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Adjacent segmental degeneration following Wallis interspinous stabilization implantation

Biomechanical explanations and the value of magnetic resonance imaging

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Abstract

Adjacent segmental degeneration (ASD) is a major issue after pedicular fixation. This study examined the degeneration of the adjacent levels due to the insertion of the Wallis interspinous stabilization system compared with discectomy, using magnetic resonance imaging (MRI).

Thirty-eight patients diagnosed with lumbar degeneration disorders at L4-L5 were reviewed: 19 patients underwent discectomy and Wallis system implantation (group A), and 19 patients underwent discectomy (group B). The Visual Analog Scale (VAS) and Oswestry Disability Index (ODI) were assessed preoperatively and postoperatively. ASD was evaluated by MRI.

There was no difference in the preoperative ODI scores between the 2 groups (non-normal distribution, median, 50 (40, 50) vs 50 (50, 50), $P = .331$), but the postoperative ODI scores were different (non-normal distribution, median, 0 (0, 32) vs 20 (20, 30), $P < .005$). Similar results were observed for VAS. In group A, ASD occurred in 4 patients (21.1%) in the disc and 8 (42.1%) in the facet joint at L3/4, and in 4 (21.1%) in the disc and 5 (26.3%) in the facet joint at L5/S1. In Group B, ASD occurred in 3 patients (15.8%) in the disc at L3/4, and in 4 (21.1%) in the disc at L5/S1. In general, there was no difference between the 2 groups ($P > .05$), except at L3/4 ($P = .015$).

ASD of the facet joint in the cranial segment occurred after Wallis system implantation, suggesting that the Wallis system cannot prevent ASD of the facet joint, but could have some other benefits for the discs.

Abbreviations: ASD = adjacent segmental degeneration, BMI = body mass index, FOV = field of view, MRI = magnetic resonance imaging, ODI = Oswestry Disability Index, TE/TR = echo time and repetition time, VAS = visual analog scale.

Keywords: adjacent segmental degeneration, disc, facet joint, pedicular fixation, Wallis system implantation

1. Introduction

Acute or progressive disc lesions lead to instability of the spinal segments.[1,2] Currently, pedicular fixation (fusion) is the gold standard treatment in terms of increasing the biomechanical rigidity and clinical fusion rates because pedicle screws are the strongest component of spinal implants.[3] Adjacent segment degeneration (ASD) is the development of a pathology at the mobile segment next to a lumbar or lumbosacral spinal fusion.[4]

Several reports revealed that ASD could be accelerated due to the relative immobility of fused spinal segments transferring stress to adjacent segments after fusion.[5–7] Symptoms and signs of ASD include pain, stenotic lesions, and instability, leading to additional surgeries such as extended fusion and neural decompression.[8] Unfortunately, there is currently no relevant literature about the prevention of ASD.

To reduce the incidence of fusion-related morbidity, non-fusion technologies have been developed, such as the Wallis interspinous stabilization system.[9] Although the implant offers some advantages over fusion (e.g., motion of the involved levels and small operation wound), the efficacy of non-fusion implants in the prevention of ASD is now well established.[3,8]

ASD was first described using x-ray indexes such as disc height and segmental range of motion, [10] but a previous animal study suggested that the changes in x-ray indexes were less sensible than those extracted from magnetic resonance imaging (MRI),[11] as supported by a study in humans. [12]

Nevertheless, it is poorly known whether the use of the Wallis system could prevent ASD. Therefore, the aim of the present study was to compare the patients who underwent discectomy and Wallis system implantation with the patients who underwent discectomy only, based on MRI examinations.

2. Methods

2.1. Study design and patients

Patients diagnosed with lumbar disc herniation at L4-L5 and operated (by the same surgeon) at the Department of Orthopedic

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Table 1

Grading of intervertebral disc degeneration.

Grade	Signal from nucleus and inner fibers of annulus	Distinction between inner and outer fibers of annulus at posterior aspect of the disc	Height of the disc
1	Uniformly hyperintense, equal to CSF	Distinct	Normal
2	Hyperintense (>presacral fat and <CSF) ± hypointense intranuclear cleft	Distinct	Normal
3	Hyperintense through <presacral fat	Distinct	Normal
4	Mildly hyperintense (slightly >outer fibers of annulus)	Indistinct	Normal
5	Hypointense (=outer fibers of annulus)	Indistinct	Normal
6	Hypointense	Indistinct	<30% reduction in disc height
7	Hypointense	Indistinct	30–60% reduction in disc height
8	Hypointense	Indistinct	>60% reduction in disc height

Grades 1, 2, and 3 are based on the signal intensity of the nucleus and inner fibers of annulus. For Grade 4, the margins between the inner and other fibers of the annulus at the posterior margin of the disc are indistinct. For Grade 5, the disc is uniformly hypointense, but there is no loss of disc space height. For Grades 6, 7, and 8, there is progressive loss of disc space height. These could be broadly classified as mild, moderate, to severe loss of disc space height. Very occasionally, although obvious disc collapse is present, the hyperintense signal from the nucleus and inner fibers of the annulus is present. This is referred to by a double entry, for example, 4/7, with the former reporting the disc signal and the latter the degree of collapse.

Surgery, Tongji Hospital affiliated to Tongji Medical University of HUST, in 2009 and 2010, were retrospectively reviewed after a 2-year follow-up. The project was approved by the institutional review boards and the ethics committee of Tongji Hospital affiliated to Tongji Medical University of HUST and followed the tenants of the Declaration of Helsinki. The need for informed consent was waived by the committee because of the retrospective nature of the study.

The inclusion criteria were: (1) history of lumbar disc herniation; (2) symptoms of sciatic and low back pain; and (3) failure of conservative treatment. The exclusion criteria were: (1) any other type of vertebral fracture; (2) patients without any indication for surgery or refused surgery; (3) adjacent segments with disc degeneration grade >5 and/or facet degeneration grade >2 according to MRI (Table 1[13] and Table 2[14]); (4) history of cardiovascular or cerebrovascular diseases, trauma, or cancer; (5) lost to follow-up; or (6) missing data.

During the study period, 100 patients were treated at our center, but after excluding patients lost to follow-up and those with missing data, and after matching the 2 groups for age, gender, and occupation, only 38 patients remained.

2.2. Surgery

The treatment approach was decided by the surgeon in consultation with patients. After oral and written explanations on the details of the surgery, all participants signed a written surgical informed consent. After discussion, the patients underwent either discectomy and Wallis implantation (n = 19, group A) or discectomy only (n = 19, group B).

The indications for discectomy were: (1) symptoms of lumber spinal cord or nerve root compression; (2) conservative treatment did not produce satisfactory outcomes; and (3) willing to undergo surgery. The indications for Wallis system implantation were: (1) the sequence was stable and (2) no complications.

2.3. Data collection

Age, gender, body mass index (BMI), and duration of pain were collected preoperatively. The intensity of pain according to the visual analog scale (VAS) and Oswestry disability index (ODI) were collected preoperatively and postoperatively. The VAS ranged from 0 (no pain) to 10 (worst pain imaginable). The patients were asked to mark a point on the scale corresponding to their pain at that time. The ODI questionnaire contained 6 statements (denoted levels 0–5) in each of the 10 sections related to impairments such as pain and abilities such as personal care, lifting, walking, sitting, standing, sleeping, sex life, social life, and traveling. In each section, the patient chose the statement that best described his/her status. If the limitation fell between 2 levels, the higher point value was selected. The chosen statements received scores 0 to 5 corresponding to the level indicated. The total scores could range from 0 (the highest level of function) to 50 (the lowest level of function).

2.4. MRI

All patients had undergone magnetic resonance imaging (MRI) before and 6 months after operation. The lumbar spine MRI examination of each participant was done by the same clinical 1.5T system (Signa 1.5 T HD, GE Healthcare, Waukesha, WI) using a 4-channel Phased Array CTL Spine Coil. T1-weighted fast spin-echo sagittal images with effective echo time and repetition times (TE/TR) of 10/400 ms, T2-weighted fast spin-echo sagittal images with TE/TR of 102/3000 ms and T2-weighted fast spin-echo axial images with TE/TR of 120/3000 ms were included in

Table 2

Grading of the facet joint degeneration.

Grade	Criteria
1	Uniformly thick cartilage covers the articular surfaces completely. Articular processes have a thin layer of cortical bone. No osteophyte.
2	Cartilage covers the entire surface of the articular processes but with erosion of the irregular region evident. Cortical bone of the articular processes is focally thickened. Possible or small osteophyte.
3	Cartilage incompletely covers the articular surfaces, with regions of the underlying bone exposed to the joint. Thickened cortical bone covers less than half of the articular processes. Definite and moderate osteophyte.
4	Cartilage is absent except for traces on the articular surfaces; dense cortical bone covers greater than half the articular process. Large osteophyte.

the examination. The field of view (FOV) was 360 mm and the matrix was 128 × 128, whereas 5-mm sections with a 1-mm section gap was used. There were 6 averages and the echo train length was 72 seconds.

The visual grading of intervertebral disc degeneration and the facet joint degeneration were based on the T2-weighted images and adjacent levels. Two operators (8 and 5 years of experience in MRI of the spine, respectively) graded the disc and facet joint in L3/4, L4/5, and L5/S1. The *G* value, defined as a measure of segment (disc and facet joint) degeneration, was obtained by adding the grades of invertebral disc degeneration (Table 1) and facet joint degeneration (Table 2). The difference in the *G*-value after surgery was defined as $\Delta G = G_{postoperational} - G_{preoperational}$ of intervertebral discs and facet joints of L3/4, L4/5, and L5/S1. Positive ΔG_{disc} and ΔG_{facet} values indicate that the grade of the intervertebral discs and facet joints worsened after surgery and the segment was marked as ASD. Negative ΔG_{disc} and ΔG_{facet} values indicate that the grade improved after surgery. The interobserver reliability of image grading was assessed using the kappa score. The final results were determined according to the results by 1 neuroradiologist.

2.5. Statistical analysis

Interobserver analyses of all MRI measurements showed fair to excellent agreement. Changes in scores from before to after surgery were calculated. Normally distributed data are presented as mean ± standard deviation and were analyzed using the Student *t* test. Non-normally distributed data are presented as median (min, max) and were analyzed using the Mann–Whitney *U* test. SPSS 23.0 (IBM, Armonk, NY) was used for statistical analysis. Two-sided *P*-values <.05 were considered statistically significant.

3. Results

Table 3 presents the characteristics of the patients. There were no differences in age, gender, BMI, and pain duration between the 2 groups (all $P > .05$). The median preoperative ODI scores in groups A and B were 50 (40, 50) and 50 (50, 50), respectively (non-normal distribution; $P = .331$). The postoperative ODI scores were 0 (0, 32) and 20 (20, 30), respectively (non-normal distribution; $P < .005$). The median preoperative VAS scores in group A and B were 9 (9, 10) and 10 (9, 10) (non-normal distribution; $P = .079$). The postoperative VAS scores were 0 (0, 6) and 2 (2, 4) (non-normal distribution; $P = .067$).

Table 3

Characteristics of the patients.

Data		Group A	Group B	*P*
N		19	19	–
Gender	Male	11	10	1.00
	Female	8	9	
Age, years		47.5 ± 13.7	47.3 ± 13.2	.96
BMI, kg/m^2		22.6 ± 1.9	22.5 ± 1.8	.87
Duration of pain		56 m, 2 weeks-17 years	37 m, 2 weeks-10 years	–
Preoperative ODI*		50 (40, 50)	50 (50, 50)	.331
Postoperative ODI*		0 (0, 32)	20 (20, 30)	<.005
Preoperative VAS*		9 (9, 10)	10 (9, 10)	.08
Postoperative VAS*		0 (0, 6)	2 (2, 4)	.07

BMI = body mass index, ODI = Oswestry disability index, VAS = visual analog scale.
* Non-normal distribution. Presented as median (range) and analyzed using the Mann–Whitney *U* test.

Table 4

Occurrence of ASD in the 2 groups.

	A	B	*P*
Disc L3/4	4	3	.484
Disc L5/S1	4	4	.869
Facet joint L3/4	8	0	.015
Facet joint L5/S1	5	0	.217

3.1. Occurrence of ASD

For all patients (n = 38), ASD occurred in 7 patients (18.4%) in the disc and 8 (21.1%) in the facet joint at L3/4, and in 8 (21.1%) in the disc and 5 (13.2%) in the facet joint at L5/S1. For group A, ASD occurred in 4 patients (21.1%) in the disc and 8 (42.1%) in the facet joint at L3/4, and in 4 (21.1%) in the disc and 5 (26.3%) in the facet joint at L5/S1. For group B, ASD occurred in 3 patients (15.8%) in the disc at L3/4 and in 4 (21.1%) in the disc at L5/S1 (Table 4).

3.2. Changes in G value during follow-up

The comparison of the $G_{preoperational}$, $G_{postoperational}$, and ΔG value of the discs and facets in the 2 groups are summarized in Table 5 and Fig. 1. There was no difference between the 2 groups for ΔG_{disc} ($P > .05$), but there was a difference for ΔG_{facet} at L3/4 ($P = .015$) but not at L5/S1 ($P = .217$). In Fig. 2, the ΔG_{disc} of the 2 groups were negative, and the changes in MRI were obvious. Detailed MRI examination of a patient from group B at the facet joints of L3/4, L4/5, and L5/S1 is shown in Fig. 3. Preoperatively, cartilage covers the surfaces of the articular processes with some erosion; the cortical bone of the articular processes is focally thickened with small/moderate osteophyte. After operation, regions of the underlying bone are exposed to the joint, with moderate/large osteophyte.

4. Discussion

ASD after lumbar spinal fusion is a potential cause of further spinal surgery, which is disquieting to both patients and surgeons. The Wallis system can be used to stabilize the spine, but its effect on ASD is unknown. Therefore, the aim of the present study was to examine the degeneration of the adjacent levels due to the insertion of the Wallis interspinous stabilization system compared with discectomy, and using MRI. The results showed that in group A, ASD occurred in 4 patients (21.1%) in the disc and 8 (42.1%) in the facet joint at L3/4, and in 4 (21.1%) in the disc and

Table 5

Comparison of the $G_{preoperational}$, $G_{postoperational}$, and ΔG of the discs and facets in the 2 groups.

G value†	Level (*P*-values) L3/4	L5/S1
$G_{pre\text{-}disc}$	.137	.079
$G_{post\text{-}disc}$	.530	.238
ΔG_{disc}	.484	.869
$G_{pre\text{-}facet}$	.693	.289
$G_{post\text{-}facet}$	.034*	.050
ΔG_{facet}	.015*	.217

* $P < .05$ was considered to be statistically significant.
† The *G* value is obtained by adding the disc degeneration grade (Table 1) to the facet degeneration grade (Table 2), as assessed by 2 radiologists.

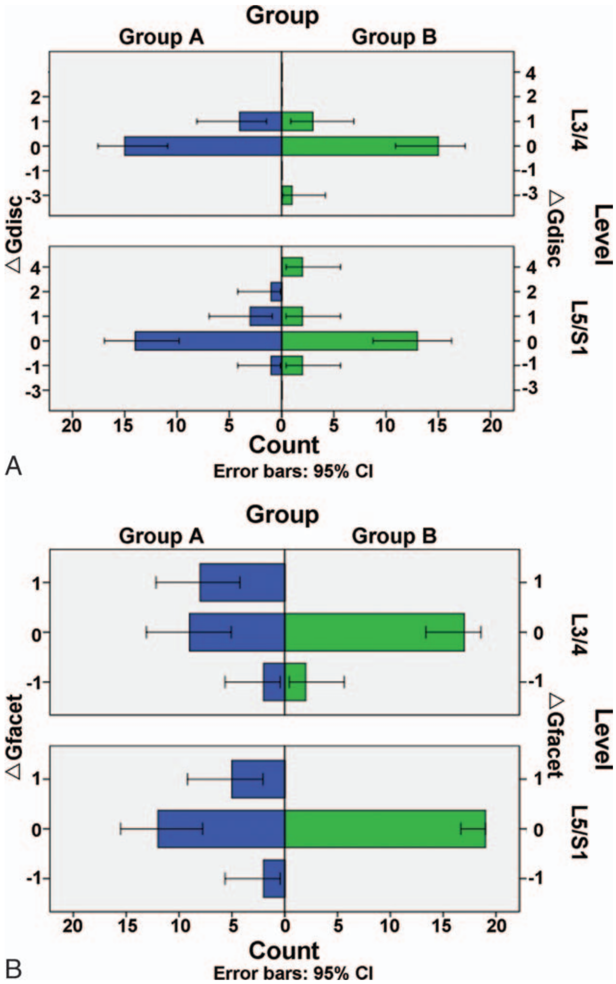

Figure 1. (A) ΔG in the discs at L3/4 and L5/S1 in groups A and B. At L3/4, there were 4 cases of ASD ($\Delta G > 0$) of the discs in group A, whereas 3 cases of ASD were found in group B. At L5/S1, there were 4 cases of ASD, whereas 4 cases of ASD were observed in group B. (B) ΔG in the facets at L3/4 and L5/S1 in groups A and B. At L3/4, there were 8 cases of ASD ($\Delta G > 0$) of the facets in group A. At L5/S1, there were 5 cases of ASD in group A. ASD = adjacent segmental degeneration.

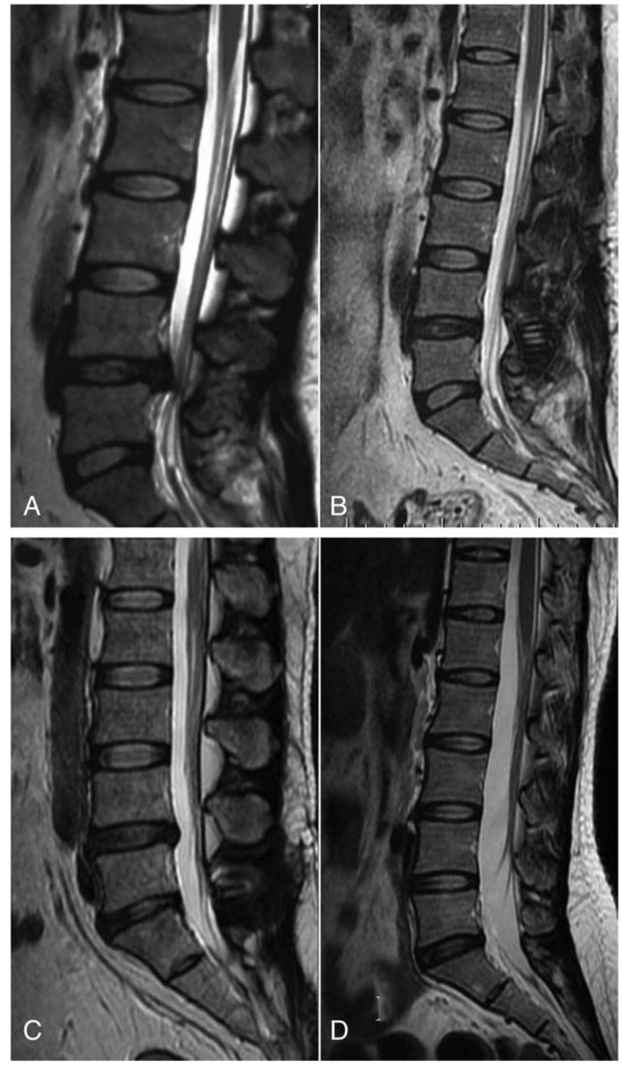

Figure 2. (A) A patient from group A before operation. The T2 signal at L4/5 is mildly hyperintense (slightly more than the outer fibers of annulus), and there is no distinction between the inner and outer fibers of annulus at the disc. The $G_{preoperational}$ is 4. (B) The same patient from group A after operation. The T2 signal at L4/5 is hyperintense (more than the outer fibers of annulus), and there is a distinction between the inner and outer fibers of annulus at the disc. The $G_{preoperational}$ is 3. (C) A patient from group B before operation. The T2 signal at L4/5 is mildly hyperintense (slightly more than the outer fibers of annulus), and there is no distinction between the inner and outer fibers of annulus at the disc. The $G_{preoperational}$ is 4. (D) The same patient after operation in group B. The T2 signal at L4/5 is hyperintense (more than the presacral fat and cerebrospinal fluid) and hypointense compared with the intranuclear cleft. There is a distinction between the inner and outer fibers of annulus at the disc. The $G_{preoperational}$ is 2.

5 (26.3%) in the facet joint at L5/S1. In Group B, ASD occurred in 3 patients (15.8%) in the disc at L3/4, and in 4 (21.1%) in the disc at L5/S1. In general, there was no difference between the 2 groups ($P > .05$), except at L3/4 ($P = .015$). Therefore, ASD of the facet joint in the cranial segment occurred after Wallis system implantation, suggesting that the Wallis system cannot prevent ASD of the facet joint, but could have some other benefits for the discs, highlighted by the significantly lower ODI scores in group A compared to group B.

Biomechanical changes of ASD consist of increased intradisc pressure, increased facet load, and increased mobility after fusion.[4,15] It is presumed that the motion is transferred from the fused level to the close free level, and therefore the incidence of proximal ASD is much higher than that of distal ASD.[6] X-ray indexes such as disc height and segmental range of motion can describe ASD to some degree,[10] but MRI indexes provide more reliable data.[11] However, fusion surgery may cause artifacts with imaging. From the results of the present study, it seems that ASD occurs above the operated segment after implantation of the Wallis system, especially at the facet joint. Based on several studies, after spinal fusion, increased stress on the adjacent facet joints and a change in the load of the adjacent disc have been proved.[6,7,16] In the studies of spinal fusion, several authors support the point of view that the load is shifted to the free and mobile cranial lumbar segments for compensation.[6,7,17] Therefore, ASD always occurred in the facet joints above the reconstructed segment. Akamaru et al[18] demonstrated that the highest increase in motion is the cranial segment (L3/4) to L4/5 after its hypolordotic floating fusion. In addition, the change in joint orientation is a major risk factor in the degenerative process of that segment.[17,18] The Wallis implants can restrict the motion

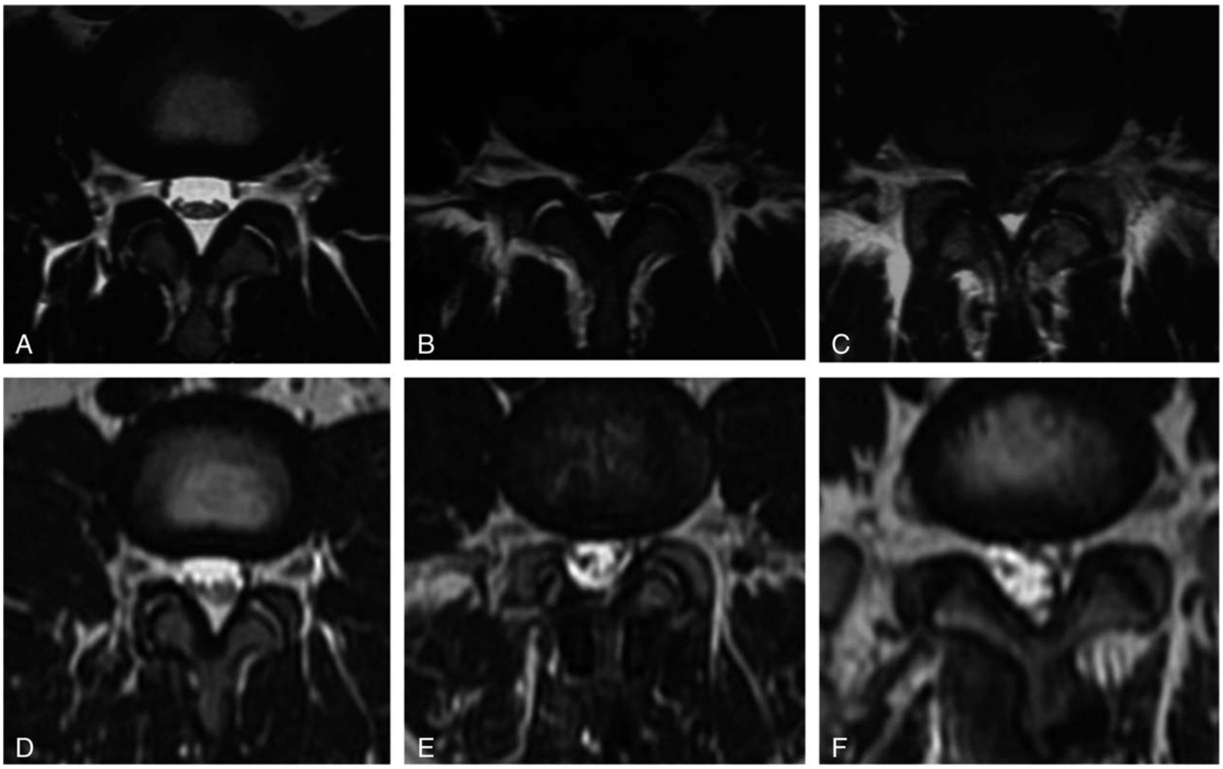

Figure 3. A patient from group B. (A) Before operation, the T2 signal of the facet joints at L3/4 cartilage covers the entire surface of the articular processes but with erosion of the irregular region; the cortical bone of the articular processes is focally thickened with small osteophyte. The $G_{preoperational}$ is 2. (B) The facet joints at L4/5 before operation, the $G_{preoperational}$ is 2. (C) The facet joints at L5/S1 before operation, the $G_{preoperational}$ is 3. The cartilage incompletely covers the articular surfaces, with regions of the underlying bone exposed to the joint. Thickened cortical bone covers less than half of the articular processes, with moderate osteophyte. (D) After operation, the T2 signal of the facet joints at L3/4. Cartilage incompletely covers the articular surfaces, with regions of the underlying bone exposed to the joint. Thickened cortical bone covers less than half of the articular processes, with moderate osteophyte. The $G_{postoperational}$ is 3. (E) The facet joints at L4/5 after operation, the $G_{postoperational}$ is 3. (F) The facet joints at L5/S1 after operation, the $G_{postoperational}$ is 4. The cartilage is absent except for traces on the articular surfaces, dense cortical bone covers greater than half the articular process with large osteophyte.

of the lumbar spine. The Wallis implant consists of an interspinous spacer that limits the extension and 2 bands that secure the implant in the interspinous space and limit flexion.[9,10] Therefore, the motion and the load is shifted from L4/5 to the adjacent segments (L3/4 and L5/S1) after Wallis system implantation atL4/5, especially at the cranial segment (L3/4). The reason for ASD at the L5/S1 facet in this study could be due to damage to the posterior structure resulting from the implantation, but this requires further investigation.

In some studies, the intradisc pressure was strongly reduced in extension after the implantation of the Wallis system,[19] but without difference in all other loading directions (flexion, lateral bending, and axial rotation), which has been observed in the present study. Nevertheless, the use of an interspinous implant could cause adjacent level facet pain or accelerated facet joint degeneration. [19] At the implanted level, the mean peak pressure, average pressure, contact area, and force were significantly reduced, but there were no significant changes at the level above the implant. The implant appears to redirect a large portion of the load away from the intervertebral disc and to transfer that load to the spinous processes. In a study by Adams et al,[20] there was a paradoxical decrease in posterior annular pressure during hyperextension at the tested level. They attributed this observation to the facet joints acting as a fulcrum and redirecting most of the force from the respective disc. When using the Wallis system, the lumbar spine is kept slightly flexed, meaning that the anterior part of the intervertebral disc is compressed, keeping the articular facets separated during movement of the lumbar spine.[21] As superior-segment facet contact has been presumed to play a role in the onset of ASD, it is unclear why the Wallis system does not prevent ASD. Nevertheless, additional mechanical studies are necessary to characterize the spinal changes leading to ASD. Unfortunately, there is currently no relevant literature about the prevention of ASD and the present study does not allow drawing conclusions about ASD prevention. Additional studies are also necessary to address these issues.

The present study is not without limitations. The sample size was small, from a single center, and was operated by a single surgeon. The ODI scores were self-assessed and could be more severe than in reality. No patient with pedicular fixation (fusion) could be included as controls because the fixation affected MRI quality. Finally, the follow-up was short and was based on retrospective data.

In conclusion, ASD of the facet joint in the cranial segment occurred after Wallis system implantation, suggesting that the Wallis system cannot prevent ASD of the facet joint, but could have some benefits for the discs.

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