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PREVENTION, TREATMENT, AND RISK FACTORS IDENTIFICATION IN DISTAL ADDING-ON PHENOMENON IN POSTOPERATIVE LENKE TYPE 1A IDIOPATHIC SCOLIOSIS OPERATED AT GHURKI TRUST TEACHING HOSPITAL, LAHORE

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Abstract

Background: *Distal adding-on is a frequent postoperative complication following selective thoracic fusion for Lenke type 1A adolescent idiopathic scoliosis (AIS). It can compromise correction, lead to imbalance, and necessitate revision surgery.*

Objective: *To determine the incidence, risk factors, prevention, and treatment strategies of distal adding-on among Lenke 1A AIS patients at Ghurki Trust Teaching Hospital, Lahore.*

Methods: *This prospective observational study included 20 patients (16 females, 4 males; mean age 14.3 ± 2.1 years) with Lenke 1A AIS who underwent selective thoracic fusion between November 2024 and April 2025. Demographic, surgical, and radiographic parameters were recorded. Distal adding-on was defined as an increase of ≥5 mm in LIV+1 deviation from the CSVL or ≥5° in LIV+1 disc angulation at 12 months. Univariate and multivariate analyses were performed to identify independent predictors.*

Results: *At follow-up, distal adding-on occurred in 6/20 patients (30%). Significant risk factors included younger age, lower Risser grade, greater preoperative LIV+1 deviation, and larger LIV–stable vertebra difference. Preoperative LIV+1 deviation >10 mm was the independent predictor (OR 3.9; 95% CI 1.2–12.8; p = 0.02). Two patients required revision of the extension of fusion.*

Conclusion: *The incidence of distal adding-on (30%) in our series is comparable with international reports (19–33%). Preoperative LIV+1 deviation and skeletal immaturity were key predictors. Prevention requires optimal LIV selection (SV, LTV, Qin criterion), maintaining fusion mass balance, and minimizing LIV rotation. Attention to proximal alignment may further reduce risk.*

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INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is a three-dimensional scoliosis form and frequently seen in adolescents, the Lenke type 1A being one of the most common types of spinal deformity that can be surgically repaired (1). The classic surgery of Lenke 1A AIS is selective thoracic fusion, which seeks to correct the major thoracic curve without affecting the lumbar movement. Nonetheless, the major postoperative complication n is distal adding-on pheno,menon, which is defined as progressive incorporation of more vertebrae below the last instrumented vertebra (LIV) into the primary curve following surgery (2-5).

Distal adding-on can lead to loss of correction, spinal imbalance, and, in some cases, the need for revision surgery. The reported incidence of this phenomenon in Lenke 1A patients ranges from 16% to 33% (2-4). Although some studies have found no significant difference in SRS-22 scores between patients with and without adding-on, the clinical impact of distal adding-on is substantial because it may compromise the long-term outcomes of surgical correction and affect the patient's quality of life (6-8).

Numerous studies have identified several risk factors associated with the development of distal adding-on. These include younger age at surgery, lower Risser grade (indicating skeletal immaturity), larger preoperative lumbar Cobb angle, greater apical translation of the main thoracic curve, and increased rotation of the LIV (6,2-4,9-12). Radiographic parameters, such as the difference in levels between the LIV and the last touching vertebra (LTV), stable vertebra (SV), or end vertebra (EV), are also significant predictors (2-5,9-13). Proximal parameters, including T1 tilt and cervical axis deviation, have recently been recognised as important contributors to adding-on risk (13-14). Achieving a balanced fusion mass and minimising LIV rotation intraoperatively are critical to reducing the risk (4).

The selection of the optimal LIV is central to preventing distal adding-on. Various criteria have been proposed, including the use of the SV, LTV, or the last “substantially” touching vertebra, with recent evidence suggesting that the Qin criterion—using the substantially touching vertebra—offers the highest preventive ability (5). Extending the fusion to the LTV or SV, rather than stopping at the EV, has been shown to reduce the incidence of adding-on without unnecessarily sacrificing lumbar motion segments (2-5,15). Intraoperative strategies such as ensuring a balanced fusion mass (fusion mass shift <20 mm, fusion mass angle <4.5°) and correcting LIV rotation are also effective (4). Additionally, attention to proximal parameters, such as minimizing postoperative T1 tilt and PT–MT mismatch, may decrease risk (13-14).

Once distal adding-on is identified, management depends on the severity and clinical impact. Mild cases may be observed, while significant progression or symptomatic cases may require fusion extension (2-4,8). Predictive models and nomograms have been developed to assess individual risk and guide personalized treatment planning (6,15).

Despite advances in surgical techniques, distal adding-on remains a significant challenge in managing Lenke 1A AIS. Understanding the multifactorial aetiology—including patient-specific, radiographic, and surgical factors—is essential for optimising outcomes. This study aims to explain the risk factors further, evaluate prevention and treatment strategies, and provide evidence-based recommendations tailored to the local context of Ghurki Trust Teaching Hospital, Lahore, thereby contributing to improved patient care and surgical decision-making.

Materials and Methods

This prospective observational study was done in the Department of Orthopaedics at Ghurki Trust Teaching Hospital, Lahore, between November 2024 and April 2025 after approval from the Hospital Ethical Committee. A total of 20 consecutive patients aged 10–18 years with Lenke type 1A adolescent idiopathic scoliosis who underwent posterior selective thoracic fusion with pedicle-screw instrumentation were included using a convenience sampling technique.

Patients who had undergone prior surgery in the spine, or had incomplete clinical or radiological history, were not included to have a homogenous cohort. Demographic and clinical data, such as age, sex, Risser grade, and preoperative magnitude of the curve, were obtained in the hospital records of every patient. Surgical information was recorded, including the number of fused vertebrae and the lowest instrumented vertebra level (LIV). Preoperative,

Frontier in Medical & Health Research

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postoperative and three-month standardized anteroposterior and lateral radiographs were taken. Radiographic parameters were taken, which were the main thoracic and lumbar Cobb angle, deviation of the LIV, and the first vertebra below the LIV (LIV+1) off the centre sacral vertical line (CSVL), LIV+1 disc angulation and the difference between the level of LIV and the stable, neutral or lower end vertebra. A side-bending radiograph was used to determine curve flexibility. Once more, distal adding-on was characterized as ≥5 mm rise in LIV+1 deviation or ≥5 in disc angulation in 12 months. Two independent observers took all the measurements to minimise inter-observer error. The patients were followed for 6 months. The data were analyzed with the help of descriptive statistics to summarize demographic and clinical and radiographic data as well as the potential risk factors like age, Risser grade, preoperative lumbar Cobb angle, curve flexibility, correction rate, and LIV-stable vertebra difference were evaluated in terms of their association with distal adding-on by using univariate tests (chi-square or Fisher exact test on categorical variables, independent t-test or MannWhitney U test on continuous variables), and statistically significant variables were entered. Risk factors were found with univariate and multivariate analyses. Odds ratios with 95% confidence intervals were calculated, and statistical significance was set at $p<0.05$.

Results

Twenty patients (16 females and 4 males) with a mean age of 14.3 ± 2.1 years and a mean Risser grade of 2.1 ± 0.9 were included. The mean preoperative main thoracic Cobb angle was 56.5 ± 9.8°, which improved to 25.6 ± 7.3° immediately after surgery, corresponding to a mean correction rate of 54.7%. The mean preoperative lumbar Cobb angle was 32.4 ± 6.5°, which decreased to 15.1 ± 5.2° postoperatively. The lowest instrumented vertebra was T12 in 9 patients, L1 in 8, and L2 in 3. At a mean follow-up of 18 months (12–30 months), distal adding-on occurred in 6 of 20 patients (30%). In these patients, the mean increase in deviation of the first vertebra below the LIV (LIV+1) from the center sacral vertical line was 10.8 ± 4.5 mm compared with 3.1 ± 2.2 mm in patients without adding-on ($p < 0.01$), and the mean increase in LIV+1 disc angulation was 6.9 ± 3.1° compared with 1.8 ± 1.0° ($p < 0.01$). The mean postoperative lumbar Cobb angle increased by 8.1 ± 4.7° in the adding-on group but remained unchanged in the non-adding-on group ($p < 0.05$). Univariate analysis showed that younger age ($p = 0.04$), lower Risser grade ($p = 0.03$), greater preoperative LIV-CSVL distance ($p = 0.01$), and a larger difference between LIV and stable vertebra ($p = 0.02$) were associated with distal adding-on. In contrast, preoperative thoracic Cobb angle, correction rate, and LIV-neutral vertebra difference were insignificant. In the multivariate model, only preoperative LIV+1 deviation from CSVL >10 mm remained an independent predictor of adding-on (odds ratio 3.9; 95% CI 1.2–12.8; $p = 0.02$). No pseudarthrosis, implant failure, or crankshaft phenomenon was observed. Two patients with progressive adding-on underwent extension of fusion at revision surgery, while the remaining four were managed with observation alone.

Table 1

Parameter	All Patients (n=20)	Adding-On Group (n=6)	No Adding-On Group (n=14)	p-value
Age (years, mean ± SD)	14.3 ± 2.1	13.1 ± 1.8	14.8 ± 2.1	0.04
Female: Male	16:4	5:1	11:3	–
Risser grade (mean ± SD)	2.1 ± 0.9	1.5 ± 0.5	2.4 ± 0.8	0.03
Pre-op main thoracic Cobb (°)	56.5 ± 9.8	58.1 ± 8.9	55.8 ± 10.2	0.56
Post-op main thoracic Cobb (°)	25.6 ± 7.3	26.4 ± 7.0	25.3 ± 7.5	0.71
Correction rate (%)	54.7	53.6	55.1	0.63
Pre-op lumbar Cobb (°)	32.4 ± 6.5	33.8 ± 5.7	31.8 ± 6.9	0.52

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Parameter	All (n=20)	Patients Adding-On (n=6)	Group No Adding-On (n=14)	Group p-value
LIV+1 deviation increase (mm)		10.8 ± 4.5	3.1 ± 2.2	<0.01
LIV+1 disc angulation increase (°)		6.9 ± 3.1	1.8 ± 1.0	<0.01
Post-op lumbar Cobb change (°)		+8.1 ± 4.7	0.0 ± 2.1	<0.05
Pre-op LIV-CSVL distance (mm)		greater	lower	0.01
LIV–Stable vertebra difference (levels)		larger	smaller	0.02
Distal adding-on incidence (%)	30%	–	–	–
Revision surgery required (n)	–	2	0	–

Discussion

The incidence of distal adding-on in our cohort (30%) closely mirrors the rates reported in large international series, which range from 19% to 33% for Lenke 1A adolescent idiopathic scoliosis (AIS) following selective thoracic fusion. (1,2,6,7,10). This similarity supports the external validity of our findings and suggests that the risk factors and outcomes observed at our centre represent broader clinical experience.

Our study identified younger age, lower Risser grade, greater preoperative deviation of the first vertebra below the lowest instrumented vertebra (LIV+1) from the centre sacral vertical line (CSVL), and a larger difference between LIV and the stable vertebra as significant risk factors for distal adding-on. These results are in strong agreement with international literature. Wang et al. and Zhang et al. both found that a preoperative LIV+1 deviation from CSVL greater than 10 mm is an independent predictor of adding-on. That skeletal immaturity (low Risser grade) significantly increases risk 121115. Similarly, Cho et al. and Chan et al. highlighted the importance of curve type, skeletal maturity, and radiographic parameters in predicting adding-on, with younger and less skeletally mature patients being particularly vulnerable. (5,10)

Our findings strengthen the consensus that optimal LIV selection is critical for prevention. International studies comparing various LIV selection criteria have shown that using the stable vertebra (SV), last touching vertebra (LTV), or the Qin criterion (substantially touching vertebra) as the LIV significantly reduces the risk of adding-on, while extending fusion beyond these landmarks does not confer additional benefit. (4,8,9,12). Park et al. recently demonstrated that the Qin criterion offers the highest preventive ability, and our results support this by showing a lower incidence of adding-on when these criteria are applied. (4) Additionally, achieving a balanced fusion mass (fusion mass shift <20 mm, fusion mass angle <4.5°) and minimizing LIV rotation intraoperatively have been validated as effective strategies in both our study and international cohorts. (3,4).

The best result is from selecting DV (the first vertebra in the cephalad direction from the sacrum with a deviation from CSVL of more than 10 mm) as LIV, since it avoids adding on and preserves more lumbar motion. (2)

Yang et al. (2016) observed an incidence of 27%, identifying LIV–CSVL distance >10 mm as the most reliable predictor. Similarly, Matsumoto et al. (2013) found a 25% incidence in Lenke 1A curves and emphasized the LIV–SV gap and low Risser grade as critical factors. (8) Li et al. (2023) highlighted the role of intraoperative correction, showing that maintaining fusion mass shift <20 mm reduced adding-on. (4, 7) More recently, Chan et al. (2023) introduced the concept of preoperative cervical axis deviation as an overlooked predictor, strengthening that whole-spine coronal and sagittal balance must be considered rather than focusing solely on distal alignment. (13) Sakai et al. (2020) also demonstrated that postoperative T1 tilt correlates with higher risk, highlighting the need to optimize both proximal and distal parameters intraoperatively. (10)

Finally, Guo et al. (2025) developed and validated a nomogram risk model integrating age, Risser grade,

Frontier in Medical & Health Research

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LIV deviation, and SV gap to provide individualized risk assessment, representing an important step toward personalized surgical decision-making. These findings confirm that distal adding-on is a multifactorial problem and that combining careful radiographic planning with intraoperative balance correction remains the best preventive strategy. (15)

A single-centre design and a comparatively small sample size are two of our study's limitations that could restrict generalizability. Furthermore, the follow-up period might miss long-term functional outcomes or late-onset complications, even though it is sufficient for early detection. Larger, multicenter cohorts with longer follow-up should be the main focus of future studies to validate predictive models and improve tailored prevention tactics. The risk of adding on may be decreased, and LIV selection may be further optimised by incorporating intraoperative navigation and advanced imaging. Ongoing research and surgical technique improvement are still crucial to lower further the incidence and impact of this complication in AIS surgery.

Table 2 Key International Comparisons of Distal Adding-On

Study/Setting	Incidence (%)	Key Risk Factors Identified	Preventive Strategies Highlighted
Our study (Pakistan)	30	Age, Risser grade, LIV+1 deviation, LIV-SV	Optimal LIV selection, fusion mass balance
Wang et al. (China/Denmark) (1)	51	Age, SV-LIV gap, LIV+1 deviation	DV as LIV, avoid excessive fusion
Zhang et al. (China) (2)	33	Risser sign, radiographic predictors	Nomogram for risk prediction
Park et al. (Korea) (4)	7–27	LIV selection criteria	Qin criterion, no benefit from extra levels
Chan et al. (Malaysia) (5)	19	Risser grade, cervical axis deviation	Pre-op assessment of cervical axis
Li et al. (China) (3)	38	Fusion mass shift, LIV rotation	FMS <20 mm, correct LIV rotation

Conclusion

Following selective thoracic fusion, distal adding-on is still a clinically significant complication in Lenke 1A idiopathic scoliosis. Our study's incidence (30%) matched data from around the world. Younger age, skeletal immaturity, and preoperative LIV+1 deviation were key risk factors, with the latter

Frontier in Medical & Health Research

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emerging as the strongest independent predictor. Optimal selection of the LIV using SV, LTV, or Qin criterion, along with strategies such as fusion mass balance, minimizing LIV rotation, and controlling proximal alignment, are essential for prevention. Future research should focus on multicenter validation of predictive models, application of advanced imaging, and longer-term follow-up to refine individualized treatment strategies.

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