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Analysis of rotational deformity correction by lateral lumbar interbody fusion with two-staged anterior-posterior combined corrective fusion surgery for adult degenerative kyphoscoliosis

Tetsutaro Abe, MD[a], Masashi Miyazaki, MD, PhD[a,*], Shozo Kanezaki, MD, PhD[a], Masashi Hirakawa, MD, PhD[a], Tatsuya Iwasaki, MD, PhD[a], Hiroshi Tsumura, MD, PhD[a]

Abstract

The present study is retrospective analysis of consecutively collected data. Lateral lumber interbody fusion (LLIF) is widely used in cases of adult spinal deformities. However, the corrective effects of LLIF cage insertion on the vertebral rotation deformity in the axial plane and the individual effects of LLIF and direct vertebral rotation (DVR) on rotational correction are unclear. To individually examine the corrective effects of LLIF and posterior corrective fusion surgery with direct DVR on vertebral rotation deformities in adult degenerative kyphoscoliosis. We analyzed 21 patients (5 males and 16 females) who underwent two-staged anterior-posterior combined corrective fusion surgery for adult degenerative kyphoscoliosis. Surgical time, blood loss, facet joint osteoarthritis (OA) grade, disc degeneration, cage height, vertebral rotational angle, and various X-ray parameters were investigated as evaluation items. The X-ray parameters showed significant postoperative improvements. The mean vertebral rotation angle was 6.4° ± 5.2° preoperatively, 3.5° ± 3.3° after LLIF (P = .014, vs preoperative), and 1.6° ± 1.7° after posterior corrective fusion surgery with DVR (P = .011, vs preoperative). Correlation analysis between the vertebral rotation angle and various measured values revealed that the vertebral rotation angle after LLIF was correlated with the cage height (r = −0.46, P = .032). The vertebral rotation angle after DVR was correlated with the facet joint OA grade (r = −0.49, P = .018) and the wedge angle after posterior corrective fusion surgery with DVR (R = 0.57, P = .006). We conclude that the effects of rotational deformity correction with LLIF cage insertion and additional posterior corrective fixation with DVR can be useful for correcting vertebral rotation deformities.

Abbreviations: CT = computed tomography, DVR = direct vertebral rotation, LL = lumbar lordosis, LLIF = lateral lumber interbody fusion, OA = osteoarthritis, PI = pelvic incidence, PT = pelvic tilt, SVA = sagittal vertical axis, TK = thoracic kyphosis.

Keywords: adult degenerative scoliosis, lumbar lateral interbody fusion, vertebral rotation deformity

1. Introduction

Degenerative kyphoscoliosis, which is characterized by abnormal sagittal and coronal curvatures with a marked loss of lordosis in the lumbar spine and rotational deformity caused by disc degeneration and facet arthritis, is a serious clinical condition that affects activities of daily living. The main symptoms of degenerative kyphoscoliosis are low back pain, neuropathy, and overall spinal imbalance. The deformities in degenerative kyphoscoliosis are mainly based on deformation of the coronal wedge disc, but are thought to be accompanied by axial rotation. The coexistence of wedges and axial rotational deformities is one of the factors associated with the progression of these spinal deformities.[1] Although the importance of axial rotation deformity in degenerative kyphoscoliosis has been recognized, information on the segmental axis rotation angle of patients with degenerative scoliosis is limited. Quantitative evaluation of the rotational deformation of an axial surface using radiographs is difficult, and these deformations can be evaluated using computed tomography (CT) axial images instead.[2,3]

Recent studies[4–6] have described the use of lateral lumbar interbody fusion (LLIF) to restore disc height, correct deformities, and stabilize degenerative scoliosis, and reported its usefulness in this regard. LLIF can effectively reduce lateral flexion and kyphosis deformity. Although some studies have evaluated disc height recovery and deformity correction with LLIF, the correlation between disc height and the amount of deformity

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

This study received approval from our institution's Ethical Committee. All procedures were performed in accordance with the ethical standards of this committee, as well as with the 1964 Helsinki Declaration and its later amendments.

[a] Department of Orthopaedic Surgery, Faculty of Medicine, Oita University, Oita, Japan.

**Correspondence: Masashi Miyazaki, Department of Orthopaedic Surgery, Faculty of Medicine, Oita University, 1-1 Idaigaoka, Hasama-machi, Yufu-shi, Oita 879-5593, Japan (e-mail address: masashim@oita-u.ac.jp).*

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correction has not been quantitatively analyzed.[4,5] On the other hand, the direct vertebral rotation (DVR) technique using pedicle screws for vertebral rotational correction has been already proven to be useful in idiopathic scoliosis.[7] Although some reports have described the effects of LLIF and posterior corrective fusion on correcting rotational deformation,[8,9] these studies evaluated the final results of the combined techniques and did not assess the individual effects of LLIF and DVR on rotational correction. Thus, the purpose of this study is to investigate the individual corrective effects of LLIF and posterior corrective fusion surgery with DVR on vertebral rotation deformity in degenerative scoliosis.

2. Materials and Methods

2.1. Study design and participants

The present study was a retrospective study. All assessments were performed after obtaining approval from our institution's ethics committee, and informed consent was obtained from all patients. We analyzed 21 patients (5 males and 16 females; average age, 69.6 ± 12.9 years) who underwent two-staged anterior-posterior combined corrective fusion surgery for adult degenerative kyphoscoliosis between July 2015 and June 2021. Spine specialists evaluated each patient's symptoms (low back pain, lower-extremity numbness, walking disorder, and posture abnormalities, etc) and the imbalance in sagittal and coronal planes on radiographs and confirmed that the symptoms originated from adult degenerative kyphoscoliosis. Adult spinal deformity was defined as thoracic kyphosis > 60°, pelvic tilt > 25°, or sagittal vertical axis > 50 mm and any coronal curve > 20° in patients aged > 18 years. Patients with basic disease as a cause of secondary scoliosis were excluded. The average follow-up period was 23.1 ± 11.3 months. The evaluation items included surgical time, blood loss, facet joint osteoarthritis (OA) grade (preoperative), disc degeneration (preoperative), cage height, vertebral rotational angle (preoperative, after LLIF, and after DVR) and various X-ray parameters (Cobb angle; C7 plumb line-central sacral vertical line; sagittal vertical axis, SVA; thoracic kyphosis, TK; lumbar lordosis, LL; pelvic tilt, PT; pelvic incidence, PI; and wedge angle, PI-LL; each measured preoperatively and 1 year postoperatively).

2.2. Surgical techniques

In the two-staged anterior-posterior combined corrective fusion surgery, the first stage involved LLIF for lumbar vertebral disc lesions at L2/3, 3/4, and 4/5 without release of the anterior longitudinal ligament in the lateral position. For LLIF, the cage size was selected according to the intervertebral disc height and the cage position was determined using the original extreme lateral interbody fusion (XLIF®; NuVasive Inc., CA) method. One week later, the patients underwent posterior corrective fusion and transforaminal lumbar interbody fusion (L5/S1) in the prone position. Facet release and grade 1 bone osteotomy was performed before the correction, which was followed by posterior correction by cantilever technique and spinal fusion from the lower thoracic spine to the iliac. Vertebral rotation correction was performed using the DVR technique using a vertebral column manipulator after a rod rotation maneuver at the rotational deformation vertebra. Patients wore the Jewett type corset for 6 months after surgery.

2.3. Radiological assessment

All patients underwent standing lateral radiography preoperatively and at the final follow-up. The following factors were analyzed on the radiographs: Cobb angle, SVA, TK, LL, PT, PI, PI-LL,[10] and wedge angle. The L2-5 Cobb angle was the angle between the upper endplate of the L2 vertebra and the lower endplate of the L5 vertebra. The wedge angle was the angle between the lower endplate of the cranial vertebra and the upper endplate of the caudal vertebra at the L2/3, 3/4, 4/5 vertebrae (Fig. 1). Wedge angle changes (Δwedge angle) were calculated as follows: Δwedge angle1 (preoperative to after LLIF) = (preoperative wedge angle) – (wedge angle after LLIF); Δwedge angle2 (after LLIF to after DVR) = (wedge angle after LLIF) – (wedge angle after DVR); and Δwedge angle3 (preoperative to after DVR) = (preoperative wedge angle) – (wedge angle after DVR). The vertebral rotation angle was measured on CT scans obtained preoperatively, after LLIF, and after DVR. The angle of rotation (RAsag) of the vertebra was measured using the angle between the junction of the laminae, the dorsal central aspect of the vertebral foramen and the middle of the vertebral body, and the sagittal plane (Fig. 2).[11] The changes in RAsag (ΔRAsag) were calculated with the following formula: ΔRAsag1 (preoperative to after LLIF) = (preoperative RAsag) – (RAsag after LLIF); ΔRAsag2 (after LLIF to after DVR) = (RAsag after LLIF) – (RAsag after DVR); and ΔRAsag3 (preoperative to after DVR) = (preoperative RAsag) – (RAsag after DVR). Facet joint OA grade was evaluated by preoperative CT (Fig. 3).[12] Four grades of OA of the facet joints were defined as follows: grade 0, normal facet joint space (width, 2–4 mm); grade 1, narrowing of the facet joint space (<2 mm) and/or small osteophytes and/or mild hypertrophy of the articular process; grade 2, narrowing of the facet joint space and/or moderate osteophytes and/or moderate hypertrophy of the articular process and/or mild subarticular bone erosions; grade 3: narrowing of the facet joint space and/or large osteophytes and/or severe hypertrophy of the articular process and/or severe subarticular bone erosions and/or subchondral cysts. Disc degeneration was evaluated by preoperative magnetic resonance imaging according to Pfirrmann classification

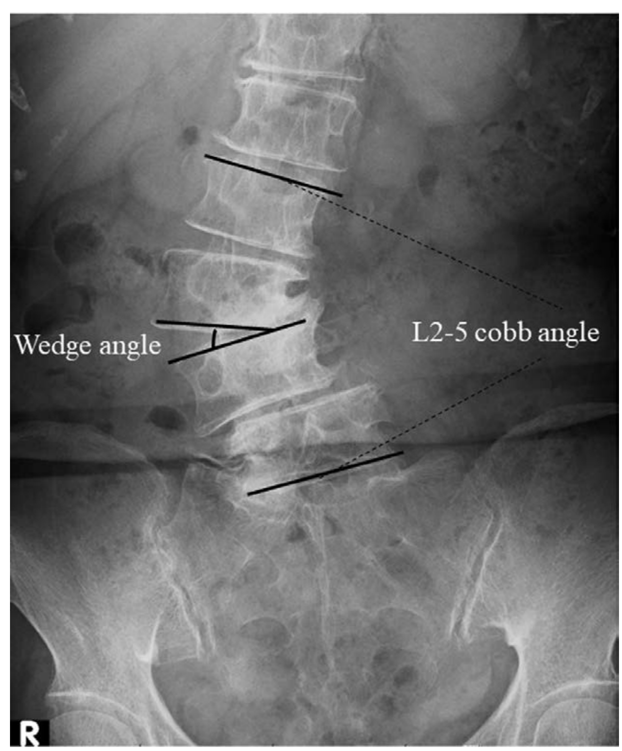

Figure 1. The L2-5 Cobb angle measured as the angle between the upper endplate of the L2 vertebra and the lower endplate of the L5 vertebra. The wedge angle measured as the angle between the lower endplate of the cranial vertebra and the upper endplate of the caudal vertebra at the L2/3, 3/4, and 4/5 vertebrae.

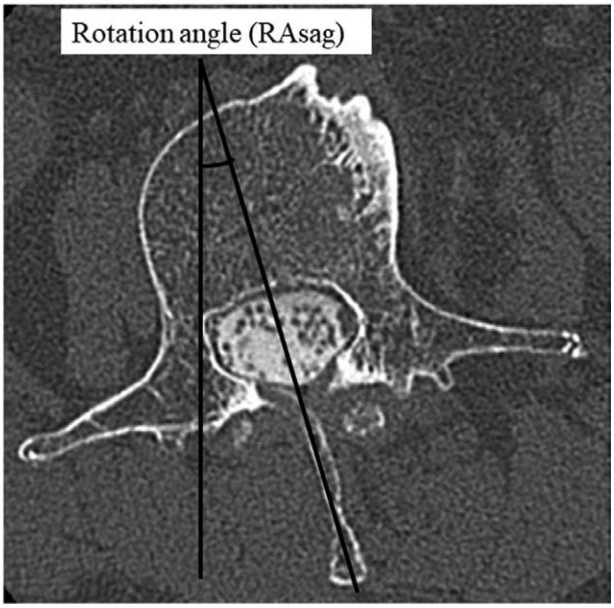

Figure 2. The angle of rotation (RAsag) of the vertebra was measured using the angle between the junction of the laminae, the dorsal central aspect of the vertebral foramen and the middle of the vertebral body, and the sagittal plane.

(Fig. 4).[13] Lumbar disc degeneration was graded as follows: grade 1, the disc structure is homogeneous with a bright hyperintense white signal intensity and a normal disc height; grade 2, the disc structure is inhomogeneous with a hyperintense white signal, the distinction between the nucleus and annulus is clear, and the disc height is normal with or without horizontal gray bands; grade 3, the disc structure is inhomogeneous with an intermediate gray signal intensity, the distinction between nucleus and annulus is unclear, and the disc height is normal or slightly decreased; grade 4, the disc structure is inhomogeneous with a hypointense dark gray signal intensity, the distinction between the nucleus and annulus is lost, and the disc height is normal or moderately decreased; and grade 5, the disc structure is inhomogeneous with a hypointense black signal intensity, the distinction between nucleus and annulus is lost, and the disc space is collapsed. Grading was performed on T2-weighted midsagittal images by 2 independent observers with good concordance (Kappa > 0.72). The 2 observers established the final classification by consensus. Two independent observers measured each parameter in consensus using electronic calipers on a Digital Imaging and Communications in Medicine viewer and workstation. The reliability of the measurement techniques was investigated, and the intra and interobserver agreement was good-to-excellent for each parameter (kappa > 0.70).

2.4. Statistical analysis

These data were prospectively collected with appropriate informed consent and presented as mean ± standard deviation. Statistical analyses were performed using paired t-test. Pearson correlation coefficient was used to assess the correlation between independent variables (surgical time, blood loss, facet joint OA grade, disc degeneration, cage height, L2-5 Cobb angle, SVA, TK, LL, PT, PI, PI-LL, Δwedge angle) and the dependent variable (ΔRAsag1 and ΔRAsag2). In multiple regression analysis, the objective variable was ΔRAsag3 at the final observation. Variables with *P* values <.10 in univariate analysis were considered for multivariate analysis. Adjusted odds ratios with 95% confidence intervals are presented with their respective *P* values. *P* values <.05 were considered to be statistically significant. All analyses were performed using SPSS (version 13; SPSS, Chicago, IL).

3. Results

3.1. Operation time, bleeding volume, facet joint OA grade, disc degeneration, and LLIF cage height

The mean operation time and mean bleeding volume for the first LLIF surgery and the second posterior corrective fusion surgery were, respectively, 207.9 ± 73.8 and 356.5 ± 96.1 minute and 150.5 ± 18.1 and 473.8 ± 41.1 mL. Data for the facet OA grade, disc degeneration, and LLIF cage height are shown in Table 1. Grade 1 facet joint degeneration was more common in L2/3 and 3/4, while grade 2 was more common in L4/5. Grade 3 was often observed in disc degeneration in all intervertebral discs. The average cage height was 8.87 ± 2.14 mm for L2/3, 9.39 ± 1.92 mm for L3/4, and 9.61 ± 2.41 mm for L4/5.

3.2. Radiographic evaluation

Various X-ray parameters improved significantly after surgery. The L2-5 Cobb angle decreased from 38.8° ± 8.4° preoperatively to 14.9° ± 5.1° after surgery (*P* = .010). The C7 plumb line-central sacral vertical line decreased from 38.6 ± 35.3 mm preoperatively to 12.6 ± 7.8 mm after surgery (*P* = .017). The SVA decreased from 11.1 ± 7.8 cm preoperatively to 4.5 ± 3.5 cm after surgery (*P* = .021). The LL increased from 1.8° ± 24.7° preoperatively to 31.7° ± 12.8° after surgery (*P* = .040). The PI-LL decreased from 49.9° ± 30.4° preoperatively to 16.7° ± 14.4° after surgery (*P* = .036). The wedge angle (L2/3) decreased from 5.1° ± 4.7° preoperatively to 2.3° ± 2.0° after surgery (*P* = .022). The wedge angle (L3/4) decreased from 5.9° ± 4.6° preoperatively to 2.1° ± 2.0° after surgery (*P* = .018). The wedge angle (L4/5) decreased from 6.8° ± 6.6° preoperatively to 1.8° ± 1.6° after surgery (*P* = .024) (Table 2).

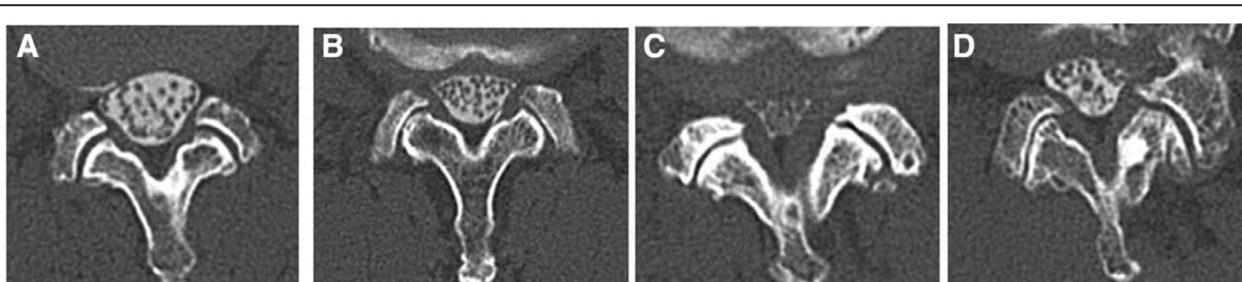

Figure 3. Four grades of osteoarthritis of the facet joints were defined as follows: (A) grade 0: normal facet joint space (width, 2–4 mm), (B) grade 1: narrowing of the facet joint space (<2 mm) and/or small osteophytes and/or mild hypertrophy of the articular process, (C) grade 2: narrowing facet joint space and/or moderate osteophytes and/or moderate hypertrophy of the articular process and/or mild subarticular bone erosions, (D) grade 3: narrowing of the facet joint space and/or large osteophytes and/or severe hypertrophy of the articular process and/or severe subarticular bone erosions and/or subchondral cysts.

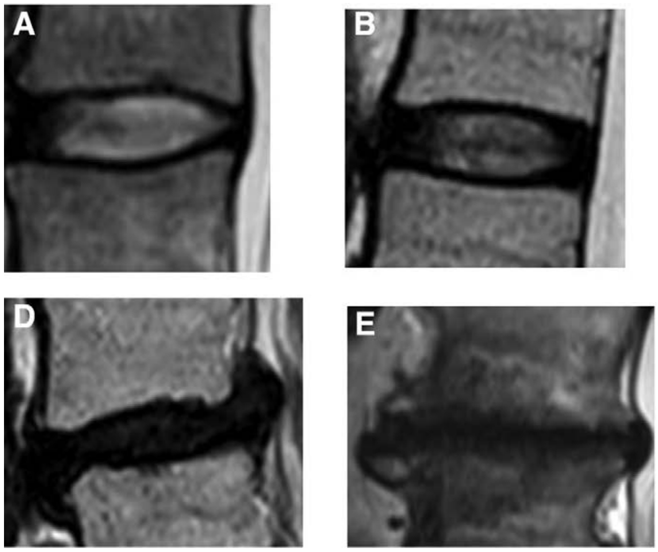

Figure 4. The grading system for the assessment of lumbar disc degeneration was follows. (A) Grade 1: the structure of the disc is homogeneous with a bright hyperintense white signal intensity and a normal disc height. (B) Grade 2: the structure of the disc is inhomogeneous with a hyper intense white signal; the distinction between nucleus and annulus is clear; and the disc height is normal with or without horizontal gray bands. (C) Grade 3: the structure of the disc is inhomogeneous with an intermediate gray signal intensity; the distinction between nucleus and annulus is unclear; and the disc height is normal or slightly decreased. (D) Grade 4: the structure of the disc is inhomogeneous with a hypointense dark gray signal intensity; the distinction between nucleus and annulus is lost; and the disc height is normal or moderately decreased. (E) Grade 5: the structure of the disc is inhomogeneous with a hypointense black signal intensity; the distinction between the nucleus and annulus is lost; and the disc space is collapsed. Grading was performed on T2-weighted midsagittal images.

Table 1

Facet joint OA grade, disc degeneration, and LLIF cage height.

	Facet joint OA grade	Disk degeneration	LLIF cage height (mm)
L2/3	I:13, II:5, III:3	I:0, II:7, III:10, IV:4, V:0	8.87 ± 2.14
L3/4	I:8, II:8, III:5	I:0, II:3, III:13, IV:5, V:0	9.39 ± 1.92
L4/5	I:5, II:13, III:3	I:0, II:2, III9, IV:9, V:1	9.61 ± 2.41

LLIF = lateral lumber interbody fusion, OA = osteoarthritis.

The changes in the rotation angle (RAsag) between each vertebra significantly improved after LLIF and after DVR in comparison with the preoperative status. The L2/3 vertebral rotation angle decreased from 7.2° ± 5.0° preoperatively to 3.2° ± 2.7° after LLIF and 2.2° ± 1.3° after DVR ($P < .05$). The L3/4 vertebral rotation angle decreased from 6.6° ± 4.8° preoperatively to 4.5° ± 3.4° after LLIF and 1.3° ± 1.2° after DVR ($P < .05$). The L4/5 vertebral rotation angle decreased from 5.5° ± 4.9° preoperatively to 2.7° ± 1.7° after LLIF and 1.2° ± 0.5° after DVR ($P < .05$). Similarly, the rotation angle from the L2 to L5 vertebral body also improved significantly ($P < .05$) (Table 3).

3.3. Correlation between the changes in vertebral rotation angle1 (δRAsag1: preoperative to after LLIF) and cage height

Correlations between the changes in each vertebral rotation angle (ΔRAsag1: preoperative to first LLIF surgery) and cage height after first LLIF surgery are shown in Table 4 (L2/3: $R = 0.53$, $P = .009$; L3/4: $R = 0.46$, $P = .032$; L4/5: $R = 0.44$, $P = .041$; L2-5: $R = 0.49$, $P = .027$).

3.4. Correlations between changes in vertebral rotation angle2 (δRAsag2: after LLIF to after DVR) and various measurement values

Correlation analysis of the changes in vertebral rotation angle (ΔRAsag2) and various measurement values after DVR revealed that the independent explanatory factors were the facet joint OA grade (L2/3: $r = -0.46$, $P = .040$; L3/4: $r = -0.44$, $P = .036$; L4/5: $r = -0.58$, $P = .010$; and L2-5: $r = -0.49$, $P = .038$), and Δwedge angle3 (L2/3: $R = 0.50$, $P = .026$; L3/4: $R = 0.45$, $P = .028$; L4/5: $R = 0.47$, $P = .037$; and L2-5: $R = 0.59$, $P = .006$; Table 5).

3.5. Multiple regression analysis of factors associated with changes in vertebral rotation angle3 (δRAsag3: preoperative to after DVR)

Multivariate analysis revealed that ΔRAsag3 was associated with Δwedge angle3 (L2/3: $\beta = 0.50$, $P = .006$; L3/4: $\beta = 0.51$, $P = .028$; L4/5: $\beta = 0.47$, $P = .010$; and L2-5: $\beta = 0.57$, $P = .006$), cage height (L2/3: $\beta = 0.45$, $P = .032$), and the facet joint OA grade (L4/5: $\beta = -0.56$, $P = .037$) (Table 6).

4. Discussion

Decompression, corrective surgery, or combination surgery can be used to treat degenerative scoliosis in adults with lumbar spinal canal stenosis that does not respond to conservative therapy. The choice of surgical method depends on the medical facility and the surgeon, and corrective surgery is recommended for patients with stenosis with overall spinal imbalance, progressive deformity, and spinal instability.[14–16] The patients in the present study showed imbalance in the coronal and sagittal planes and vertebral rotational deformity, so two-staged anterior-posterior combined corrective fusion surgery was performed by combining LLIF and DVR.

Longitudinal studies investigating the progression of spinal deformities by assessing the Cobb angle and rotational deformity reported an increase of more than 10° in the grades II and III (Nash and Moe methods) cases with at least 10 years of follow-up.[17] These studies showed that axial rotation was a factor associated with progression in degenerative lumbar stenosis patients.[18,19] Korovessis et al[20] and Ferrero et al[21] reported the development of disc asymmetry followed by rotational subluxation, including intervertebral skidding

Table 2

Radiographical parameters.

	Preoperative	Postoperative 1 yr	*P* value
L2-5 Cobb angle (°)	38.8 ± 8.4	14.9 ± 5.1	.010*
C7PL-CSVL (mm)	33.6 ± 35.3	12.6 ± 7.8	.017*
SVA (cm)	11.1 ± 7.8	4.5 ± 3.5	.021*
TK (°)	17.6 ± 19.6	27.8 ± 11.9	.041*
LL (°)	1.8 ± 24.7	31.7 ± 12.8	.040*
PT (°)	36.6 ± 10.8	15.1 ± 11.9	.042*
PI (°)	51.7 ± 10.7	48.4 ± 13.7	n.s.
PI-LL (°)	49.9 ± 30.4	16.7 ± 14.4	.036*
Wedge angle (L2/3) (°)	5.1 ± 4.7	2.3 ± 2.0	.022*
Wedge angle (L3/4) (°)	5.9 ± 4.6	2.1 ± 2.0	.018*
Wedge angle (L4/5) (°)	6.8 ± 6.6	1.8 ± 1.6	.024*

C7PL-CSVL = C7 plumb line-central sacral vertical line, LL = lumbar lordosis, n.s. = not significant differences, PI = pelvic incidence, PT = pelvic tilt, SVA = sagittal vertical axis, TK = thoracic kyphosis.
**P* < .05.

Table 3

Vertebral rotation angle (RAsag).

	Preoperative	After LLIF	*P* value	After DVR	*P* value
L2/3 (°)	7.2 ± 5.0	3.2 ± 2.7	.021*	2.2 ± 1.3	.043**
L3/4 (°)	6.6 ± 4.8	4.5 ± 3.4	.040*	1.3 ± 1.2	.018**
L4/5 (°)	5.5 ± 4.9	2.7 ± 1.9	.033*	1.2 ± 0.5	.039**
L2-5 (°)	6.4 ± 4.1	3.4 ± 2.7	.038*	2.0 ± 1.3	.025**

DVR = direct vertebral rotation, LLIF = Lateral lumber interbody fusion.
*Significant difference between preoperative and after LLIF (*P* < .05).
**Significant difference between preoperative and after DVR (*P* < .05).

and rotation, which causes new degenerative scoliosis as a 3-dimensional deformation mechanism of the spine. In addition, deformation of the vertebral body, facet joint shape, cage angle, cage position after insertion, adjacent facet cavity shape, and osteoporosis may also be involved.[22,23] Our study showed no correlation between disc degeneration and correction of the rotational deformity. Although disc degeneration was involved in progression of the spinal deformity, it was not an indicator of the rotational corrective effect. However, the facet joint OA grade affected the correction of the vertebral rotational deformity.

Our results also showed that the combined LLIF and DVR procedure can correct axial rotational deformation in adult degenerative scoliosis. Effective correction of axial rotation was obtained at the levels where LLIF was performed. With LLIF, the ligament-movement effect can provide correction of the axial plane by increasing the height of the disc by laterally releasing the annulus fibrosis of the disc and stretching the ligament.[5] Indeed, in the present study, correction of vertebral rotation deformity could be obtained by inserting the LLIF cage. This tendency was observed especially in L2/3, which shows strong rotational deformity. The rotational deformation correction increased with a larger cage in the present study.

The results obtained with local segmentation correction showed that LLIF facilitates correction of rotational deformation in all 3 planes. Steib et al[24] reported reliable distortion of the cross section with in situ contouring in surgical correction of scoliosis. Despite the movement of the multi-axis screw head, the straight rod of the frontal plane, which was bent along the target alignment of the sagittal plane, was considered to work to correct the axial plane. This is because posterior fixation

Table 4

Correlation analysis results between the change of vertebral rotation angle1 (ΔRAsag1: preoperative to after LLIF) and cage height.

	Correlation coefficient	95% confidence interval	*P*
L2/3			
Cage height (L2/3)	0.53	0.12 to 0.78	.009*
L3/4			
Cage height (L3/4)	0.46	0.03 to 0.74	.032*
L4/5			
Cage height (L4/5)	0.44	0.01 to 0.73	.041*
L2-5			
Cage height (average)	0.49	0.07 to 0.76	.027*

LLIF = Lateral lumber interbody fusion.
**P* < .05. Pearson correlation analysis

Table 5

Correlation analysis results between the change of vertebral rotation angle2 (ΔRAsag2: after LLIF to after DVR) and various measurement values.

	Correlation coefficient	95% confidence interval	*P*
L2/3			
Facet joint OA grade	−0.46	−0.74 to −0.03	.040*
Δ wedge angle3	0.50	0.09 to 0.77	.026*
L3/4			
Facet joint OA grade	−0.44	−0.73 to −0.01	.036*
Δ wedge angle3	0.45	0.02 to 0.74	.028*
L4/5			
Facet joint OA grade	−0.58	−0.81 to −0.20	.010*
Δ wedge angle3	0.47	0.05 to 0.75	.037*
L2-5			
Facet joint OA grade	−0.49	−0.76 to −0.07	.038*
Δ wedge angle3	0.59	0.21 to 0.81	.006*

DVR = direct vertebral rotation, LLIF = Lateral lumber interbody fusion, OA = osteoarthritis.
**P* < .05. Pearson correlation analysis.

Table 6

Multiple regression analysis of factors associated with the change of vertebral rotation angle3 (ΔRAsag3: preoperative to after DVR).

	β	95% confidence interval	*P*
L2/3			
Cage height (L2/3)	0.45	0.02 to 0.74	.032*
Facet joint OA grade	−0.32	−0.66 to 0.13	.410
Δ wedge angle3	0.50	0.09 to 0.77	.006*
L3/4			
Cage height (L3/4)	0.22	−0.23 to 0.59	.780
Facet joint OA grade	−0.30	−0.64 to 0.15	.650
Δ wedge angle3	0.51	0.10 to 0.77	.028*
L4/5			
Cage height (L4/5)	0.11	−0.34 to 0.52	.850
Facet joint OA grade	−0.56	−0.79 to −0.17	.037*
Δ wedge angle3	0.47	0.05 to 0.75	.010*
L2-5			
Cage height (L2-5)	0.25	−0.20 to 0.61	.078
Facet joint OA grade	−0.39	−0.70 to 0.05	.180
Δ wedge angle3	0.57	0.18 to 0.80	.006*

DVR = direct vertebral rotation, OA = osteoarthritis.
*$P < .05$, multiple regression analysis.

using the pedicle-screw system provides mechanical stabilization and additional correction effects. Surgical correction of a combination of wedges and rotational deformities is important to improve the clinical symptoms resulting from intervertebral foramen and spinal canal stenosis. The DVR technique using monoaxial pedicle screws for vertebral rotational correction has already been proven in idiopathic scoliosis.[7,25] Urbanski et al[7] reported that DVR using a pedicle screw and a corrective connection device resulted in 29.3% rotational correction of idiopathic scoliosis. Our study also showed the effect of rotational correction after DVR, which was particularly negatively correlated with the facet joint OA grades. This tendency was particularly remarkable at the L4/5 level, where the OA change was severe. Thus, dissection of the facet joint should be considered during posterior surgery if the OA change is severe.

Our study had some limitations. First, we did not evaluate the position of the LLIF cage in the intervertebral space. The cage position can affect the lordosis angle as well as the wedge and axis rotation angles. Furthermore, the number of target patients was small. Therefore, large-scale prospective and long-term studies are required to validate these findings. Since we did not consider segmental stiffness and anterior osteophyte size and distribution, our findings did not clarify whether this procedure can reproduce the corrective effect in other patients.

5. Conclusion

We conclude that the effects of rotational deformity correction with LLIF cage insertion and additional posterior corrective fixation with DVR can be useful for correcting vertebral rotation deformities. Correction of vertebral rotation deformities can be achieved by inserting the LLIF cage, and the corrective effect will increase with a larger cage. The degree of facet joint OA grade can influence affect the correction of rotational deformity after posterior corrective fusion surgery.

Author contributions

Conceptualization: Masashi Miyazaki, Shozo Kanezaki.
Data curation: Masashi Hirakawa, Tatsuya Iwasaki.
Investigation: Tetsutaro Abe, Toshinobu Ishihara.
Supervision: Hiroshi Tsumura.
Writing – original draft: Tetsutaro Abe.

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