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ORIGINAL ARTICLE

L3 translation predicts when L3 is not distal enough for an "ideal" result in Lenke 5 curves

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Abstract

Purpose Determining whether to fuse a Lenke 5 curve to L3 or to L4 is often a difficult decision. The purpose of this study was to determine preoperative variables predictive of an "ideal" or "less than ideal" outcome for Lenke 5 curves instrumented to L3.

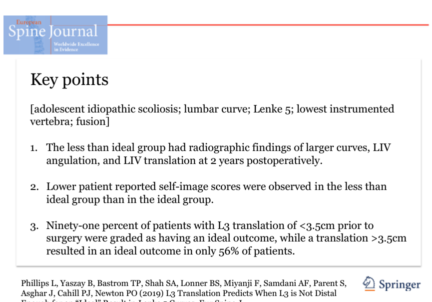
Methods A multicentre registry of adolescent idiopathic scoliosis patients was queried for surgically treated Lenke 5 curves with a lowest instrumented vertebra (LIV) of L3 and minimum 2 years of follow-up. Five seasoned surgeons qualitatively rated the 2-year postoperative images as "ideal" or "less than ideal" with respect to correction and alignment. Preoperative and postoperative radiographic variables were compared between the two groups. Multivariate regression analysis was performed to determine variables most predictive of a "less than ideal" outcome.

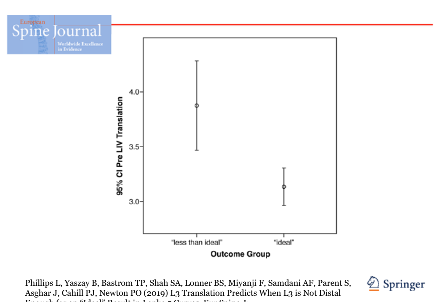
Results One hundred and thirty-nine patients met criteria. Twenty-three were considered "less than ideal" by ≥ 3 surgeons; 81 were unanimously "ideal". Preoperatively, the "less than ideal" group had significantly stiffer curves, greater apical translation, and greater LIV angulation and translation. Multivariate regression found that preoperative L3 translation ($p = 0.009$) was the single most important predictor of a "less than ideal" outcome: < 3.5 cm consistently resulted in an "ideal" outcome, while > 3.5 cm risked a "less than ideal" result.

Conclusion While multiple variables are important in achieving an "ideal" outcome in Lenke 5 curves, this study found preoperative L3 translation was the most important predictor of success with an L3 translation < 3.5 cm being a potential threshold for selecting L3 as the LIV.

Graphical abstract

These slides can be retrieved under Electronic Supplementary Material.





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Extended author information available on the last page of the article

Keywords Adolescent idiopathic scoliosis · Thoracolumbar/lumbar curve · Lenke 5 · Lowest instrumented vertebra · Fusion

Introduction

A Lenke 5 curve is defined as an isolated, structural, idiopathic curve with an apex between T12 and L4. The main thoracic and proximal thoracic curves must be smaller, bend to less than 25°, and do not have any significant sagittal kyphosis [1]. Using these criteria, the treatment of Lenke 5 curves has been an area of debate as scoliosis surgery has evolved. Controversy arises over anterior versus posterior approach, compensation of uninstrumented curves, and determining ideal fusion levels, particularly the lowest instrumented vertebra (LIV). Correctly identifying the LIV of a fusion construct is essential. Too distal and the result is needless loss of motion segments. Too proximal and the concentrated force of the proximal fusion mass can lead to curve decompensation or “adding-on” [2, 3].

In terms of level selection, significant variability exists between individuals based on experience, preference, and approach. For either anterior or posterior approaches, Li et al. [4] recommended levelling and centring the LIV when correcting Lenke 5 curves to create a spine with good global balance. In general, this involves a fusion spanning from the upper end vertebra to the lower end vertebra, but may extend one level distal to include a convex disc below the end vertebra [5]. Most surgeons preferably choose L3 opposed to L4 as their LIV to maximize the lumbar motion segments and hopefully minimize future disc degeneration [6, 7]. Limited data exist to decide exactly what preoperative factors predict a successful outcome when treating Lenke 5 curves with an LIV of L3. Some authors advocate selecting the LIV based on LIV tilt, while others utilize the position or rotation of L3 on bending films [4, 8]. The goal of this study was to determine the preoperative variables that predict either an “ideal” or “less than ideal” outcome for Lenke 5 curves instrumented to L3 (i.e. Should they have been fused to L4?).

Methods

Data from a multicentre database of surgically treated patients with adolescent idiopathic scoliosis (AIS) were utilized for this study. The database was queried for patients with Lenke 5 curve patterns (primary structural thoracolumbar curves) with an LIV of L3 and minimum 2-year follow-up. Demographic, surgical, patient-reported outcomes (SRS-22 questionnaire), and radiographic variables from pre- and postoperative visits were evaluated.

An independent surgeon survey was performed in order to identify patients with “ideal” and those with “less than ideal” outcomes. Five fellowship trained surgeons with substantial experience with AIS in the clinical, operative, and research arenas were asked to evaluate 139 cases and record their assessment of the outcome in terms of correction and alignment. While subjective to each surgeon, an “ideal” outcome was thought to be a curve that was well balanced with minimal residual deformity that maximized the longevity of the uninstrumented lumbar spine.

Preoperative radiographic variables were compared between cases with agreement of an “ideal” outcome versus those where there was agreement of a “less than ideal” outcome amongst the surgeons. Those variables found to be significant in the univariate analysis were entered into a multivariate binary logistic regression analysis to determine the variables most predictive of a “less than ideal” outcome. Postoperative outcomes were also compared between the groups. Postoperative SRS-22 scores were compared between the “ideal and less than ideal” groups to evaluate for any significant differences in patient-reported outcomes. Revision rates were recorded for each group. All analyses were performed using SPSS version 12 (SPSS Inc., Chicago, IL), and alpha was set at $p < 0.05$ to declare significance.

Results

The results of the surgeon survey identified 81 patients with unanimous agreement of an “ideal” outcome (Fig. 1). Twenty-three patients were categorized as “less than ideal” by 3 or more surgeons (Fig. 2). In the majority of cases, a derotation manoeuvre was performed ($n = 119$; 6 did not include a derotation manoeuvre and 30 had incomplete documentation). Details on the type of derotation manoeuvre used were not available. Implant density was ≥ 80% screw in all but three cases that had hybrid constructs. The types of screws utilized (uniplanar, polyaxial, monoaxial, reduction) were varied both between patients and within patients.

The two groups were comparable in their demographics. The majority of patients in both groups were female (83% female in “ideal” and 87% in “less than ideal”, $p = 0.76$). The average age of both groups was comparable (15.1 ± 2 years “ideal” vs. 15.3 ± 2 years “less than ideal”, $p = 0.69$). There was no significant difference between the groups in distribution of approach types (58% posterior, 42% anterior in “ideal” and 61% posterior, 39% anterior in “less than ideal”, $p = 0.76$). There were no significant differences between the

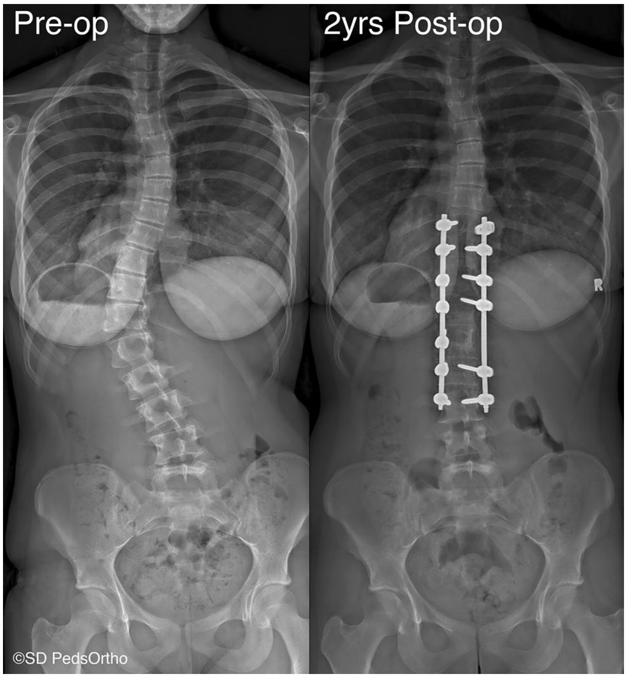

Fig. 1 Representative examples of an "ideal" outcome at 2 years postoperative

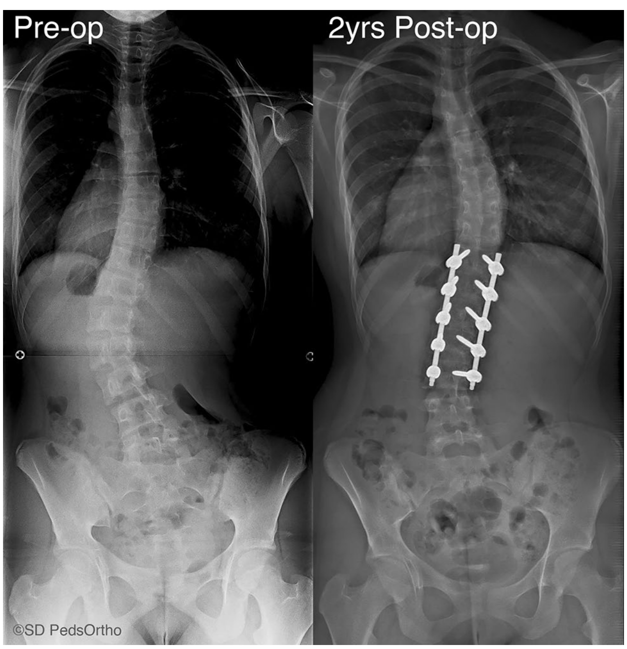

Fig. 2 Representative examples of a "less than ideal" outcome at 2 years postoperative

groups in terms of skeletal maturity, as assessed by Risser stage ($p=0.096$) and triradiate cartilage ($p=0.56$).

At 2 years postoperatively, the "less than ideal" group had greater residual deformity than the "ideal" group (Table 1).

Table 1 Summary of 2-year postoperative radiographic measurements between groups

2-Year postoperative variable	"Less than ideal"	"Ideal"	*p* value
Thoracic curve magnitude	20 ± 11°	16 ± 8°	**0.027**
% Thoracic correction	27 ± 32%	36 ± 34%	0.223
Lumbar curve magnitude	26 ± 6°	15 ± 7°	**< 0.001**
% Lumbar correction	46 ± 13%	66 ± 14	**< 0.001**
LIV angulation	11 ± 6°	5 ± 3°	**< 0.001**
LIV translation	2.6 ± 0.8 cm	1.4 ± 0.8 cm	**< 0.001**
LIV disc angulation	4.2 ± 3.2°	3.4 ± 2.7°	0.25

Bold values indicate statistical significance

Table 2 Summary of univariate analysis for predicting "less than ideal" outcome

Preoperative variable	"Less than ideal"	"Ideal"	*p* value
Thoracic curve magnitude	27 ± 9°	26 ± 10°	0.588
Lumbar curve magnitude	49 ± 9°	45 ± 7°	**0.029**
Thoracic bend magnitude	11 ± 7°	12 ± 7°	0.697
Lumbar bend magnitude	26 ± 10°	18 ± 11°	**0.003**
Lumbar flexibility percentage	48 ± 16%	61 ± 21	**0.008**
C7-CSVL magnitude	3.0 ± 1.2 cm	2.9 ± 1.3 cm	0.781
Thoracic apical translation	2 ± 1.3 cm	1.7 ± 1.2 cm	0.393
Lumbar apical translation	6.1 ± 1.7 cm	5.3 ± 1.3 cm	**0.009**
LIV angulation	28 ± 8°	25 ± 6°	**0.036**
LIV translation	3.9 ± 1 cm	3.1 ± 0.8 cm	**< 0.001**
LIV disc angulation	4.1 ± 4.1°	3.7 ± 3.1°	0.649
T5–T12 kyphosis	27 ± 9°	28 ± 11°	0.66
T10–T12 kyphosis	6 ± 10°	4 ± 11°	0.43
Lumbar lordosis	55 ± 11°	59 ± 11°	0.16
Distal junctional lordosis	21 ± 9°	20 ± 8°	0.67

Bold values indicate statistical significance

The "less than ideal" group had greater thoracic and lumbar curve magnitudes and a lower per cent correction in the lumbar spine. Additionally, the "less than ideal" group had greater LIV angulation and LIV translation. There were no differences in LIV disc angulation between the groups.

Analysis of the patient-reported outcomes showed that the "less than ideal" group had significantly lower self-image SRS-22 scores than the "ideal" group (4.2 vs. 4.5, $p=0.01$). There were no significant differences between the groups in any of the other SRS-22 domains (pain, general function, mental health, satisfaction) or total scores ($p>0.05$) 2 years postoperatively.

Table 2 contains the preoperative radiographic measurements that were compared between the "ideal" and "less than ideal" groups in the univariate analysis. Preoperatively,

Table 3 Results of the multivariate binary logistic regression

	p value	Odds ratio	95% CI for odds ratio	
			Lower	Upper
Lumbar curve magnitude	0.29	0.94	0.84	1.05
Lumbar bend magnitude	0.07	1.06	1.00	1.13
Apical translation—lumbar	0.70	1.12	0.64	1.94
LIV angulation	0.67	1.02	0.92	1.14
LIV translation	**0.009**	2.80	1.30	6.06

LIV lowest instrumented vertebra, *CI* confidence interval

Bold values indicate statistical significance

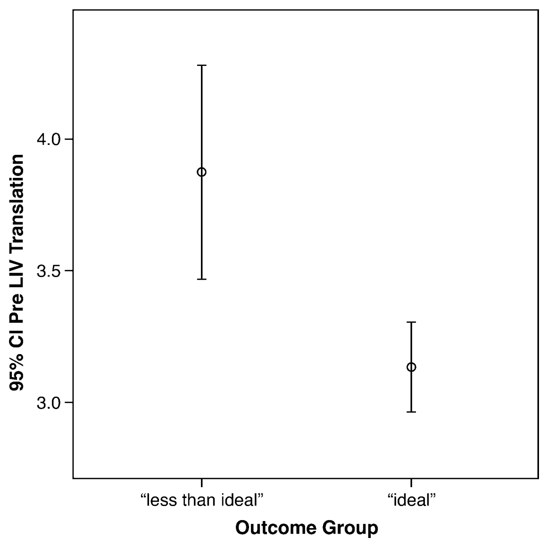

Fig. 3 Error bar plot of preoperative LIV translation between outcome groups

the "less than ideal" group was significantly stiffer and had greater apical translation with an LIV that was more angulated and more translated. No differences were found between the groups in any measurements of sagittal alignment. Multivariate regression found that of the variables significantly different between the groups, L3 translation ($p=0.009$) was the sole significant predictor of a "less than ideal" outcome (OR = 2.80, 95% CI 1.3–6.06, Table 3). Error bar plots demonstrate that the lower bound of the 95% confidence interval (CI) for preoperative L3 translation in the "less than ideal" group was 3.5 cm, whereas the upper bound in the "ideal" group was 3.3 cm (Fig. 3). Ninety-one per cent of patients with an L3 translation of < 3.5 cm prior to surgery were graded as having an "ideal" outcome, while a translation > 3.5 cm resulted in an "ideal outcome" in only 56% of patients ($p<0.001$).

There were three patients (13%) who underwent revision procedures in the "less than ideal" group, which consisted of (1) screw replacement after loss of fixation to the bone, (2) reinsertion of the rod into the screw from which it disengaged, and (3) extension of both the proximal and distal fusion levels due to pseudarthrosis and adding-on. In the "ideal" group, one patient underwent two (2.5%) revision procedures: (1) symptomatic, prominent hardware trimmed and (2) hardware removed following continued pain. One patient in the "ideal" group returned to the operating room for an irrigation and debridement only, but was not included in the revision rates as there were no alterations to the instrumentation.

Discussion

Patients treated with fusion to L3 for Lenke 5 curves who had a "less than ideal" outcome were found to have significantly larger residual coronal deformity. They had less correction of the lumbar curve, which resulted in a larger lumber Cobb with greater LIV angulation and translation. This correlated with lower SRS-22 self-image scores, meaning that these radiographic conclusions were clinically significant. This also represents decompensation changes at the distal end of the instrumented segment. L3 translation was found to be the single most important predictor of a "less than ideal" outcome. We believe this is an easily measured and reproducible predictor of a successful outcome with fusion to L3. Other studies published recently have found similar results and also advocated for other measures predicting success in the treatment of structural lumbar curves.

Wang et al. [9] reinforced the importance of the LIV selection in maintaining 2-year correction and balance and suggested a preoperative LIV translation of 28 mm and a tilt of 25° be used as criteria for selecting the LIV. Li et al. [4] reached similar conclusions regarding the influence of the LIV tilt. They found that a preoperative tilt equal to or greater than 25° and failure of this tilt to reduce to less than 8° postoperatively were at risk of developing coronal imbalance. When the proposed LIV tilt exceeds 25°, they recommend fusing one more level distal. This raises an interesting consideration regarding intraoperative decision-making versus preoperative planning. Barsi et al. studied LIV tilt and disc angle during correction using intraoperative prone fluoroscopy and with upright radiographs postoperatively out to 2 years. They found that LIV tilt improvement obtained during correction was not maintained throughout the follow-up period, with a mean progression of 5° identified (3.6° to 8.6°). Disc angle, however, remained stable after 2 years of follow-up (2.5° to 2.8°) [10]. Potentially, further corrective manoeuvres could improve the LIV tilt or disc angle that would provide lasting protection against decompensation and imbalance.

Koller et al. performed a retrospective review of thoracolumbar/lumbar curves to identify target outcomes that reduced the risk of failure and distal adding-on. They found that the target criteria for achieving a postoperative lumbar curve less than or equal to 20° included fusing to the stable vertebra minus one level and obtaining a disc angle less than 3.5° [11]. Sun et al. studied the 2-year results of selective posterior fusion to the end vertebra versus the end vertebra plus one level in moderate-sized curves (30°–60°). They found no difference in coronal or sagittal balance on follow-up but recommended fusion to the end vertebra plus one for curves greater than 60° [12]. Hu et al. [13], on the other hand, found that fusing to the end vertebra plus one resulted in increased coronal imbalance when compared to fusion to the end vertebra.

Previous work has shown that the Cobb angle measurement error can range from 3° to 7° [14]. If this is applied to preoperative predictors of lowest end vertebra tilt or disc angulation, it is easy to see how measurement error could contribute to the treating physician choosing an inappropriate fusion level. We advocate the use of lowest end vertebra translation as the single most important factor for deciding whether a fusion construct can stop distally at L3 in Lenke 5 curves. Other studies support the use of preoperative translation as a cut-off and its ease in measurement makes it applicable across different providers and institutions.

There are some limitations to this study. First, the “ideal” outcome was subjectively determined by surgeons. However, this methodology has been previously employed in similar studies [15] and a consensus was utilized instead of any one individual’s opinion. The two groups were also clinically different in their SRS self-image scores, which was independent of surgeon bias. Second, the ideal outcomes were not evaluated in the sagittal plane. Considering that the decision to instrument between L3 and L4 is typically determined by concern for coronal decompensation or adding-on, we believed this was appropriate for the study. Third, the small sample size did not allow for further sub-analysis of the less than ideal group to determine when an L3 translation greater than 3.5 cm may be acceptable. Likely, there are other factors that influence outcomes, including surgical technique, which were not possible to evaluate in this cohort of patients. Fourth, although understanding the 2-year postoperative outcomes is important, it remains unknown how these findings will impact the patients’ long-term quality of life. Finally, no information could be provided about individual surgical technique. It is likely that this is the reason there were cases with an LIV translation greater than 3.5 cm that achieved an ideal outcome. With an LIV translation below 3.5 cm, an ideal outcome could be uniformly achieved by all surgeons with any approach or technique.

Conclusion

The goal of surgery in Lenke 5 curves is to get an “ideal” clinical and radiographic outcome with the shortest fusion. Frequently, the decision is whether to fuse to L3 or to L4 distally. While multiple variables are important in this process, this study found preoperative L3 translation less than 3.5 cm was an important predictor of success that can reassure the treating surgeon of obtaining an ideal outcome.

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Compliance with ethical standards

Conflict of interest Dr. Phillips has nothing to disclose. Dr. Yaszay reports grants from Setting Scoliosis Straight Foundation, during the conduct of the study; grants and personal fees from K2M, grants and personal fees from DePuy Synthes Spine, personal fees from Nuvasive, personal fees from Medtronic, personal fees from Orthopediatrics, personal fees from Stryker, personal fees from Globus, grants from Setting Scoliosis Straight Foundation, outside the submitted work; In addition, Dr. Yaszay has a patent K2M with royalties paid. Ms. Bastrom reports grants from Setting Scoliosis Straight Foundation to her institution, during the conduct of the study. Dr. Shah reports grants from Setting Scoliosis Straight Foundation, during the conduct of the study; personal fees from DePuy Synthes Spine, grants from Setting Scoliosis Straight Foundation, personal fees from Nuvasive, outside the submitted work. Dr. Lonner reports grants from Setting Scoliosis Straight Foundation, during the conduct of the study; grants from Setting Scoliosis Straight Foundation, personal fees from DePuy Synthes Spine, personal fees from K2M, personal fees from Paradigm Spine , personal fees from Spine Search , personal fees from Ethicon, non-financial support from Spine Deformity Journal, grants from John and Marcella Fox Fund Grant , grants from OREF , personal fees from Zimmer Biomet, personal fees from Apifix, outside the submitted work. Dr. Miyanji reports grants from Setting Scoliosis Straight Foundation, during the conduct of the study. Dr. Samdani reports grants from Setting Scoliosis Straight Foundation, during the conduct of the study; personal fees from DePuy Synthes Spine, personal fees from Ethicon, personal fees from Globus Medical, personal fees from Misonix, personal fees from Stryker, personal fees from Zimmer Biomet, other from Setting Scoliosis Straight Foundation, other from Scoliosis Research Society, other from Children’s Spine Study Group, outside the submitted work. Dr. Parent reports grants and personal fees from EOS Imaging, grants and personal fees from Spinologics, grants, personal fees and other from DePuy Synthes Spine, grants, personal fees and other from Metronic, personal fees from K2M, other from Scoliosis Research Society, other from Canadian Spine Society, grants from Canadian Institutes of Health Research, grants from Canadian Foundation for Innovation, grants from Natural Sciences and Engineering Council of Canada, grants from Fonds de Recherche Quebec - Sante, grants from Orthopedic Research and Education Foundation, grants from Setting Scoliosis Straight Foundation, outside the submitted work. Dr. Asghar reports grants from Setting Scoliosis Straight Foundation, during the conduct of the study; personal fees and non-financial support from Omega innovative Technologies, personal fees from Life Spine, personal fees from Globus Medical, outside the submitted work. Dr. Cahill reports personal fees from Biogen, Inc., personal fees from NuVasive, Inc. , outside the submitted work; and AAOS: Board or committee memberÐournal of Bone and Joint Surgery - American: Editorial or gov-

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Ethical approval IRB approval was received for this study.

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