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Effect of vertebral rotation on adjacent segment degeneration after the early stage of lumbar fusion surgery

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Abstract

Objective Related studies have shown that the torsional vertebral after fused significantly increase adjacent disc stress and accelerate degeneration. This suggests that vertebral rotation (VR) may accelerate adjacent segment degeneration (ASD). To investigate: (1) the correlation between VR and radiographic adjacent segment degeneration (rASD) after the early stage of lumbar fusion (2), the incidence of rASD with different VR degrees (3), whether the incidence of rASD can be reduced by surgically reducing instrumented vertebrae (IV) rotation.

Methods A retrospective analysis was conducted on the cases of 195 patients with lumbar degenerative disease (LDD) who were selected based on inclusion and exclusion criteria. The grade and angle of VR were measured for accurate analysis. The final follow-up evaluated the clinical improvement of the patients and the rASD. The impact of various factors on rASD was observed using univariate and multivariate logistic regression analyses. With different VR grades, Kaplan-Meier survival analysis was used to describe the incidence of rASD at various follow-up intervals.

Results The results indicate that preoperative adjacent vertebrae (AV) rotation (OR = 1.852, 95% CI = 1.064–3.224, $P = 0.029$) and IV rotation at final follow-up (OR = 2.748, 95% CI = 1.458–5.177, $P = 0.002$) are the independent risk factors for rASD. The results of the Kaplan-Meier analysis showed that with different VR grades, the follow-up period was different when the cumulative incidence of rASD reached 50%. The AV rotation decreased in the patients whose IV rotation decreased after the operation ($P < 0.001$), and the incidence of rASD was also lower ($P = 0.004$), especial in the fused to S1 group.

Conclusions VR is a risk factor for rASD at the early stage of lumbar fusion surgery. Reducing VR during surgery can alleviate the speed of ASD and reduce the incidence of rASD in fused to S1.

Keywords Vertebral rotation, Lumbar degenerative diseases, Adjacent segment degeneration, Derotation

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Introduction

The lumbar spine's posterior approach fusion procedure is now frequently used to treat a variety of LDD [1]. ASD is divided into rASD and clinical adjacent segment degeneration (cASD) due to different manifestations [2–6]. rASD refers to only imaging manifestations, such as intervertebral disc degeneration and intervertebral stenosis. cASD indicates clinical symptoms, such as low back pain and numbness. According to the literature review, the incidence of rASD is between 4.8% and 92.2%, and cASD is between 0% and 30.3% [5]. About 1/4 – 1/3 of the patients with rASD will progress to cASD [2]. A second operation is necessary for patients with severe symptoms brought on by cASD, which significantly increases the burden on patients and social medical resources [2, 5–7]. Therefore, it is significant to identify the risk factors that affect the occurrence of ASD. Many scholars have studied the correlation between age, gender, BMI, osteoporosis, segments, follow-up period, smoking or other factors and ASD, but some factors are still controversial [8–13].

Studies have shown that the asymmetry of the facet joints will increase the pressure on the adjacent discs and biomechanically promote the occurrence of ASD after fusion [14], and VR is correlated with facet asymmetry [15]. Current research has shown that VR may be associated with lumbar spine degeneration. A finite element analysis of a lumbar fusion model found that in the torsional state, the stress of the intervertebral disc in the segment adjacent to fusion increases significantly and accelerates disc degeneration [16]. Another study used a model of rotational motion and discovered that the facet joints experience a notable concentration of stress during rotation [17]. It indicates that VR may change the stress of the corresponding segment and accelerate the occurrence of ASD. In addition, among the many factors related to ASD, the degree of VR can be intervened by surgery, so it is significant to study the correlation between VR and ASD. This study sought to determine the relationship between VR and rASD following early lumbar fusion and the impact of surgically reducing VR on rASD incidence.

Materials and methods

Study subjects

A retrospective analysis of 1628 LDD patients who underwent surgery in our hospital from 2012 to 2019 was conducted, and 195 patients met the inclusion and exclusion criteria. The case fused distally to S1 have the proximal adjacent segment but no the distal adjacent segment, on the contrary, the case fused distally to L1 have the distal adjacent segment but no the proximal adjacent segment.

This work has been carried out in accordance with the Declaration of Helsinki (2000) of the World Medical Association. This study was approved by The Medical Ethics Committee of the First Affiliated Hospital of the Air Force Medical University [LLSP76930228476]. Written informed consent was obtained from individual or guardian participants.

Inclusion criteria: (1) Diagnosed with lumbar disc herniation, lumbar spinal stenosis, or degenerative spondylolisthesis; (2) Primary lumbar surgery, and underwent transforaminal lumbar interbody fusion surgery; (3) Age: older than18 years and younger than 70 years; 4.With complete imaging data including lumbar AP and lateral view X-rays, flexion and extension X-rays, CT and MRI at preoperative and final follow-up, the follow-up period greater than 1 year and less than 5 years (all images were taken at our hospital in the same standard. For example, to ensure that the pelvis does not rotate abnormally during an AP plane, both buttocks must be fastened to the examination bed in the supine position); 5. No preoperative degenerative in the adjacent segments. **Exclusion criteria**: (1) Incomplete clinical data or loss to follow-up; (2) History of lumbar fracture, infection, tumor, congenital spinal/pelvis deformity.

Study method

Since the adjacent segment involves both upper and lower vertebrae, i.e., the vertebrae instrumented by pedicle screws at the cephalic or caudal of the fused segment (IV) and the adjacent unoperated vertebrae (AV), therefore, this study evaluated the occurrence of rASD and measured the amount of rotation in both the IV and AV (Figure S1A). Other risk factors reported in previous studies, including Body Mass Index (BMI), Bone Mineral Density (BMD), age, sex, fusion level, and follow-up period, as well as hypertension, diabetes, smoking, and alcohol consumption were counted together in the study to adjust the confounding bias. In addition, patients' clinical symptoms before surgery and at the last follow-up were compared to assess the effectiveness of surgical treatment.

Clinical assessment

Oswestry Disability Index (ODI), Japanese Orthopedic Association (JOA), Visual Analogue Scale (VAS), and MOS item short from Health Survey (SF-36) were calculated before surgery and at the final follow-up for the clinical assessment.

Radiological evaluation

The rotation of IV and AV during preoperative and postoperative follow-up was evaluated separately. The Nash-Moe grading system [18] was used to determine the grade of VR (Figure S1B). The specific rotation angle of the vertebrae was also measured using the Aaro-Dahlborn method based on axial CT images [19] (Figure S2).

The diagnostic criteria for rASD were as follows: (1) Compared to preoperative lateral X-ray, adjacent disc height(length of line between midpoints of the upper and lower endplate) loss of more than 10% or 3 mm in final follow-up; (2) Spondylolisthesis at adjacent segment > 3 mm in final lateral X-rays; (3) The flexion and extension angle changes more than 10°; (4) UCLA classification (University of California, Los Angeles) [20] progress ≥ 1 level (Table S1).

Groups

Based on preoperative and postoperative IV rotation variations, we divided all segments into two groups. The segment whose IV rotation existed before operation and was reduced in the final follow-up was distributed to the reduced group; on the contrary, the segment of IV rotation without reduction was distributed to the not reduced group. However, the segment that IV without rotation before surgery was excluded.

Statistical methods

The factors influencing rASD was analyzed using univariate and multivariate logistic regression, and variables with $P < 0.1$ were included in the multivariate regression model. The Mann-Whitney U test was used for data that did not behave normally, and the chi-square test was used to compare groups. $P < 0.05$ was considered statistically significant. Kaplan-Meier survival analysis was used to describe the incidence of rASD of different VR degrees at different follow-up period and to calculate median survival time. Survival curves were compared using the Log-Rank test. SPSS (Version 26.0; IBM Corp., Armonk, NY, USA) was used for statistical analysis.

Results

The cases were fused in the following ways: 95 cases were fused distally to S1, and 1 case was fused proximally to L1. A total of 294 adjacent segments were studied (154 men and 140 women), of which 194 were proximal adjacent segments, and 100 were distal adjacent segments (Figure S3). The mean follow-up period was 31 months. There were 26 segments from cases with three or more fused segments, 212 segments from single-segment fusion cases, and 56 segments from double-segment fusion cases (Table S2).

1. To investigate the correlation between VR and rASD after the early stage of lumbar interbody fusion.

Univariate regression analysis showed that fusion level (OR = 1.811, 95% CI = 1.299–2.525, $P < 0.001$), follow-up period (OR = 1.014, 95% CI = 1.003–1.024, $P = 0.013$), age (OR = 1.054, 95% CI = 1.030–1.080, $P < 0.001$), preoperative IV rotation (OR = 3.76, 95% CI = 2.371–5.962, $P < 0.001$) and AV rotation (OR = 3.229, 95% CI = 2.134–4.885, $P < 0.001$), IV rotation at final follow-up (OR = 4.444, 95% CI = 2.744–7.198, $P < 0.001$) and AV rotation at final follow-up (OR = 2.924, 95% CI = 1.970–4.341, $P < 0.001$) were significantly associated with the occurrence of rASD (Fig. 1). Moreover, a multivariate logistic regression model included variables with $P < 0.1$ in the univariate analysis. Therefore, the result suggested that preoperative AV rotation (OR = 1.852, 95% CI = 1.064–3.224, $P = 0.029$) and final follow-up IV rotation (OR = 2.748, 95% CI = 1.458–5.177, $P = 0.002$) were independent risk factors for rASD (Table S3). The degree of rotation of the IV can more accurately predict the risk of postoperative rASD (AUC = 0.702, $p < 0.001$), according to ROC curves plotted for preoperative AV and final follow-up IV based on the findings of multifactorial regression analysis. Overall, the model quality indicated a robust predictive model (Fig. 2).

2. To investigate the incidence of rASD with different degrees of VR.

Based on the results of multivariate regression analysis, the K-M survival curves were analyzed for Nash-Moe grading of preoperative AV and final follow-up IV, respectively. The analysis revealed that for patients with Nash-Moe grades I and ≥ II of preoperative AV, respectively, the follow-up period was 50 months and 36 months before patients reached a cumulative rASD prevalence of 50% (Fig. 3). In contrast, for IV, the follow-up period required for patients to achieve a 50% cumulative incidence of rASD at Nash-Moe grade 0, I and ≥ II was 84 months, 40 months and 36 months spectively (Fig. 4). The comparison indicates a shorter follow-up in patients whose cumulative incidence of IV rotation reached 50%, indicating a stronger impact of IV on rASD.

3. To investigate whether the incidence of rASD can be decreased by reducing IV rotation surgically.

By comparing the rotation degree of IV at preoperative and final follow-up, we analyzed whether reducing the rotation degree of IV would affect AV rotation and rASD. The segments that IV without rotation before surgery was excluded, the remaining 111 segments, which had IV rotation before surgery, were studied in this part, of which the rotation angles of 41 segments had decreased post-surgery, and 8 segments (19.5%) had rASD. 70 segments' rotation angle did not decrease post-surgery, and 33 segments (47.1%) had rASD. As statistical significance showed ($p = 0.004$), there was a difference between the two groups. Further comparisons by fusion level showed that the effect of IV rotation correction on reducing the incidence of rASD was only 13.8%, more pronounced

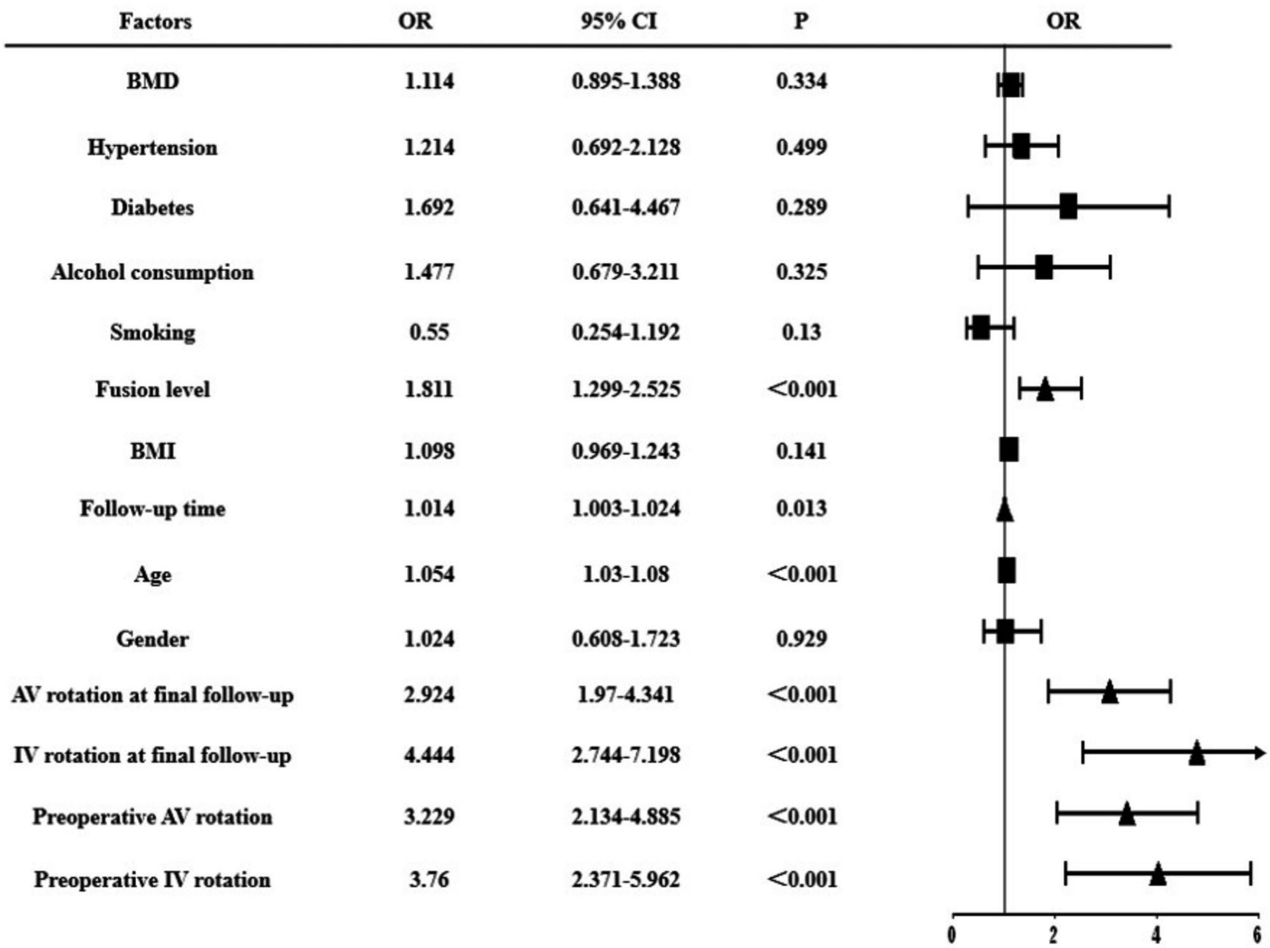

Fig. 1 Univariate regression analysis of rASD

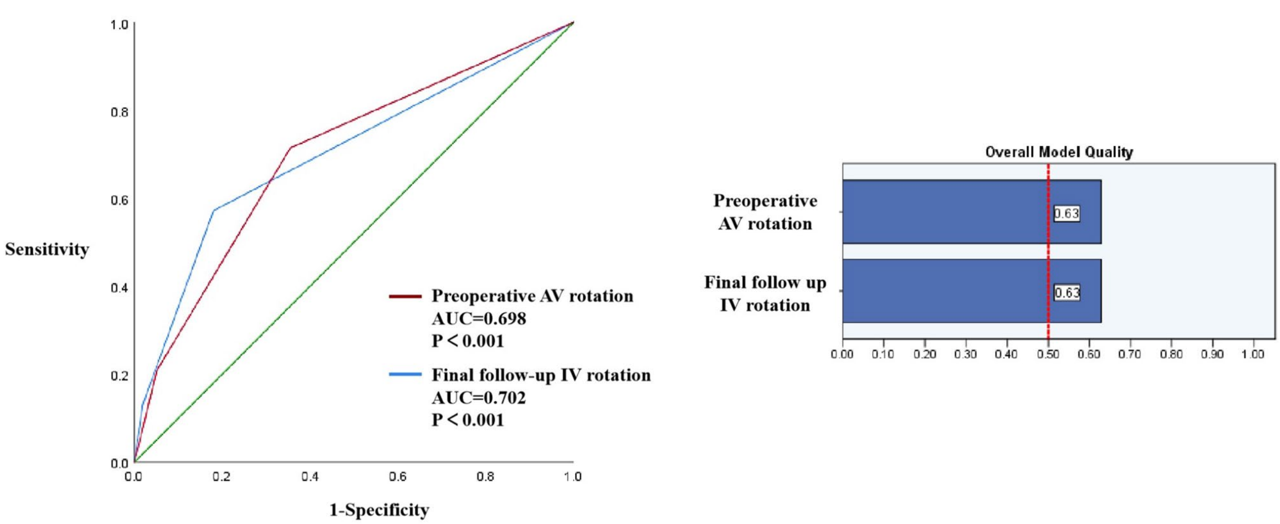

Fig. 2 ROC curve analysis of AV and IV

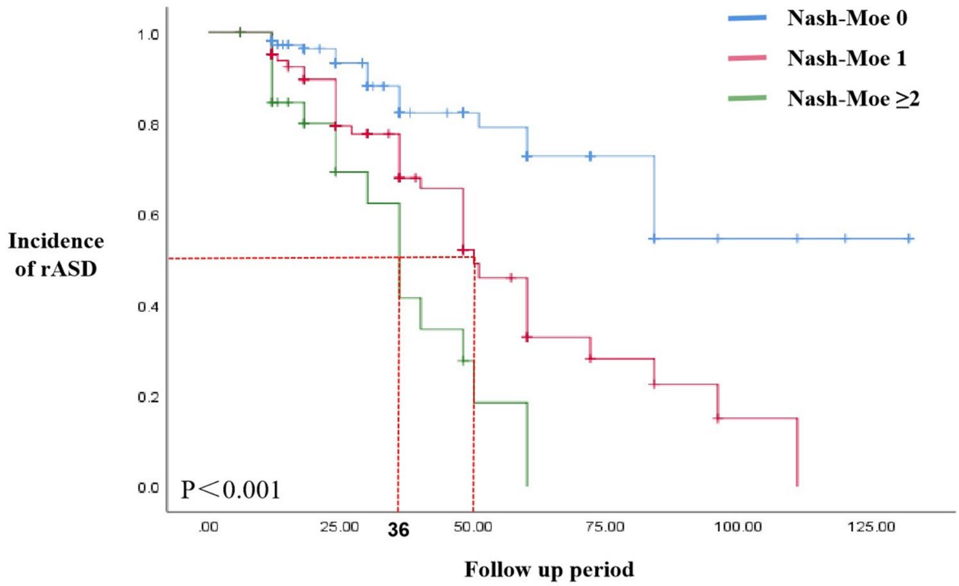

Fig. 3 Kaplan-Meier survival analysis of AV

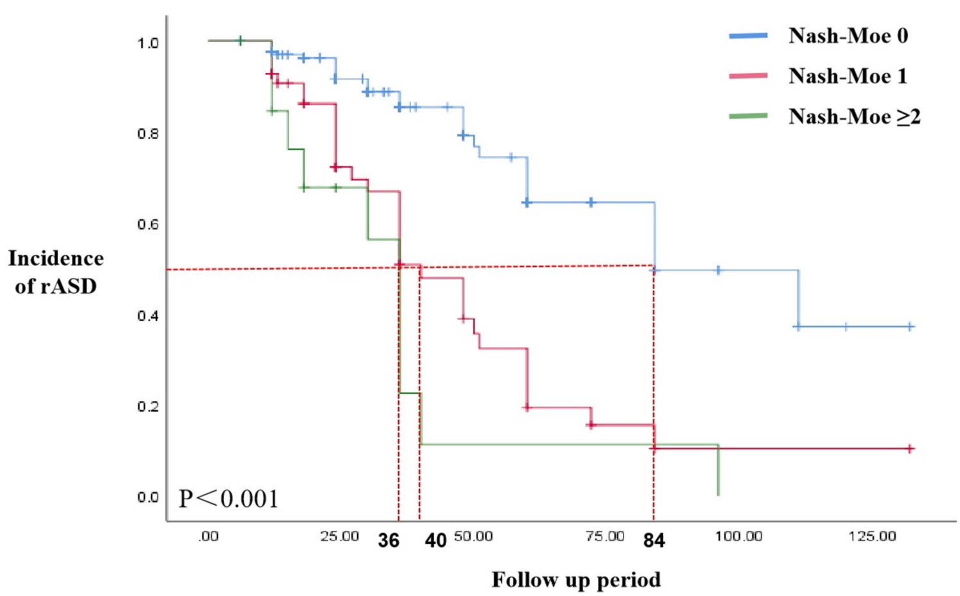

Fig. 4 Kaplan-Meier survival analysis of IV

in single-level surgery, but 33.3% in ≥ 2 levels (Table 1). Additionally, results indicated that the reduced group's AV rotation angle was also reduced more ($P < 0.001$) when comparing the two groups' AV rotation angles between preoperative and final follow-up (Table 2).

According to fused to S1 or not, 111 segments were divided into two groups. 36 segments were in the Fused to S1 group and 75 segments in the No-fused to S1group. We didn't find the significantly different r-ASD rate between the two groups ($P = 0.768$). In the subgroup analysis, we found that, in the fused to S1 group, reduced subgroup had the lower r-ASD rate (12.5%), significantly different from the Not reduced group (60%), but the difference didn't found in the no fused to S1 group ($P = 0.125$) (Table 1).

4. Other relevant findings.

Comparing the changes in ODI, VAS, JOA scores, and SF-36 scale between preoperative and the final follow-up, patients showed significant improvement in low back pain, function, social activity, and mental health (Table S4, Fig. 5).

Table 1 Effect of reducing postoperative IV rotation on rASD

Rotation angle of IV			rASD	*N*-rASD	Ratio	*P*
Total	Reduced		8	33	19.5%	0.004*
	Not reduced		33	37	47.1%	
Total	Fused to S1	Reduced	2	14	12.5%	0.004*
		Not reduced	12	8	60%	
	No fused to S1	Reduced	6	19	24%	0.125
		Not reduced	21	29	42%	
Single level	Reduced		4	25	13.8%	0.048*
	Not reduced		14	26	35.0%	
≥ 2 levels	Reduced		4	8	33.3%	0.078
	Not reduced		19	11	63.3%	

IV, Instrumented vertebrae

*, Represents a significant difference between the two groups(P<0.05)

Table 2 Effect of reducing postoperative IV rotation on AV

Rotation angle of IV	Rotation angle of AV (X ± S) (°)		*P*
	Preoperative	Final follow up	
Reduced	4.6 ± 2.3	2.7 ± 2.1	< 0.001*
Not reduced	6.7 ± 3.6	5.8 ± 3.2	0.121

IV, Instrumented vertebrae. AV, Adjacent Vertebrae

*, Represents a significant difference between the two groups(P<0.05)

Of the 294 segments in this study, according to the presence of rASD, all segments were divided into the rASD group and the No-rASD group (N-rASD). rASD occurred in 77 (26%) at the final follow-up. While 22 (22%) cauda segments had rASD, 55 (28%) of the 194 proximal segments did (Table 3). Narrowing of the intervertebral space and spondylolisthesis were two symptoms of rASD (Figure S4). The mean age of patients with rASD was 56.6 ± 11.7 years, significantly higher than the 49.4 ± 11.7 years in the N-rASD group (P < 0.001). The mean follow-up period was 37.2 ± 22.3 months in the rASD group, significantly higher than the N-rASD group, 29.4 ± 23.2 months (P = 0.011). Comparing the ODI, VAS, JOA scores, and SF-36 scale at final follow-up between the rASD group and No-rASD group, all difference were no significant (P < 0.005). Regarding fusion level, the incidence of rASD was 20.8% in cases with single-level fusion, 33.9% in 2-level fusion, and 53.8% in 3-level fusion or more, with statistically significant differences (P < 0.001). (Table 3) It demonstrated that patients

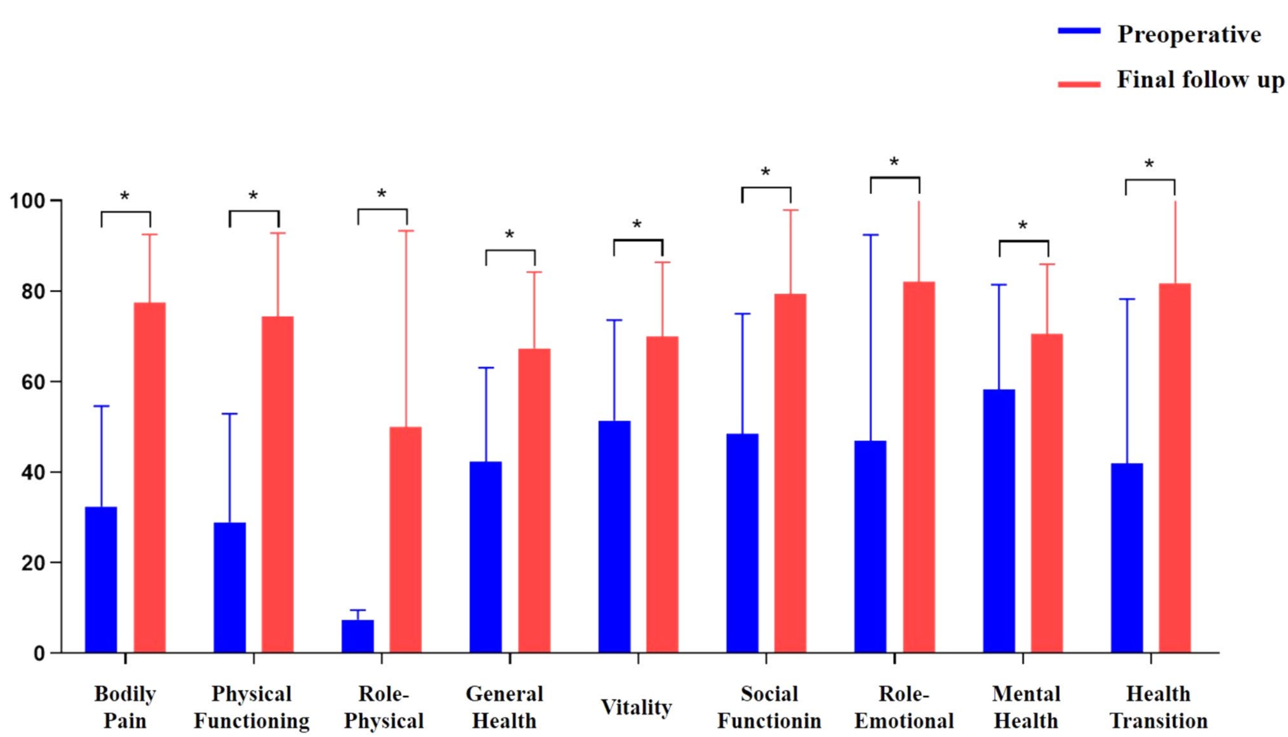

Fig. 5 Comparison of SF-36 scales

Table 3 Comparison of the prevalence of rASD

		rASD N/(X ± S)	N-rASD N/(X ± S)	rASD Ratio	P
Age (y)		56.6 ± 11.7	49.4 ± 11.7	/	< 0.001*
Follow-up time (moth)		37.2 ± 22.3	29.4 ± 23.2	/	0.011*
Adjacent segment	Total	77	217	26.2%	/
	Cephalic	55	139	28.4%	0.241
	Cauda	22	78	22.0%	
Diseases	Disc herniation	54	114	32.1%	0.96
	Spinal stenosis	25	54	36.2%	
	Degenerative spondylolisthesis	16	31	34.0%	
Fusion levels	1 level	44	168	20.8%	< 0.001*
	2 levels	19	37	33.9%	
	≥ 3 levels	14	12	53.8%	

*, Represents a significant difference among the groups(P<0.05)

with longer follow-ups, older ages, and multilevel fusion had a higher proportion of rASD. In order to investigate the effect of the relative rotation between the fused and adjacent unfused vertebrae on rASD, we compared the change of relative rotation angle (preoperative relative rotation angle - postoperative relative rotation angle) between the rASD group and the N-rASD group, the results showed that the change was significantly larger in rASD group than.

Discussion

Lumbar fusion surgery is now commonly used to treat a variety of LDDs with long-term clinical efficacy [1]. However, postoperative degeneration of adjacent segments is an unavoidable problem for patients, causing pain and an additional financial burden [21–23]. Hiroaki et al. [7] performed a retrospective case-control study of 101 individuals and showed that the incidence of rASD (5 years after lumbar fusion) ranged from 36 to 84%, and the incidence of cASD ranged from 5.2 to 16.5%. The incidence of rASD was up to 92.2%, and cASD was up to 30.3% in a meta-analysis by Xia et al. [5] that included 94 studies with 34,716 patients from 19 countries. At 31 months of follow-up, the study's findings revealed a mean incidence of 26%. The incidence results varied among studies and were related to the surgical approach, fusion level, and follow-up period. The mean follow-up period of this study is 31 months, focusing on the early stage of rASD. On the other hand, the shorter follow-up period also limits the interference of time-related natural degenerative processes to a certain degree, which highlights more accurately the risk factors for ASD [24].

Numerous studies have shown altered biomechanics of adjacent segments after fusion surgery, with significant increases in disc pressures [14, 25–29]. Senteler et al. [30] reported a 29% increase in shear forces in adjacent segments after lumbar spine fusion. High stresses may hasten the degeneration of adjacent discs as they age [31]. There is also a compensatory increase in adjacent segment mobility beyond the physiological range, accelerating the onset of ASD [6]. In addition, preoperative ASD is a significant risk factor. Kim et al. [9] analyzed 100 patients with lumbar fusion surgery and found that preoperative adjacent facet degeneration (OR = 3.075, P = 0.011) and adjacent disc degeneration (OR = 2.783, P = 0.003) were risk factors for rASD. Kim et al. [14] found that in a lumbar fusion model, adjacent facet asymmetry increases the pressure on adjacent discs and biomechanically promotes ASD. Moreover, numerous studies have shown the correlation between facet asymmetry and various LDDs [32–38]. Our previous study has shown that VR was associated with facet asymmetry [15]. In a finite element model of lumbar fusion, Chen et al. [16]found that the adjacent segment's disc was significantly more stressed in the torsional state, which could hasten disc degeneration. VR may therefore speed up degeneration by altering the stresses in the discs and facets of nearby segments. However, no studies have directly demonstrated the correlation between preoperative VR and ASD. To some extent, this study illuminates the association between VR and rASD.

This study showed a significant correlation between rASD and VR in 294 adjacent segments following lumbar fusion. The most significant effect on rASD was the postoperative rotation of IV (OR = 2.748, 95% CI = 1.458–5.177, p = 0.002). Postoperative rotation of IV indicates surgical intervention, and if surgical de-rotation is ineffective and postoperative rotation of IV is obvious, rASD is more likely to occur. Moreover, preoperative AV rotation was also a risk factor for rASD (OR = 1.852, 95% CI = 1.064–3.224, P = 0.029). The more severe the preoperative VR is, the higher the corresponding segment's degeneration risk and the greater the likelihood of postoperative rASD. Kaplan-Meier analysis showed that for the same degree of rotation preoperative, patients with more postoperative IV rotation developed rASD earlier. A comparison of IV rotation correction revealed that segments with reduced postoperative IV rotation had a lower probability of rASD (p = 0.004). It has been proposed that surgical de-rotation of the IV can reduce the incidence of rASD. Further analysis of the fusion level revealed that this effect was more pronounced in single-segment surgery (P = 0.048). In addition, the analysis showed that surgical correction of IV rotation would indirectly reduce the degree of AV rotation, which is reasonable because facets connect two adjacent vertebrae. The rotation of one vertebra acts on the adjacent vertebra via the facet, causing a change in their rotational status [17, 39]. Surgical de-rotation of the IV can reduce the postoperative degenerative factors of the adjacent segment brought by rotation, thus reducing the occurrence of rASD.

In our study, we found that surgical de-rotation of the IV can reduce the incidence of rASD. In the subgroup study, the results showed that the significant effect on reducing rASD only was found in the fused to S1 group, no in the group of no fused to S1. In theory, fused to S1, all the forces of derotation by surgical operation will be transmitted to the proximal segment, reducing the proximal disc rotation degree and then reducing the occurrence of rASD.

This study has the following limitations. First, due to the small sample size, the number of cases in each group was relatively small when performing subgroup analyses. Second, the average follow-up period of the included cases was 31 months, which is a short follow-up period and can only account for the early stage of follow-up. The longer effect of VR on rASD needs to be studied by including more cases with long-term follow-up. Last, this retrospective study provided limited evidence, to get a more accurate result generally required a prospective study design with interventions.

This study suggests that VR is an early risk factor for the development of rASD after lumbar fusion. IV derotation can reduce the rotation of AV and the incidence of rASD. This effect is more pronounced in single-level fusion surgery and fused to S1 surgery.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12893-025-02871-3.

Supplementary Material 1

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Not applicable.

Author contributions
Bin Ye and Yachao Ma carried out the studies, participated in collecting data. Bin Ye, Yachao Ma, Zhuojing Luo and Xueyu Hu drafted the manuscript. Zhipeng Tu, Peipei Huang and Zhou Yao performed the statistical analysis and participated in its design. Zhe Wang participated in acquisition, analysis, or interpretation of data and draft the manuscript. All authors read and approved the final manuscript.

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Data availability
Data is provided within the manuscript or supplementary information files.

Declarations

Ethics approval and consent to participate
This work has been carried out in accordance with the Declaration of Helsinki (2000) of the World Medical Association. This study was approved by The Medical Ethics Committee of the First Affiliated Hospital of the Air Force Medical University [LLSP76930228476]. Written informed consent was obtained from individual or guardian participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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