Differences in clinical and imaging features of low lumbar osteoporotic vertebral collapse in patients with or without Parkinson’s disease: Rapid destructive progression and appearance of a cauda equina sign in Parkinson’s disease patients

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Research article

Keywords: osteoporotic vertebral collapse, Parkinson's disease, low lumbar spine, clinical features, image findings, complications

DOI: https://doi.org/10.21203/rs.3.rs-89192/v1

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Abstract

Background

Osteoporosis and Parkinson's disease (PD) are age-related diseases, and surgery for osteoporotic vertebral collapse (OVC) in PD patients become more common with aging of society. OVC commonly affects the thoracolumbar spine, but low lumbar OVC is frequent in patients with lower bone mineral density (BMD) and a higher mechanical failure rate, compared with those with thoracolumbar junction collapse. The aim of this study was to identify differences in clinical and imaging features, and in outcomes of low lumbar OVC with or without PD and to discuss the appropriate treatment for lower lumbar OVC in patients with PD.

Methods

The subjects were 43 patients with low lumbar OVC below L3 who were treated surgically, including 11 patients with PD. Clinical symptoms, morphological features of affected vertebrae, neurological status, surgical procedures, and complications were compared in patients with and without PD.

Results

The main clinical symptoms were radicular leg pain in non-PD cases (68.8%) and a cauda equina sign in PD cases (72.7%). Rapid progression and destructive changes of OVC were seen in patients with PD at 24.5 ± 10.5 days after injury. The morphological features of OVC were flat-type in non-PD cases with old compression fracture at the thoracolumbar lesion, and destruction-type in PD cases without old compression fracture. Progression of PD was associated with decreased lumbar lordosis, lower lumbar YAM, and severe sarcopenia, all of which can affect postoperative instrumentation-related complications. High postoperative complication rates may be due to vertebral fragility and longer fusion surgery.

Conclusions

Rapid progression and destructive changes of low lumbar OVC may occur in PD patients, and significantly more PD cases have a cauda equina sign and require urgent surgery. Progression of postural instability as a natural course of PD may lead to mechanical stress and instrumentation failure, especially at an upper adjacent level. Given the progression of PD after surgery, invasive long-fusion surgery should be avoided for single low lumbar OVC. A surgical strategy considering the severities of PD and osteoporosis, and aggressive control of PD before and after surgery are important to prevent complications.

Background

The incidence of osteoporotic vertebral collapse (OVC) is likely to increase with aging of the population. Conservative management is effective in most cases, but OVC with back pain, neurological complications or a concern of paralysis requires surgery to permit a return to activities of daily life (ADL). In a
multicenter cohort of 403 patients in Japan who underwent fusion surgery for OVC with neurological deficits, a thoracolumbar junction lesion at T12 and L1 was most frequent, but 18.9% of cases had low lumbar OVC below L3 [1]. Clinical and imaging features in low lumbar OVC may differ from those in thoracolumbar OVC, based on our previous findings [2].

Low lumbar OVC is also frequently found in patients with lower bone mineral density (BMD) and a higher mechanical failure rate, compared with thoracolumbar junction collapse [3]. Complications after surgery for OVC occurred in 14.1% of cases in a multicenter cohort study, with age, liver disease, and Parkinson’s disease (PD) found to be independent risk factors for postoperative complications [4]. In the same series, a comparison of patients with thoracolumbar spine (T10-L2) with and without PD found higher rates of perioperative complications and lower walking ability at follow-up in the PD group, although there were no differences in radiological and symptomatic improvements [5].

PD is a common neurodegenerative disease with features of locomotor dysfunction, including resting tremors, rigidity, and bradykinesia. Patients with PD also often have low bone quality, severe muscular dysfunction, and an abnormal posture. PD affects 1% of the population over age 60 and up to 4% over age 80, and the prevalence generally increases with age [6]. Thus, both OVC and PD are age-related diseases with low bone quality. Higher rates of postoperative complications and revision surgeries have been reported after spine surgery for patients with PD, such as fusion surgery for degenerative diseases and thoracolumbar OVC. However, clinical status, neurological symptoms, radiological findings, and surgical strategies for patients with low lumbar OVC with PD have not been described.

We hypothesized that the different clinical and imaging features in patients with low lumbar OVC with and without PD may be related to neurological symptoms. In this study, we examined these relationships, with the goal of proposing appropriate surgical treatments.

**Methods**

**Study population**

Between 2005 and 2018, 43 patients underwent surgeries for symptomatic low lumbar OVC at vertebral levels below L3 at our hospital and had a minimum follow-up period of 2 years. Eleven of these patients had PD, and clinical features and imaging findings in these patients were compared with those for non-PD cases (n=32). No patients had comorbidities that caused lower extremity sensory or motor deficits directly. All patients underwent plain radiography, computed tomography (CT) (≤2 mm slice thickness), high-resolution magnetic resonance imaging (MRI) (1.5 or 3.0 T), and a BMD scan before surgery.

**Outcomes and radiological measurements**

Data for age, gender, body mass index (BMI), disease duration from diagnosis of compression fracture to that of burst fracture and/or appearance of neurological symptoms, surgical procedures, and postoperative complications were acquired from medical charts. In patients with PD, the Hoehn & Yahr
stage before surgery and at follow-up was assessed. Clinical symptoms, low back pain, radicular leg pain, and cauda equine sign were also stratified based on cleft formation. The Japanese Orthopaedic Association (JOA) score for neurological status was obtained before surgery and at follow-up, with all neurological evaluations performed by senior spine surgeons. Plain radiographs were used to identify other vertebral collapses, the type of vertebral collapse, lumbar lordosis and local lumbar lordosis before surgery and at follow-up.

Each OVC was classified as one of four types based on its appearance on a lateral projection in a neutral position (Fig. 1) [2]: type 1 is a wedge-type collapse defined as a ratio of the anterior to posterior height of the vertebral body of <60%; type 2 is a flat or vertebra plana-like fracture with uniform compression; type 3 is a concave or H-shaped fracture with anterior spur formation or sclerotic change; and type 4 is a burst fracture with severe destruction of the anterior vertebral body. Type 2 collapse often appears as intervertebral cleft formation on radiographs or MRI. Dual-energy X-ray absorptiometry (QDR 1000; Hologic) was used to measure BMD of the lumbar spine (L1-L4) in the posteroanterior projection, with the results expressed as the % young adult mean (YAM). To assess the degree of sarcopenia, the sum of the left and right psoas area on the axial image in the middle of the L3 vertebral body divided by the area of the L3 vertebral body was calculated using a Picture Archiving and Communication System [7]. All measurements were performed in triplicate by each of two observers blinded to data related to surgery, and the average value was used.

**Surgical procedures**

Vertebroplasty (VP) (n=5) and a combination of decompression, VP; pedicle screw fixation, and posterolateral fusion (VP+PSF) (n=13) were performed for cases with clefs at affected vertebra; whereas decompression, PSF, and posterolateral fusion (PSF) (n=7), and posterior lumbar interbody fusion (PLIF) (n=6) were used for cases without cleft formation. Other surgeries included correction osteotomy, including pedicle subtraction osteotomy (PSO) and vertebral column resection (VCR) (n=2); anterior spinal fusion (ASF) using a plate system with iliac bone or a metal cage (n=2); combined ASF with PSF (APSF) (n=4); and laminotomy (LM) without fusion (n=4).

**Statistical analysis**

Data are shown as mean ± SD. Differences between groups were examined by Wilcoxon signed rank test, Mann-Whitney U-test or chi-square test, with P<0.05 denoting significance. Inter- and intraobserver reliabilities were assessed using intraclass correlation coefficients (ICC). All calculations were performed using SPSS software (SPSS, Chicago, IL).

**Results**

**Demographics of patients with and without Parkinson disease**
Demographic data for patients who underwent surgery for low lumbar OVC below L3 are shown in Table 1. OVC occurred at L3 in 18 cases, L4 in 18, and L5 in 7. Of the 43 patients, 11 had PD, and 32 did not have PD (non-PD). There were no significant differences in gender, mean age at the time of surgery, affected vertebra levels, surgical procedures, and JOA scores before surgery and at follow-up in PD and non-PD patients. BMI was lower in PD cases, but with no significant difference to that in non-PD cases (19.7±3.9 vs. 22.4±3.7 kg/m², p=0.17). The mean follow-up period was 3.5±1.4 (range 1-5) and 3.2±2.2 (1-8.5) years in PD and non-PD cases, respectively. The Hoehn & Yahr stage before surgery was stage 5 in 5 patients and stage 6 in 6. Progression of severity of PD occurred in 4 of 11 patients (36.4%): 3 of 5 (60.0%) in stage 5 reached stage 6, and 1 of 6 (16.7%) in stage 6 reached stage 7.

Clinical and imaging findings in patients with low lumbar OVC with and without PD

Symptoms and durations from diagnosis of compression fracture to that of burst fracture with neurological symptoms are summarized in Table 2. Most patients with and without PD complained of severe low back pain, but there was a significant difference in neurological symptoms between PD and non-PD cases. The main clinical symptom in non-PD cases was radicular leg pain (p=0.016), whereas a cauda equina sign was most common in PD cases (p=0.0047). Importantly, rapid progression of OVC was much clearer in PD cases compared with non-PD cases (24.5±10.5 vs. 58.5±33.4 days, p<0.01).

Differences in imaging findings between patients with and without PD are shown in Table 3. On plain radiographs, non-PD cases were significantly more likely to have old compression fractures at the thoracolumbar level (1, 9.1% vs. 23, 71.9%, p=0.0003). No patients had type 1 OVC (wedge-type). There was a higher rate of cases with type 2 OVC (flat-type) in non-PD cases and of type 4 (destruction-type) in PD cases (p=0.0073). Twelve of 23 type 2 cases (52.2%) had intervertebral cleft formation at the affected vertebra, but with no significant difference between the two groups. Preoperative lumbar YAM (P=0.043) and L3 total psoas area/vertebral body area ratio (P=0.044) were significantly lower in PD cases. There was no significant difference in preoperative lumbar lordosis and local lumbar lordosis before and after surgery, but PD cases had decreased lumbar lordosis at follow-up (p=0.02).

Postoperative complications and related factors

Postoperative complications occurred in 5 PD (45.5%) and 11 non-PD (34.4%) patients, including loosening and migration of pedicle screws, progression of vertebral collapse and infection. The rate of revision surgery was higher in PD cases, but with no significant difference compared with non-PD cases (27.3% vs. 9.4%, p=0.14) (Table 4). Data related to postoperative complications are shown in Table 5. Patients with postoperative complications had significantly lower preoperative lumbar YAM (p=0.015), change of lumbar lordosis (p=0.047), and longer fused vertebrae (p=0.041), but no significant differences in BMI (p=0.60), presence of PD (p=0.51), type of OVC (p=0.92), change of local lumbar lordosis (p=0.84), L3 total psoas area/vertebral body area (p=0.75), and surgical procedures (p=0.87).

Discussion
Fragility fractures are more likely to occur in patients with PD than in similarly aged non-PD subjects because of a higher risk of falls and lower BMD due to weight loss and lower mobility [8,9]. A meta-analysis in 69,387 patients showed an increased risk of fracture of 2 to 3 times in PD patients compared to controls [10]. A nationwide population-based study in 3,370 PD patients found a significantly increased risk of osteoporosis (hazard ratio 1.32) and surgery for OVC (hazard ratio 2.69) in these patients compared to non-PD subjects [11]. Since osteoporosis and PD tend to develop in elderly people, surgery for OVC in patients with PD is likely to become more common with aging of society. The thoracolumbar spine is the most commonly affected region in OVC, but this condition also affects the lumbar spine. Moreover, clinical and imaging features, and treatment strategies differ in thoracolumbar and low lumbar OVC due to anatomical differences in nerve structures and spinal alignment [2].

PD is a systemic and progressive disease, which suggests that the natural course of PD should be considered in treatment for OVC in a patient with PD. These aspects of PD might also influence clinical features and imaging findings in OVC. Rapid progression and destructive changes of low lumbar OVC in patients with PD, and significantly more PD cases with a cauda equina sign requiring urgent surgery were important findings in this study. Weight loss and sarcopenia are common in PD patients and correlate with greater motor changes, a higher rate of fall, and disease progression [12]. In a cross-sectional study, 55.8% of PD cases had sarcopenia compared to only 8.2% of controls [13]. There is also a strong negative correlation of BMD with the severity of PD, particularly for the lumbar spine [14,15]. Similarly, lower BMI, lumbar YAM, and sarcopenia were present in PD cases in the current study.

In the classification of OVC based on preoperative lateral radiographs, the wedge type (type 1) was common in thoracolumbar OVC, but this type was not found in low lumbar OVC. Flat-type (type 2) low lumbar OVC was dominant in non-PD cases, whereas destructive-type (type 4) was found in most PD cases. Old compression fracture at the thoracolumbar level was found in most non-PD cases, but in few PD cases, but decreased lumbar lordosis before surgery was found in both groups, indicating the nature of PD. Spinal alignment changes may increase middle and/or posterior low lumbar spine loading, and lower bone quality and severe sarcopenia in PD might cause rapid progression and destructive changes of OVC (Fig. 2).

We found a significant improvement in the mean neurological score postoperatively, but there were also relatively high rates of postoperative complications of 45.5% in PD cases and 34.4% in non-PD cases, mainly related to instrumentation. The rate of revision surgery was particularly high in PD cases (27.3%). The higher risks of postoperative complications and revision surgery for patients with PD are well recognized in spine surgery. In a large-scale cohort study of thoracolumbar spine fusion surgery using a national insurance database in the US, PD was significantly associated with an increased risk for medical complications (odds ratio 1.22) and revision surgery (odds ratio 1.70) [16]. Another large-scale matched-pair cohort study using an inpatient database in Japan also suggested that PD was a significant predictor of postoperative complications (odds ratio 1.74) following spine surgery, with delirium being most frequent [17]. In our study, postoperative complications were associated with lower preoperative lumbar YAM, decreased lumbar lordosis, and longer fusion surgery.
In a multicenter study of lumbar spine surgery, surgical failure was more frequent in PD cases in fusion (45.8%) and corrective (67.7%) surgeries than in laminectomy only (33.3%). Thus, lower preoperative lumbar lordosis may be associated with failure of initial surgery, which suggests that use of rigid fixation to achieve and maintain proper lumbar lordosis may be effective in PD cases [18]. We agree with the necessity of long-segment corrective fusion surgery to maintain spinopelvic harmony for global sagittal malalignment, especially such as camptocormia in patients with a stooped posture due to PD progression. However, poorer outcomes and lower fusion rates in multi-level fusion surgery have also been reported for PD cases [19,20], and PD patients treated with long instrumentation, surgery including the thoracic spine, and with less effective spinopelvic realignment tend to require earlier revision [21].

In the present study, lumbar lordosis at follow-up was significantly lower in PD patients, although there was no significant difference in local lumbar lordosis at follow-up between PD and non-PD cases. A biomechanical study showed that a flexion loading condition increased stress by 39.5%-42.7% in the suprajacent disc [22], and adjacent disc stress in longer fusion and fusions involving lower lumbar segments is higher than that in upper lumbar segments [23]. These results suggest that progression of postural instability in the natural course of PD could lead to mechanical stress and instrumentation failure, especially at an upper adjacent level. Most low lumbar OVC cases have decreased lumbar lordosis, but rarely show kyphotic changes due to the low rate of wedge-type collapse [2]. An epidemiological study revealed camptocormia in 4.1% of PD patients [24], and we found that sagittal spinopelvic alignment did not differ in low lumbar OVC cases with and without postoperative complications. Long-fusion surgery should be avoided for patients with single-vertebra OVC because poor sagittal alignment is less common in such cases, but short fusion from a posterior approach cannot correct a spinopelvic mismatch and instrumentation should not be ended in a kyphotic segment.

The surgical indication and strategy should be considered based on the high possibility of deterioration of ADL in the natural course of PD, even if no postoperative complications occur. In general, patients have independent ADL without major difficulties at Hoehn & Yahr stage 1 or below, some restrictions are seen in stage 2, and independent life becomes difficult at stage 3 or above. PD severity of stage 3 or above has been found to be a significant risk factor for further lumbar spine surgery [25], and the surgical indication for OVC should be considered for patients at stage 3 or below. In assessing long-term outcomes of PD patients, it should also be recognized that the rates of reaching stages 2 and 3 by 5, 10, and 15 years after onset are 30.2% and 6.5%, 57.2% and 27.9%, and 83.5% and 41.2%, respectively [26]. In addition, the rates of dyskinesia, which increases the risk of instrumentation failure, at these time points are 8.4%, 35.1%, and 62.8%, respectively. Appearance of depression decreasing the motivation for rehabilitation after surgery and deterioration of ADL associated with progression of PD is also important in treatment of OVC. Depression can have a significant impact on severity of PD based on health-related quality of life [27]. In our study, 4 of 11 cases (36.4%) had progression of severity of PD at follow-up. Thus, medical management as well as surgical strategy are important to improve the outcomes of spinal surgery in patients with PD.
In surgery for type 2 or 3 low lumbar OVC in non-PD cases, short fusion from a posterior approach is ideal due to easier decompression for the lumbar canal and intervertebral foramen stenosis for fractured vertebra [2]. VP+PS is recommended for cases with cleft formation at the affected vertebra, whereas PS+PLF or PLIF are chosen for cases without cleft formation, in which the affected vertebra often shows sclerotic changes with appearance of intervertebral instability. The optimal surgical strategies for low lumbar OVC in PD cases based on the present study are shown in Figure 3. For most patients with PD, additional reconstruction of the anterior column should be considered, especially for type 4 OVC. Anterior reconstruction using an expandable cage from a lateral lumbar approach and 1-above 1-below fixation might be ideal. In type 2 OVC in PD cases, VP+PS may be more likely to cause instrumentation failure and/or flesh compression fracture than in non-PD cases, due to progression of postural abnormalities and decreased lumbar lordosis in the natural course of PD, which may lead to upper adjacent segment disease and degenerative spondylolisthesis. Because of rare PD cases with sclerotic changes such as in type 3 OVC, PS+PLF or PLIF are often not indicated. VP only (that is, without short fusion) is not recommended in PD and non-PD cases because loading on the middle or posterior lesions of the affected vertebra is increased in low lumbar OVC and collapse of the affected vertebra could easily occur. In most type 2 or 3 cases with vertebral body height loss ≥70%, there is a poor outcome of VP without short fusion [28]. For a few patients with radicular pain or a high risk of instrumentation failure, there may be an option to wait for bone union with aggressive control of PD, and then perform laminectomy.

This study has certain limitations, including its retrospective, single-center design, small number of patients, and lack of use of minimally invasive surgeries, including anterior reconstruction and percutaneous pedicle screw fixation, which have been developed in recent years. Thus, the results may not show true failure and complication rates. Despite these limitations, we believe that our findings provide key insights on management of surgery for low lumbar OVC in patients with PD, since there are few reports on this condition in this patient population.

**Conclusion**

This study showed important differences in low lumbar OVC in patients with or without PD. The main clinical symptoms were radicular leg pain in non-PD cases and a cauda equina sign in PD cases, which also had rapid destructive progression of OVC. Progression of PD was associated with decreased lumbar lordosis, lower lumbar YAM, and severe sarcopenia, which might affect postoperative instrumentation-related complications. Decompression and shorter fusion surgery, including anterior support, should be used in patients with PD, rather than long-fusion surgery. Surgical strategy, treatment of osteoporosis, and aggressive control of PD before and after surgery are important to prevent surgical complications.

**Abbreviations**

PD: Parkinson's disease; OVC: osteoporotic vertebral collapse; BMD: bone mineral density; ADL: activities of daily life; CT: computed tomography; MRI: magnetic resonance imaging; BMI: body mass index; JOA: Japanese Orthopaedic Association; YAM: young adult mean; VP: vertebroplasty; PSF: pedicle screw
Declarations

Ethics approval and consent to participate

The study protocol was approved by the Human Ethics Review Committee of our University Medical Faculty and strictly followed the Clinical Research Guidelines of the Ministry of Health, Labor, and Welfare of the Japanese Government (Approval Number 2014046). All participants in this study provided written informed consent.

Consent for publication

Not applicable.

Availability of data and materials

Data generated and analyzed during this study are included in this published article. Data and materials are available from the corresponding author subject to reasonable request and subject to the ethical approvals in place and materials transfer agreements.

Competing interests

The authors declare no competing interests.

Funding

No funding was received for this work

Authors’ contributions

HN designed various aspects of the study and wrote the manuscript. HN analyzed the clinical and radiological results. SW, KH, and AK assisted with data analysis. AM made critical revisions of the article for important intellectual content. All authors approved the final version of the manuscript.

Acknowledgements

Not applicable.

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Tables

Table 1. Demographic data for patients with low lumbar osteoporotic vertebral collapse with and without Parkinson's disease
| Item                                                                 | PD patients | Non-PD patients | p  |
|----------------------------------------------------------------------|-------------|-----------------|----|
| Number of patients                                                  | 11          | 32              |    |
| Male                                                                | 2           | 7               | 0.80|
| Female                                                              | 9           | 25              |    |
| Age (years)                                                         | 76.2 ± 4.1  | 76.4 ± 7.6      | 0.90|
| Hoehn & Yahr stage before surgery (at follow-up)                   | Stage II: 5 (2) | —               |    |
|                                                                    | Stage II: 6 (8) |              |    |
|                                                                    | Stage II: 0 (1) |              |    |
| BMI (kg/m²)                                                         | 19.7 ± 3.9  | 22.4 ± 3.7      | 0.17|
| Affected vertebra: number                                           | L3: 6       | L3: 12          | 0.72|
|                                                                    | L4: 4       | L4: 14          |    |
|                                                                    | L5: 1       | L5: 6           |    |
| Surgical procedures: number                                         | VP: 1       | VP: 4           | 0.11|
|                                                                    | VP+PSF: 5   | VP+PSF: 9       |    |
|                                                                    | APSF: 2     | PSF: 7          |    |
|                                                                    | 3CO: 1      | PLIF: 6         |    |
|                                                                    | LM: 2       | ASF: 2          |    |
|                                                                    |             | APSF: 1         |    |
|                                                                    |             | 3CO: 1          |    |
|                                                                    |             | LM: 2           |    |
| Preoperative JOA score                                              | 11.8 ± 2.4  | 12.7 ± 3.7      | 0.52|
| JOA score at follow-up                                              | 21.0 ± 2.4  | 22.1 ± 3.4      | 0.32|
| Follow-up period (years)                                            | 3.7 ± 1.0   | 3.5 ± 2.0       | 0.77|

PD, Parkinson disease; BMI, body mass index; VP, vertebroplasty; PSF, pedicle screw fixation; PLIF, posterior lumbar interbody fusion; ASF, anterior spinal fusion; APSF, anterior and posterior spinal fusion; 3CO, 3 column osteotomy; LM, laminotomy

Table 2. Differences in clinical symptoms and duration in patients with and without Parkinson's disease
| Item                      | PD patients (n=11) | Non-PD patients (n=32) | p    |
|---------------------------|--------------------|------------------------|------|
| Symptom                   |                    |                        |      |
| Low back pain             | 10 (90.9%)         | 26 (81.3%)             | 0.45 |
| Radicular pain            | 3 (27.3%)          | 22 (68.8%)             | 0.016*|
| Cauda equina sign         | 8 (72.7%)          | 8 (25.0%)              | 0.0047*|
| Duration (days) †         | 24.5 ± 10.5        | 58.5 ± 33.4            | < 0.01*|

† Duration from diagnosis of compression fracture to that of burst fracture and/or appearance of neurological symptoms

PD, Parkinson disease

*p<0.05

Table 3. Differences in imaging findings in patients with and without Parkinson's disease

| Item                                                      | PD patients (n=11) | Non-PD patients (n=32) | p       |
|-----------------------------------------------------------|--------------------|------------------------|---------|
| Presence of compression fracture at thoracolumbar level (%) | 1 (9.1%)           | 23 (71.9%)             | 0.0003* |
| Type of osteoporotic vertebral collapse                   |                    |                        |         |
| Type 1: 0                                                 |                    |                        |         |
| Type 2: 3 (27.3%)                                         |                    |                        |         |
| Type 3: 2 (18.2%)                                         |                    |                        |         |
| Type 4: 6 (54.5%)                                         |                    |                        |         |
| Type 1: 0                                                 |                    |                        | 0.0073* |
| Type 2: 20 (62.5%)                                        |                    |                        |         |
| Type 3: 9 (28.1%)                                         |                    |                        |         |
| Type 4: 3 (9.4%)                                          |                    |                        |         |
| Preoperative lumbar YAM (%)                               | 55.2 ± 4.9         | 60.5 ± 7.7             | 0.043*  |
| Appearance of intervertebral cleft (%)                    | 3 (27.3%)          | 13 (40.6%)             | 0.43    |
| Preoperative lumbar lordosis                              | 15.8 ± 7.9         | 20.7 ± 12.0            | 0.24    |
| Preoperative local lumbar lordosis                        | 5.9 ± 11.6         | -2.2 ± 16.8            | 0.31    |
| Lumbar lordosis at follow-up                             | 7.7 ± 9.2          | 20.1 ± 13.5            | 0.02*   |
| Local lumbar lordosis at follow-up                        | 7.7 ± 10.6         | 7.8 ± 9.2              | 0.97    |
| L3 total psoas area/vertebral body area                   | 0.45 ± 0.13        | 0.56 ± 0.20            | 0.044*  |

PD, Parkinson disease; YAM, young mean adult
Table 4. Postoperative complications in patients with and without Parkinson's disease

| Item                              | PD patients (n=11) | Non-PD patients (n=32) | p     |
|-----------------------------------|--------------------|------------------------|-------|
| Fused segments                    | 3.3 ± 1.8          | 2.4 ± 1.4              | 0.26  |
| Postoperative complications       | 5 (45.5%)          | 11 (34.4%)             | 0.51  |
| Loosening and migration of pedicle screw | 4 (36.4%)          | 6 (18.8%)              | 0.23  |
| Progression of vertebral collapse | 3 (27.3%)          | 5 (15.6%)              | 0.39  |
| Infection                         | 1 (9.1%)           | 1 (3.1%)               | 0.42  |
| Revision surgery                  | 3 (27.3%)          | 3 (9.4%)               | 0.14  |

PD, Parkinson disease

Table 5. Factors related to postoperative complications
| Item                                      | With complications (n=16) | Without complications (n=27) | p   |
|-------------------------------------------|---------------------------|-------------------------------|-----|
| Age (years)                               | 74.6 ± 7.9                | 77.3 ± 6.8                    | 0.30|
| BMI (kg/m²)                               | 22.3 ± 3.7                | 21.5 ± 4.0                    | 0.60|
| With PD                                   | 5 (31.3%)                 | 6 (22.2%)                     | 0.51|
| Affected vertebra                         |                           |                               |     |
| L3: 8                                     |                           | L3: 10                        |     |
| L4: 6                                     |                           | L4: 12                        |     |
| L5: 2                                     |                           | L5: 5                         |     |
| Type of osteoporotic vertebral collapse   |                           |                               |     |
| Type 2: 8 (50.0 %)                        |                           | Type 2: 15 (55.6 %)           | 0.92|
| Type 3: 4 (25.0 %)                        |                           | Type 3: 7 (25.9 %)            |     |
| Type 4: 4 (25.0 %)                        |                           | Type 4: 5 (18.5 %)            |     |
| Preoperative lumbar YAM                   | 53.8 ± 6.4                | 62.1 ± 7.0                    | 0.015*|
| Changes of lumbar lordosis                | -5.3 ± 9.6                | 0.86 ± 6.1                    | 0.047*|
| Changes of local lumbar lordosis          | 3.6 ± 13.2                | 2.8 ± 8.2                     | 0.84|
| L3 total psoas area/vertebral body area   | 0.56 ± 0.17               | 0.54 ± 0.21                   | 0.75|
| Surgical procedures                       | VP: 2                     | VP: 3                         | 0.87|
|                                          | VP+PSF: 4                 | VP+PSF: 9                     |     |
|                                          | PSF: 4                    | PSF: 3                        |     |
|                                          | PLIF: 3                   | PLIF: 3                       |     |
|                                          | APSF: 1                   | ASF: 2                        |     |
|                                          | 3CO: 1                    | APSF: 3                       |     |
|                                          | LM: 1                     | 3CO: 1                        |     |
|                                          |                            | LM: 3                         |     |
| Fused vertebra                            | 3.1 ± 1.2                 | 2.2 ± 1.5                     | 0.040*|

BMI, body mass index; PD, Parkinson disease; YAM, young mean adult; VP, vertebroplasty; PSF, pedicle screw fixation; PLIF, posterior lumbar interbody fusion; ASF, anterior spinal fusion; APSF, anterior and posterior spinal fusion; 3CO, 3 column osteotomy; LM, laminotomy

*p<0.05