Influence of comorbid knee osteoarthritis on surgical outcome and sagittal spinopelvic/lower-extremity alignment in elderly patients with degenerative lumbar spondylolisthesis undergoing transforaminal lumbar interbody fusion

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OBJECTIVE This retrospective study aimed to clarify the influence of comorbid severe knee osteoarthritis (KOA) on surgical outcome in terms of sagittal spinopelvic/lower-extremity alignment in elderly patients with degenerative lumbar spondylolisthesis (DLS).

METHODS In total, 110 patients aged at least 65 years (27 men, 83 women; mean age 74.0 years) who underwent short-segment lumbar fusion were included in the present study. Using the Kellgren-Lawrence (KL) grading system, patients were categorized into those with no to mild KOA (the mild-OA group: KL grades 0–2), moderate KOA (moderate-OA group: KL grade 3), or severe KOA (severe-OA group: KL grade 4). Surgical results were assessed using the Japanese Orthopaedic Association (JOA) scoring system, and spinopelvic/lower-extremity parameters were compared among the 3 groups. Adjacent-segment disease (ASD) was assessed over a mean follow-up period of 4.7 years (range 2–8.1 years).

RESULTS The study cohort was split into the mild-OA group (42 patients), the moderate-OA group (28 patients), and the severe-OA group (40 patients). The severe-OA group contained significantly more women ($p = 0.037$) and patients with double-level listhesis ($p = 0.012$) compared with the other groups. No significant differences were found in mean postoperative JOA scores or recovery rate among the 3 groups. The mean postoperative JOA subscore for restriction of activities of daily living was only significantly lower in the severe-OA group compared with the other groups ($p = 0.010$). The severe-OA group exhibited significantly greater pelvic incidence, pelvic tilt, and knee flexion angle (KFA), along with a smaller degree of lumbar lordosis than the mild-OA group both pre- and postoperatively (all $p < 0.05$). Overall, the rate of radiographic ASD was observed to be higher in the severe-OA group than in the mild-OA group ($p = 0.015$). Patients with ASD in the severe-OA group exhibited significantly greater pelvic tilt, pre- and postoperatively, along with less lumbar lordosis, than the patients without ASD postoperatively (all $p < 0.05$).

CONCLUSIONS A lack of lumbar lordosis caused by double-level listhesis and knee flexion contracture compensated for by far greater pelvic retroversion is experienced by elderly patients with DLS and severe KOA. Therefore, corrective lumbar surgery and knee arthroplasty may be considered to improve sagittal alignment, which may contribute to the prevention of ASD, resulting in favorable long-term surgical outcomes.

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KEYWORDS degenerative lumbar spondylolisthesis; knee osteoarthritis; spinopelvic alignment

ABBREVIATIONS ADL = activities of daily living; ASD = adjacent-segment disease; BMI = body mass index; DLS = degenerative lumbar spondylolisthesis; JOA = Japanese Orthopaedic Association; KFA = knee flexion angle; KL = Kellgren-Lawrence; KOA = knee OA; MCID = minimum clinically important difference; OA = osteoarthritis; TKA = total knee arthroplasty; TLIF = transforaminal lumbar interbody fusion.

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DEGENERATIVE disorders of the lumbar region and knee joint are often experienced by elderly people with active lifestyles.^{9,22} Lumbar fusion surgery in elderly individuals with degenerative lumbar spondylolisthesis (DLS) is performed to improve the quality of life of these patients. The incidence of several degenerative comorbidities, such as osteoarthritis (OA) of the knee and hip joints, tends to increase with age; therefore, these age-related comorbidities can influence outcomes following spinal fusion for DLS.³⁹ Previous studies have examined the relationship between spinal alignment and knee extension among patients affected by either spinal or knee joint disorders or both, the so-called knee-spine syndrome.^{19,25,32} Thus, evaluations of spinal sagittal alignment have investigated the pathomechanism and treatment of spinal disorders. However, to the best of our knowledge, few detailed studies have been conducted to evaluate the various problems of this surgery or the interactions between sagittal spinopelvic malalignment, knee flexion contracture, and clinical outcome among surgically treated patients with DLS and knee OA (KOA).

This study evaluated demographic and radiographic data and the prevalence and severity of KOA in elderly patients with DLS who underwent transforaminal lumbar interbody fusion (TLIF) in order to clarify whether comorbidities adversely affect overall function, activities of daily living (ADL), and sagittal spinopelvis/lower-extremity alignment. We hypothesized that elderly DLS patients with severe KOA as a comorbidity of DLS will have different pelvic parameters, increased sagittal malalignment, and lower clinical scores after TLIF than those with absent or mild KOA.

Methods

Study Subjects

The study and all its protocols were approved by the institutional review board at Yokohama Ekisaikai Hospital; all patients provided written informed consent. We retrospectively reviewed a prospectively collected database of 222 consecutive patients (66 men, 156 women) with DLS who underwent primary surgical intervention at our institution between January 2011 and August 2017. We defined DLS as the forward translation of a vertebral body with respect to the vertebra below, with a coronal Cobb angle of less than 10°. None of the patients had previously undergone spinal surgery. Exclusion criteria were as follows: age less than 65 years, history of hip pathology or previous lower-extremity surgery, need for lumbar decompression, incomplete data, or lack of 2-year follow-up data. All patients underwent decompression and reduction of each level of listhesis using a pedicle screw and rod fixation system, as well as interbody fusion with a cage filled with graft material. Comorbid spinal and knee disorders are frequently encountered in the clinical care of elderly patients; therefore, preoperative standing anteroposterior knee radiographs were taken for all patients undergoing lumbar surgery to enable functional assessment of any potential source of disability other than that of the lumbar spine. Then, the severity of KOA was assessed using the Kellgren-Lawrence (KL) grading system (grades 0–4),²⁰

and patients were categorized into 3 groups according to severity; specifically no to mild KOA (mild-OA group; KL grade 0–2), moderate KOA (moderate-OA group; KL grade 3), or severe KOA (severe-OA group; KL grade 4). When each side was graded differently, the patient was categorized according to the higher KOA grade. All radiographic examinations of knee joints were independently interpreted by two orthopedic surgeons who specialize in KOA and who were blinded to all patient information except for the radiographic images. In the case of a disagreement, a final consensus was reached by discussion. The following demographic information was recorded for each patient: age, sex, weight, height, body mass index (BMI; calculated as weight/height², kg/m²), disease duration, and duration of follow-up. Clinical outcomes were assessed pre- and postoperatively using the Japanese Orthopaedic Association (JOA) scoring system for low-back pain;⁴³ the score ranges from –6 to 29 based on subjective symptoms, clinical signs, restriction of ADL, and urinary bladder function. The recovery rate was calculated using the following equation:²¹ [(postoperative score – preoperative score)/(29 – preoperative score)] × 100%.

Next we investigated the pre- and postoperative sagittal alignment of the spinopelvic/lower-extremity axis. Patients were instructed to stand upright in a relaxed and natural manner with both hands placed on the clavicle and feet together on flat ground, unless the patient had insufficient muscle strength or found it difficult to maintain this position without external support. Whole-spine radiographs were obtained first, followed by lower-extremity radiographs, and patients were asked to maintain the position throughout the entire duration of the examination. Spinopelvic and lower-extremity parameters were measured manually from digitized preoperative images using a digital caliper; the parameters were measured by an observer who was blinded to the study. Sagittal vertical axis was measured as the distance between the C7 plumb line and the superior posterior corner of the S1 vertebral body. Thoracic kyphosis was defined as the Cobb angle between the upper endplate of T5 and the lower endplate of T12. Lumbar lordosis was defined as the Cobb angle between the upper L1 endplate and the upper S1 endplate. Segmental lordosis was defined as the Cobb angle between the endplates of the upper and lower vertebrae at the fused level. Pelvic parameters included pelvic incidence, pelvic tilt, and sacral slope, which were analyzed using published methods.⁴¹ The knee flexion angle (KFA) was defined as the angle between the line connecting the hip axis and the center of the distal femur, and the tibial axis (Fig. 1). Both lower extremities were evaluated separately for each patient. The mean of the two measurements was calculated and taken as the value of the KFA.

Adjacent-segment disease (ASD) was evaluated from lumbar lateral radiographs (in neutral, flexion, and extension positions) and defined as any narrowing of disc height of ≥ 3 mm on neutral lateral radiograph or posterior opening of ≥ 5° or progress of slippage of ≥ 3 mm in comparison with preoperative lateral flexion radiographs.^{24,33,35} Follow-up medical records were examined for evidence of revision surgery for symptomatic ASD or primary total knee arthroplasty (TKA) for treatment of KOA. Clinical

FIG. 1. Illustration of the lateral view of a standing radiograph. The KFA is defined as the angle between the line connecting the hip axis and the center of the distal femur and the tibial axis.

cal scores and radiological measurements of patients who underwent the aforementioned surgical interventions were examined preoperatively, just before and after each intervention; for all other patients, these measurements were taken preoperatively and at the final follow-up. Assessments of clinical outcomes and data collection were carried out by an independent investigator who was not involved with the operation.

Statistical Analysis

Descriptive statistics are presented as frequencies and percentages for categorical variables and as mean $\pm$ standard deviation for continuous variables. Differences between groups were assessed using the Mann-Whitney U-test, Kruskal-Wallis test with post hoc procedures, or the Wilcoxon signed-rank test for continuous variables and the Fisher's exact test for categorical variables. A p value of < 0.05 was considered statistically significant. Statistical analysis was performed using the Predictive Analytics Software Statistics 23.0 program (IBM Corp.).

Results

Of the 222 patients recruited for the study, 112 were excluded as they met the exclusion criteria. Finally, 110 patients with DLS (27 men, 83 women; mean age 74.0 years, range 65–90 years) who were followed up for at least 2 years after TLIF were included in the analysis (Fig. 2). The mean follow-up period was 4.7 years (range 2–8.1 years). Baseline clinical characteristics are reported in Table 1. Of the total cohort, 42 patients were categorized into the mild-OA group (KL grade 0, $n = 10$; grade 1, $n = 4$; grade 2, $n = 28$), 28 into the moderate-OA group (all KL grade 3), and 40 into the severe-OA group (all KL grade 4). No

FIG. 2. Flowchart of patient enrollment. Patients with surgically treated DLS were recruited for the present study.

TABLE 1. Baseline characteristics of the 3 groups

Characteristic	Mild-OA Group (n = 42)	Moderate-OA Group (n = 28)	Severe-OA Group (n = 40)	p Value
Age (yrs)	73.1 ± 5.2	75.8 ± 5.0	73.7 ± 7.0	0.07
Female sex	31 (74)	17 (61)	35 (88)	0.037*
BMI (kg/m ²)	22.6 ± 3.2	23.4 ± 3.2	23.9 ± 2.9	0.14
Disease duration (mos)	20.2 ± 33.8	16.1 ± 26.2	12.4 ± 23.2	0.36
No. of listhesis segments	1.1 ± 0.3	1.3 ± 0.5	1.4 ± 0.5†	0.015*
Double-level listhesis	5 (12)	8 (31)	16 (40)	0.012*
Follow-up period (yrs)	4.6 ± 2.3	4.3 ± 1.8	5.2 ± 1.9	0.15

Continuous data are expressed as the mean ± SD. Categorical data are presented as number (%).

* p < 0.05.

† p < 0.05 compared with the mild-OA group.

significant differences were noted in age, BMI, disease duration, or duration of follow-up among the 3 groups. The number of women was significantly higher in the severe-OA group than in the other 2 groups. The mean number of listhesis segments was significantly greater in the severe-OA group than in the mild-OA group, and a significantly higher rate of double-level listhesis was observed in the severe-OA group compared with the other groups.

All patients suffered from sciatic nerve pain in the leg or exhibited cauda equina syndrome with or without low-back pain, while all patients with KOA had little or no knee joint pain immediately before TLIF. Overall, the mean JOA score improved significantly from 16.3 preoperatively (range 4–23) to 25.4 postoperatively (range 13–29) (p < 0.001). No intergroup differences were found in

the mean postoperative JOA score or recovery rate; however, the mean postoperative JOA subscore for restriction of ADL was significantly lower in the severe-OA group compared with the other 2 groups (p = 0.010) (Table 2).

Preoperative and postoperative radiological parameters of sagittal spinopelvis/lower-extremity alignment for each group are shown in Table 3. The mean pre- and postoperative pelvic incidences were significantly greater in the severe-OA group than in the mild-OA group; the severe-OA group also exhibited significantly greater pre- and postoperative pelvic tilt and KFA and smaller lumbar lordosis than the mild-OA group.

Table 4 presents a comparison of radiographic ASD according to the number of fused levels and revision surgery for symptomatic ASD among the 3 groups. Overall, the

TABLE 2. Clinical outcomes after TLIF

Outcome	Mild-OA Group (n = 42)	Moderate-OA Group (n = 28)	Severe-OA Group (n = 40)	p Value
JOA score				
Preop	16.7 ± 4.3	15.4 ± 4.2	16.6 ± 3.6	0.27
Postop	25.8 ± 3.2	26.3 ± 2.3	24.6 ± 3.8	0.18
Subjective symptoms (points)				
Preop	4.1 ± 1.4	4.0 ± 1.4	3.8 ± 1.3	0.21
Postop	7.5 ± 1.4	7.7 ± 0.9	7.1 ± 1.9	0.54
Clinical signs (points)				
Preop	3.8 ± 1.0	4.1 ± 0.9	4.2 ± 0.9	0.27
Postop	5.3 ± 0.9	5.1 ± 0.8	5.1 ± 1.0	0.74
Restriction of ADL (points)				
Preop	9.3 ± 2.8	8.5 ± 2.4	9.6 ± 2.0	0.14
Postop	13.2 ± 1.3	13.4 ± 0.8	12.5 ± 1.6*†	0.010‡
Urinary bladder function				
Preop	-0.6 ± 1.2	-1.3 ± 1.7	-1.0 ± 1.6	0.25
Postop	-0.1 ± 0.5	0	-0.1 ± 0.5	0.71
Recovery rate (%)§	74.1 ± 25.9	79.2 ± 18.0	62.0 ± 38.7	0.10

Continuous data are expressed as mean ± SD.

* p < 0.05 compared with the mild-OA group.

† p < 0.05 compared with the moderate-OA group.

‡ p < 0.05.

§ Recovery rate during the postoperative period.

TABLE 3. Radiological parameters after TLIF

Parameter	Mild-OA Group (n = 42)	Moderate-OA Group (n = 28)	Severe-OA Group (n = 40)	p Value
SVA (mm)				
Preop	45.6 ± 36.2	52.5 ± 34.8	53.7 ± 38.4	0.73
Postop	43.5 ± 40.2	45.9 ± 35.6	53.0 ± 41.0	0.58
TK (°)				
Preop	26.1 ± 10.8	27.5 ± 11.2	27.0 ± 14.2	0.90
Postop	28.0 ± 11.8	28.7 ± 12.0	27.9 ± 13.5	0.93
LL (°)				
Preop	45.6 ± 13.0	43.6 ± 12.4	38.7 ± 12.2*	0.038†
Postop	48.2 ± 13.3	46.0 ± 11.5	40.0 ± 14.9*	0.017†
SL (°)				
Preop	14.2 ± 7.9	45.6 ± 7.5	13.4 ± 7.3	0.85
Postop	16.2 ± 7.4	14.7 ± 8.4	15.3 ± 7.7	0.63
PI (°)				
Preop	51.8 ± 9.6	52.1 ± 11.3	56.7 ± 8.7*	0.045†
Postop	51.6 ± 9.3	52.0 ± 11.2	56.6 ± 8.7*	0.040†
PT (°)				
Preop	20.1 ± 8.3	22.8 ± 9.5	28.8 ± 9.3*	<0.001†
Postop	17.4 ± 7.0	20.6 ± 8.5	26.7 ± 8.9*‡	<0.001†
SS (°)				
Preop	31.7 ± 8.8	29.3 ± 8.5	27.9 ± 8.7	0.17
Postop	34.2 ± 8.6	31.5 ± 9.4	29.9 ± 9.2	0.11
KFA (°)				
Preop	4.9 ± 6.8	6.6 ± 4.8	10.1 ± 5.3*	0.016†
Postop	4.8 ± 7.3	6.2 ± 5.2	9.7 ± 5.1*	0.021†

LL = lumbar lordosis; PI = pelvic incidence; PT = pelvic tilt; SL = segmental lordosis at the level of fusion; SS = sacral slope; SVA = sagittal vertical axis; TK = thoracic kyphosis.

Continuous data are expressed as mean ± standard deviation.

* $p < 0.05$ compared with the mild-OA group.

† $p < 0.05$.

‡ $p < 0.05$ compared with the moderate-OA group.

rate of radiographic ASD was higher in the severe-OA group (15/40; 38%) than in the other groups. No significant differences were noted in pre- or postoperative JOA score, recovery rate, or the rate of radiographic ASD among the 3 groups with respect to single- or double-level fusion.

Table 5 details the radiographic parameters of sagittal spinopelvis/lower-extremity alignment of patients with or without radiographic ASD in the severe-OA group. Patients with radiographic ASD in the severe-OA group exhibited significantly greater pre- and postoperative pelvic tilt and smaller postoperative lumbar lordosis than those without ASD. Receiver operating characteristic analysis was used to determine the cutoff values of preoperative pelvic tilt in the absence or presence of radiographic ASD by maximizing the Youden index,⁴⁴ which yields a threshold level where both the sensitivity and specificity are high. Patients in the severe-OA group who exhibited a preoperative pelvic tilt value above the optimal cutoff value of 29.2° with an area under the curve of 0.719 were more likely to have radiographic ASD (OR 8.0; sensitivity = 0.67, specificity = 0.8, positive predictive value = 0.67).

During the study period, primary knee arthroplasty was performed on 17 knees of 14 patients with severe OA between 9 months and 8 years after TLIF. Table 6 presents the clinical outcomes and radiographic parameters of patients who underwent additional TKA. The mean JOA score improved significantly from 15.5 points preoperatively to 24.3 points in the early postoperative period after TLIF and remained stable at 23.9 points in the postoperative period, even after TKA. No significant difference was noted between the mean recovery rate in the postoperative period after TLIF and that after TKA. The mean values for spinopelvic angle, lumbar lordosis, segmental lordosis, and sacral slope in the postoperative period after TLIF increased significantly compared with preoperative baseline values ($p = 0.03$, 0.001, and 0.022, respectively). The mean pelvic tilt and KFA decreased significantly from preoperative values ($p = 0.022$ and 0.035, respectively). No significant differences were noted in the lumbar lordosis, segmental lordosis, and sacral slope in the postoperative period after TLIF compared with after TKA ($p = 0.13$, 0.21, and 0.06, respectively); however, further significant

TABLE 4. Clinical outcomes and ASD after single- or double-level fusion

Outcome	Mild-OA Group (n = 42)	Moderate-OA Group (n = 28)	Severe-OA Group (n = 40)	p Value
Single-level fusion	37 (88)	20 (71)	24 (60)	
Preop JOA score	16.5 ± 4.5	15.2 ± 4.6	16.4 ± 3.5	0.41
Postop JOA score	25.8 ± 3.0	25.9 ± 3.3	25.0 ± 3.4	0.45
Recovery rate (%) [*]	74.3 ± 23.8	75.8 ± 25.4	67.1 ± 30.4	0.36
ASD†	6 (16)	2 (10)	8 (33)	0.13
Double-level fusion	5 (12)	8 (29)	16 (40)	
Preop JOA score	18.2 ± 2.4	16.0 ± 3.2	16.8 ± 3.9	0.49
Postop JOA score	26.2 ± 4.7	26.0 ± 2.3	23.9 ± 4.4	0.43
Recovery rate (%) [*]	73.1 ± 41.9	78.8 ± 14.2	53.7 ± 48.8	0.36
ASD†	0 (0)	1 (13)	7 (44)	0.14
Overall cohort				
ASD†	6 (14)	3 (11)	15 (38)	0.015‡
Revision surgery				
Symptomatic ASD	1 (2)	1 (4)	2 (5)	0.83

Categorical data are presented as number (%). Continuous data are expressed as mean ± SD.

^{*} Recovery rate during the postoperative period.

† Determined radiographically.

‡ $p < 0.05$.

decreases in mean pelvic tilt and KFA in the postoperative period were only observed after TKA ($p = 0.009$ and 0.005 , respectively).

Discussion

This study compared surgical outcomes as well as sagittal spinopelvic/lower-extremity alignment between elderly patients with DLS who were comorbid with no to mild, moderate, or severe KOA in whom lumbar short-section fusion was performed. The major findings of our research were as follows: the severe-OA group had a higher proportion of women and prevalence of double-level listhesis. Neurological recovery was not significantly different between the groups, although the postoperative JOA subscore for ADL was lower in the severe-OA group than it was in the other groups. Higher values of pelvic incidence were recorded for patients in the severe-OA group when measured in the standing position, as well as greater sagittal malalignment with a lack of lumbar lordosis and knee flexion contracture. This triggered compensatory mechanisms such as pelvic retroversion. Moreover, a higher rate of postoperative radiographic ASD was observed in the severe-OA group.

Several studies have shown that increased age, female sex, high BMI, and genetic factors are among the potential causes of development and progress of DLS and KOA, although the exact pathomechanisms of these conditions remain to be identified.^{8,12,38} We found the proportion of women to be relatively high in the mild- or moderate-OA group, in agreement with other studies.^{1,4,16} More remarkably, we found a higher proportion of women to be significantly closely related to severe OA. Therefore, the severe-OA group may be more susceptible to certain sex-associated factors, such as some types of sex hormones.²³

A large cohort study on the association of sex factors with these degenerative diseases would help to clarify this point.

In the sagittal plane, principal cytoskeletal components of the spine, pelvis, and lower extremities are closely related and mutually influence each other so that ambulatory humans can maintain a stable and ergonomic upright standing position with minimal energy expenditure.^{7,30} However, degenerative comorbidities of the lumbar spine or knee joint are common among elderly people; therefore, it may be difficult to distinguish whether knee joint flexion contractures are associated with the loss of lumbar lordosis. It may also be difficult to determine whether the initial factor is loss of lordosis caused by listhesis or knee contracture owing to OA.^{13,19,32,34} Duval-Beaupère et al.¹⁴ described the pelvic incidence index as an invariable morphological parameter that is not affected by aging, posture, or pelvis position. Moreover, some reports on the association between DLS and pelvic parameters have shown that a high pelvic incidence in women is a predisposing factor for the development and progression of the condition, as well as for vertebral slippage.^{1,3} Patients with multilevel DLS have a higher pelvic incidence than those with single-level DLS.¹⁷ In contrast, a recent study reported that the pelvic incidence of patients with severe KOA, either with or without low-back pain, who were identified as having no radiographic skeletal abnormalities was comparable with that of controls, suggesting that these patients had normal sagittal morphology of the pelvis. Collectively, these findings informed our hypothesis that a higher pelvic incidence may not be closely associated with KOA but rather with DLS; therefore, the observed loss of lordosis in the severe-OA group with a high pelvic incidence value is highly suggestive of an initial factor. Thus, a possible explanation is that the mechanical stress of maintaining lordosis might be focused on the facet joints resulting in arthritis, loosening, and—final-

TABLE 5. Radiological parameters of patients with or without ASD in the severe-OA group

Parameter	Patients w/ ASD (n = 15)	Patients w/o ASD (n = 25)	p Value
SVA (mm)			
Preop	62.1 ± 33.1	49.1 ± 41.1	0.34
Postop	65.6 ± 33.8	46.1 ± 43.7	0.15
TK (°)			
Preop	26.2 ± 13.5	27.5 ± 14.9	0.86
Postop	26.1 ± 12.7	28.9 ± 14.2	0.53
LL (°)			
Preop	34.9 ± 14.6	40.6 ± 9.9	0.26
Postop	32.2 ± 15.7	44.6 ± 12.5	0.011*
SL (°)			
Preop	11.8 ± 8.1	14.4 ± 6.7	0.26
Postop	13.9 ± 8.5	16.1 ± 7.2	0.64
PI (°)			
Preop	60.0 ± 8.6	54.7 ± 8.3	0.15
Postop	59.9 ± 8.6	54.6 ± 8.3	0.13
PT (°)			
Preop	34.1 ± 10.8	26.2 ± 7.0	0.021*
Postop	30.9 ± 10.6	24.2 ± 6.9	0.040*
SS (°)			
Preop	25.9 ± 10.7	28.5 ± 7.0	0.42
Postop	29.0 ± 11.3	30.4 ± 8.0	0.85
KFA (°)			
Preop	10.3 ± 5.0	10.1 ± 5.7	0.90
Postop	10.1 ± 4.7	9.5 ± 5.4	0.94

Continuous data are expressed as mean ± SD.

*p < 0.05.

ly—vertebral slip due to the increased curvature of lumbar lordosis associated with a higher pelvic incidence. Further compensatory mechanisms may then lead to degeneration of adjacent segments and instability resulting in double-level listhesis, pelvic retroversion, and hyperextension of the thoracic segments. This pathomechanism is supported by several reports that local sagittal malalignment of several segments is compensated by adjacent mobile segments and then by pelvic tilt if necessary.^{4,29} Finally, when the pelvic retroversion is no longer efficient, another compensatory mechanism may be activated, which involves hip extension and knee flexion along with posterior pelvic tilting. Therefore, the increased knee flexion during standing and increased stress on articular cartilage and other joint structures may lead to initiation or progression of KOA, resulting in joint pain and flexion contractures, which influence posterior pelvic tilting and loss of lumbar lordosis. There is also evidence that the risk of KOA is increased in individuals who work in a standing position with knee flexion, which supports the suggested pathomechanism.¹⁵

Poor clinical outcomes after spinal decompression with fusion for DLS can be attributed to a complex combination of factors. Aging is associated with a decline in physical performance, such as muscle strength as well as static

TABLE 6. Clinical outcomes and radiological parameters of 14 patients with severe KOA who underwent TKA after TLIF

Parameter	Preop	After TLIF	After TKA
JOA score (points)	15.5 ± 3.5	24.3 ± 4.7*	23.9 ± 3.5*
RR (%)		63.9 ± 40.9	61.2 ± 39.3
SVA (mm)	54.6 ± 37.3	57.5 ± 40.9	55.8 ± 43.4
TK (°)	26.8 ± 14.0	25.8 ± 13.0	27.2 ± 12.9
LL (°)	40.6 ± 10.3	43.0 ± 10.3*	42.9 ± 10.6
PI (°)	54.4 ± 8.5	54.4 ± 8.6	53.9 ± 8.9
SL (°)	15.0 ± 7.7	18.5 ± 7.6*	18.9 ± 8.2*
PT (°)	26.0 ± 7.5	22.7 ± 6.8*	21.1 ± 5.9*†
SS (°)	28.4 ± 5.3	31.7 ± 6.6*	32.7 ± 6.6*
KFA (°)	11.4 ± 6.1	10.8 ± 6.0*	6.0 ± 7.2*†

RR = recovery rate.

Continuous data are expressed as mean ± SD.

*p < 0.05 compared with preoperative status.

†p < 0.05 compared with post-TLIF.

and dynamic balance, which lead to reduced activity and postural stability.^{2,6,37} However, several studies have shown that lumbar fusion surgery is effective for improving quality of life outcomes, even in elderly patients.^{5,10,11,18} Patients in the severe-OA group should, therefore, have favorable clinical results after TLIF because of the improvements in neurological deficits. However, in the present study, some exhibited a severely impaired ability to walk due to the development or progression of KOA, suggesting that poor long-term clinical results may be inevitable. Furthermore, these clinical results are limited by the fact that their numerical scores lack a direct, clinically significant meaning. The concept of a minimum clinically important difference (MCID) has recently been suggested as a measure of the clinical threshold required to consider a treatment effective.³⁶ Unfortunately, we could not assess how many patients met the MCID for the JOA scoring system for low-back pain, including subscores, because no studies have assessed the MCID for the score in lumbar degenerative disease.

Several authors have reported that good functional outcome in the case of DLS is largely dependent on restoration of the sagittal spinopelvic alignment; posterior pelvic tilting may be associated with an increased prevalence of low-back pain,²⁶ and patients with decreased pelvic tilt after fusion tend to report good clinical outcomes.²⁸ In the present study, the absence of lumbar lordosis due to double-level listhesis and knee contracture due to KOA were compensated for by far greater pelvic retroversion in the severe-OA group. These patients might experience difficulties with ADL because of chronic low-back pain caused by increased muscle activity. The TLIF procedure does not aim to correct sagittal alignment; therefore, inadequate correction of lumbar lordosis and tilting of the pelvis—which was observed postoperatively in the severe-OA group—contribute to poor clinical results and subsequent development of ASD.

ASD is a major concern after spinal fusion and fixation. Several studies have shown that patients with abnormal sagittal spinopelvic parameters experience a statistically

significant increase in the risk of ASD following lumbar fusion for degenerative disease.^{27,31} One study suggested that high preoperative pelvic tilt value is significantly associated with development of ASD.⁴² Another study noted significantly higher pelvic incidence values after lumbar fusion among patients who subsequently developed ASD.³³ Postoperative hypolordosis following lumbar fusion may lead to increased loading of the posterior column of adjacent segments.⁴⁰ In our study, patients in the severe-OA group who had a high pelvic incidence and underwent short-segment lumbar fusion were found to be more likely to develop ASD due to undercorrection of the retroverted pelvis following failure to achieve optimal lumbar lordosis. Therefore, surgical strategies for patients with DLS and sagittal malalignment should take into consideration the spinopelvic/lower-extremity parameters, with or without knee flexion contracture due to KOA, in order to predict postoperative sagittal alignment and decide the best type of correction with fusion surgery. Furthermore, where increased knee contracture due to severe KOA has led to increased pelvic retroversion as a compensatory mechanism, additional and corrective knee surgery should be considered for improvement of the sagittal lower axis.

Limitations

This study has several limitations that should be acknowledged. First, the retrospective case-control study design included a small sample size, which precludes the multivariate analysis needed to firmly link KL grades to spinal surgical outcomes. Multicenter registry analyses involving a larger number of patients are required to elucidate risk factors which could independently affect surgical outcomes, such as the severity of KOA, number of listhesis segments, development of ASD, and parameters of sagittal alignment. Second, although patient posture was standardized using the fist-on-the-clavicle position, some patients could not maintain a standing posture with the body upright due to insufficient muscle strength. Therefore, it was difficult to measure parameters of sagittal alignment in these patients, and muscle strength of the trunk and upper body was not appropriately evaluated, nor was the circumference of the pelvis and knees. Thus, the possible influence of muscle weakness in addition to spine/lower-extremity inflexibility on sagittal malalignment remains uncertain. Although these parameters should be assessed, conservative treatment, including excursion training and muscle strengthening exercise, should be performed initially when possible.

Conclusions

Elderly patients with DLS and comorbid severe KOA have a different pelvic morphology, increased sagittal malalignment with a lack of lumbar lordosis due to double-level listhesis, and greater knee flexion contracture than patients with no to mild and moderate KOA. As a result, compensatory mechanisms, such as greater pelvic retroversion, are activated in these patients. Lumbar decompression with short-segment fusion is effective for improvement of surgical outcomes even among elderly patients; however, assuming that the greater loss of lumbar

lordosis and severe knee contracture is compensated for by far greater pelvic retroversion, corrective lumbar surgery alone may be insufficient, and additional knee surgery should be considered to improve sagittal alignment of the spinopelvic/lower-extremity axis. This may contribute to the prevention of ASD, resulting in favorable long-term surgical outcomes. Therefore, it seems necessary to further investigate the surgical strategies for patients with DLS and severe KOA to restore sagittal spinopelvic alignment, followed by decreased pelvic retroversion.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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Conception and design: Kohno, Iwamura, Inasaka, Higashihira, Kawai, Niimura. Acquisition of data: Kohno, Akiyama. Analysis and interpretation of data: Kohno. Drafting the article: Kohno. Critically revising the article: Iwamura. Approved the final version of the manuscript on behalf of all authors: Kohno. Statistical analysis: Kohno. Study supervision: Inaba.

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