Research Square

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# Preoperative and Early Postoperative Spinopelvic Predictors of Sagittal Alignment Deterioration After Short-Segment Lumbar Fusion

**Hayato Takei**
University of Yamanashi
**Tetsuro Ohba**
tooba@yamanashi.ac.jp

University of Yamanashi
**Toshiyuki Shimono**
University of Yamanashi
**Nobuki Tanaka**
University of Yamanashi
**Kotaro Oda**
University of Yamanashi
**Kai Mizukami**
University of Yamanashi
**Go Goto**
University of Yamanashi
**Hiroshi Yokomichi**
University of Yamanashi
**Hirotaka Haro**
University of Yamanashi

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## Abstract

# Purpose

To identify preoperative and early postoperative spinopelvic parameters associated with loss of global sagittal correction after short-segment lumbar fusion in patients with preoperative sagittal imbalance.

# Methods

This retrospective single-center study included 124 patients aged 60 years or older with preoperative SVA of 50 mm or greater who underwent 1- to 3-level lumbar interbody fusion. Full-length standing lateral radiographs were obtained preoperatively, 4–6 weeks postoperatively, and 2 years postoperatively. Spinopelvic parameters included SVA, lumbar lordosis (LL), global tilt (GT), and lordosis distribution index (LDI). Correlation, multivariable logistic regression, and ROC analyses were performed.

# Results

Mean SVA improved from 89.8 +/- 34.7 mm to 59.9 +/- 42.8 mm early postoperatively, but worsened to 85.7 +/- 61.1 mm at 2 years. Preoperative LDI correlated positively with delta SVA ($r = 0.43$, $p < 0.0001$). Early postoperative SVA, GT, and LDI also correlated positively, whereas postoperative LL correlated negatively ($r = -0.601$, $p < 0.0001$). Preoperative LDI remained independently associated with delta SVA of 50 mm or greater (odds ratio 2.99, 95% confidence interval 1.24–7.21, $p = 0.015$). ROC-derived cutoffs were 78% for preoperative LDI and 17.6 degrees for postoperative LL. Two-year SVA correlated with ODI ($r = 0.536$, $p < 0.001$).

# Conclusion

Higher preoperative LDI and insufficient early postoperative LL restoration were associated with recurrent sagittal imbalance 2 years after short-segment lumbar fusion. These parameters may help identify patients at increased risk of loss of correction after short fusion.

## Introduction

Short-segment lumbar fusion is widely used for degenerative lumbar disease because it can relieve symptoms while limiting surgical invasiveness. In patients with pre-existing sagittal malalignment, however, the initial postoperative correction may deteriorate over time, and worsening global sagittal balance has been associated with adjacent-segment degeneration, mechanical complications, and worse clinical outcomes [1–6].

Long fusion can provide more reliable global realignment, but it is more invasive and may be less attractive for older patients with comorbidities [7–9]. Therefore, when short-segment fusion is selected in patients with sagittal imbalance, surgeons need practical radiographic factors that can identify patients at risk of losing correction during follow-up.

Most previous studies have focused on static postoperative alignment rather than longitudinal change. We therefore evaluated the 2-year change in sagittal vertical axis (delta SVA) after 1- to 3-level lumbar interbody fusion and examined whether preoperative and early postoperative spinopelvic parameters were associated with loss of global sagittal alignment. We hypothesized that preoperative lordosis distribution and insufficient early postoperative lumbar lordosis would be associated with greater loss of correction.

## Materials and methods

# Study design and patients

This retrospective observational study included consecutive patients with degenerative lumbar disease (anterolisthesis, retrolisthesis, degenerative disc disease, foraminal stenosis, lumbar stenosis with facet arthropathy, spondylosis, recurrent disc herniation, or combinations thereof) who underwent 1- to 3-level lumbar interbody fusion at a single institution during a 2-year enrollment period.

Eligible patients were 60 years or older and had a preoperative sagittal vertical axis (SVA) of 50 mm or greater. Patients who underwent reoperation within 2 years after the index surgery or who lacked complete radiographic or ODI follow-up were excluded. Of 141 screened patients, 124 were included in the final analysis. Institutional review board approval was obtained (Approval No. 1883), and written informed consent was obtained from all participants.

## Surgical technique

All procedures were performed at a single institution under the supervision of experienced spine surgeons. Posterior pedicle screw fixation with lumbar interbody fusion was used in all cases. The interbody approach - posterior lumbar interbody fusion, transforaminal lumbar interbody fusion, or lateral lumbar interbody fusion - as well as cage material and the number of cages were selected by the treating spine surgeon.

## Radiographic assessment

Full-length standing lateral radiographs were obtained preoperatively, 4–6 weeks postoperatively, and 2 years postoperatively. Radiographs were acquired with patients standing freely with their fingers placed on the clavicles.

Measured parameters were thoracic kyphosis (TK; T5-T12), lumbar lordosis (LL; T12-S1), pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), SVA, and global tilt (GT). GT was defined as the angle between a line from the center of C7 to the center of the sacral endplate and a line from the center of the femoral heads to the center of the sacral endplate. Lordosis distribution index (LDI) was calculated as L4-S1 lordosis divided by L1-S1 lordosis. For threshold analyses, LDI was also expressed as a percentage (ratio multiplied by 100). The primary radiographic outcome, delta SVA, was defined as the 2-year postoperative SVA minus the preoperative SVA.

Radiographic measurements were performed independently by two board-certified spine surgeons who were blinded to clinical data, and the mean of the two measurements was used for analysis. The intraclass correlation coefficient was 0.872.

## Clinical outcome

Clinical status was evaluated preoperatively and 2 years postoperatively using the Oswestry Disability Index (ODI) [10].

# Statistical analysis

Patients were categorized into delta SVA-negative and delta SVA-positive groups according to whether 2-year SVA decreased or increased relative to the preoperative value. Continuous variables are presented as mean +/- standard deviation and categorical variables as number (percentage). Group comparisons were performed using Student's t test, Mann-Whitney U test, or Fisher's exact test, as appropriate.

Associations between radiographic parameters and ODI or delta SVA were evaluated using Pearson correlation coefficients. Multivariable logistic regression was used to examine factors associated with delta SVA of 50 mm or greater. ROC curve analysis was used to derive cutoff values. Summary statistics and group comparisons were performed using Prism version 9.0 (GraphPad Software, La Jolla, CA, USA), and ROC analyses were performed in R version 4.3.3 using the ROCR package. Statistical significance was defined as $p < 0.05$.

## Results

# Patient characteristics

The final cohort comprised 124 patients. Mean fusion length was 1.92 +/- 0.6 levels. Seventy-one patients were categorized as delta SVA-negative and 53 as delta SVA-positive at 2 years. Fusion length was greater in the delta SVA-positive group, whereas age, sex, and body mass index were not significantly different between groups. Among preoperative spinopelvic parameters, only LDI differed significantly between groups, with a higher value in the delta SVA-positive group (Table 1).

# Temporal changes in alignment

Mean SVA for the overall cohort improved from 89.8 +/- 34.7 mm preoperatively to 59.9 +/- 42.8 mm at 4-6 weeks postoperatively, but increased to 85.7 +/- 61.1 mm at 2 years. Mean LL increased from 21.7 +/- 12.8 degrees preoperatively to 30.1 +/- 15.1 degrees early postoperatively and remained stable at 2 years. Mean LDI values were 0.83 preoperatively, 0.85 early postoperatively, and 0.78 at 2 years (Figure 1).

# Correlation with ODI at 2 years

At 2 years, ODI correlated positively with SVA ($r = 0.536$, $p < 0.001$), GT ($r = 0.486$, $p < 0.001$), and LL ($r = 0.441$, $p = 0.001$), and negatively with PI ($r = -0.208$, $p = 0.03$) (Table 2).

# Correlation with loss of sagittal correction

Preoperative LDI correlated positively with delta SVA ($r = 0.43$, $p < 0.0001$). Among early postoperative parameters, SVA, GT, and LDI correlated positively with delta SVA, whereas postoperative LL correlated negatively ($r = -0.601$, $p < 0.0001$) (Table 3).

In multivariable logistic regression including age, sex, fusion length, preoperative SVA, and preoperative LDI, only preoperative LDI remained independently associated with delta SVA of 50 mm or greater (odds ratio 2.99, 95% confidence interval 1.24-7.21, $p = 0.015$). Age ($p = 0.072$), sex ($p = 0.897$), fusion length ($p = 0.362$), and preoperative SVA ($p = 0.325$) were not significant. ROC analysis identified a cutoff of 78% for preoperative LDI (area under the curve 0.756) and a cutoff of 17.6 degrees for postoperative LL (area under the curve 0.861) for predicting delta SVA of 50 mm or greater at 2 years (Figures 2 and 3).

## Discussion

In this cohort of older patients with preoperative sagittal imbalance, short-segment lumbar fusion improved global sagittal alignment early after surgery, but part of that correction was lost by 2 years. Two findings are clinically important. First, preoperative LDI was associated with subsequent loss of correction and remained independently associated with delta SVA of 50 mm or greater. Second, early postoperative LL showed the strongest inverse relationship with delta SVA, suggesting that not only the amount of lordosis restoration but also the early alignment profile influences maintenance of global balance.

The importance of LL restoration after short fusion has been reported previously [6, 14, 15]. Our data support that concept and further suggest that lordosis distribution should be considered alongside total LL. A high LDI reflects a relatively distal concentration of lordosis at L4-S1. When total LL is insufficient, that pattern may leave the upper lumbar spine and thoracolumbar junction relatively hypolordotic,

favoring recurrent anterior trunk translation during follow-up. This interpretation is consistent with reports linking abnormal postoperative lordosis distribution, L3-L4 hyperlordosis, and decreased lower lumbar lordosis with adjacent-segment disease or poorer sagittal alignment after short fusion [16–24].

The thresholds identified by ROC analysis may be useful for risk stratification. A preoperative LDI of 78% or greater and an early postoperative LL below 17.6 degrees were associated with a higher risk of delta SVA of 50 mm or greater at 2 years. These values should not be interpreted as absolute indications for or against short fusion. Rather, they may help guide surgical planning, postoperative surveillance, and discussion of risk in patients who already present with sagittal imbalance.

The relationship between radiographic alignment and clinical status also supports the relevance of these findings. At 2 years, worse SVA was associated with worse ODI, which is consistent with the broader literature on sagittal balance and disability [2, 11–13]. Preventing recurrent sagittal deterioration therefore appears relevant not only radiographically but also clinically.

This study has limitations. It was retrospective and single-center, and the surgical approaches and fusion patterns were heterogeneous. The sample size was modest for multivariable modeling. Detailed comorbidity data and segmental analyses of unfused levels were unavailable, and the proposed thresholds were not externally validated. In addition, the inclusion criteria (age at least 60 years and preoperative SVA of at least 50 mm) and exclusion of patients requiring reoperation may limit generalizability. Nevertheless, the study focuses on a clinically common decision point: selecting short-segment fusion in older patients with sagittal imbalance.

In summary, higher preoperative LDI and insufficient early postoperative LL restoration were associated with loss of global sagittal alignment correction 2 years after short-segment lumbar fusion. These parameters may help identify patients at increased risk of recurrent sagittal imbalance.

## Statements and Declarations

**Funding:** No funding was received for this study.

**Ethics approval:** Institutional review board approval was obtained (Approval No. 1883).

**Consent to participate:** Written informed consent was obtained from all participants.

**Consent for publication:** Not applicable because no patient-identifiable information is included in this manuscript.

**Data availability:** The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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# Tables

**Table 1. Baseline demographic and preoperative spinopelvic characteristics.**

| Characteristic | Overall (n = 124) | delta SVA-negative (n = 71) | delta SVA-positive (n = 53) | P value |
|---|---|---|---|---|
| **Demographic and surgical variables** | | | | |
| Age (years) | 73.0 +/- 8.1 | 73.5 +/- 8.1 | 73.34 +/- 8.3 | 0.92 |
| Sex, female/male | 92/32 | 53/18 | 39/14 | 0.64 |
| BMI (kg/m^2) | 24.45 +/- 3.7 | 23.93 +/- 3.4 | 24.66 +/- 4.1 | 0.84 |
| Fusion length (levels) | 1.92 +/- 0.6 | 1.71 +/- 0.79 | 2.18 +/- 0.87 | 0.0097 |
| **Preoperative spinopelvic parameters** | | | | |
| PT (degrees) | 27.3 +/- 6.89 | 26.3 +/- 6.46 | 28.6 +/- 7.3 | 0.13 |
| SS (degrees) | 23.2 +/- 8.42 | 23.9 +/- 8.98 | 22.2 +/- 7.65 | 0.34 |
| LL (degrees) | 21.7 +/- 12.8 | 23.2 +/- 11.6 | 19.9 +/- 14.1 | 0.23 |
| LDI (ratio) | 0.83 +/- 0.78 | 0.62 +/- 0.51 | 1.09 +/- 0.96 | 0.004 |
| PI-LL (degrees) | 28.8 +/- 11.8 | 27.1 +/- 11.5 | 30.9 +/- 11.9 | 0.14 |
| SVA (mm) | 89.8 +/- 34.7 | 93.1 +/- 35.7 | 85.5 +/- 33.4 | 0.31 |
| GT (degrees) | 36.4 +/- 9.18 | 35.8 +/- 9.84 | 37.3 +/- 8.31 | 0.44 |

*Values are presented as mean +/- standard deviation unless otherwise indicated. BMI body mass index, PT pelvic tilt, SS sacral slope, LL lumbar lordosis, LDI lordosis distribution index, PI pelvic incidence, SVA sagittal vertical axis, GT global tilt.*

**Table 2. Correlation between spinopelvic parameters and ODI at 2 years postoperatively.**

| Parameter | r | P value |
|---|---|---|
| TK (degrees) | 0.111 | 0.24 |
| SS (degrees) | -0.277 | 0.06 |
| PT (degrees) | 0.074 | 0.44 |
| PI (degrees) | -0.208 | 0.03 |
| SVA (mm) | 0.536 | <0.001 |
| GT (degrees) | 0.486 | <0.001 |
| LL (degrees) | 0.441 | 0.001 |
| LDI (ratio) | 0.063 | 0.51 |

*Correlation between spinopelvic parameters and ODI at 2 years postoperatively. Pearson correlation coefficients are shown. ODI Oswestry Disability Index, TK thoracic kyphosis, SS sacral slope, PT pelvic tilt, PI pelvic incidence, SVA sagittal vertical axis, GT global tilt, LL lumbar lordosis, LDI lordosis distribution index.*

**Table 3. Correlation between spinopelvic parameters and delta SVA.**

| Time point | Parameter | r | P value |
|---|---|---|---|
| **Preoperative** | | | |
| Preoperative | TK (degrees) | 0.118 | 0.28 |
| Preoperative | SS (degrees) | -0.200 | 0.065 |
| Preoperative | PT (degrees) | 0.133 | 0.221 |
| Preoperative | PI (degrees) | -0.093 | 0.393 |
| Preoperative | SVA (mm) | -0.172 | 0.113 |
| Preoperative | GT (degrees) | 0.034 | 0.757 |
| Preoperative | LL (degrees) | -0.204 | 0.059 |
| Preoperative | LDI (ratio) | 0.43 | <0.0001 |
| **Early postoperative** | | | |
| Early postoperative | SVA (mm) | 0.531 | <0.0001 |
| Early postoperative | GT (degrees) | 0.527 | <0.0001 |
| Early postoperative | LL (degrees) | -0.601 | <0.0001 |
| Early postoperative | LDI (ratio) | 0.522 | <0.0001 |

*Delta SVA was defined as 2-year postoperative SVA minus preoperative SVA.*

# Figures

Fig. 1

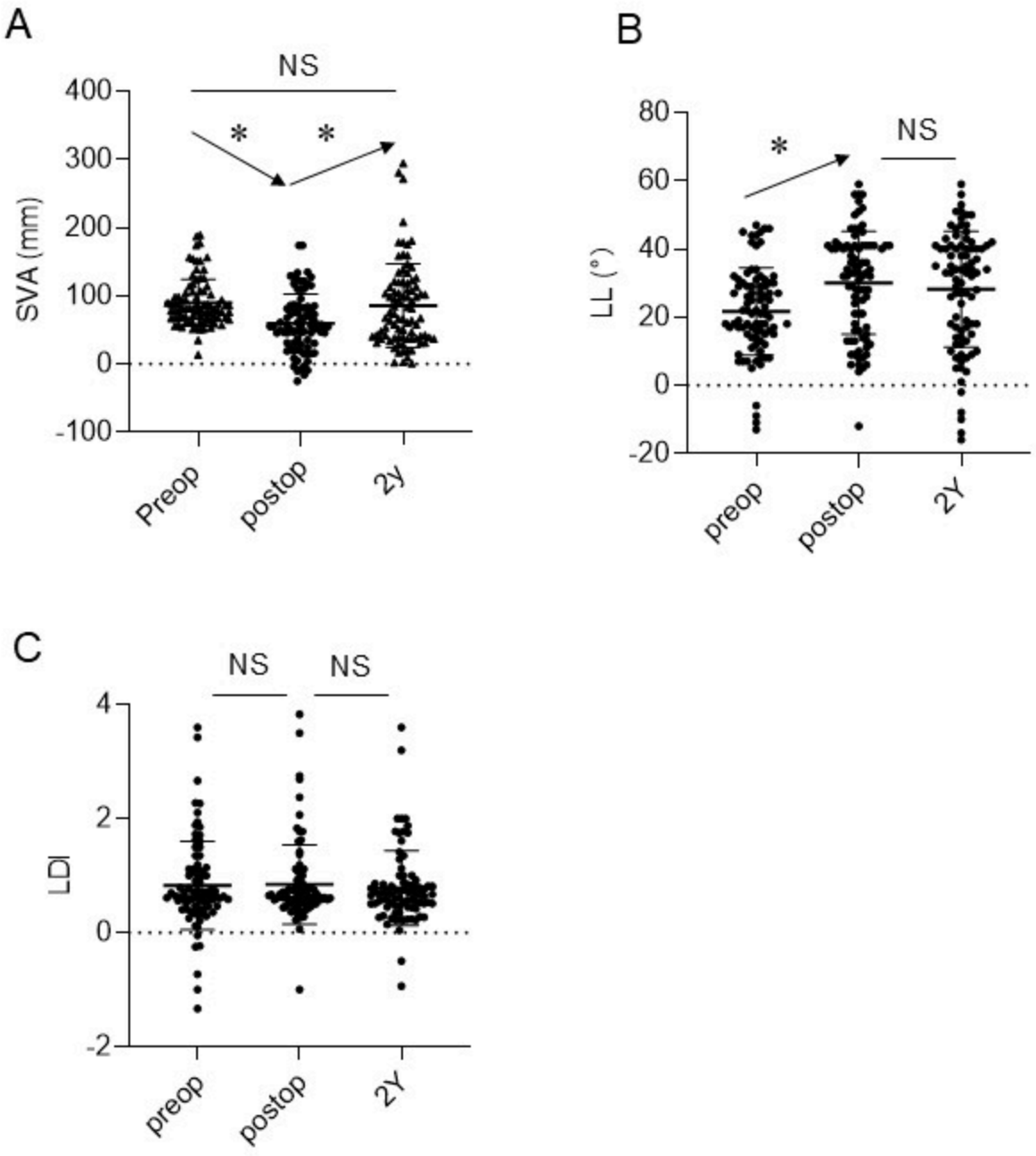



**Figure 1**

Scatter plots showing changes in sagittal vertical axis (A), lumbar lordosis (B), and lordosis distribution index (C) at the preoperative, 4-6-week postoperative, and 2-year postoperative evaluations. Abbreviations: NS, not statistically significant; SVA, sagittal vertical axis; LL, lumbar lordosis; LDI, lordosis distribution index.

Fig. 2

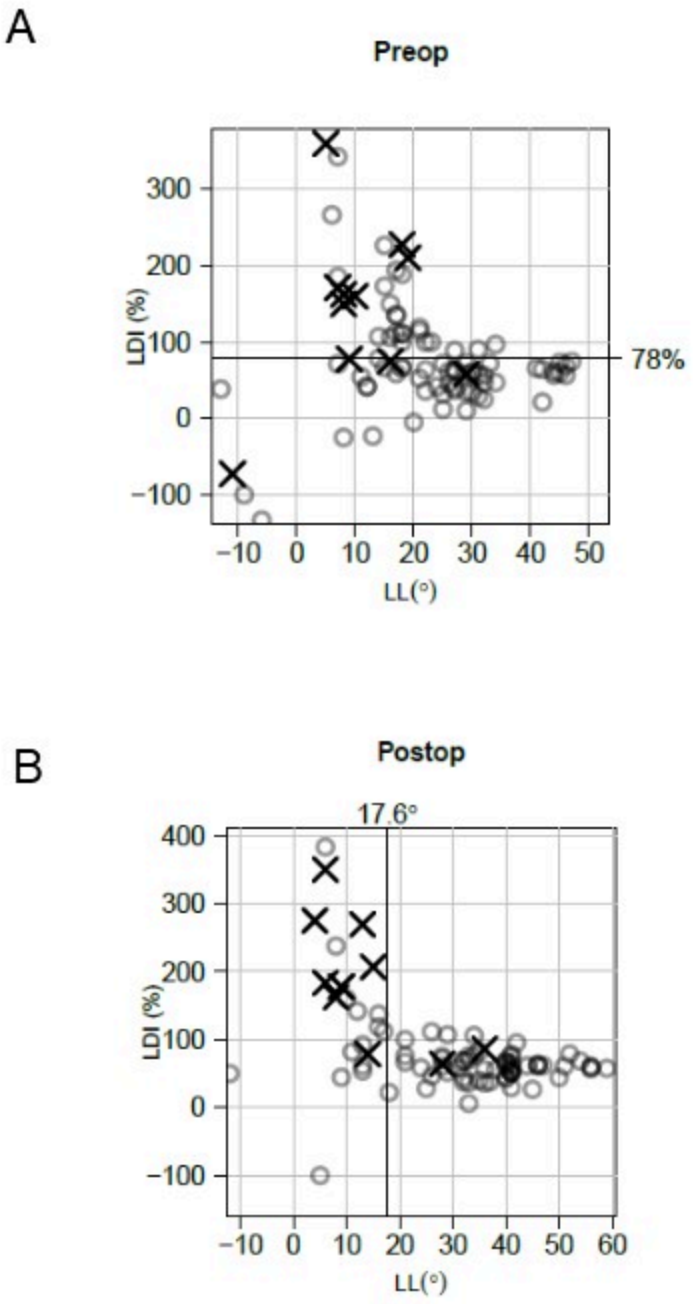



**Figure 2**

Scatter plots of lumbar lordosis and lordosis distribution index relative to the derived thresholds. A, preoperative LL and LDI with the 78% preoperative LDI cutoff. B, early postoperative LL and LDI with the 17.6 degrees postoperative LL cutoff. Each point represents one patient.

Fig. 3

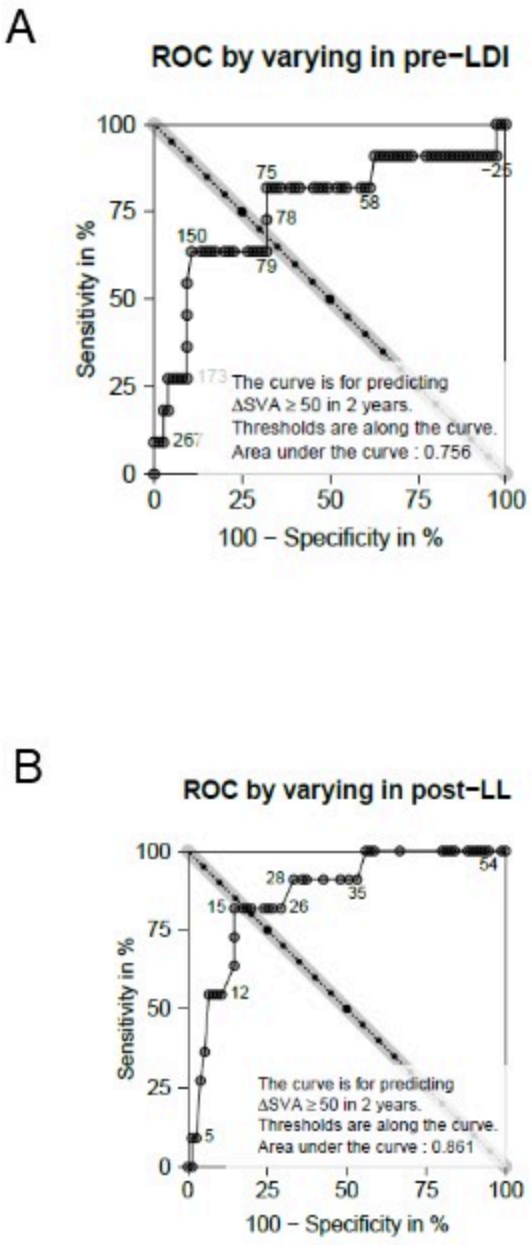



**Figure 3**

Receiver operating characteristic curves for predicting delta SVA of 50 mm or greater at 2 years using preoperative LDI (A) and early postoperative LL (B). The areas under the curve were 0.756 and 0.861, respectively. Numbers along the curves indicate representative thresholds.