table-1. Demographic and surgical characteristics according to postoperative DOA status

Variable	Non-DOA group, n = 67	DOA group, n = 5	p value
Age, years	14.45 ± 2.05	15.20 ± 1.92	0.407
Sex			1.000
Female	51 (76.1)	4 (80.0)	
Male	16 (23.9)	1 (20.0)	
Lenke type			0.312
Type 1	46 (68.7)	5 (100.0)	
Type 2	21 (31.3)	0 (0.0)	
Lumbar modifier			0.418
A	27 (40.3)	3 (60.0)	
B	17 (25.4)	0 (0.0)	
C	23 (34.3)	2 (40.0)	
Risser grade			0.625
0–3 (0)	19 (28.4)	2 (40.0)	
4–5 (1)	48 (71.6)	3 (60.0)	
Surgery time, minutes	336.79 ± 84.73	273.33 ± 77.68	0.235

Values are mean ± standard deviation or n (%), unless otherwise indicated.

Table-2. Preoperative and postoperative spinopelvic parameters for Lenke Type 1A subgroup

Variable	Non-DOA group, n = 18	DOA group, n = 3	p value
Preoperative Parameters			
Pelvic incidence, °	47.67 ± 11.73	41.67 ± 14.84	0.436
Pelvic tilt, °	5.72 ± 5.62	0.00 ± 11.14	0.170
Thoracic kyphosis, °	33.28 ± 15.98	19.33 ± 7.57	0.161
Lumbar lordosis, °	-64.50 ± 11.25	-60.00 ± 5.57	0.512
First Erect (Postoperative)			
Pelvic tilt, °	8.39 ± 6.41	-3.67 ± 12.50	**0.016**
Thoracic kyphosis, °	24.67 ± 10.42	19.33 ± 5.13	0.403
Lumbar lordosis, °	-57.78 ± 9.50	-55.67 ± 9.50	0.726
PI-LL mismatch	-9.06 ± 6.24	-16.67 ± 16.86	0.724
SVA, mm	-19.61 ± 33.15	-10.67 ± 56.58	0.697

Pre: Preoperative, PI: Pelvic Incidence, PT: Pelvic Tilt, TK: Thoracic Kyphosis, LL: Lumbar Lordosis, PI-LL: Pelvic Incidence- Lumbar Lordosis Mismatch, TPA: T1-Pelvic Angle, CL: Cervical Lordosis, SVA: Sagittal Vertical Axis, FE: First Erect, SD: Standard Deviation

Table-3. Comparison of coronal and other parameters between non-DOA and DOA groups

Variable	Non-DOA group, n = 18	DOA group, n = 3	p value
Pre PT Cobb (°)	26.22 ± 7.09	24.67 ± 6.03	0.725
Pre MT Cobb (°)	55.50 ± 12.13	52.67 ± 7.10	0.702
Pre TL/L Cobb (°)	34.28 ± 9.96	30.00 ± 2.65	0.477
Amount of Correction (%)	77.32 ± 8.56	79.20 ± 1.08	1.000
Postoperative MT Cobb (°)	12.33 ± 4.39	11.00 ± 2.00	0.617
Number of Instrumented Level	10.94 ± 1.31	11.00 ± 1.73	0.948
ROI (HU)	206.19 ± 53.01	179.33 ± 37.17	0.418
25-OH Vitamin D (ng/ml)	16.89 ± 9.02	13.33 ± 4.04	0.533

PT: Proximal Thoracic, MT: Main Thoracic, TL/L: Thoracolumbar/Lumbar, ROI: Region of Interest, HU: Hounsfield Unit

Table-4. Analysis of LIV selection relative to the LTV in Lenke Type 1A subgroup

Variable	Non-DOA group, n = 18	DOA group, n = 3	p value
LIV position relative to LTV			**0.030**
Proximal to LTV	3 (16.7)	0 (0.0)	
At LTV	4 (22.2)	3 (100.0)	
Distal to LTV	11 (61.1)	0 (0.0)	
LIV position relative to SV			0.146
Proximal to SV	7 (38.9)	3 (100.0)	
At SV	7 (38.9)	0 (0.0)	
Distal to SV	4 (22.2)	0 (0.0)	
LIV position relative to NV			
Proximal to NV	5 (27.8)	2 (66.7)	0.247
At NV	4 (22.2)	1 (33.3)	
Distal to NV	9 (50.0)	0 (0.0)	

LIV: lowest instrumented vertebra; LTV: last touched vertebra; SV: stable vertebra; SVA: sagittal vertical axis; PI-LL: pelvic incidence-lumbar lordosis.

DISCUSSION

Our study observed an overall DOA rate of 6.9% in Lenke 1 and 2 patients at a minimum 2-year follow-up. This incidence is consistent with, and in some cases lower than, previously reported rates in the literature (6,9,10). The relative consistency of our overall DOA rate with these established cohorts provides a useful foundation from which to explore the specific mechanical signals observed in our failed cases.

The central observation of this study is that DOA in Lenke 1A curves may not be fully prevented by LIV selection based solely on the LTV criterion. In addition, our data suggest that early postoperative pelvic anteversion may be associated with subsequent DOA. Although the retrospective design precludes causal inference, these preliminary findings support a more comprehensive, three-dimensional approach to LIV selection and postoperative assessment pending further validation.

Interpretation of the Lenke 1A Signal

By focusing our analysis on the Lenke 1A subgroup, we aimed to study the distal junction in its most isolated mechanical form. While one might expect traditional coronal landmarks like the LTV to be highly reliable in these patients with relatively straight lumbar spines, our data raises questions about this assumption. In our cohort, 42.8% of Lenke 1A patients fused at the LTV experienced DOA, although this estimate is based on a very small number of cases, suggesting that the LTV is an insufficient standalone landmark when the sagittal profile is not considered. Because the number of DOA events was small, the estimates should be interpreted cautiously and may not be fully generalizable to broader AIS populations.

The Sagittal Compensation Signal: Potential Driver or Radiographic Coincidence?

The most notable finding in our Lenke 1A analysis was the significantly lower postoperative PT in the DOA group. While the association is statistically significant, it must be interpreted with caution. It remains unclear whether this tendency toward a lower, more anteverted pelvic tilt represents a primary failure of sagittal compensation or a secondary, compensatory radiographic response to early, occult junctional instability. However, the observed shift toward lower PT values in failed

cases may suggest that DOA is not a purely coronal phenomenon, but rather a three-dimensional failure with a significant sagittal component. Given the small event rate, further prospective studies are needed to validate whether this sagittal 'signal' serves as a reliable mechanical associated factor.

Limitations

A major limitation of this study is the small number of DOA events (n=3) within the Lenke 1A subgroup. Given that DOA is not a frequently encountered complication, event numbers remain low even in larger series. This limited sample size precludes the use of robust multivariate models to control for all potential confounders and renders the results statistically fragile. In addition, the retrospective single-center design limits causal inference and may introduce selection bias. Furthermore, the minimum follow-up of 2 years may not capture late-onset distal adding-on or long-term functional outcomes. Therefore, our findings should be interpreted as hypothesis-generating rather than definitive factors associated. We emphasize that these results should not be used as a predictive tool, but rather as an early identification of an area requiring further research.

CONCLUSION

DOA remains a rare but relevant clinical challenge. Our preliminary findings suggest that the LTV may be an insufficient standalone landmark in Lenke 1A subtypes, and that pelvic anteversion may serve as a potential mechanical warning sign for junctional failure. These observations underscore the necessity of a more comprehensive, three-dimensional approach to LIV selection and warrant further study for external validation.

Statements of Declarations

Acknowledgements: No acknowledgement to declare

Ethical Approval and Consent to Participate

This study protocol was approved by the ethics committee of Başakşehir Cam and Sakura City Hospital Ethics Committee and was conducted in accordance with the principles of the Declaration of Helsinki. Given the retrospective design, the requirement for informed consent was waived by the same ethics committee (KAEK/04.03.2026.146).

Clinical trial number: Not applicable

Consent for Publication: Not applicable. All data were analyzed de-identified and the manuscript does not contain any individual person's data

Data Availability Statement: The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing Interests: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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References

1. Sponseller PD, Flynn JM, Newton PO, et al. The Association of Patient Characteristics and Spinal Curve Parameters With Lenke Classification Types. *Spine (Phila Pa 1976)*. 2012;37(13):1138-1141. doi:10.1097/BRS.0b013e31824054a5
2. Miyaoka Y, Uehara M, Banno T, et al. Selective Versus Non-Selective Thoracic Fusion for Adolescent Idiopathic Scoliosis Lenke 1B/1C Curves: Multi-Center Clinical and Radiographic Analysis at 2-Year Follow-Up. *Medicina (B Aires)*. 2025;61(5):909. doi:10.3390/medicina61050909
3. Ifthekar S, Ahuja K, Sudhakar PV, et al. Is it Safe to Save Levels and Choose the Lowest Instrumented Vertebra as Touched Vertebra While Selectively Fusing Lenke 1/2 Curves? A Proportional Meta-Analysis of Existing Evidence. *Global Spine J*. 2023;13(1):219-226. doi:10.1177/21925682221091744
4. Joo YS, Hwang CJ, Cho JH, et al. Does Sacral Slanting Affect Distal Adding-on in Lenke Type 1A Adolescent Idiopathic Scoliosis? *Spine (Phila Pa 1976)*. 2018;43(17):E990-E997. doi:10.1097/BRS.0000000000002722
5. Li T, Li Y, Wang X, Long Y. Risk factors for the progression of distal adding-on phenomenon after surgery in patients with Lenke type 1 and 2 adolescent idiopathic scoliosis. *Sci Rep*. 2025;15(1):30237. doi:10.1038/s41598-025-15714-1

6. Yang M, Zhao Y, Yin X, et al. Prevalence, Risk Factors, and Characteristics of the “Adding-On” Phenomenon in Idiopathic Scoliosis After Correction Surgery. *Spine (Phila Pa 1976)*. 2018;43(11):780-790. doi:10.1097/BRS.0000000000002423
7. Qin X, Xia C, Xu L, et al. Natural History of Postoperative Adding-On in Adolescent Idiopathic Scoliosis: What Are the Risk Factors for Progressive Adding-On? *Biomed Res Int*. 2018;2018:1-8. doi:10.1155/2018/3247010
8. Lenz M, Oikonomidis S, Harland A, et al. Scoliosis and Prognosis—a systematic review regarding patient-specific and radiological predictive factors for curve progression. *European Spine Journal*. 2021;30(7):1813-1822. doi:10.1007/s00586-021-06817-0
9. Cho RH, Yaszay B, Bartley CE, Bastrom TP, Newton PO. Which Lenke 1A Curves Are at the Greatest Risk for Adding-On... and Why? *Spine (Phila Pa 1976)*. 2012;37(16):1384-1390. doi:10.1097/BRS.0b013e31824bac7a
10. Wang Y, Hansen ES, Høy K, Wu C, Bünger CE. Distal Adding-On Phenomenon in Lenke 1A Scoliosis. *Spine (Phila Pa 1976)*. 2011;36(14):1113-1122. doi:10.1097/BRS.0b013e3181f51e95