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How is spinal range of motion affected by disc- and facet degeneration and spinopelvic anatomy?

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ABSTRACT

Background: We aimed to investigate how disc- and facet joint degeneration relate to ROM and spinopelvic alignment parameters. Their interrelation, however, is not yet understood, although eminent in patient specific modeling approaches and surgical decision making. Further is not yet sufficiently understood whether spinal alignment parameters relate to the degenerative states.

Methods: The ROM of lumbar spinal segments was quantified using flexion/extension radiographs of 90 patients. The grades of degeneration of discs (IDD, Pfirrmann grades, n=440) and facet joints (FJD, Weishaupt classification, n=406) were assessed in CT and MRI scans.

Results: The grade of IDD was significantly related to changes in ROM (p<0.01) whereas no association was observed with the amount of FJD. Grade V IDD was associated with a significant decrease in motion (p<0.01) compared to all other IDD grades (II-IV), which did not differ significantly among each other. The combined occurrence of IDD and FJD revealed the largest angular segmental ROM in segments with the lowest IDD (II) and lowest FJD (0). The lowermost ROM was present in fused segments (control), followed by those with severe IDD (V). In combination with FJD, the destabilizing effect of initial IDD was only observed if FJD was already in an advanced state.

Conclusions: While the degree of facet joint degeneration seems not significantly associated with limitations in spinal motion, severe lumbar disc degeneration limits segmental motion, nearly equal to spinal fusion. This should affect counseling patients undergoing spinal fusion with questions on the probability of adjacent segment degeneration compared to the natural course.

Short Summary Sentence

While the degree of facet joint degeneration seems not significantly associated with limitations in spinal motion, severe lumbar disc degeneration limits segmental motion, nearly equal to spinal fusion.

Introduction

With ever increasing age of the general population, a rise in healthcare expenditures due to spinal degeneration is expected and therefore will even intensify the already high socio-economic burden [1].

Whilst fusion is often required due to degenerative changes of spinal motion segments it is associated with complete loss of segmental range of motion (ROM)[2]. Loss of segmental motion may further alter mechanical loading at spinal motion segments and, in concept, lead to accelerated degeneration of neighboring segments [3]. This effect is known as adjacent segment disease (ASD), with a reported incidence of 2- 14% after lumbar spondylodesis [4].

In accordance with the concept of disc degeneration as introduced by Kirkaldy-Willis and Farfan in 1982 [5] previous studies generally agree that with progressing disc degeneration the motion at the affected segment initially increases until a restabilization occurs at the end-stage of IDD (intervertebral disc degeneration). Lost motion due to advanced IDD in lower lumbar levels was found to not be compensated at remaining unfused segments, and consequently, the overall lumbar ROM in severely degenerated spines is reduced[6]. *In vivo* data in the literature regarding the effect of FJD (facet joint degeneration) on angular segmental motion is less consistent: Fujiwara et al. associated abnormal

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Table 1
Classification and criteria for grading disc degeneration according to Pfirrmann et al. [9]

Grade	Structure	Distinction Nucleus/Annulus	Signal Intensity	Height of Intervertebral Disc
I	Homogeneous, bright white	Clear	Isointense to cerebrospinal fluid	Normal
II	Inhomogeneous with or without horizontal bands	Clear	Hyperintense, isointense to cerebrospinal fluid	Normal
III	Inhomogeneous, gray	Unclear	Intermediate	Normal to slightly decreased
IV	Inhomogeneous, gray to black	Lost	Intermediate to hypointense	Normal to moderately decreased
V	Inhomogeneous, black	Lost	Hypointense	Collapsed disc space

tilting movement in flexion with both IDD and FJD [7], whereas Paholpak et al. found rotational motion not to be affected by FJD yet showed a relationship between IDD and FJD [8]. The comparability of literature is compromised by differences in kinematic measurement methods, grading schemes, and heterogeneity of study populations. Hence, the translation of previous findings into clinical practice remains difficult. To date, it remains unclear how FJD and IDD in combination affect segmental ROM in patients with indication for lumbar fusion, or how degeneration and motion are related to spinopelvic anatomy.

Materials and methods

Hypothesis

There is an interrelation between degenerative changes of the intervertebral discs and facets and spinopelvic anatomy with flexion/extension angular ROM for a study population of patients undergoing lumbar spinal fusion surgery. The occurrence of IDD and FJD affects lumbar flexion-extension ROM. Degeneration and motion are related to the anatomy of the spine and pelvis (LL, PI, PT, SS, global spinal balance).

Study population

97 patients with flexion/extension (inclination/reclination) radiographs acquired prior to spondylodesis due to degenerative changes between January 2016 and April 2017 were selected for retrospective analysis. Seven patients were excluded from analysis due to missing information on pathology (IDD/FJD rating) or incomplete kinematic datasets (flexion/extension radiographs). The previous history of low back surgery and the VAS pain score was noted for each patient. This study has been approved by the local ethics committee and has been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments (Reference number 2017-01308).

Kinematic and anatomical measurements

Endplate angles at lumbar segments were measured using mediCAD® (version 4.0, mediCAD Hectec GmbH, Germany). The segmental ROM was calculated as differences of intervertebral wedge angles between reclined and inclined postures (Fig. 1). Accordingly, the extent of overall lumbar rotational motion was defined as the difference of L1S1 lordosis between re- and inclined postures. Spinopelvic parameters such as lumbar lordosis (LL), pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), and C7 plumb line were evaluated on a standard clinical lateral x-ray in a weight-bearing upright standing position.

Grading of intervertebral disc and facet joint degeneration

Grades of intervertebral disc degeneration (IDD) and facet joint degeneration (FJD) for lumbar segments from L12 until L5S1 (5 lumbar levels) were determined based on MRI and CT data, respectively. For IDD the Pfirrmann classification [9] (Table 1) and for FJD the Weishaupt classification [10] (Table 2) were employed. For some levels, the degenerative pathology was not depicted in MRI or CT scan and therefore

Table 2
Classification and criteria for grading osteoarthritis of facet joints. [10]

Grade	Criteria
0	Normal facet joint space (2-4 mm)
1	Narrowing of the facet joint space (< 2 mm) and/or small osteophytes and/or mild hypertrophy of the articular process
2	Narrowing of the facet joint space and/or moderate osteophytes and/or moderate hypertrophy of the articular process and/or mild subarticular bone erosions
3	Narrowing of the facet joint space and/or large osteophytes and/or severe hypertrophy of the articular process and/or severe subarticular bone erosions and/or subchondral cysts

could not be measured. The levels without rating were omitted from all subsequent segmental statistical analyses, and patients with missing levels were excluded from all subsequent analyses involving overall lumbar ROM. IDD and FJD were not graded for previously fused segments.

Data analysis

Grouped data were analyzed by one way ANOVA analysis, preceded by Kolmogorov-Smirnov test to verify sample data normal distribution. To check for group differences a post-hoc Bonferroni corrected multiple comparison test was employed. Pearson's correlation analysis was performed to check for linear correlation between two variables. Linear trends and best-fit linear curves were obtained by regression analysis. All statistical analysis was performed in Prism (v. 8.0, GraphPad Software, USA).

A variety of segment-wise analyses were conducted: the segmental motion was compared between lumbar levels and tested for linear trends from cranial to caudal segments. The dependency of the segmental ROM on the grade of either IDD or FJD was investigated by performing a one way ANOVA analysis and multiple comparisons. The analysis was only performed for subjects who did not previously have lumbar spinal fusion surgery, as the intervention is expected to affect segmental motion at the index and adjacent segments [11]. Second, the interdependency of IDD and FJD was analyzed, as well as the combined effect of IDD and FJD on the segmental motion. Last but not least, prospective fusion segments were compared to healthy segments in terms of average segmental motion, IDD, and FJD. Finally, the overall lumbar motion was tested for the linear relationship with patients' average degeneration grades (IDD, FJD) across all lumbar levels (L12 until L5S1). Additionally, the linear correlations of spinopelvic parameters with average degeneration grades per patient were analyzed.

Results

Patient selection and applying exclusion criteria yielded a total number of 90 patients, of which 20 underwent previous lumbar spinal fusion surgery. Fusion was most often performed at levels L45 (n=17), followed by L5S1 (n=8) and L34 (n=7). Levels L12 and L34 underwent previous fusion in 2 and 3 cases, respectively. For two patients IDD could not be

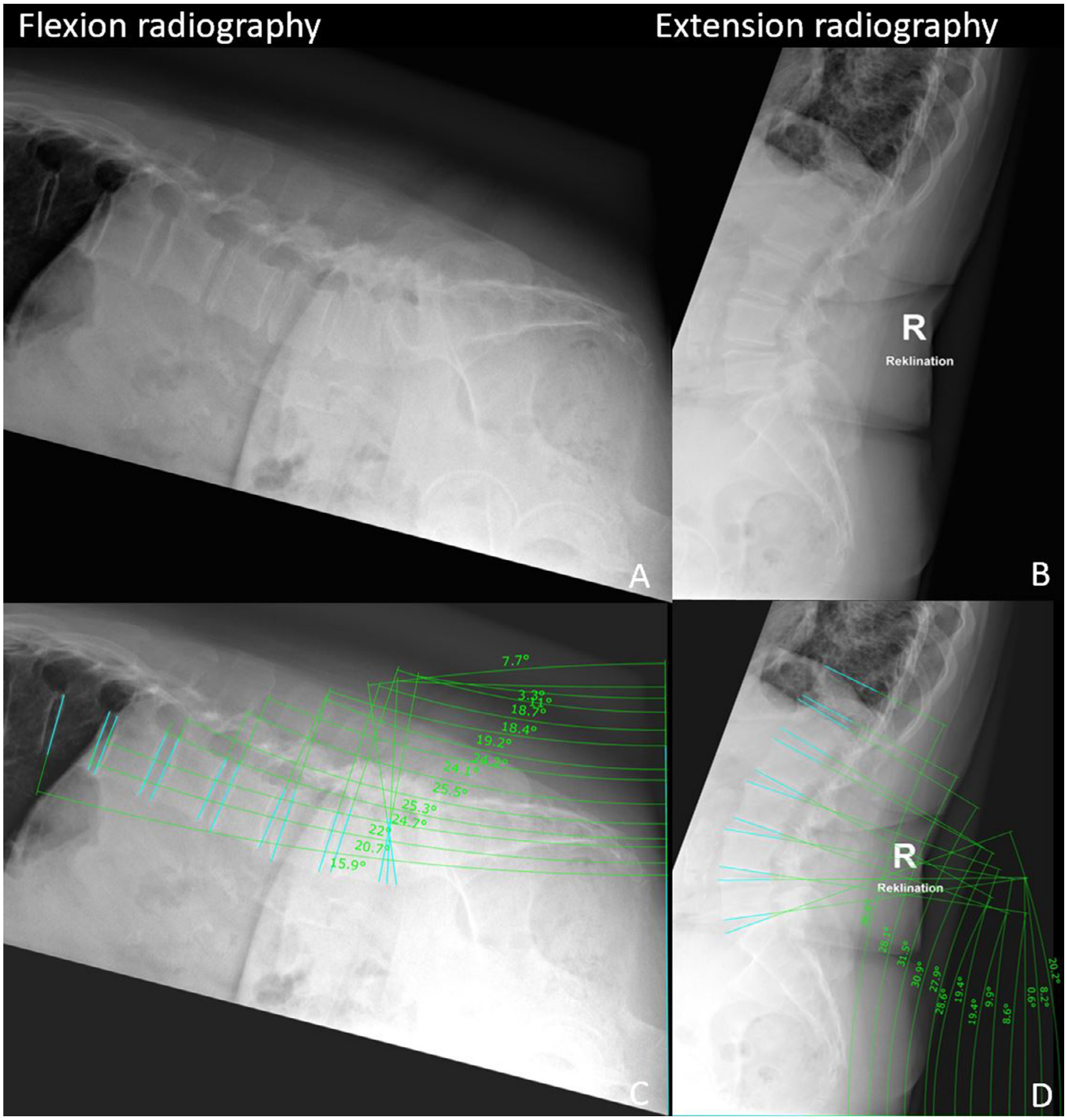

Fig. 1. Lateral flexion (A) and extension (B) radiographs of the lumbar spine of a 75 year old patient. On both images (C and D), lumbar wedge angles of the endplates were evaluated using mediCAD®.

Table 3
Demographic characteristics of the patient populations used in the analyses.

		Age	Gender	Weight [kg]	Height [cm]	BMI	VAS
All patients	n=90	63.6(13.5)	F: 53M: 37	76.6(15.7)	167.2(10.0)	27.3(4.8)	5.6(3.3)
w/o previous fusion	n=70	61.9(13.4)	F: 41M: 29	76.6(15.6)	167.3(9.4)	27.3(5.0)	5.9(3.3)

rated, and in 33 patients FJD could not be determined on several upper lumbar segments.

In total, 440 segments and 88 full lumbar spines were rated for IDD, and 406 segments and 57 full lumbar spines for FJD (Fig. 2). Severe disc degeneration (grade V) was more prevalent in inferior lumbar levels (L45: 29, L5S1: 41) than in upper segments (L12: 11, L23: 14, L34: 14), whereas mild IDD (grades II, III) was more often present in upper lumbar levels (L12: 53, L23: 42, L34: 35) than in lower levels (L45: 16, L5S1: 24). Similarly, severe FJD (grade 3) was more frequently diagnosed in lower levels (L45: 33, L5S1: 30) than in upper levels (L12: 13, L23: 19, L34: 22), yet no clear trend for non- to moderately degenerated facets (grades 1, 2) was found (Fig. 3). The mean demographic characteristics and spinopelvic parameters of the study population are shown in Table 3 and Table 4, respectively.

The mean angular segmental motion continuously decreased from upper to lower segmental levels (Fig. 4) (L12: 7.5°, L23: 7.4°, L34: 7.0°, L45: 6.2°, L5S1: 5.8°; linear regression: p=0.0184). Differences between levels were not statistically significant.

Segment-wise motion and degeneration

Motion at segments with IDD=V was significantly different ($p \leq 0.002$) from motion at those levels with lower grades of IDD, whereas between groups of IDD=II, III, and IV no significant difference was found

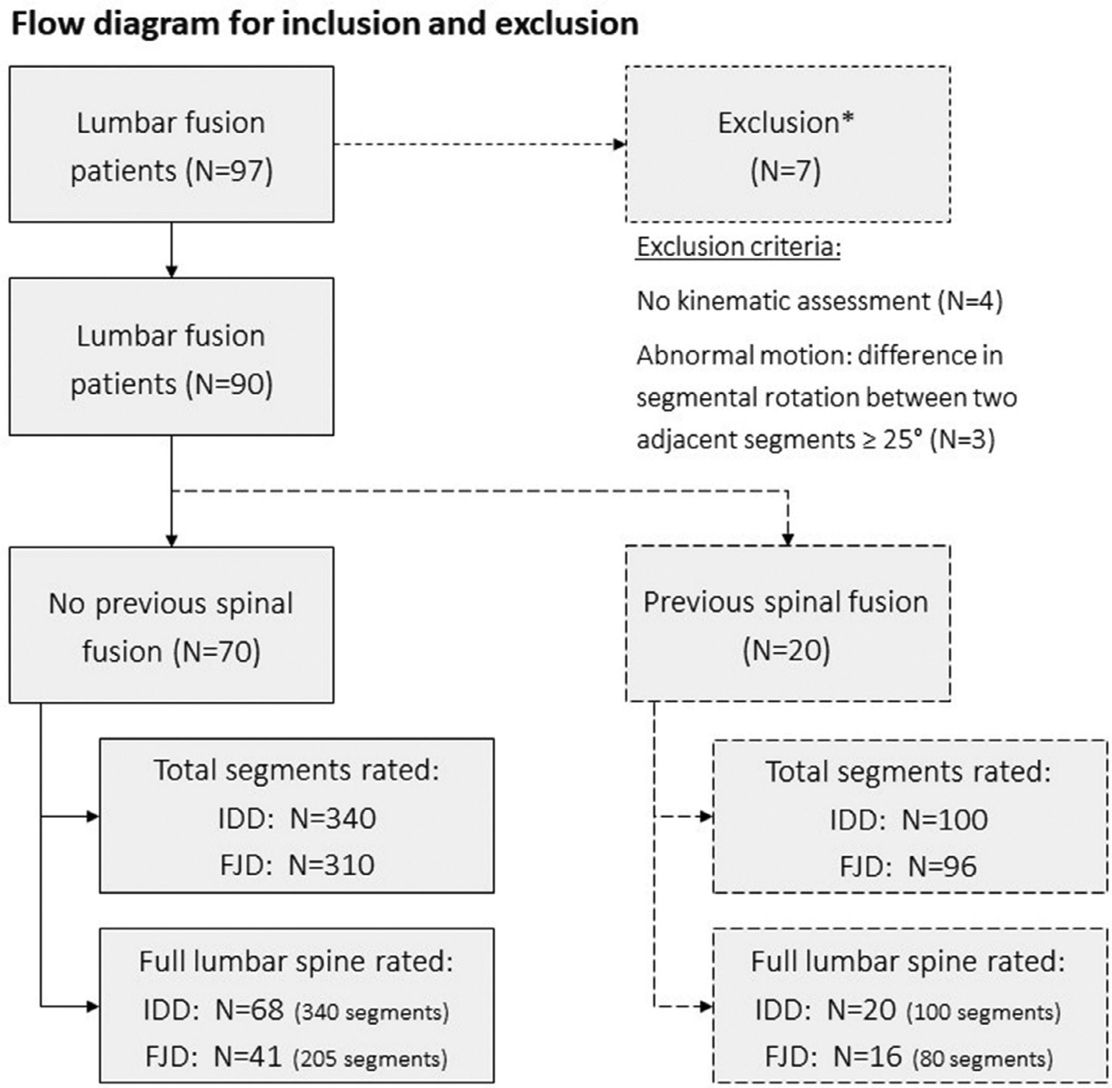

Fig. 2. Number of investigated patients with a history of previous spinal fusion surgery, and the total number of IDD and FJD ratings (total number of rated segments and full lumbar spines i.e., all lumbar segments of a patient were rated).

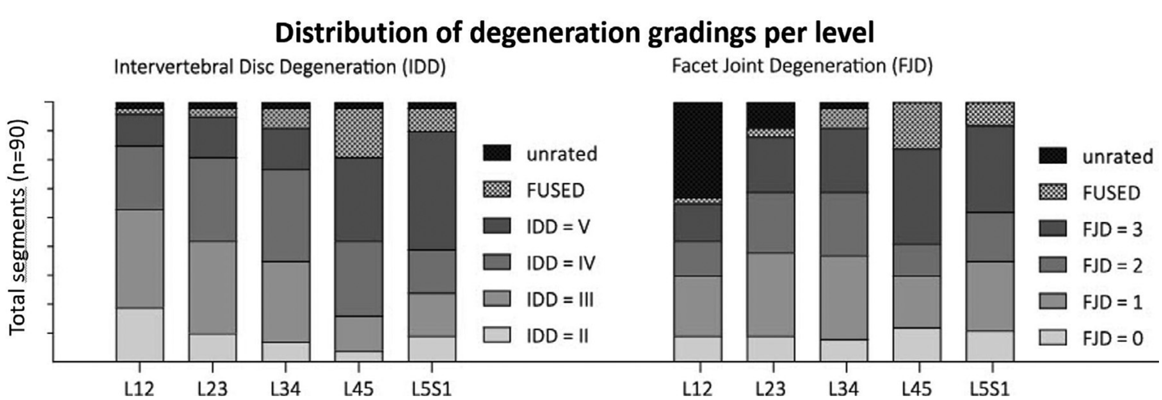

Fig. 3. Distribution of degeneration gradings per level (left: IDD, right: FJD). Indicated are also previously fused segments and those which could not be rated.

Table 4
Spinopelvic parameters of the patient populations used in the analyses.

		LL [°]	PI [°]	SS [°]	PT [°]	PILL [°]
All patients	n=90	55.2(±15.1)	59.4(±13.4)	38.6(±10.1)	21.5(±11.1)	4.3(±14.0)
w/o previous fusion	n=70	55.5(±15.2)	58.8(±13.9)	39.1(±10.6)	20.4(±11.8)	3.3(±14.5)

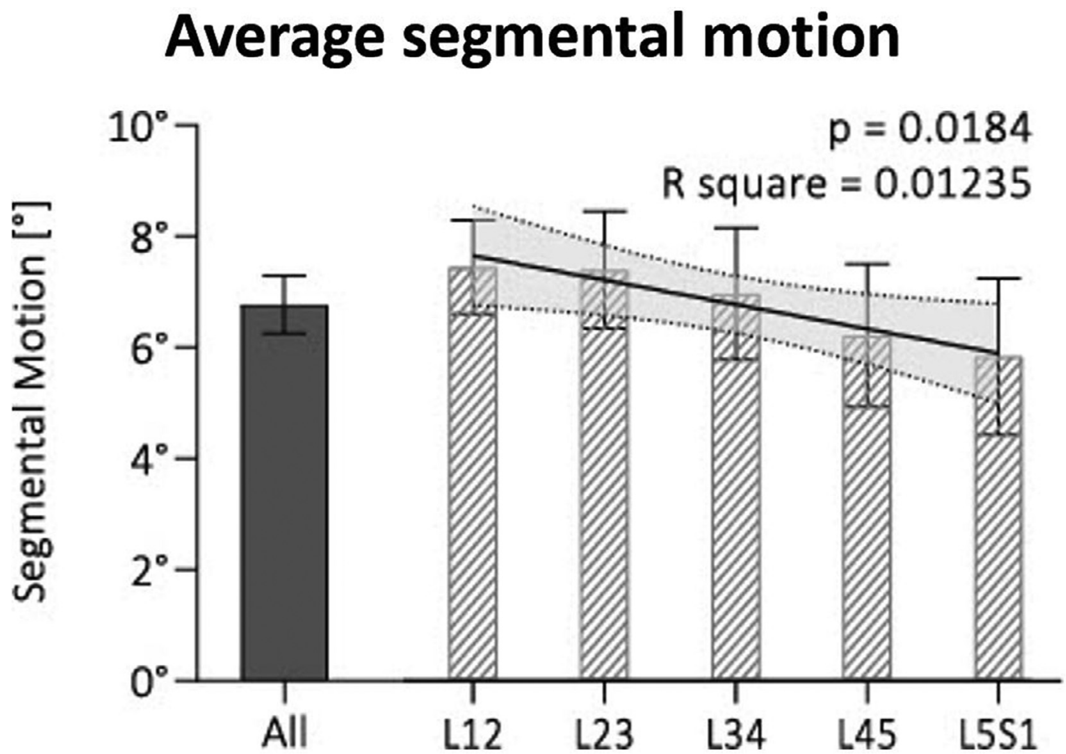

Fig. 4. Average segmental motion (with. 95% confidence intervals) of all measurements and per level (left). Linear regression of level wise segmental motion (right).

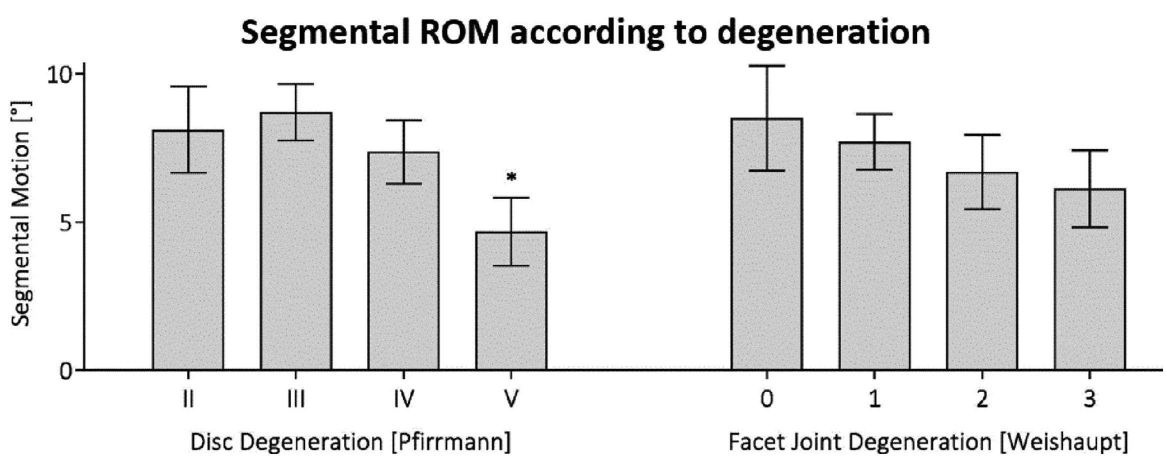

Fig. 5. Mean values of the segmental ROM [°] per intervertebral disc degeneration (left, Pfirrmann classification (Table 1)) and facet joint degeneration group (Weishaupt classification (Table 2)). Error bars represent 95% confidence intervals. P-values of post-hoc multiple comparisons are provided in Table 5 (IDD) and Table 6 (FJD).

(Fig. 5, Table 5). Mean values of the segmental ROM in disc degeneration groups II to V were 8.1°, 8.7°, 7.4°, and 4.7°, respectively. No segment was rated IDD=I, thus disc degeneration grade I is not included in the presented results. In the case of facet joint degeneration (FJD), no statistical differences were found between neither of the groups when comparing the segmental ROM of patients without spinal fusion history.

Mean values of the segmental ROM for FJD grades 0 to 3 were 8.5°, 7.7°, 6.7°, and 6.1°, respectively. Linear regression analysis revealed a significant decreasing trend ($p=0.007$) for segmental motion with progressing FJD (Fig. 5, Table 6). In comparison to motion at previously fused segments, all grades of FJD still showed a significantly larger amount of segmental motion.

The results on segmental motion revealed similar ROMs per degeneration group if the analysis included patients who previously underwent lumbar spinal surgery. In comparison to any grade of degeneration of both kinds, spondylodesis caused the strongest reduction in motion. The remaining motion was significantly different from all but the most severe grade of disc degeneration and all grades of facet joint degeneration (Table 5 and Table 6, an extra column on the right). Overall, in comparison to non-fused segments without surgical intervention history (n=413), fused segments (n=37) had significantly lower segmental ROM (mean 7.1° vs. 3.5°, respectively; $p=0.0002$).

A positive linear relationship was found between the severity of IDD and FJD ($p<0.001$, Fig. 6). In general, segments with the highest grade of disc degeneration (IDD=V) had a significantly higher FJD score than those with a lower IDD rating (IDD=II: $p=0.01$, IDD=III: $p=0.002$, respectively). The combined effect of IDD and FJD on segmental motion is shown in the heat-map plot (Fig. 6, right) along with average segmental rotation values for each combination of IDD and FJD. The largest ROM was found in segments with the lowest IDD (II) and the lowest FJD (0).

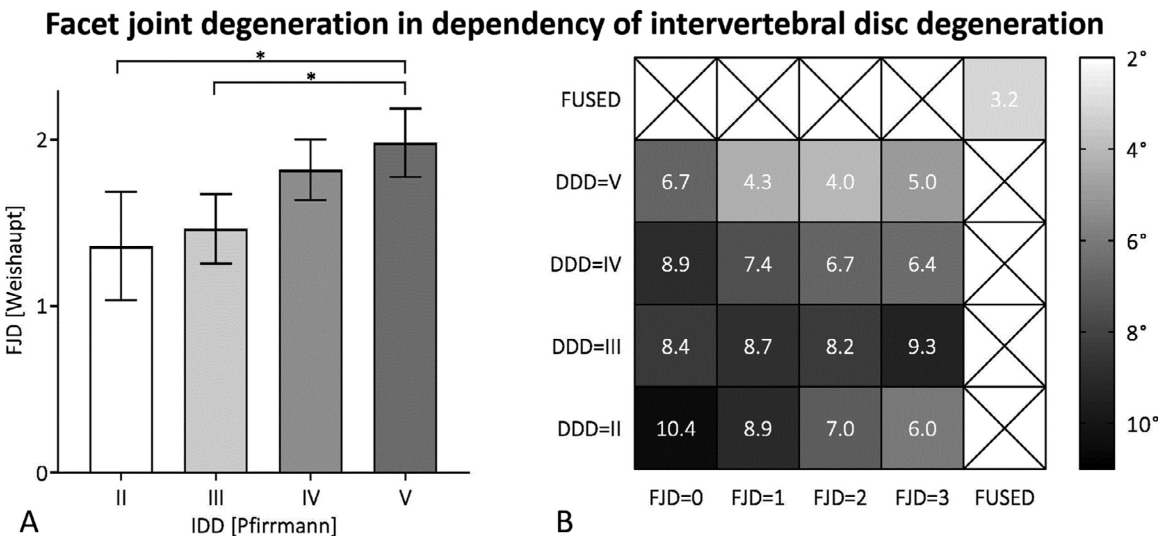

Fig. 6. A: FJD ratings in dependency of IDD ratings. Segments rated IDD=5 had significantly different FJD from segments rated IDD=2 and IDD=3 (p=0.01 and p=0.002, respectively). The interrelationship between IDD and FJD underlies a significant linear trend (p<0.001) with a slope of 0.234 (R square=0.036). B: Heat-map plot showing average segmental ROM found in segments with a particular combination of IDD and FJD grades.

Table 5
P-values of post-hoc comparison of segmental motion [°] between different groups of IDD (Pfirrmann classification, Table 1).

Adjusted p-values	3	4	5	fusion
(mean differences)	(n=105)	(n=99)	(n=91)	(n=100)
2	p=0.92	p=0.85	p=0.002	P=0.002
(n=45)	(+0.58°)	(-0.75°)	(-3.44°)	(-4.32°)
3		p=0.26	p<0.001	p<0.001
(n=105)		(-1.33°)	(-4.02°)	(-5.21°)
4			p=0.002	p=0.005
(n=99)			(-2.69°)	(-3.48°)
5				p=0.76
(n=91)				(-1.20°)
Total rated segments: n=340				n=440

Table 6
P-values of post-hoc comparison of segmental motion [°] between different groups of FJD (Weishaupt classification, Table 2).

Adjusted p-values	1	2	3	incl. fusion
(mean differences)	(n=105)	(n=68)	(n=91)	(n=96)
0	p=0.84	p=0.32	p=0.08	p<0.001
(n=46)	(-0.80°)	(-1.81°)	(-2.38°)	(-5.48°)
1		p=0.65	P=0.19	p<0.001
(n=105)		(-1.00°)	(-1.57°)	(-4.33°)
2			p=0.92	p=0.01
(n=68)			(-0.57°)	(-3.56°)
3				p=0.03
(n=91)				(-3.14°)
Total rated segments: n=310				n=406

The lowermost ROM was present in fused segments, followed by those with severe IDD (V). The effect of destabilization in grade II IDD was only observed if FJD was also in an advanced state (2, 3, +1.2°, +3.3° respectively) – in cases of non- or mildly degenerated facets (grades 0, 1) the motion in IDD grade III was lower than in IDD grade II (-2.0°, -0.2° respectively).

In segments planned to undergo fusion surgery (prospective fusion levels, n=100) the average ROM is 6.23° and significantly lower (p=0.001) than in segments not intended for fusion (n=215, ROM=8.35°). Also, degeneration states differed significantly: on average, IDD in prospective fusion levels was 1.1 scores higher (IDD=4.4 vs. IDD=3.3, p<0.0001) and FJD was 0.44 higher (FJD=1.92 vs. FJD=1.48, p=0.0007) than in levels without indication for fusion (Fig. 7).

Overall lumbar spine motion and degeneration

In those patients of whom all levels were evaluated for IDD or FJD (n=68 and n=41, respectively) the amount of total lumbar motion negatively correlates with the average IDD score per lumbar spine (p=0.009, R square = 0.0972). On the contrary, for FJD the relationship between the average degeneration score and the overall motion was not significant (p=0.295, R square = 0.0267) (Fig. 8). Patients with prior surgery in the lumbar spine exhibited a significantly (p=0.001) lower overall extent of lumbar motion as compared to those who did not undergo previous surgical treatment (mean overall motion 25.3° vs. 40.9°, respectively). Patient age (p=0.313) and pain according to the VAS (p=0.418) however, had no significant influence on the overall lumbar spine motion.

Discussion

Intervertebral discs and facet joints play a crucial biomechanical role in the kinetic and kinematic behavior of the lumbar spine. In the context of degenerative spinal diseases, both structures are involved in the cascade of degenerative events [12]. These in turn may lead to abnormal spinal motion or instability at the affected segment [7,13]. Although previously investigated, both *in vitro* [7,14,15] and *in vivo* [16–18], the effect of FJD on spinal kinematics and the combined effect of lumbar IDD and FJD remain poorly understood [8,13,19,20]. The interrelation between IDD, FJD, overall and segmental lumbar angular motion, and spinopelvic parameters in a cohort of lumbar fusion patients has not been particularly addressed, and it remains unclear findings in this population compare to previous ones.

In the investigated patient cohort mild-to-moderate IDD (grades II, III) was most prevalent in the uppermost lumbar level (L12), while the majority of severely degenerated discs were found in the lowest lumbar level (L5S1). Mild-to-moderate osteoarthritic changes in the facet joint (grades 0, 1, 2), on the other hand, did not show a predominant presence in any of the analyzed levels, although the occurrence of severe FJD (grade 3) continuously increased from upper towards lower levels (Fig. 3). The observed level specific occurrence of IDD is in accordance with previous studies [16]. The elevated rate of severe FJD at lower levels furthermore reflects the positive correlation between IDD

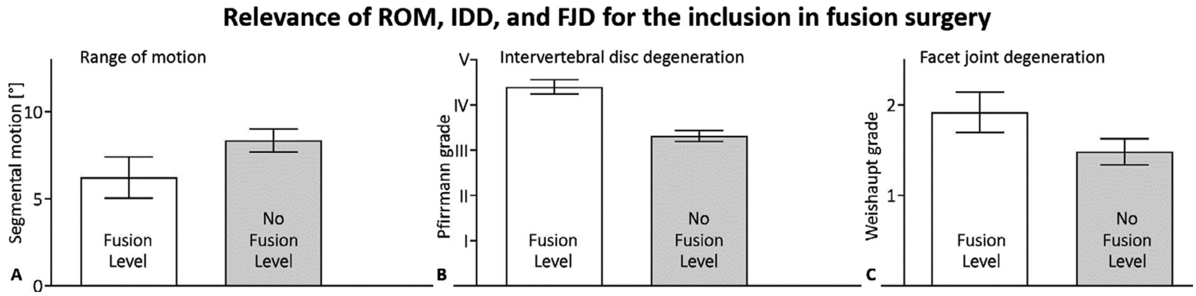

Fig. 7. Dependencies of ROM, IDD, and FJD on whether a segment is intended to be included in spondylodesis surgery. Segmental motion (A) was significantly smaller for prospective fusion levels (6.23° vs. 8.35°, p=0.001), and average disc degeneration score (B), as well as facet degeneration score (C), were both significantly higher (4.40 vs. 3.31, p<0.0001 and 1.92 vs. 1.48, p=0.0007, respectively) at the levels for which fusion surgery was planned.

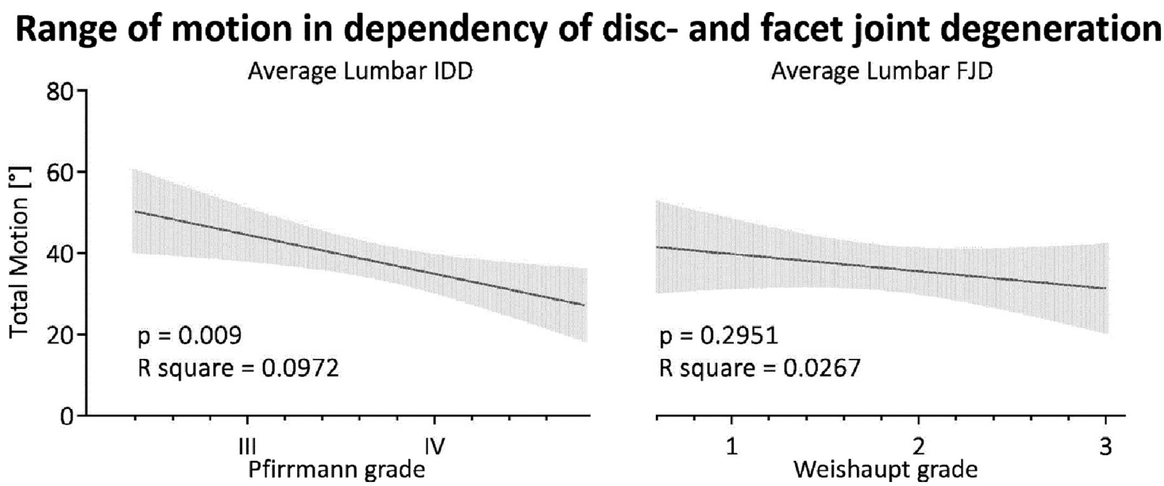

Fig. 8. Total lumbar range of motion (L1-S1) in dependency of mean IDD (left) and FJD (right) per patient (linear regression: p=0.009, R square=0.0972 and p=0.295, R square=0.0267 for IDD and FJD, respectively). The shaded area indicates the 95% confidence interval of the best fit regression line.

and FJD that has been recently reported and confirmed in this study (Fig. 6). Observed ROM between levels did not significantly differ from each other. Although age has previously been reported to be one of the strongest predictors of global lumbar motion, no influence was found in this study [21]. However, current [8] findings in the literature remain controversial as heterogeneous results regarding level specific ROM in the literature are present [22,23].

Measured segmental mobility in different grades of IDD (Fig. 5) compared favorably with literature and support the concept of the three stages of IDD: dysfunction, instability and re-stabilization [24]. Furthermore, a significant linear negative correlation (p=0.007) of ROM with increasing grades of FJD was found, yet the difference in average observed ROM per degeneration grade was not significant. Previously, both relationships have been similarly reported by Kong et al. [19] and Paholpak et al. [8], respectively.

Results on the combined effect of IDD and FJD indicate that FJD is a necessary contributor to instability in phase II IDD, as an increased motion was only observed if FJD was also in an advanced state. However, the combined analysis of IDD and FJD was limited in the present study by a relatively small number of segments analyzed per combination of IDD and FJD (n=23.3 on average, standard deviation ±12.8). Therefore, larger numbers of measurements and ideally also considering level specific differences are required to provide more distinct and statistically relevant results on the combined effect of IDD and FJD on ROM.

The significant negative correlation of overall lumbar motion with average lumbar IDD indicates that motion lost at severely degenerated segments may not be compensated at levels with lower grades of IDD, which is in agreement with the literature [6]. However, conclusions on ROM at segments adjacent to fusion should not be drawn based on this finding; an increase of ROM at adjacent levels may still be present, despite the reduced overall ROM.

Data of this study suggest that high grade lumbar disc degeneration limits spinal motion to the extent of spondylodesis. Many patients are concerned about the loss of motion after lumbar spinal fusion. According to the findings in this study, we can inform patients that there will be no further loss of the segmental motion after spinal fusion of highly degenerated lumbar segments. However, if adjacent segment disease is part of the natural history of lumbar segment degeneration[25,26], as high grade disc degeneration increases the mechanical load of adjacent segments and therefore causes adjacent segment disease similar to what is observed after fusion remains unknown. It also remains unclear if fusion surgery of segments affected by end stage disc degeneration also accelerates degeneration of adjacent segments, as motion cannot be further decreased.

Conclusion

While the degree of facet joint degeneration seems not significantly associated with limitations in spinal motion, severe lumbar disc degeneration limits segmental motion, nearly equal to spinal fusion. This should affect counseling patients undergoing spinal fusion with questions on the probability of adjacent segment degeneration compared to the natural course.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.xnsj.2021.100076.

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