

Sagittal alignment changes and postoperative complications following surgery for adult spinal deformity in patients with Parkinson's disease: a multi-institutional retrospective cohort study

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Abstract

Background: Parkinson's disease (PD) has been reported to increase the risk of postoperative complications in patients with adult spinal deformity (ASD). However, those studies are limited, and few have made direct comparisons with patients who do not have PD.

Methods: A retrospective cohort study. We retrospectively reviewed all surgically treated ASD patients with at least a 2-year follow-up. Among them, 27 had PD (PD(+) group). Clinical data were collected on early and late postoperative complications as well as any revision surgery. Radiographic parameters were evaluated before and immediately after surgery and at final follow-up, including sagittal vertical axis (SVA), thoracic kyphosis, lumbar lordosis, sacral slope, and pelvic tilt. We compared the surgical outcomes and radiographic parameters of PD patients with those of non-PD patients.

Results: For early complications, the PD(+) group demonstrated a higher rate of delirium than the PD(-) group. With regard to late complications, the rate of radiological pseudarthrosis was significantly higher in the PD(+) group. Rates of rod failure and revision surgery due to mechanical complications also tended to be higher, but not significantly, in the PD(+) group ($p = 0.17$, $p = 0.13$, respectively). SVA at final follow-up and loss of correction in SVA were significantly higher in the PD(+) group.

Conclusion: Extra attention should be paid to perioperative complications, especially delirium, in PD patients undergoing surgery for ASD. Furthermore, loss of correction and rate of radiological pseudarthrosis were greater in these patients.

Background

Parkinson's disease (PD) is a neurodegenerative disorder, and the main symptoms include rigidity, bradykinesia, and gait disorder. With an aging population, the number of patients with this age-related disorder is on the rise [1]. In severe cases, PD can lead to postural disorders, such as anterocollis, Pisa syndrome, and camptocormia [2-5]. Studies have reported that these various postural abnormalities can increase susceptibility to the formation of rigid spinal deformities [2, 3] and that patients with PD develop adult spinal deformity (ASD) more frequently than the general population in the same age groups [6].

Recent studies have reported that ASD negatively affects the health-related quality of life [7, 8]. Surgical treatment has been shown to provide better health-related quality of life outcomes than non-surgical treatment, especially in patients with a severe deformity [9]. However, higher complication rates have been reported, with revision rates of up to 47% [10, 11]. Surgical complications are generally divided into perioperative or late complications. Perioperative complications include epidural hematoma, deep vein thrombosis (DVT), and pulmonary embolism (PE), which usually appear during or soon after surgery. Late complications, such as junctional kyphosis, rod fracture, and pseudarthrosis, typically occur more than one month following surgery and are primarily due to continuous mechanical stress.

Generally, PD patients are presumed to be afflicted with a higher risk of surgical complications, especially mechanical complications due to postural instability, a higher risk of falls, and decreased bone quality [12-15]. However, to date, only few small case series have investigated the complications after surgery for ASD in PD patients [16-19]. In addition, risk factors for complications and revision surgery in PD patients have not yet been confirmed. Therefore, we conducted this multicenter study in order to investigate 234 surgically treated ASD patients with at least a two-year follow-up. We compared the surgical outcomes and radiographic parameters of the PD patients with those of non-PD patients.

Methods

This retrospective observational cohort study follows the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines. We reviewed 233 ASD patients treated surgically from January 2009 to December 2016 at our hospital and related institutions. Institutional review board approval was obtained at each site for the patient enrolment and data collection protocols. Inclusion criteria included: age 21 years or older at the time of surgery, follow-up period of at least 2 years, and surgery including posterior instrumentation of four spinal levels with sufficient radiographic data. A total of 27 patients with PD were identified. Data was collected on mean PD duration and Hoehn and Yahr (HY) stage and medication for PD.

The ASD patients were diagnosed when they met at least one of the following: coronal Cobb angle of >20 degrees, sagittal vertical axis of >5 cm, pelvic tilt of >25 degrees, and thoracic kyphosis of >60 degrees. Etiologies included degenerative kyphosis/kyphoscoliosis, post lumbar surgery, and previous vertebral fracture. Operative time and intraoperative blood loss were recorded. Surgical complications are generally divided into early and late complications. Early complications were defined as complications that occurred during and within 1 month following surgery, including neurological disorders, implant failure, DVT, PE, cerebrovascular disease, respiratory disorders, cardiovascular disorders, delirium, surgical site infection, and spinal epidural hematoma. The number of revision surgeries due to perioperative complications was also recorded. Late complications usually occur more than one month after the operation, and are primarily due to continuous mechanical stress. This stress leads to the collapse of either the hardware or the vertebra; this is defined as a mechanical complication, and includes, for example, proximal junctional kyphosis (PJK), distal junctional kyphosis, pseudarthrosis, rod breakage, and vertebral fracture. PJK was defined as a kyphosis $> 10^\circ$ between the upper-instrumented vertebra and two-level proximal vertebrae[20]. Radiological pseudarthrosis was diagnosed by each surgeon using plain radiographs with the following features: absence of continuous bony trabeculation between adjacent vertebrae, peri-implant radiolucency, and/or motion on static/dynamic films. As rod failure often accompanies pseudarthrosis, we considered radiological pseudarthrosis and/or rod failure as possible clinical pseudarthrosis. Mechanical failure was defined as mechanical complications requiring revision surgery.

Demographic data were collected including age, sex, BMI, medical comorbidities, and bone mineral density (BMD) at the femoral neck. Measurements on radiographs included SVA, T4–T10 thoracic

kyphosis, T10-L2 thoracolumbar kyphosis (TLK), L1–S1 lumbar lordosis (LL), sacral slope (SS), pelvic incidence (PI), and pelvic tilt. These parameters were evaluated in the standing position, both before and at 4 weeks post-surgery. X-ray images were also evaluated at the final follow-up. A three-column osteotomy was defined as a procedure using pedicle subtraction osteotomy or vertebral column resection. The radiographic parameter of $-10^\circ < \text{PI-LL} < 10^\circ$ was defined as ideal alignment, based on the SRS-Schwab ASD classification.

We compared surgical outcomes and radiographic parameters of PD patients with those of the non-PD patients. Statistical analysis was performed using IBM SPSS Statistics for Macintosh, Version 25.0 (Released 2017 IBM Corp, Armonk, NY). We divided all patients into two groups: patients with PD (PD(+)) group) and patients without PD (PD(-)) group. We used a paired t-test or chi-squared test to compare the PD(+) and the PD(-) groups. Also, t-tests were used to compare the means of continuous variables, and chi-square tests to compare the proportions of categorical variables between the groups. A p -value < 0.05 was considered statistically significant. Missing values were imputed using the last observation carried forward method. In addition, we further matched background data using propensity score matching. Propensity score matching analysis which has been widely used in previous studies to adjust for known confounding biases, was also applied to our study [21-23]. The propensity score for the mechanical failure was initially calculated with the variables as follows: patient age and sex, BMI, fusion levels, and preoperative SVA. We performed the procedure using a logistic regression model. The C-statistic suggested that the fit was 0.67, which is a fairly good score. PD and non-PD patients were matched based on propensity scores, with the condition that the caliper be lower than 0.2. 24 pairs of patients with and without PD were created after the matching. Postoperative complications of the matched cases were compared between the two groups.

Results

Table 1 shows the patient characteristics of the PD(+) group and the PD(-) group. There was no significant difference between the two groups with respect to age, sex, BMI, or BMD. The number of fixed spinal levels was significantly higher in the PD(+) group than in the PD(-) group (9.3 ± 2.6 vs 7.8 ± 1.9 , $p = 0.006$), and the rates of three-column osteotomy tended to be higher in the PD(+) group (63.0% vs 48.5%, $p = 0.14$). For preoperative radiographic parameters, SVA was significantly higher in the PD(+) group than in the PD(-) group (196.0 ± 63.8 mm vs 135.4 ± 69.9 mm, $p < 0.001$). Other parameters were not significantly different between the groups. In terms of etiology, ASD caused by previous vertebral fracture was significantly higher in the PD(+) group than in the PD(-) group (previous vertebral fracture/degenerative/post lumbar surgery: 38.5%/53.8%/7.7% vs 10.1%/64.7%/25.1%, $p = 0.005$). Among 27 PD patients, dopamine precursors were used in 23 patients, dopamine agonists were used in eight patients, and no medication was administered in four patients.

Table 1. Demographic and operative characteristics of the PD group and non-PD group.

	PD	Non-PD	<i>P</i> -value
No. of cases	27	206	-
Age at surgery (years)	70.6±6.3	72.5±8.5	0.18
Sex (male/female: cases)	5/22	32/174	0.58
BMI	22.8±4.2	23.2±3.7	0.59
BMD (t-score)	-1.900±1.249	-1.863±0.924	0.93
Medications for PD			
Dopamin precursors (yes/no)	23/4 (85.2%)	-	-
Dopamin agonists (yes/no)	8/19 (29.6%)	-	-
Monoamine oxidase type B inhibitors (yes/no)	6/21 (22.2%)	-	-
Others	4/23 (14.8%)	-	-
Medical comorbidities			
Diabetes (yes/no)	1/26 (3.7%)	22/184 (10.7%)	0.49
Rheumatoid arthritis (yes/no)	0/27	9/197 (4.4%)	0.60
Renal dysfunction (yes/no)	0/27	19/187 (9.2%)	0.14
Cardiovascular disease (yes/no)	2/25 (7.4%)	26/180 (12.6%)	0.75
Cerebrovascular disease (yes/no)	5/22 (18.5%)	14/192 (6.8%)	0.053
Respiratory disease (yes/no)	0/27	21/185 (10.2%)	0.14
Follow-up period (months)	50.3±16.2	49.0±14.1	0.68
Number of fixed levels			
3CO (yes/no)	17/10	100/106	0.14
Etiologies(post fracture/degenerative/previous lumbar fusion)	10/15/2	21/133/52	0.001
Fix to sacrum (yes/no)	22/5 (81.5%)	174/32	0.78

			(84.1%)
Pre SVA (mm)	196.0±63.7	135.4±69.9	<0.001
Pre LL (degree)	2.1±19.3	3.5±20.5	0.75
Pre TLK (degree)	18.1±16.0	19.2±17.0	0.28
Pre TK (degree)	24.1±15.4	27.4±20.0	0.37
Pre SS (degree)	17.1±8.0	14.7±11.4	0.34
Pre PT (degree)	36.6±8.6	34.5±13.2	0.47
PI (degree)	53.6±9.6	49.8±9.1	0.088
No, number; PD, Parkinson disease; BMI, bone mass index; BMD, bone mineral density; 3CO, three column osteotomy; SVA, sagittal vertical axis; LL, lumbar lordosis; TK, Thoracic kyphosis; SS, Sacral slope; PT, Pelvic tilt; PI, pelvic incidence			

Table 2 shows the surgical invasiveness and postoperative complications for both groups. There were no significant differences in either operative time or intraoperative blood loss between the two groups. For early complications, the PD(+) group showed a higher rate of delirium than the PD(-) group. In the PD(+) group, rates of DVT and PE tended to be higher (DVT: 14.8% vs 6.8%, $p = 0.12$; PE: 3.7% vs 0.5%, $p = 0.081$), although the difference was not statistically significant. There were no differences between the groups in the rates of other complications, including neurological deficits, implant failure, cerebrovascular disorder, respiratory disorders, cardiovascular disorders, and surgical site infection. There was no significant difference in the rate of revision surgery due to early complications. For late complications, the rate of radiological pseudarthrosis was significantly higher in the PD(+) group (15.3% vs 3.9%; $p = 0.013$). Rates of rod failure and revision surgery due to mechanical complications also tended to be higher, but not significantly, in the PD(+) group (rod failure: 25.9% vs 13.1%, $p = 0.174$; revision surgery: 33.3% vs 18.0%, $p = 0.13$).

Table 2. Postoperative complications of the PD (+) group and the PD (-) group.

	PD (+)	PD (-)	P-value
No. of cases	27	206	-
Surgical time (min)	490±154	454±113	0.14
Blood loss (g)	2069±1336	1984±1422	0.28
Early complications			
Neurological complications (yes/no)	3/24 (11.1%)	23/183 (11.2%)	0.96
Implant failure (yes/no)	2/25 (7.4%)	20/186 (9.7%)	0.74
DVT (yes/no)	4/23 (14.8%)	14/192 (6.8%)	0.12
PE (yes/no)	1/26 (3.7%)	1/205 (0.5%)	0.081
Cerebrovascular disorder (yes/no)	0/27 (0%)	2/204 (1.0%)	0.61
Respiratory disorder (yes/no)	1/26 (3.7%)	7/199 (3.4%)	0.91
Cardiovascular disorder (yes/no)	0/27 (0%)	6/200 (2.9%)	0.38
Delirium (yes/no)	7/20 (25.9%)	15/191 (7.3%)	0.001
Surgical site infection (yes/no)	1/26 (3.7%)	6/200 (2.9%)	0.79
Spinal epidural hematoma (yes/no)	0/27 (0%)	14/192 (6.8%)	0.17
Late complications			
Mechanical complication (yes/no)	15/12 (55.6%)	99/107 (48.1%)	0.59
Radiological pseudarthrosis (yes/no)	5/22 (18.5%)	8/198 (3.9%)	0.013
Rod failure (yes/no)	7/20 (25.9%)	27/179 (13.1%)	0.17
Radiological pseudarthrosis and/or rod failure	10/17 (37.0%)	31/175 (15.0%)	0.005
PJK (yes/no)	7/20 (25.9%)	57/149 (27.7%)	0.91
DJK (yes/no)	3/24 (11.1%)	15/191 (7.3%)	0.95
Vertebral fracture (yes/no)	7/20 (25.9%)	43/163 (20.9%)	0.81
Revision (yes/no)	9/18 (33.3%)	37/169 (18.0%)	0.13
No, number; PD, Parkinson disease; DVT, deep vein thrombosis; PE, pulmonary embolism; PJK, proximal junction kyphosis; DJK, distal junction kyphosis			

Table 3 summarizes changes in the radiographic parameters postoperatively and at final follow-up. Postoperative SVA was similar between the PD(+) and PD(-) groups, although preoperative SVA was much higher in the PD(+) group. The change in SVA between pre- and postoperative radiographs was significantly higher in the PD(+) group (-142.5 ± 82.0 mm vs -94.6 ± 69.7 mm, $p = 0.014$). In addition, SVA at the final follow-up tended to be higher in the PD(+) group ($p = 0.062$). Loss of correction in SVA also tended to be higher in the PD(+) group ($p = 0.11$). No significant differences were found in the other radiographic parameters (Fig. 1), including the proposed ideal alignment target of $PI-LL < 10$.

Table 3. Postoperative radiographic parameters of the PD group and non-PD group.

	PD (+)	PD (-)	P-value
No. of cases	27	207	-
Post SVA (mm)	53.5±41.6	40.0±46.2	0.17
Change of SVA (post-pre) (mm)	-142.5±82.0	-94.6±69.7	0.003
Final SVA (mm)	89.2±68.1	59.9±52.2	0.062
SVA correction loss (mm)	35.7±62.1	19.2±43.4	0.11
Post LL (degree)	41.4±10.8	39.7±11.3	0.64
Final LL (degree)	38.6±12.3	36.4±12.5	0.74
LL correction loss (degree)	-0.64±20.9	-0.20±21.3	0.93
Post TK (degree)	37.1±12.9	36.5±14.5	0.85
Final TK (degree)	44.3±14.8	43.0±16.5	0.70
TK correction loss (degree)	7.3±7.1	6.5±10.6	0.87
Post SS (degree)	27.1±6.6	26.2±8.6	0.56
Final SS (degree)	27.4±9.6	24.7±17.3	0.48
SS correction loss (degree)	-0.3±6.4	1.7±16.8	0.58
Post PT (degree)	26.5±9.4	23.0±10.2	0.12
Final PT (degree)	26.2±11.3	24.7±19.0	0.59
-10<post PI-LL<10 (yes/no)	12/15	108/99	0.83

No, number; PD, Parkinson disease; SVA, sagittal vertical axis; LL, lumbar lordosis; TK, Thoracic kyphosis; SS, Sacral slope; PT, Pelvic tilt; PI, pelvic incidence.

Table 4 displays the preoperative demographics, postoperative radiographic parameters, and surgical characteristics of the PD group comparing those who underwent revision surgery (revision subgroup) with those who did not (non-revision subgroup). No significant difference was found in the radiographic

parameters between these two groups. For preoperative demographics, the duration of PD was significantly higher in the revision subgroup (87.0 ± 56.9 months vs 32.5 ± 48.0 months, $p = 0.037$). HY stage was higher in the revision subgroup, although this was not significantly different (2.8 ± 1.2 vs 2.2 ± 1.3 , $p = 0.29$).

Table 4. Postoperative radiographic parameters and demographics of revision group and non-revision group in the PD group.

	revision (+)	revision (-)	P-value
No. of cases	9	18	-
Pre SVA (mm)	187.0±62.3	193.4±63.6	0.84
Post SVA (mm)	60.2±27.4	57.7±39.2	0.87
Pre LL (degree)	-3.5±27.3	4.9±16.3	0.51
Post LL (degree)	33.7±13.4	44.6±8.6	0.11
Pre TLK (degree)	9.3±6.9	11.2±12.5	0.26
Post TLK (degree)	11.4±11.4	0.2±11.6	0.074
Pre TK (degree)	15.0±16.0	26.3±13.7	0.17
Post TK (degree)	30.0±18.5	40.1±9.8	0.25
Pre SS (degree)	16.2±11.8	17.0±6.5	0.87
Post SS (degree)	24.3±7.8	28.5±6.2	0.28
Pre PT (degree)	35.5±7.3	37.0±9.3	0.71
Post PT (degree)	27.3±5.2	26.2±10.7	0.74
PI (degree)	51.7±8.7	54.6±10.4	0.53
Age at surgery (years)	68.5±3.7	71.6±6.5	0.19
BMI	21.9±3.7	23.8±4.3	0.33
The number of levels fixed	9.0±2.5	10.2±2.5	0.35
Disease duration of PD (months)	87.0±56.9	32.5±48.0	0.037
Hoehn and Yahr stage	2.8±1.2	2.2±1.3	0.29
BMD (T score)	-2.1±1.7	-1.8±1.2	0.81
No, number; PD, Parkinson disease; SVA, sagittal vertical axis; LL, lumbar lordosis; TLK, Thoracolumbar kyphosis; TK, Thoracic kyphosis; SS, Sacral slope; PT, Pelvic tilt; PI, pelvic incidence; BMI, bone mass index, BMD, bone mineral density			

Table 5 shows the demographics and postoperative complications in the PD(+) and PD(-) groups after propensity score matching. 24 pairs of patients, one with PD and one without PD, were created after the matching. Age at surgery, sex, BMI, BMD, fusion levels, preoperative SVA, and LL were almost completely

matched. The rate of radiological pseudarthrosis was significantly higher in the PD(+) group (16.7% vs 0%; $p = 0.037$). Revision surgery due to mechanical complications tended to be higher, but not significantly, in the PD(+) group (revision surgery: 33.3% vs 12.5%, $p = 0.086$).

Table 5. Demographic and postoperative complications of the PD group and non-PD group after the propensity score matching.

	PD	Non-PD	P-value
No. of cases	24	24	-
Age at surgery (years)	70.8±6.5	70.6±11.5	0.95
Sex (male/female: cases)	5/19	3/21	0.70
BMI	23.2±4.1	24.0±4.1	0.49
BMD (t-score)	-1.7±1.2	-2.0±0.75	0.55
Number of fixed levels	9.0±2.4	9.0±2.0	0.95
3CO (yes/no)	7/17	11/13	0.37
Fix to sacrum (yes/no)	24/0	24/0	-
Pre SVA (mm)	185.7±62.4	182.9±76.9	0.89
Pre LL (degree)	0.04±21.8	-1.0±20.0	0.86
Mechanical complication (yes/no)	14/10 (58.3%)	11/13 (45.8%)	0.38
Radiological pseudarthrosis (yes/no)	4/20 (16.7%)	0/24 (0%)	0.037
Rod failure (yes/no)	6/18 (25.0%)	4/20(16.7%)	0.48
Radiological pseudarthrosis and/or rod failure	10/14(41.7%)	4/20 (16.7%)	0.057
PJK (yes/no)	7/17 (29.2%)	8/16 (33.3%)	0.78
DJK (yes/no)	2/22 (8.3%)	0/24 (0%)	0.15
Vertebral fracture (yes/no)	6/18 (25.0%)	8/16 (33.3%)	0.53
Revision (yes/no)	8/16 (33.3%)	3/21 (12.5%)	0.086
Post SVA (mm)	50.0±46.5	48.3±42.8	0.89
Post LL (degree)	41.7±10.2	41.9±12.1	0.95
Final SVA (mm)	89.9±62.2	65.6±46.9	0.13
Final LL (degree)	39.4±12.1	38.3±14.2	0.95
SVA correction loss (mm)	39.8±48.7	17.3±38.8	0.08
LL correction loss (degree)	-3.3±20.8	-3.5±19.9	0.97
No, number; PD, Parkinson disease; BMI, bone mass index; BMD, bone mineral density;			

3CO, three column osteotomy; SVA, sagittal vertical axis; LL, lumbar lordosis;

PJK, proximal junction kyphosis; DJK, distal junction kyphosis.

Discussion

PD patients have been demonstrated to manifest more postoperative surgical complications due to various musculoskeletal problems. Studies have investigated high rates of perioperative and postoperative complications following hip and knee surgery in PD patients using a nationwide inpatient database [24, 25]. Furthermore, other surgical studies on the PD population have suggested higher rates of postoperative medical complications such as pneumonia, delirium, and sepsis [5]. However, there have been only a few case series which have examined the relationship between PD and complications following corrective surgery for ASD. Furthermore, few studies have compared PD patients with non-PD patients in terms of detailed radiographic parameters. Thus, we retrospectively analyzed both postoperative complications and radiographic parameters in this multicenter database of ASD patients, and compared PD patients with non-PD patients. The strengths of this study are 1) collecting detailed data of radiographic parameters and early/ late complications, 2) comparison of PD and non-PD in both crude analysis and propensity matching analysis, 3) at least 2-year follow-up, 4) number of samples with statistical power.

The results of this study demonstrated that the rate of delirium was significantly higher, and the rates of PE and DVT also tended to be higher in the PD(+) group. In accordance with our result, Watanabe et al. previously reported that postoperative delirium was more common in patients with PD (23.1%) than in the control group (3.4%) [26]. The patients who developed delirium were on at least one medication for PD, with a HY scale of more than 2 in our study. Thus, this higher rate of delirium is possibly due to the use of PD drugs as well as the neurodegenerative state in PD patients. Although delirium is thought to be a reversible condition, previous studies reported that postoperative delirium increased morbidity and mortality leading to prolonged hospitalization. Additional complications may also occur due to falls or movement beyond the limits of restriction. Thus, we need to pay extra attention to the modifiable risk factors including sedation management, deliriogenic medications, immobility, sleep disruption especially in patients with PD. For thrombotic events, the incidence was relatively high in PD patients, but we could not find statistically significant difference in this study. However, a previous study suggested the significantly increased risk for PE in PD patients using large national database[27]. PE is recognized as a possible adverse reaction to dopamine precursors, such as levodopa [28]. Yamane et al. reported a higher incidence (20%) of DVT in PD patients with a postural abnormality [29]. Since the corrective surgery for ASD itself has a higher risk of PE due to its long operation duration time and immobilization period after surgery, it is estimated that the risk of PE of this surgery in PD patients is high. Thus, surgeons should consider thrombotic events when patients develop chest pain and dyspnea after surgery especially in PD patients. Preoperative screening of D-dimer or ultrasound examination of DVT can be a viable option to prevent the complications.

In this study, we found significantly higher preoperative SVA and larger correction of SVA in the PD(+) group. We also found SVA at the final follow-up was higher in the PD (+) group. The loss of correction in SVA was slightly higher in PD patients, even though fusion of a greater number of vertebral segments was performed in the PD(+) group. This finding suggests that the deformities in the PD(+) group were severe but primarily flexible, and were largely corrected by the surgery. However, the improved SVA could not be well maintained in this group. The exact reasons of increased SVA after surgery in PD patients are unknown. However, the stooping posture related PD itself can deteriorate the overall sagittal balance, and this may be one of the causes for the poorer outcome in PD patients. Kawaguchi et al. reported that longer fusion, up to the T4 level, yielded a good clinical outcome in a PD patient after corrective surgery from L1 to S1 was unsuccessful [30]. Watanabe et al. reported that surgically treated ASD patients with PD demonstrated poor clinical outcomes, with a high non-union rate and adjacent segmental disease [31]. Thus, it is crucial to consider possible prevention strategies, including fusion of a greater number of segments.

This study demonstrated that the revision rate due to mechanical complications was 33.3%, which was almost double for the PD(+) group as compared with the PD(-) group. Similar to our study, Sheu et al. investigated 66 PD patients who underwent thoracolumbar or lumbar instrumented surgery due to degeneration or deformity; 29% of them required revision surgery due to mechanical complications [15]. Bouyer et al. reported a high revision rate of 42% in 48 ASD patients with PD, 89% of which were due to mechanical complications [18]. In terms of each complication, PJK has been reported to be significantly higher in PD patients[5]. In contrast, a history of PD had no significant impact on the PJK rate in this study. Alternatively, rates of radiological pseudarthrosis and rod failure were higher in the PD(+) group. Even after matching on fusion levels and preoperative SVA using propensity matched score analysis, the rate of radiological pseudarthrosis was higher in the PD (+) group. Pseudarthrosis can initiate pain and hardware issues, such as loosening of screws and rod fracture. Thus, for PD patients, the surgeon should consider prevention strategies, such as the administration of teriparatide.

Several studies have investigated the risk factors for revision surgery in PD patients. Schroeder et al. reported that an HY stage > 2, diabetes mellitus, treatment for osteoporosis, and a combined anterior and posterior surgical approach were risk factors for revision surgery in 94 lumbar spine surgeries [14]. According to Sheu et al., HY stage > 2, cancer history, osteoporosis, and a three-column osteotomy, were risk factors for revision surgery [15]. Evaluation of walking ability using the HY scale can be affected by symptoms of ASD, and thus the stage itself may not reflect the exact severity of PD in ASD patients. However, in our study, the HY stage tended to be higher in the revision subgroup. In addition, disease duration of PD was significantly longer in the revision subgroup. Thus, it is vital to consider disease duration of PD, as well as the severity of the PD, when performing surgical treatment in ASD patients.

There are several limitations to this study. First, there was a selection bias in which the surgeon could change the choice of surgical procedure based on the patient's PD status. Second, as this is a multicenter study, we used simple criteria in order to identify mechanical complications using plain-film X-ray in this study. Thus, the diagnosis for mechanical complications by plain-film X-ray may underestimate the rate

of nonunion. Third, the background of PD and non-PD patients were different. Thus, we conducted a matching analysis to compare the PD and non-PD patients. Fourth, our study was retrospective in nature, and the number of PD patients was relatively low. When considering the rate of radiological pseudarthrosis in the PD and non-PD groups in this study, the effect size (w) was 0.376. Then, a post hoc analysis revealed that the statistical power for the chi-square test was $\beta = 0.99$, when type I error rate (α) was set at 0.05 (G*power 3.1). Therefore, we consider that the sample size was of sufficient size regarding the main result of this study, and we actually found a significant difference in the rate of radiological pseudarthrosis. However, this does not necessarily mean that the sample size was large enough for all of the analyses. Studies with more appropriate designs and a larger sample size are needed.

Despite these limitations, this study demonstrated important findings: 1) Delirium was more frequent in the PD patients on the early postoperative days, 2) The rate of radiological pseudarthrosis and revision surgery was higher in the PD patients on the late postoperative days even after adjusting the background data.

Conclusion

In patients with PD, postoperative delirium was common. Late complications included rod fracture, radiological pseudarthrosis, and revision surgery, which were higher in the PD(+) group. The rate of revision surgery due to mechanical complications was approximately double that of the PD(-) group. In the PD(+) group, SVA was significantly larger before surgery and at final follow-up, as was the loss of correction in SVA, suggesting that PD-specific postural abnormalities are involved in sagittal parameter deterioration. The PD duration was significantly higher in the PD patients who underwent revision surgery than in those who did not.

List Of Abbreviations

ASD: adult spinal deformity; BMI: body mass index; BMD: bone mineral density; DVT: deep vein thrombosis; DJK: distal junctional kyphosis; HY: Hoehn and Yahr; LL: L1–S1 lumbar lordosis; PD: Parkinson's disease; PI: pelvic incidence; PJK: proximal junctional kyphosis; PE: pulmonary embolism; T4–T10: thoracic kyphosis; UIV: upper-instrumented vertebra

Declarations

Ethics approval and consent to participate

The study was approved by the ethics committee of all institutions involved. Informed consent was waived by the above ethics committee as the present retrospective cohort study involved already existing data and records at the time of investigation, and did not retain personal identifiers of the gathered information.

The ethical committee, Tokyo Medical and Dental University; M2017-115

The ethical committee, Saiseikai Kawaguchi General Hospital; 29-2

The ethical committee, Kudanzaka Hospital; 2019-5

Consent for Publication

Not applicable

Availability of data and materials

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

Competing interests

Not applicable

Funding

Not applicable

Authors' contributions

AK analysed the data and wrote the original draft. TY conceived of, reviewed, and edited the paper. SM, KS, TH, MY, HI, YM, MT, IT, and KK acquired the data. KO performed the investigation. YA validated the paper. YA, SS, and AO supervised the researched. All authors contributed to the writing of the final manuscript. All authors approved the manuscript to be published and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Figures

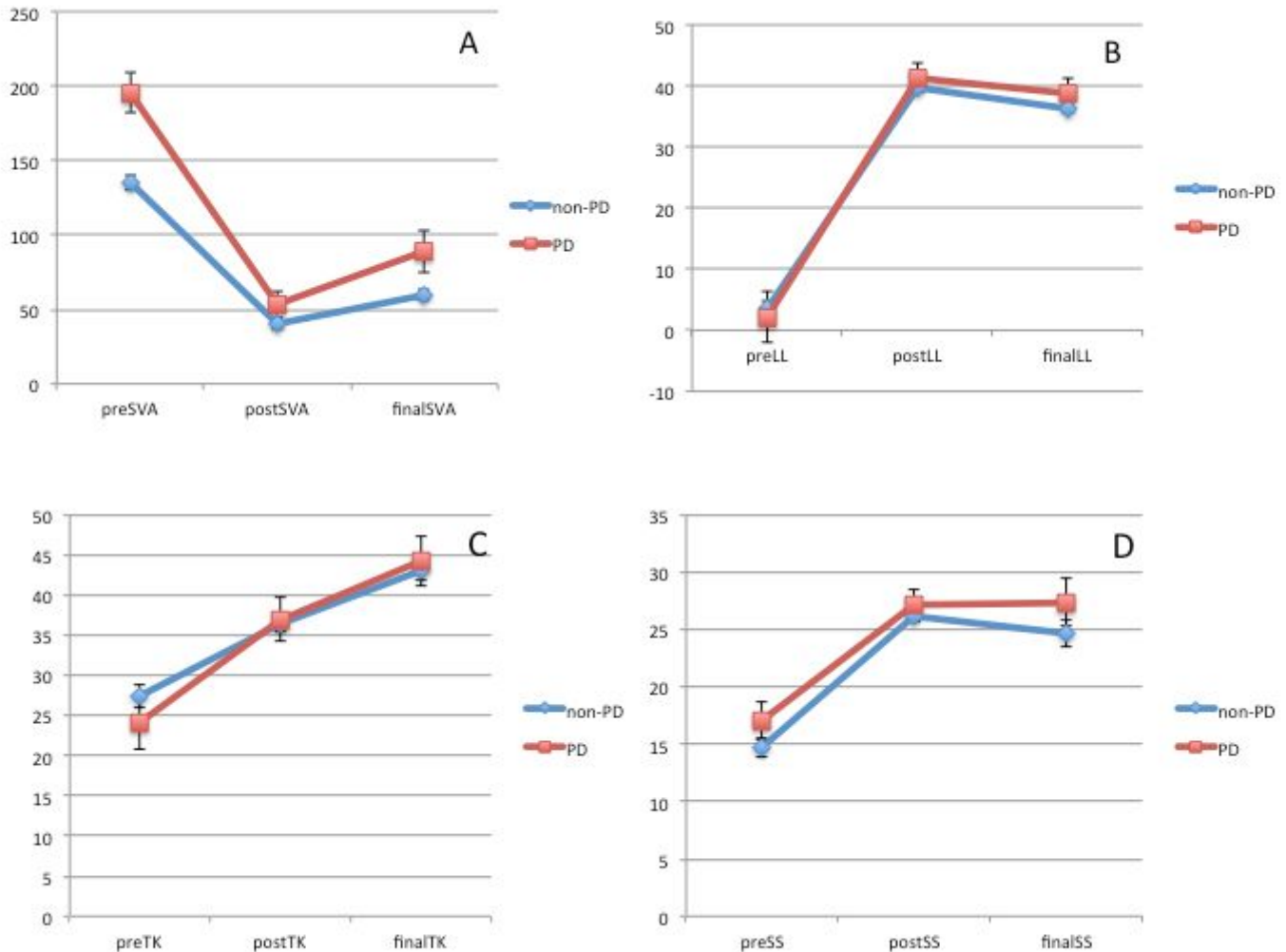


Figure 1

Comparison of change in radiographic parameters between patients with Parkinson's disease (PD) and those without PD (non-PD) Line graph showing change in mean radiographic parameters preoperatively, postoperatively, and at final follow-up. Black bars indicate standard errors. (A) Patients with PD show higher preoperative sagittal vertical axis than those without PD. Both groups show significant correction in sagittal vertical axis postoperatively; patients with PD showed higher correction loss at final follow-up. (B)(C)(D) No significant differences were found preoperatively, postoperatively, and at the final follow-up

value for other radiographic parameters, including correction and correction loss. Figure created using Microsoft Office PowerPoint 2011.

Supplementary Files

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