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Original Article

Impact of Paraspinal Muscle Degeneration on Surgical Outcomes and Radiographical Sagittal Alignment in Adult Spinal Deformity: A Multicenter Study

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Objective: This multicenter study aimed to evaluate the impact of paravertebral muscles (PVMs) degeneration, particularly fat infiltration, on preoperative sagittal imbalance, and postoperative complications and sagittal alignment change in patients with adult spinal deformity (ASD).
Methods: A retrospective analysis was conducted on 454 patients who underwent ASD surgery across 5 institutions. Patients were classified into 2 groups based on paraspinal muscle fat infiltration on MRI: those with significant infiltration (FI-PVM(+)) and those with minimal or no infiltration (FI-PVM(-)). Propensity score matching was performed to adjust for demographic factors and preoperative radiographical parameters. Spinopelvic parameters were assessed preoperatively, postoperatively, and at a 2-year follow-up. Mechanical complications were compared between the groups.
Results: The FI-PVM(+) group showed greater sagittal vertical axis (86.4 ± 57.5 vs. 51.8 ± 59.2, $p < 0.001$) preoperatively and required more extensive surgical correction with a significantly greater number of fused vertebral levels (7.3 ± 3.7 vs. 6.7 ± 3.7, $p < 0.039$). After propensity score matching, both groups showed significant improvement in spinopelvic alignment postoperatively, maintained throughout the 2-year follow-up. However, the FI-PVM(+) group demonstrated a trend toward a higher incidence of distal junctional kyphosis (6.3% vs. 0.9%, $p = 0.070$) and exhibited significantly greater decrease in pelvic tilt postoperatively (4.3° ± 7.6° vs. 1.3° ± 8.2°, $p = 0.006$).
Conclusion: Fat infiltration in PVM is associated with increased surgical complexity and a higher risk of mechanical complications. Preoperative assessment of muscle quality, along with targeted rehabilitation and closer postoperative monitoring, may be crucial for improving long-term outcomes in ASD surgery.

Keywords: Spine, Bone malalignment, Paraspinal muscles

INTRODUCTION

Adult spinal deformity (ASD) affects approximately 60% of individuals over the age of 60, with its prevalence expected to rise as the global population continues to age.[1] ASD is a complex, multifactorial condition that significantly impairs the quality of life of affected individuals, leading to severe spinal imbalance, chronic pain, and debilitating functional disabilities.[2,3] Despite advances in surgical techniques and technology, postoperative reciprocal changes and mechanical complications can lead to alterations in spinal alignment, potentially causing symptom recurrence.[4,5] These complications often compromise long-term outcomes, necessitating additional interventions and revision surgeries, which further hinder recovery.[6]

One crucial factor linked to the biomechanical instability and sagittal imbalance seen in ASD is degeneration of the paravertebral muscles (PVMs), particularly characterized by fat infiltration and muscle mass loss.[7-11] Studies have shown that patients with significant PVM degeneration often exhibit poor preoperative sagittal balance, as the muscle's ability to adequately support the spinal column deteriorates.[7,11-13] Fat infiltration, especially within the multifidus and erector spinae muscles, reduces the structural integrity of the spine, compromising the muscle's capacity to provide sufficient support.[7-11] This muscular degradation not only increases the risk of implant failure but also exacerbates long-term spinal instability. Moreover, fat infiltration is often associated with systemic degenerative conditions, such as sarcopenia and osteoporosis, which complicate both the management of ASD and the recovery process.[7]

Although, much of the existing research on PVM degeneration focuses on short segments of the spine, there are limited large-scale studies investigating the relationship between ASD and PVM degeneration.[7,11,14] While several reports have suggested an association between PVM degeneration and increased mechanical complication rates, including proximal junctional kyphosis (PJK),[7] the precise relationship between spinal alignment changes and the degree of PVM degeneration, both before and after surgery, remains unclear. Additionally, the influence of PVM degeneration on the incidence of mechanical complications in ASD, particularly in relation to spinal alignment, has not been thoroughly examined in multicenter studies.

This multicenter study aims to address these gaps by exploring the role of PVM fat infiltration in ASD surgery. Specifically, we investigated the impact of fat infiltration on pre- and postoperative spinopelvic sagittal alignment and the complication rate during midterm postoperative follow-up. Utilizing propensity score matching, we compared radiographical outcomes between patients with substantial fat infiltration (FI-PVM(+)) and those with minimal or no infiltration (FI-PVM(-)). Through this robust statistical approach, our study aims to provide a better understanding of the biomechanical challenges associated with compromised muscle quality and to identify potential strategies for improving surgical outcomes.

MATERIALS AND METHODS

1. Study Population

This multicenter study was conducted retrospectively across 5 institutions, focusing on ASD surgery. Between 2017 and 2020, 521 patients underwent posterior spinal fusion procedures for ASD, with a minimum follow-up of 2 years. This study was conducted in compliance with the tenets of the Declaration of Helsinki and approved by the Institutional Review Board of Nagoya University Hospital (No. 2016–0177). Written informed consent was obtained from all participants for the use of their anonymized data. The study is reported according to the Strengthening the Reporting of Observational Studies in Epidemiology checklist.

The inclusion criteria were: age 20 years and older, ASD diagnosis based on at least one of the following radiographical criteria: sagittal vertical axis (SVA) greater than 5 cm, pelvic incidence (PI) minus lumbar lordosis (LL) mismatch greater than 10°, or a global coronal Cobb angle exceeding 10°. All patients underwent posterior spinal fusion with instrumentation involving at least 4 vertebral levels and had preoperative and postoperative full-length radiographs and magnetic resonance imaging (MRI) scans available for review.

Patients were excluded from the study if they had a history of trauma, neurological deficits, severe spinal instability, or if they suffered from infectious, inflammatory, or malignant diseases affecting the spine. Patients with incomplete radiographic or clinical data were also excluded.

2. Evaluation of Paraspinal Muscle Fat Infiltration

Paraspinal muscle (PVM) fat infiltration was evaluated using preoperative lumbar MRI scans at the L4–5 level. Both T1-weighted and T2-weighted axial images were analyzed to assess the degree of fat infiltration within the PVM (Fig. 1). We utilized the classification system established by Kjaer et al. (2007) and Suzuki et al. (2022),[9,15] which grades fat infiltration into 3 categories based on the percentage of fat infiltration observed: grade 0 (0%–10% fat infiltration), grade 1 (10%–50%), and grade 2 (> 50%). Patients were classified as fat infiltration-positive group (FI-PVM(+)) if they had grade 2 infiltration and fat infiltration-negative (FI-PVM(-)) if they had grade 0 or 1.

3. Surgical Procedures

All surgeries involved posterior pedicle screw fixation and

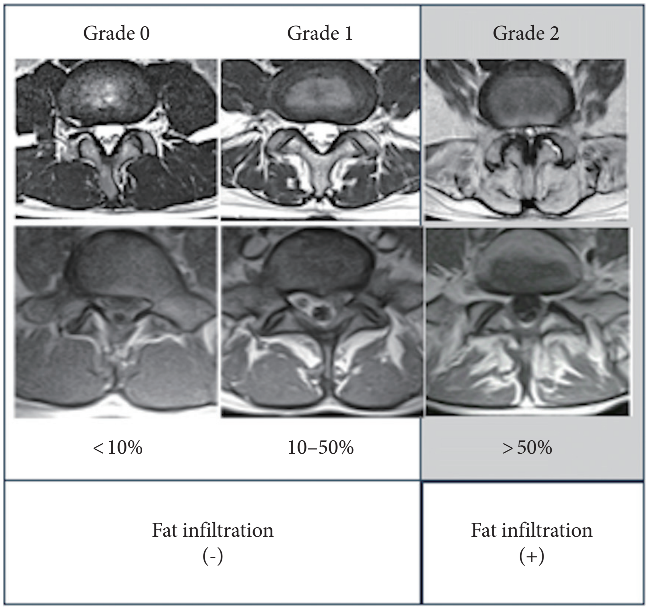

Fig. 1. Classification of paraspinal muscle fat infiltration based on magnetic resonance imaging (MRI). This figure illustrates the classification of paraspinal muscle fat infiltration using preoperative MRI axial images at the L4–5 vertebral level. The classification is based on the percentage of fat infiltration within the paraspinal muscles. The 2 patient groups are divided into "no fat infiltration" (grade 0 and grade 1) and "significant fat infiltration" (grade 2). MRI images were taken prior to surgery to assess the degree of fat infiltration.

instrumentation, spanning 4–17 vertebral levels, with pelvic fixation when necessary. Surgical neural decompression was performed as needed, followed by gradual correction of the spinal alignment.

To standardize surgical quality, only cases performed by senior surgeons with at least 10 years of experience in spinal deformity surgery were included in the analysis. Additionally, surgical complexity was standardized by defining the criteria for instrumentation and fixation across institutions, ensuring a consistent approach. We excluded minimally invasive surgery cases to focus on traditional open posterior spinal fusion outcomes. This allowed us to reduce variability introduced by different surgical approaches.

4. Radiographical and Clinical Profiles Associated With PVM Fat Infiltration

Radiographic evaluations were performed at 3 time points: preoperatively, immediately postoperatively (2 weeks), and at the 2-year follow-up. Standing lateral radiographs were used to measure: thoracic kyphosis (TK), LL, lower lumbar lordosis (LLL), pelvic tilt (PT), sacral slope (SS), PI, SVA, and global tilt (GT).

Clinical data, including age, sex, height, weight, body mass index (BMI), comorbidities, Charlson Comorbidity Index (CCI), and bone mineral density, was collected and analyzed. These clinical and radiographical profiles were compared between the FI-PVM(+) and FI-PVM(-) groups to identify significant differences. Furthermore, a multivariate analysis was conducted to determine the factors predictive of FI-PVM(+) status. Bone mineral density was assessed preoperatively using an established method based on computed tomography scans, with Hounsfield unit (HU) values recorded.[16]

5. Comparison of Clinical and Radiographical Outcomes

We compared perioperative complications (within 30 days), mechanical complications (up to 2 years) including PJK, distal junctional kyphosis (DJK), adjacent segment disease, implant loosening, and implant breakage, and reoperation due to mechanical complications.

Radiographic parameter changes were analyzed at 2 intervals: preoperative to 2 weeks postoperative, and 2 weeks postoperative to 2 years postoperative, to evaluate immediate and long-term outcomes while controlling for baseline characteristics through matching.

6. Statistical Analysis

Analyses were performed using R ver. 4.2.1 (R Foundation for Statistical Computing, Vienna, Austria). Continuous variables were compared using the Wilcoxon rank-sum test, and categorical variables using Fisher exact test. Variables with $p < 0.2$ in univariate analysis were included in multivariate analysis. Propensity score matching was employed to reduce confounding factors. For multiple time point comparisons, the Friedman test with Bonferroni correction was applied. Statistical significance was set at $p < 0.05$.

RESULTS

1. Patient Demographics and Surgical Characteristics

Of the 521 initially enrolled patients, 454 were included in the final analysis after excluding 67 patients with incomplete spinopelvic sagittal parameter measurements. The study population had a mean age of 59.5 ± 21.6 years, with female predominance (296 patients, 65.3%). The mean anthropometric measurements were: height 155.3 ± 9.7 cm, weight 56.5 ± 13.0 kg, and BMI 23.3 ± 4.4 kg/m^2 (Table 1). Comorbidities were present in 239 patients (52.6%), including hypertension (154 patients, 33.9%), diabetes (78 patients, 17.2%), cardiac disease (48 patients,

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Table 1. Demographics of all patients (n = 454)

Characteristic	Value
Age (yr)	59.5 ± 21.6
Female sex	296 (65.3)
Height (cm)	155.3 ± 9.7
Weight (kg)	56.5 ± 13.0
Body mass index (kg/m^2)	23.3 ± 4.3
Comorbidities (any)	239 (52.6)
Hypertension	154 (33.9)
Diabetes	78 (17.2)
Cardiac disease	48 (10.6)
pulmonary disease	12 (2.6)
Preexisting vertebral fracture	51 (11.2)
Charlson Comorbidity Index	3.0 ± 2.2
Hounsfield unit values of vertebrae	150.5 ± 76.6
PVM fat infiltration	
Grade 1	123 (27.1)
Grade 2	211 (46.5)
Grade 3	120 (26.4)
Fusion levels	6.9 ± 3.7
Fusion to pelvis	195 (43.0)

Values are presented as mean ± standard deviation or number (%).
PVM, paravertebral muscle.

10.6%), and pulmonary disease (12 patients, 2.6%). Preexisting vertebral fractures were observed in 51 patients (11.2%). The mean vertebral HU value was 150.5 ± 76.6. Regarding surgical characteristics, the mean number of fused vertebral levels was 6.9 ± 3.7, with pelvic fusion required in 195 patients (43.0%). PVM fat infiltration was graded as: grade 1 in 123 cases (27.1%), grade 2 in 211 cases (46.5%), and grade 3 in 120 cases (26.4%). Based on these grades, 120 cases were classified into the FI-PVM(+) group.

2. Factors Associated With PVM Fat Infiltration

Univariate analysis comparing FI-PVM(-) and FI-PVM(+) groups revealed significant differences in multiple parameters (Table 2): age, sex, height, BMI, cardiac disease, preexisting vertebral fracture, CCI, bone density (HU), number of fusion levels, rate of pelvic fixation, and several radiographic parameters (LL, LLL, PT, SS, PI–LL, SVA, and GT). In the subsequent multivariate analysis, age emerged as the only independent factor associated with fat infiltration (odds ratio, 1.061; 95% confidence interval, 1.030–1.096; $p < 0.001$) (Table 3).

Table 2. Comparison of clinical/radiographical profiles of FI-PVM(-) and FI-PVM(+) groups

Characteristic	FI-PVM(-) (n = 334)	FI-PVM(+) (n = 120)	p-value
Demographic			
Age (yr)	55.7 ± 22.9	70.0 ± 12.3	< 0.001*
Female sex	207 (62.0)	89 (74.2)	0.019*
Height (cm)	157.1 ± 9.5	150.3 ± 8.2	< 0.001*
Weight (kg)	57.3 ± 13.4	54.5 ± 11.5	0.086
Body mass index (kg/m^2)	23.1 ± 4.4	24.0 ± 4.2	0.021*
Comorbidities (any)	158 (47.3)	81 (67.5)	0.664
Hypertension	102 (30.5)	52 (43.3)	0.418
Diabetes	60 (18.0)	18 (15.0)	0.368
Cardiac disease	28 (8.4)	20 (16.7)	0.015*
Pulmonary disease	10 (3.0)	2 (1.7)	0.740
Preexisting vertebral fracture	30 (9.0)	21 (17.5)	0.017*
Charlson Comorbidity Index	2.8 ± 2.3	3.7 ± 1.8	< 0.001*
Hounsfield unit values of vertebrae	160.5 ± 77.3	122.9 ± 67.4	< 0.001*
Fusion levels	6.7 ± 3.7	7.3 ± 3.7	0.039*
Fusion to pelvis	123 (36.8)	72 (60.0)	< 0.001*
Radiographic			
TK (°)	25.8 ± 14.9	24.8 ± 15.9	0.797
LL (°)	31.1 ± 20.7	22.6 ± 21.2	< 0.001*
LLL (°)	24.5 ± 12.4	21.5 ± 13.4	0.013*
PT (°)	22.3 ± 12.3	28.7 ± 13.8	< 0.001*
SS (°)	27.1 ± 12.8	22.7 ± 12.6	0.006*
PI (°)	49.4 ± 11.9	51.3 ± 13.3	0.287
PI–LL (°)	17.5 ± 22.1	29.2 ± 21.6	< 0.001*
SVA (mm)	51.8 ± 59.2	86.4 ± 57.5	< 0.001*
GT (°)	24.6 ± 19.8	33.5 ± 21.0	< 0.001*

Values are presented as mean ± standard deviation or number (%).
FI-PVM, fat infiltration in the paravertebral muscles; TK, thoracic kyphosis; LL, lumbar lordosis; LLL, lower lumbar lordosis; PT, pelvic tilt; SS, sacral slope; PI, pelvic incidence; SVA, sagittal vertical axis; GT, global tilt.
*$p < 0.05$, statistically significant differences.

3. Comparison of Matched FI-PVM(+) and FI-PVM(-) Groups

Propensity score matching was performed based on the significantly different patient and radiographic factors identified in the initial analysis. This yielded 2 matched groups of 112 patients each (total n = 224). The matched cohorts showed no significant differences in baseline characteristics (Table 4).

Clinical outcomes and complications were compared between the matched groups (Table 5). While perioperative complica-

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Table 3. Results of logistic regression analysis of factors involved in fat infiltration in the paraspinal muscles

Variable	OR	95% CI	p-value
Age	1.061	1.030–1.096	< 0.001*
Height	0.978	0.847–1.146	0.768
Weight	0.934	0.750–1.133	0.514
Body mass index	1.204	0.764–2.008	0.449
Hounsfield unit values of vertebrae	1.000	0.995–1.004	0.995
Female sex	0.795	0.418–1.509	0.481
Comorbidities of cardiac disease	1.741	0.872–3.453	0.112
Comorbidities of vertebral fracture	1.037	0.515–2.052	0.919
Charlson Comorbidity Index	0.850	0.696–1.030	0.103

OR, odds ratio; CI, confidence interval.
*$p < 0.05$, statistically significant differences.

tions (within 30 days) and mechanical complications (at 2 years) were similar between groups, the FI-PVM(+) group showed a trend toward higher DJK occurrence within the fixed range (6.3% vs. 0.9%, $p = 0.070$).

4. Changes of Spinopelvic Sagittal Parameters

Radiographical parameter changes were analyzed across 2 time periods (Table 6): from preoperative to 2 weeks postoperative, and from 2 weeks to 2 years postoperative. During the immediate postoperative period (pre- to 2-week postoperation), both groups showed comparable changes in all sagittal parameters.

However, during the follow-up period (2-week to 2-year postoperation), the FI-PVM(+) group demonstrated distinct changes: a tendency toward greater increase in TK and a significant increase in PT compared to the FI-PVM(-) group. These findings suggest that at 2-year postoperation, the FI-PVM(+) group developed more pronounced pelvic retroversion accompanied by TK compared to the FI-PVM(-) group.

Table 4. Clinical/Radiographical profiles of FI-PVM(-) and FI-PVM(+) groups after matching

Characteristic	FI-PVM(-) (n = 112)	FI-PVM(+) (n = 112)	p-value
Demographic			
Age (yr)	69.5 ± 12.0	69.5 ± 12.5	0.965
Female sex	77 (68.8)	81 (72.3)	0.389
Height (cm)	154.1 ± 9.6	151.5 ± 11.2	0.132
Weight (kg)	56.1 ± 11.4	54.8 ± 11.6	0.365
Body mass index (kg/m^2)	23.5 ± 3.6	24.1 ± 4.2	0.321
Comorbidities (any)	67 (59.8)	75 (67.0)	0.332
Hypertension	40 (35.7)	50 (44.6)	0.220
Diabetes	24 (21.4)	17 (15.2)	0.300
Cardiac disease	18 (16.1)	18 (16.1)	1.000
Pulmonary disease	7 (6.3)	2 (1.8)	0.171
Preexisting vertebral fracture	12 (10.7)	17 (15.2)	0.426
Charlson Comorbidity Index	2.8 ± 1.5	2.6 ± 1.4	0.277
Hounsfield unit values of vertebrae	127.0 ± 53.4	127.5 ± 67.1	0.604
Fusion levels	6.2 ± 3.3	6.7 ± 3.6	0.250
Fusion to pelvis	63 (56.2)	67 (59.8)	0.685
Radiographic			
TK (°)	26.6 ± 14.0	24.6 ± 15.9	0.397
LL (°)	21.9 ± 18.8	21.9 ± 21.1	0.848
LLL (°)	19.5 ± 11.9	21.3 ± 13.6	0.367
PT (°)	27.9 ± 10.8	28.7 ± 13.9	0.432
SS (°)	22.7 ± 11.0	22.6 ± 12.7	0.821
PI (°)	50.6 ± 10.3	51.3 ± 13.4	0.974
PI–LL (°)	28.4 ± 20.2	29.5 ± 21.7	0.752
SVA (mm)	87.3 ± 61.8	86.4 ± 57.5	0.914
GT (°)	34.0 ± 19.1	33.5 ± 20.9	0.755

Values are presented as mean ± standard deviation or number (%).
FI-PVM, fat infiltration in the paravertebral muscles; TK, thoracic kyphosis; LL, lumbar lordosis; LLL, lower lumbar lordosis; PT, pelvic tilt; SS, sacral slope; PI, pelvic incidence; SVA, sagittal vertical axis; GT, global tilt.

DISCUSSION

This multicenter study demonstrates that PVM fat infiltration appears to affect surgical outcomes in ASD patients. Our findings corroborate previous research, showing that FI-PVM(+) patients present with more severe preoperative sagittal imbalance, requiring more extensive surgical corrections. This is evidenced by the increased number of instrumented vertebral levels in the FI-PVM(+) group, reflecting the greater biomechanical challenges associated with compromised muscle quality. Notably, while both groups achieved postoperative improvements in spinopelvic alignment that were maintained at 2-year follow-up, important differences emerged in their compensation patterns.

A principal finding of this study is the persistent pelvic retroversion observed in the FI-PVM(+) group postoperatively, suggesting that muscle degeneration may perpetuate sagittal imbalance despite initial surgical realignment. This observation indicates that compensatory mechanisms persist due to weakened PVMs, potentially leading to degenerative changes in the unfixed spinal segments and consequent PT to maintain balance. Such reciprocal behavior could increase the risk of long-

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Table 5. Comparison of clinical outcome between FI-PVM(-) and FI-PVM(+) groups after matching

Variable	FI-PVM(-) (n = 112)	FI-PVM(+) (n = 112)	p-value
Perioperative (< 30 days)			
Deterioration of neurological symptoms	8 (7.1)	10 (8.9)	0.807
Dural injury	8 (7.1)	8 (7.1)	1.000
SSI	3 (2.7)	6 (5.4)	0.499
Implant malposition	2 (1.8)	5 (4.5)	0.446
Delirium	3 (2.7)	3 (2.7)	1.000
Hematoma	3 (2.7)	2 (1.8)	1.000
UTI	2 (1.8)	1 (0.9)	1.000
Oter	3 (2.7)	5 (4.5)	0.722
Two years after			
Implantloose	22 (19.6)	25 (22.3)	0.743
PJK	18 (16.1)	16 (14.3)	0.853
DJK	1 (0.9)	7 (6.3)	0.070
Implantbreak	3 (2.7)	4 (3.6)	0.333
Other	3 (2.7)	3 (2.7)	1.000
Reoperation	9 (8.0)	12 (10.7)	0.648

Values are presented as number (%).
FI-PVM, fat infiltration in the paravertebral muscles; SSI, surgical site infection; UTI, urinary tract infection; PJK, proximal junctional kyphosis; DJK, distal junctional kyphosis.

Table 6. Comparison of changes of radiographical parameters between FI-PVM(-) and FI-PVM(+) groups after matching

Variable	FI-PVM(-) (n = 112)	FI-PVM(+) (n = 112)	p-value
Preoperative to postoperative			
TK change	3.2 ± 11.8	4.0 ± 11.9	0.500
LL change	14.6 ± 19.4	16.4 ± 19.2	0.474
LLL change	3.6 ± 12.1	2.9 ± 13.5	0.714
PI change	-0.7 ± 7.3	-1.5 ± 9.1	0.478
PT change	-6.0 ± 10.5	-7.1 ± 13.8	0.499
SS change	5.1 ± 11.2	5.7 ± 11.9	0.693
PI–LL change	-15.8 ± 20.5	-18.6 ± 21.6	0.401
GT change	-10.4 ± 15.3	-9.8 ± 14.9	0.745
SVA change	-42.1 ± 56.7	-41.2 ± 54.8	0.914
Postoperative to 2 years after operation			
TK change	2.5 ± 10.5	5.5 ± 10.7	0.050
LL change	-1.9 ± 10.3	-3.7 ± 10.9	0.224
LLL change	1.0 ± 7.3	0.0 ± 9.7	0.589
PI change	1.0 ± 7.6	1.4 ± 8.0	0.836
PT change	1.3 ± 8.2	4.3 ± 7.6	0.006*
SS change	-1.1 ± 9.3	-2.8 ± 10.4	0.173
PI–LL change	3.3 ± 11.5	4.6 ± 10.5	0.234
GT change	3.6 ± 8.6	3.3 ± 10.0	0.678
SVA change	13.9 ± 39.3	12.3 ± 46.2	0.946

Values are presented as mean ± standard deviation.
FI-PVM, fat infiltration in the paravertebral muscles; TK, thoracic kyphosis; LL, lumbar lordosis; LLL, lower lumbar lordosis; PT, pelvic tilt; SS, sacral slope; PI, pelvic incidence; SVA, sagittal vertical axis; GT, global tilt.
*$p < 0.05$, statistically significant differences.

term mechanical complications.[17] Several previous studies have demonstrated an association between sarcopenia, characterized by progressive and systematic loss of muscle mass and quality, and mechanical complications following ASD surgery.[18,19] Consistent with these previous observations, our findings suggest a trend toward higher rates of DJK in patients with muscle fat infiltration. To better understand the pathogenesis of these alignment changes, future prospective studies should stratify patients based on factors such as fusion extent. Clinical implications include the need for tailored interventions focusing on muscular support and reduction of compensatory mechanisms. Specific strategies may include preoperative core strengthening and postoperative physical therapy targeting pelvic stability and muscle balance to mitigate long-term complications.

Another significant finding was the higher occurrence of fractures within the fixed range in the FI-PVM(+) group. Although not reaching statistical significance, this observation emphasizes the crucial role of soft tissue integrity in spinal biomechanical stability. For patients with severe PVM degeneration, extending the distal fixation range or implementing pelvic fixation might prevent revision surgery due to mechanical complications.[20] Passias et al.[21] linked DJK to preoperative trunk anteversion angle and SVA, while Pu et al.[22] identified excessive postoperative kyphosis and advanced PVM fat degeneration as DJK risk factors. In current study, despite matched baseline sagittal alignment between groups, the trend toward increased DJK in patients with muscle fat degeneration reinforces the critical importance of muscle integrity for postfusion biomechanical stability.

The relationship between muscle quality and bone health merits particular consideration. ASD patients, especially those with PVM degeneration, frequently present with osteoporosis, potentially compromising implant stability and increasing risks of screw loosening and vertebral fractures.[23] Our findings suggest that optimizing both muscle and bone health is essential for improving long-term surgical outcomes. Specifically, bone mineral density management may enhance the durability of surgical corrections in patients with severe muscle degeneration.[24]

These results underscore the importance of incorporating muscle quality assessment into routine preoperative evaluation. While visual grading of PVM fat infiltration[9,15] remains common, advanced imaging techniques, such as chemical shift encoding-based water–fat MRI-based volumetric analysis, offer superior precision and warrant investigation in future studies.[25] Additionally, implementing prehabilitation programs for PVM strengthening before surgery, combined with early postoperative rehabilitation focusing on muscle maintenance, may potentially help optimize outcomes and reduce long-term complications.[26]

Several limitations should be considered when interpreting our findings. First, the retrospective study design introduces potential biases, particularly in patient selection and data collection, which may affect the reliability of our results. Second, the limited number of participating institutions may restrict the generalizability of our findings. Third, while practical, the visual grading method for PVM degeneration assessment is susceptible to interobserver variability. Future research should employ standardized, quantitative imaging techniques to improve accuracy and cross-institutional comparability. Finally, although our study provides valuable midterm outcomes, longer follow-up periods are essential to fully elucidate the long-term impact of PVM degeneration on mechanical complications and surgical success.

CONCLUSION

This study demonstrates the influence of PVM fat infiltration appears to affect surgical outcomes in ASD patients. Patients with substantial muscle degeneration face greater challenges in maintaining long-term spinal alignment and have an elevated risk of mechanical complications. To optimize patient outcomes, preoperative planning should incorporate MRI-based muscle quality assessment, complemented by targeted rehabilitation programs. These findings highlight the importance of considering soft tissue quality in the surgical management of ASD.

NOTES

Conflict of Interest: The authors have nothing to disclose.

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