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The Importance of Lumbar Curve Flexibility and Apical Vertebral Rotation for the Prediction of Spontaneous Lumbar Curve Correction in Selective Thoracic Fusion for Lenke Type 1 and 2 C Curves: Retrospective Cohort Study with a Mean Follow-Up of More than 10 years

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Abstract

Study Design: Retrospective analysis of a prospectively collected data.

Objective: Lumbar flexibility(LF) is generally defined with preoperative side bending films;it is not clear what percentage of LF predicts the spontaneous lumbar curve correction (SLCC) at long term follow up. Aim of this study was to find out cut-off value of preoperative LF,apical vertebra rotation(AVR) and apical vertebral translation(AVT);which may predict more than 50% SLCC.

Methods: Patients with Lenke 1C&2C curves,treated with posterior STF,with a minimum 10 years follow up were included.The patients who had more than 50% SLCC(Group A) or less than 50% (Group B) were compared in terms of LF,AVR and AVT to understand a cut-off value of those parameters.Statistically, Receiver Operating Characteristic(ROC) test was used.

Results: Fifty five AIS patients (54F, 1M) with mean age 14 (11-17) were included to study.Thoracic curve correction rate was 75%;lumbar curve correction rate was 59% at the latest follow up.Group A included 45(82%) patients at the latest follow up.Three patients (5%) showed coronal decompensation at early postop and 2 of them became compensated at f/up.ROC analyses showed 69% flexibility as the cut-off value for SLCC ($P < .01$).The difference between groups in terms of preop mean AVRs was significant ($P = .029$) (Group A = 1.9; Group B = 2.4).

Conclusion: In Lenke 1C&2C curves,whenever LF on the preoperative bending x-ray is greater than 70% ($P < .01$)and AVR is equal or less than grade 2,STF provides satisfactory clinical and radiological SLCC with more than mean 10 years f/up.This flexibility rate and apical vertebral rotation can be helpful in decision making for successful STF.

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Keywords
adolescent idiopathic scoliosis, selective thoracic fusion, lumbar curve flexibility, spontaneous lumbar curve correction, apical vertebra rotation, apical vertebra translation, posterior instrumentation, lumbar modifier c

Introduction

Selective thoracic fusion (STF) for the treatment of adolescent idiopathic scoliosis (AIS) preserves lumbar motion segments but leaves a residual deformity that can show different behaviors in the early and late postoperative periods. By avoiding fusion of the lumbar spine, a greater mobility may be preserved.[1-8]

Selective thoracic fusion was first described by Von Lackum in 1949. He performed fusion of the primary thoracic curve alone without instrumentation and reported successful spontaneous correction of compensatory curves. He emphasized that overcorrection of the primary curve resulted in subsequent loss of balance in his series. In 1983, King et al. introduced King-Moe classification and described the selective thoracic fusion criteria, especially for Type II curves (major thoracic curve with compensatory lumbar curve).[9] However, coronal imbalance and decompensation have been reported due to inappropriate curve selection and/or excessive thoracic correction in these curves.[10-15]

In 2001 Lenke et al. reported that the King criteria for King Type II curves was not sufficient for selective thoracic fusion. They recommended additional criteria including the apical vertebral rotation (AVR) ratio, apical vertebral translation (AVT) ratio, Cobb angle and flexibility rate of the 2 curves, as well as the sagittal plane assessment of the thoracolumbar junction and recommended STF for Lenke type 1, 2, 3 and 4 curves with B and C modifiers.

Selective thoracic fusion performed for lumbar “C” modifier generally has excellent long-term outcomes but care must be taken to ensure that the thoracic curve is not overcorrected beyond the ability of the lumbar curve compensation. The lumbar flexibility rate should be assessed carefully before surgery to determine the optimum amount of thoracic curve correction. Although the lumbar flexibility is defined with side bending x-rays, it is not clear what percentage of lumbar flexibility predicts SLCC at the long term follow up.

The aim of the study was to review the clinical, radiographic and postoperative outcomes of Lenke type 1 and 2 with the lumbar modifier C curves and to evaluate the relationship between preoperative lumbar flexibility rate, apical lumbar vertebra rotation (AVR) and apical vertebral translation (AVT) with spontaneous lumbar curve correction following STF at long term follow up.

Methods

We retrospectively reviewed the data of patients who underwent surgery for AIS in our institution between 1999 and 2012. The clinical and radiological data of the patients were collected and analyzed. Inclusion criteria were AIS patients having Lenke 1 and 2 C curves, selective thoracic fusion using posterior instrumentation, the lowest instrumented vertebra was L1 or proximal, a complete set of preoperative and postoperative radiographs, and minimum of 8 years follow up. The preoperative curve flexibility was assessed with supine side bending X-rays. Initially 71 patients were included in the study. Sixteen patients were excluded. Four patients were not reachable because they had changed their residency to leaving abroad, while twelve patients had an incomplete set of radiographs at their final follow-up. Overall, 55 patients (54 females and one male) fulfilled the minimum follow-up.

All procedures were performed by the senior author (AH) with posterior approach in a similar manner using all pedicle screw construct. The deformity correction technique depended on the thoracic curve flexibility and presence of hypokyphosis. Cantilever technique, global derotation, segmental derotation segment by segment, and in situ bending maneuvers were used for scoliosis correction and restoration of the thoracic kyphosis. After the final correction we aimed to avoid overcorrection of the thoracic curve more than the lumbar residual curve on the preoperative bending x-rays to prevent postoperative coronal decompensation. Allografts and local autografts were used in all cases to achieve posterior facet fusion.

Previously SLCC rates after posterior STF were reported between 33% and 66%. Pasha et al. reported a minimum 55% SLCC for opimal STF results where Schulz et al. reported a minimum threshold 37%.[16,17] During data analysis of the our study, for an area =.9-1.0 (excellent positive predictive value) under ROC curve, a 50% SLCC was set and patient cohort was divided into 2 groups according to this data. Group A included patients who had more than 50% spontaneous lumbar curve correction (SLCC) without adding on or decompensation at follow up period (Figure 1). Group B included patients with less than 50% SLCC (Figure 2). The radiologic data obtained in the latest follow-up including anterior-posterior and lateral radiographic x-rays obtained while standing were evaluated. The preoperative standing, preoperative supine side bending, early postoperative standing, and follow-up x-rays were reviewed and characteristics of the lumbar curve were assessed. Two groups were compared in terms of the lumbar flexibility rate (Preoperative standing AP lumbar curve Cobb angle-Supine side bending lumbar curve Cobb angle x 100 /Preoperative standing AP lumbar curve Cobb angle), Apical Vertebral Rotation (AVR) and Apical Vertebral Translation (AVT). Lumbar flexibility rate information were collected from preoperative to latest follow up x-ray in order to evaluate the cutoff value of those parameters for more than 50% SLCC. AVR and AVT values were recorded from preoperative standing long

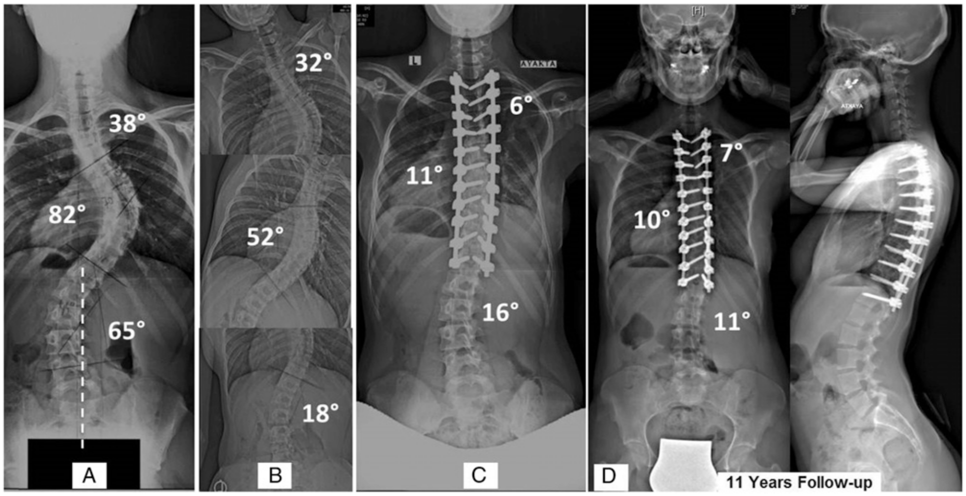

Figure 1. 15 years female patient. A: Preop AP Standing X-ray; B: Bending X-rays; C: Early-postop AP Standing Xray; D: 11 years Follow-up AP and LAT Standing X-rays; AP: Anteroposterior; LAT: Lateral.

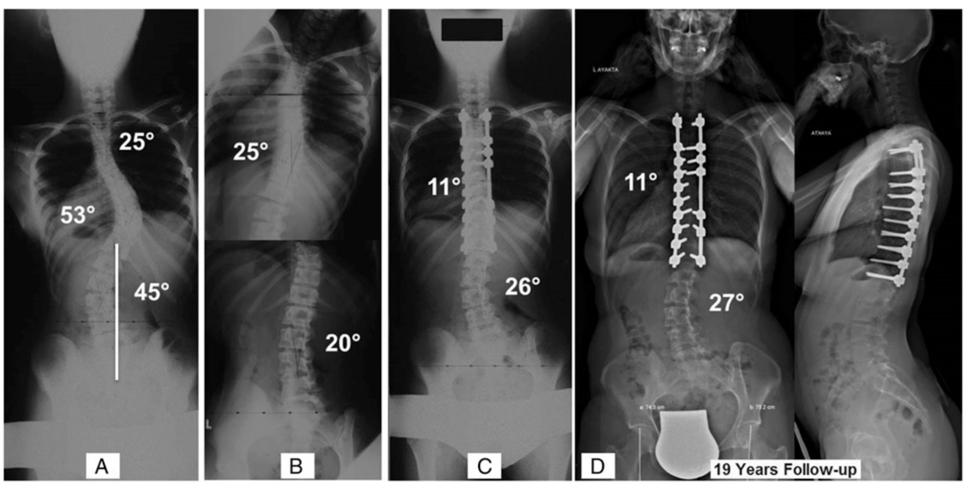

Figure 2. 14 years female patient. A: Preop AP Standing X-ray; B: Bending X-rays; C: Early-postop AP Standing Xray; D: 19 years Follow-up AP and LAT Standing X-rays; AP: Anteroposterior; LAT: Lateral.

scoliosis x-rays. AVR analysis was performed according to the Nash-Moe AVR grading system.[18] Determination of the AVR was performed according to appearance of Pedicle shadow at the convex side of the vertebra. No rotation (0:) pedicles in symmetric position; Grade I rotation:convex pedicle is slightly toward midline and concave pedicle overlaps edge of vertebra; Grade II rotation convex pedicle 2/3 toward midline and concave pedicle is barely visible; Grade III rotation concave pedicle is not visible and convex pedicle is at midline and in Grade IV rotation convex pedicle beyonds midline.For measurement of AVT; the ''C7 plumbline (C7PL)" was dropped from the middle of the C7 vertebral body and was drawn parallel to the vertical edge of the radiograph.The center sacral vertical line (CSVL) was drawn from the middle of S1 upwards and parallel to vertical edge of the radiograph. If there was no coronal decompensation, AVT was defined as the distance between middle point of apical vertebra and coincidence of C7PL and CSVL; if there was coronal decompesation AVT was defined as the distance between C7PL and middle point of apical vertebra for thoracic curves.In the lumbar curves AVT was measured between CSVL and lumbar apical vertebra.

Between the 2 groups, HRQoL scores at final follow-up were compared by SRS 22r. Statistical analysis was performed using Receiver Operating Characteristic (ROC) test. The independent variables (AVR, AVT) between groups were analyzed with nonparametric Mann Whitney U test. For comparison of nominal variables between groups such as LIV, Pearson Chi square test was performed.

(1) Informed consent was obtained from all participants before the study.

Results

There were 29 patients with Lenke Type 1C curves, 26 patients with type 2C curves. All patients were defined as lumbar curve Type C modifier whenever the center sacral vertical line (CSVL) did not touch the apical vertebral body or the bodies of the immediate vertebrae above and below the apical disc. The lowest instrumented vertebra was as follows; L1 in 7 patients (12.7%) in Group A and in 1 patient (1.8%) in Group B, T12 in 12 patients (21.8%) in Group A and in 6 patients (10.9%) in Group B, and T11 in 26 patients (47.2%) in Group A and in 3 patients (5.4%) in Group B. The difference in the level of lowest instrumented vertebrae (LIV) between groups was explored with Pearson Chi-Square test and there was no significant difference (P = .126) between groups in terms of LIV. The mean follow up period was 12.2 years (minimum 8 and maximum 23 years).

Group A included 26 Lenke 1C and 19 Lenke 2C patients. For Group A the mean preoperative thoracic Cobb measurement was 55.2° (45- 130), decreasing to 28.5° (15- 110) in side bending and decreasing to 13.2° (2- 40) at early postoperative assessment and measured as 12.5° (2- 38) at the latest follow-up. Mean thoracic correction was 77% for group A.

Group B included 3 Lenke 1C and 7 Lenke 2C patients. For Group B the mean preoperative thoracic Cobb measurement was 55.3° (46- 65), decreasing to 24.4° (17- 31) in side bending and decreasing to 18.0° (10- 24) at early postoperative, and measuring 18.2° (12- 26) at the latest follow-up. Mean thoracic curve correction was 67% for group B.

For Group A the mean preoperative lumbar Cobb measurement was 43.4° (31- 89) decreasing to 9.5° (0 - 41) in supine side bending and decreasing to 19° (6 - 45) at early postoperative, and measured 16.5° (4 - 43) at the latest follow-up. Mean non-fused lumbar curve correction was 62% for group A.

For Group B the mean preoperative lumbar Cobb measurement was 44° (30 - 56), decreasing to 17° (0 - 24) in supine side bending and decreasing to 20°(10-24) at early postoperative and measured to 23° (14-38) at the latest follow-up. Mean non-fused lumbar correction was 47% for group B.

Preoperative lumbar flexibility was 78.1% in Group A, 61.4% for group B. ROC analyses showed that 69% preoperative lumbar flexibility is the cut off value to obtain more than 50% SLCC at the latest follow up (P < .05, area = 1.00).

According to early postoperative grouping characteristics of Group A and Group B preoperative mean AVRs were; for Group A = 1.9 (0-3) and for Group B=2.4 (2-3). Mann Whitney U test was performed for differences between groups where a P value <.05 was set for statistical meaningful difference. There was a significant difference between the groups in terms of preoperative lumbar AVR (P = .029) while no statistical difference was found in AVT (P > .05) at preoperative standing x-rays. Preoperative mean AVTs were similar; 25.8mm (18 – 46.7) and 27.1mm (21.7 – 32) for both groups. (P > .05)

Group A included 35 patients in early postoperative period and 10 of the lumbar curves improved from Group B by the time and the total number of Group A increased to 45 (82%) at the follow up. Three patients (5%) showed decompensation at early postoperative period and 2 of them became compensated at follow up. Group B included 20 patients in early postoperative period and decreased by the time and total number was 10 at final follow up. None of the patients included to present study had any mechanical complications (pseudoarthrosis, screw loosening, rod breakage,hardware failure) at follow ups. One patient underwent debridement due to an early infection. HRQoL scores improved similarly in both groups from preop to f/up (Table1).

Discussion

The aim of selective thoracic fusion is to maintain a balanced spine whenever possible while also achieving spontaneous correction of the unfused lumbar curves. The difficulty lies in determining which patient should undergo selective thoracic fusion and which parameters can be used to achieve spontaneous lumbar curve correction in the long term.[10-15,19,20]

King et al. recommended selective thoracic fusion for King type 2 curves if the lumbar curve is more flexible and smaller than the thoracic curve.[9] In 1992, Lenke et al. defined certain criteria for STF with Cotrel-Dobusset instrumentations (CDI). A Cobb angle ratio >1.2, AVR ratio> 1.0, AVT ratio >1.2 between thoracic and lumbar curves were radiographic parameters for successful outcomes after STF.[12] Several authors also suggested that when the lumbar curves were >60°, Nash-Moe's rotation grade >2.5 or AVT >4.0 cm there was a high risk for failure of selective thoracic fusion. In these patients the thoracic and lumbar curves should be fused.[12-15]

In our current study preoperative Cobb angle ratio between thoracic and lumbar curves was 1.33, preoperative mean lumbar AVR was 1.45 and preoperative mean lumbar AVT was 1.25 similar to what Lenke had described previously for STF. When we divided our patients in terms of SLCC, more than 50% (Group A) and less than 50% (Group B); preoperatively, there was a statistical difference between groups regarding the preoperative lumbar AVR. Group A had a lower AVR; 1.9 compared to Group B; 2.4. On the other hand, preoperative mean lumbar AVT was 25.8 mm and 27.1 mm respectively, but there was no significant difference between the 2 groups.

Measurement of apical vertebral rotation (AVR) is an integral part of AIS evaluation, as it predicts the risk of progression and is necessary for planning the levels of instrumentation. Various methods have been described to determine AVR. The Nash–Moe index is an approximate measure of vertebral rotation and is still one of the most popular methods used in clinical practice.[19-21] Previous studies up to date reported a well-defined relation between AVR and coronal plane deformity and also flexibility. Additionally, our study showed that the degree of preoperative lumbar AVR is more important than the amount of preoperative lumbar AVT for SLCC. Similar

Table 1. Patients demographic data, Lenke types and SRS22r outcome scores of the patients.

	Group-A	Group-B	Total	*P* Value
N	45	10	55	
Age	14 (12-16)	13.6 (12-17)	14 (11-17)	
Gender	44F, 1M	10F	54F, 1M	
Follow-up (year)	11.6 (8-22)	15 (10-23)	12.2 (8-23)	
Lenke type				
1C	26	3	29	
2C	19	7	26	
UIV				
T2	35(63.6%)	8 (14.5%)		
T3	3 (5.4%)	2 (3.6%)		
T4	7 (12.7%)	-		
LIV				.126
T11	26 (47.2%)	3 (5.4%)		
T12	12 (21.8%)	6 (10.9%)		
L1	7 (12.7%)	1 (1.8%)		
Preoperative lumbar flexibility				
(%)	78.1	61.4		.000
AVR	1.9(0-3)	2.4(2-3)		.029
AVT	25.8mm (18-46.7)	27.1mm (21.7-32)		>.05
SRS-22r Scores at F/up (mean (range))				
Pain	4.3 (2.4 – 5)	4 (3 – 5)	4.2 (2.4 – 5)	.064
Self-image	4.1 (3 – 5)	4 (2.6 – 5)	4 (2.6 – 5)	.955
Function	4.6 (3.6 – 5)	4.5 (3.6 – 5)	4.6 (3.6 – 5)	.193
Mental health	3.9 (2.4 – 4.8)	4 (3 – 5)	3.9 (2.4 – 5)	.867
Satisfaction	4.62 (3-5)	4.81 (4.5-5)	4.66 (3-5)	.562
Sub-total	4.3 (3.1 - 4.9)	4.2 (3.3 - 5)	4.3 (3.1 - 5)	.751

Abbreviations: UIV, Upper instrumented vertebra; LIV, lower instrumented vertebra; AVR, Apical vertebra rotation; AVT, Apical vertebra translation.
A *P* value <.05 was set for statistical significance.

to our results, Behensky et al. found that the derotation amount of lumbar apical vertebral from standing AP to supine bending x-ray is more predictive than AVT in terms of postoperative coronal spinal imbalance.[19]

Most of the previous studies focus on the maximum preoperative lumbar curve magnitude and/or residual lumbar bending degree which can be accepted for STF.[21-35] Some authors recommend a maximum of 40° for preoperative lumbar Cobb angle as one of the criteria of selective thoracic fusion[35]; others consider 45 or 60° [12,23,25,26] for satisfactory clinical and radiologic results. In 1992, McCall et al reported that larger (>45°) and stiffer lumbar curves are at a higher risk for decompensation when STF is performed for King Type 2 patients. Based on their evaluation, they recommend STF as long as the lumbar curve magnitude is less than 45° to prevent postoperative coronal decompensation.[23] In our study we had 30 cases who had preoperative lumbar curves greater than 45° (mean lumbar Cobb 49°). Twenty-two of them showed more than 50% SLCC at the latest follow-up. Also, there were 3 patients with preoperative lumbar Cobb of more than 60° in our series and 2 of these patients showed more than 50% SLCC at the latest follow-up. Preoperative lumbar flexibility and lumbar AVR are more critical factors than preoperative lumbar curve magnitude in the decision-making to perform a selective thoracic fusion.[19-21,31,33]

In our series, residual lumbar curves of 10 patients who had less than 50% SLCC at the early postoperative period and who were initially defined as Group B, improved by time, showed more than 50% SLCC at the latest follow-up and then included to Group A. Eight of those 10 patients had more than 70% flexibility preoperatively. On the other hand, 3 patients who had more than 70% lumbar flexibility in preoperative assessment from Group A, had coronally decompensation at the early postoperative period. However, 2 of these 3 patients became compensated coronally at their latest follow-up. Although the number of patients who experienced decompensation in our case series was limited, preoperative lumbar flexibility of 70% and above and AVR grade below 2 may enable us to predict the recovery of residual curve in long-term follow-up.

The other controversy is related to the preoperative residual lumbar curve magnitude on the bending x-ray as a criterion for selective thoracic fusion. Residual lumbar bending degree has been accepted as 25°, 30° and 45° by Lenke,[25] Majd[27] and

Chang,[31] respectively as a radiographic criterion for decision making when using modern segmental instrumentations. In our study we evaluated preoperative lumbar flexibility rate (%) by using supine bending x-rays to predict SLCC and give a cut off value regardless of the residual lumbar curve magnitude.

Only a few studies reported lumbar flexibility value as a radiographic criteria for STF with modern pedicle instrumentations.[27,34] In a review article in 2003, Majd et al. reported that lumbar curve flexibility should be >50% and lumbar curve magnitude should decrease <30° on a bending x-ray to achieve a satisfactory results with STF in King Type 2 curves.[27] Qiu et al. tried to describe a new classification system for AIS in 2005.[34] They suggested that a lumbar flexibility >70% in double curves constituted one of the criteria to perform a selective thoracic fusion. Accordingly, in our study the preoperative flexibility of the lumbar curve was 78.1% for group A in which SLCC was higher than 50% of the preoperative lumbar curve magnitude. However, the preoperative flexibility of the lumbar curve was 61.4% for group B in which SLCC was less than 50% of the preoperative lumbar curve magnitude. When the 2 groups were analyzed in terms of preop lumbar flexibility and the latest follow-up x-rays of SLCC >50%; ROC analyses showed that 69% flexibility is the cut-off value to achieve and maintain more than 50% SLCC at final follow-up ($P < .05$, area = 1.00). This current study found similar results with the study of Qui et al.,[34] who stated that 70% flexibility rate ($P < .005$ for preoperative lumbar Cobb is the cut off value for Lenke type C curves to obtain more than 50% SLCC in the final follow-up.

The main advantage of this study is its longer follow-up period compared to previous studies, and all surgeries were performed by a single surgeon at a single institution. It has a mean of 12.2 (minimum 8 to maximum 23 years) years of follow-up. The other superiority of our study is that all patients had only type C modifier curves. Many of the published studies reported their results of STF either with Harrington hook and rod system or Cotrel-Dubousset implants.[2,9-15] In our study, we used only pedicle screw fixation.

The main principle of STF is to preserve flexibility and motion in the lumbar spine, while correcting the main deformity and maintain a well balanced spine.Overall SRS22r scores were improved in all patients. (In both groups)

According to SRS22r function and self image subdomains in group A, patients have higher mean scores but the differences were not statistically significant. This finding is tought to be due to small number of patients in groups.[36]

In conclusion when the flexibility in the preoperative bending x-ray is more than 70% ($P < .01$) and when AVR is equal or less than 2 grades in Lenke 1C and Lenke 2 C curves, STF provides satisfactory clinical and radiological SLCC at a mean follow up of 12.2 (minimum 8 and maximum 23) years. In addition, our study showed that a flexibility rate of the lumbar curve greater than 70% and a preoperative AVR grade equal to or less than 2 grades are more important criteria than the preoperative lumbar curve magnitude and preoperative AVT distance in the decision making of STF and for the prevention of coronal plane decompensation in Lenke 1-2 C curves.

(1) The Authors declare that there is no conflict of interest.

Declaration of Conflicting Interests

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Ethical Approval

This study was performed at Istanbul Spine Center, Florence Nightingale Hospital, Istanbul, Turkey.

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