

Clinical Study

# Reoperation rates and risk factors for revision 4 years after dynamic stabilization of the lumbar spine

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## Abstract

**BACKGROUND CONTEXT:** The concept of dynamic stabilization (DS) of the lumbar spine for treatment of degenerative instability has been introduced almost two decades ago. Dynamic stabilization follows the principle of controlling movement in the coronal plane by providing load transfer of the spinal segment without fusion and, at the same time, reducing side effects such as adjacent segment disease (ASD). So far, only little is known about revision rates after DS due to ASD and screw loosening (SL).

**PURPOSE:** The present study aimed to evaluate the longitudinal revision rates following dynamic pedicle screw stabilization in the lumbar spine and to determine specific risk factors predictive for ASD, SL, and overall reoperation in a large cohort with considerable follow-up.

**DESIGN:** We carried out a post hoc analysis of a prospectively collected database in a level I spine center.

**PATIENTS EXAMPLE:** The patient sample comprised 283 (151 female/132 male) consecutive patients suffering from painful degenerative lumbar segmental instability with or without spinal stenosis who underwent DS of the lumbar spine (Ulrich Cosmic, Ulrich Medical, Ulm, Germany) between January 2008 and December 2011.

**OUTCOME MEASURES:** Longitudinal reoperation rate and risk factors predictive for revision surgery were evaluated.

**METHODS:** We analyzed the longitudinal reoperation rate due to ASD and SL and overall reoperation. Risk factors such as age, gender, body mass index, lumbar lordosis (LL), number of segments, and number of previous surgeries were taken into account. Regular and mixed model logistic regressions were performed to determine risk factors for revision surgery on a patient and on a screw level.

**RESULTS:** The mean age was 65.7±10.2 years (range 31–88). One hundred thirty-two patients were stabilized in 1 segment, 134 in 2 segments, 15 in 3 segments, and 2 patients in 4 segments. Reoperation rate for ASD and SL after 1 year was 7.4 %, after 2 years was 15.0%, and after a mean follow-up of 51.4±15 months was 22.6%. Reasons for revision were SL in 19 cases (6.6%), ASD in 39 cases (13.7%), SL and ASD in 6 cases, hematoma in 2 cases (0.7%), cerebrospinal fluid fistulae in 3 cases (1.1%), infection in 6 cases (2.1%), and implant failure in 1 case (0.4%). The patients' age, the number of stabilized segments, and the number of previous surgeries and postoperative LL had a significant influence on the probability for revision surgery.

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**CONCLUSIONS:** Reoperation rates after DS of the lumbar spine are comparable with rigid fixations. The younger the patient and the more segments are involved, the lower the LL and the more previous surgeries were found, the higher was the risk of revision. Risk of revision was almost twice as high in men compared with women. We therefore conclude that for clear clinical indication and careful evaluation of preoperative imaging data, DS using the Cosmic system seems to be a possible option. The presented data will help to further tailor indication and patient selection. © 2018 Elsevier Inc. All rights reserved.

**Keywords:** Adjacent segment disease; Dynamic stabilization; Lumbar spine; Reoperation rate; Screw angles; Screw loosening

## Introduction

Rigid stabilization and fusion has become a well-accepted procedure for the treatment of painful degenerative segmental instability in the lumbar spine with or without spinal stenosis [1,2]. Nevertheless, initially good clinical results might be extenuated by adjacent segment degeneration (ASD) [3,4], with reported rates of symptomatic ASD of 2.0%–5.5% per year after lumbar fusion surgery [5–7]. Especially in the elderly, ASD in the cranial segment is a common problem after lumbar stabilization [4]. Relative hypermobility of the adjacent segment in relation to the rigid fixation was considered to be a relevant factor predisposing ASD [4,8]. In an attempt to reduce relative hypermobility in adjacent segments by allowing motion in stabilized segments and thereby diminishing altered biomechanical stress at adjacent segments, the concept of dynamic stabilization (DS) of the lumbar spine for treatment of degenerative instability has been introduced almost two decades ago [9–11]. Dynamic stabilization is based on the principle of controlling the movement by providing load transfer of spinal segments without fusion and, at the same time, reducing relative movements of the adjacent segment, when compared with rigid fixation [12]. Thus, the concept of DS is following the objective of reducing side effects such as ASD [13]. Morishita et al. [14] found significantly lower disc degeneration after DS of the lumbar spine in comparison to rigid fixation. By allowing movement in the spinal segment without fusion, the transmission of forces will be mainly dependent on the bone-screw interface, leading to higher forces in the transition zone at the bone-screw interface possibly inducing different side effects such as loosening of the screw [10,12].

The objective of the present study is therefore to determine the longitudinal reoperation rates after DS of the lumbar spine focusing on ASD and SL. Additionally, various risk factors including age, gender, body mass index (BMI), number of segments, postoperative lordosis, and previous surgery, potentially predicting the probability of revision surgery, are evaluated. Screw angles (SAs) in the axial plane within a segment, as well as intersegmental and in-segmental delta angles, are assessed as independent risk factors for ASD and SL.

## Materials and methods

### Ethics

The analysis was approved by our local ethics committee (registration number: 159/16S) and was conducted in accordance with the Declaration of Helsinki.

### Patients

We performed a post hoc analysis of our prospectively collected database for all patients that underwent DS of the lumbar spine (including levels T12 to S1) using the dynamic Cosmic system (Ulrich Medical, Ulm, Germany). Between January 2008 and December 2011, 283 patients (151 [53.4%] female and 132 [46.6%] male) were operated on and included for further analysis. Indication for surgery was degenerative spondylolisthesis (maximum Meyerding Grade I) in 263 (92.9%) patients and severe osteochondrosis and spondyloarthrosis in 20 (7.1%) patients. Patient demographics including information on previous surgeries are presented in Table 1. Mean follow-up was 51.4±15 months. Twelve patients (4.2%) were lost to follow-up after a mean time of 17.9 months (range 12–24 months) without revision surgery until last follow-up. For patients who were not able to attend the regular follow-up, the family doctors were contacted by phone to complete history and further surgeries.

Table 1  
Patient demographics

Demographics	Number (%), range, SD)
Patients F/M	151(53.4%)/132 (46.6%)
Age at surgery	65.5 (range 31–88)
BMI	27.6±5.3
Diagnosis (N, %)	
Degenerative stenosis*	263 (92.9)
Osteochondrosis and spondylarthrosis	20 (7.1)
Previous surgery (N, %)	97 (34.2)
Decompression alone (central and/or lateral)	45 (15.9)
Disc herniation	20 (7.1)
Previous fusion	14 (5)
Intervertebral Spacer implantation	18 (6.4)

BMI, body mass index; SD, standard deviation.

\* Spondylolisthesis (maximum Meyerding I) and central and/or foraminal stenosis.

## Surgery

All surgeries were performed in a standardized way by eight different board-certified neurosurgeons. Patients were operated on in prone position under general anesthesia and prophylactic antibiotics. A standard midline approach was used in 90.0% (255) of surgeries, 10.0% (28) of patients underwent minimally invasive surgery using the Wiltse approach [15]. In 23.0% (65) of patients, a three-dimensional navigation system was used for insertion of pedicle screws. Additional decompression via laminectomy or hemilaminectomy according to clinical symptoms was performed in 94.7% of patients. Thirteen patients (4.6%) received additional fusion (bone graft, transforaminal lumbar interbody fusion) in one or more segments. In those cases, stabilization was performed as hybrid construction with fusion of the most caudal one or two segments. One hundred thirty-two (46.6%) patients were stabilized in one segment, 134 (47.3%) in 2 segments, 15 (5.3%) in 3 segments, and 2 (0.7%) patients in 4 segments.

Dynamic stabilization implants consist of Bonit-coated pedicle screws with an additional hinge at the junction between the screw body and screw head allowing for small movements in the sagittal plane. Screws are fixed with a regular titanium rod (Fig. 1).

## Radiographic measurements and evaluation

Lumbar lordosis (LL) was measured on postoperative lateral x-ray from the upper end plate of L1 to the upper end plate of S1. The SAs were measured on postoperative computed

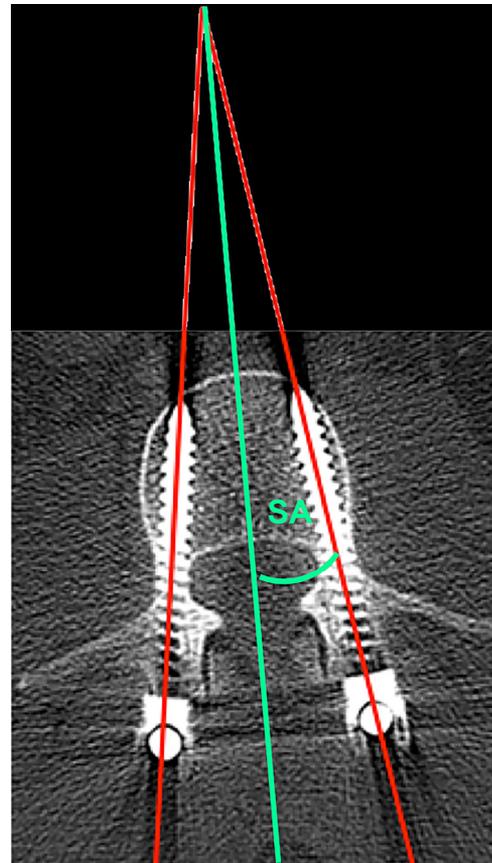


Fig. 2. Measurement of the screw angle (SA). The SA is the angle between the length of the screw and the ap-axis of the vertebral body. The delta between ipsilateral SAs of two adjacent segments and the delta between two SAs in one segment were calculated for further statistical analysis.



Fig. 1. Dynamic stabilization system: (A) a Bonit-coated screw with the hinge between the screw and the screw head and (B) screw-hinge-rod construction (with permission of Ulrich Medical, Ulm, Germany, March 22, 2018).

tomography (CT) scans. This is the angle between the midline axis of each instrumented vertebra and the longitudinal axis of the screw (Fig. 2). Twenty-four (8.5%) patients did not have postoperative CT scans, so SAs were measured on postoperative anteroposterior and lateral x-ray via the tangent function  $\tan(\alpha)=a/b$ . The length of projection was determined on the anterior-posterior x-ray, and the projection  $b$  was measured on lateral x-ray. The ratios and absolute differences of SAs between both screws in one vertebra, as well as between two adjacent vertebrae, were calculated. To calculate the ratios, the bigger angle was divided by the smaller angle and then log-transformed. For “outer” vertebrae, the ratio and absolute differences between their angles and the angles of the adjacent vertebra were computed. For “inner” vertebrae, the ratio and absolute differences between their angles and both adjacent vertebrae were computed. The more extreme of these values was then used for further calculations.

## Screw loosening (SL) and adjacent segment disease (ASD)

Screw loosening was primarily detected as “halo zone sign” or “double halo sign” on standard lateral and anteroposterior x-ray of the lumbar spine [16] and confirmed on CT scans

before reoperation. Adjacent segment disease was evaluated on lumbar lateral and anteroposterior x-rays for adjacent segment instability and on T2-weighted magnetic resonance imaging scans for ASD [17] and spinal stenosis before revision surgery. All x-rays and CT scans were evaluated by two neurosurgeons. In case of discrepancy, consensus decision was found.

### Statistical analysis

Descriptive statistics of chosen variables of interest were compiled and are presented in Table 2. We defined vertebrae next to a non-instrumented level as “outer,” whereas vertebrae in between two instrumented levels were defined as “inner.” Adjacent segment disease can only affect “outer” vertebrae, whereas SL can affect every level. Furthermore, the outcome reoperation (RO), including ASD, SL, and chronic pain, was considered.

First, we evaluated outcomes on the patient level. The first outcome investigated was whether or not a patient underwent revision surgery (RO), independent of its cause. The patients’ age, gender, BMI, number of segments, postoperative LL, and whether or not a patient had undergone previous surgery were used as predictors in univariate logistic regression models. All significant predictors were included in the final multivariable logistic regression model. Next, we evaluated whether a patient underwent revision surgery due to SL or ASD. The patients’ age, gender, BMI, number of segments, postoperative LL, and whether or not a patient had undergone previous surgery were used as predictors in univariate logistic regression models. For “SL,” all significant predictors were again included in a multivariable logistic regression model. Because only the gender was found to have a significant effect on ASD, no final model for “ASD” was specified.

Second, we evaluated outcomes on the screw level. The SAs, the delta angles within vertebrae, the log ratios within vertebrae, the delta angles between vertebrae, the log ratios between vertebrae, and whether a vertebra was an “outer” vertebra were used as predictors. Similar to the analyses on the patient level, univariate mixed model logistic regression models were fitted for all three outcomes: ASD, SL, and the combined end point RO. A random patient intercept was always included. If after fitting the univariate models for the binary

outcomes more than one predictor showed a significant effect on the outcomes, all such predictors were assembled in final models. Calculated p-values serve descriptive purposes; hence, no multiple testing corrections were applied. Additionally, all patients undergoing revision surgery no matter if reoperated in our department or elsewhere were included in our analysis on the patient level, whereas on the screw level, only patient undergoing revision surgery in our department could be involved as no pre-revision CT scans were available. All analyses were performed using R 3.4.3 (R Foundation for Statistical Computing, Vienna, Austria).

### Results

Overall reoperation rate for ASD and SL of dynamic lumbar pedicle screw stabilization after 1 year was 7.4%, after 2 years was 15.0%, and after a mean follow-up of  $51.4 \pm 15$  months (range 27–92 months) was 22.6% (Table 2). During follow-up, 31 (10.9%) patients were revised for other reasons: 6 for chronic pain (2.1%) within the first 2 years, 2 for postoperative hematomas (0.7%), 3 for postoperative cerebrospinal fluid fistulae (1.1%), 6 for infections (2.1%) (5 early wound infections, 1 late deep infection), 1 for implant failure (0.4%) (rod failure at 4 months), and 13 for screw malpositioning. Further, 4.6% (12) of patients were lost to follow-up after a mean time of 17.9 months. Radiographic follow-up is shown in Fig. 3.

Mean preoperative LL was  $46 \pm 12.5^\circ$ , whereas mean postoperative LL was  $46.1 \pm 14.1^\circ$ . There was no significant difference in LL ( $p=0.45$ ; using a one sample *t* test) between preoperative and postoperative measurements.

On the patient level, all predictors showed at least a borderline significant ( $p < 0.1$ ) effect on the combined outcome RO and were hence included in the final model. After fitting the final model, age, postoperative LL, and previous surgery showed a significant ( $p < 0.05$ ) effect on the outcome RO, whereas gender was borderline significant. A one-unit increase in LL postsurgery decreases the risk of RO by roughly 1.7%. The risk of RO was 1.9 times higher after one previous surgery. Men have a 1.7 times higher risk of RO than women.

In the final model for the outcome SL on the patient level, age, previous surgery, and number of segments showed a significant effect. A one-unit increase in the number of segments increased the risk of revision surgery by 108.0%. A one-unit increase in the age decreased the risk of revision surgery by 5.0%. The risk of revision due to SL is 3.4 times higher after one previous surgery. For ASD only, gender was found to be a significant predictor of reoperation. The risk of revision surgery due to ASD is 2.0 times higher in men than in women (Tables 3 and 4).

Based on the screw level, a total of 1,482 screws were implanted within 741 vertebrae. Fifty-nine (4%) of all screws in 23 patients were revised for loosening during follow-up. In the final model, the SA, the log ratio of the SA angle within a level, absolute SA difference within, and whether the

Table 2  
Revision rates per year for SL and ASD after initial surgery

Time period to reoperation	N (%) SL	N (%) ASD	N (%) SL+ASD	Total N (%)
≤1 y	7 (2.5)	13 (4.6)	1 (0.35)	21 (7.4)
1≤2 y	8 (2.83)	11 (3.89)	3 (1.06)	22 (7.8)
2≤3 y	3 (1.06)	7 (2.5)		10 (3.5)
3≤4 y		5 (1.77)		5 (1.77)
>4 y	1 (0.35)	3 (1.06)	2 (0.7)	6 (2.1)
Total	<b>19 (6.7)</b>	<b>39 (13.8)</b>	<b>6 (2.1)</b>	<b>64 (22.6)</b>

ASD, adjacent segment disease; SL, screw loosening.

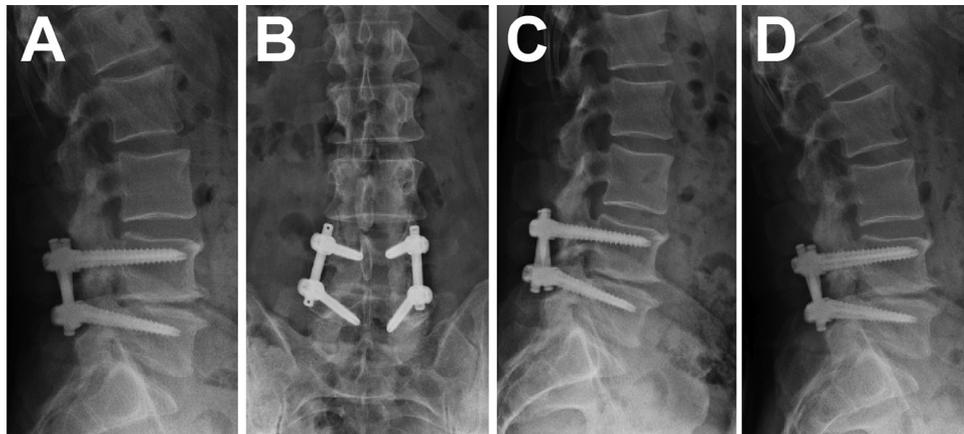


Fig. 3. Postoperative radiography. Dynamic stabilization of the spine. A one-level stabilization at 4-year follow-up: (A) ap- and (B) lateral views of the spine. (C) Flexion and (D) extension imaging.

vertebra was an outer vertebra were significant predictors of RO on the screw level. Specifically, the greater the log ratio of the SA within a vertebra, the lower the risk of RO. If the vertebra including the two screws is an outer vertebra, the risk is 30 times higher than in an inner vertebra independent of their level in the lumbar spine. For SL only, the SA was a significant predictor, and for ASD, no parameter was significant on the screw level (Tables 5 and 6). Although those parameters were significant risk factors in our model, the overall marginal risk per screw is extremely low, as the

following example shows: in a patient with a stabilization of L3–L5, the following SAs were measured: L3 left 12°, L3 right 15°, L4 left 30°, L4 right 1°, L5 left 20°, L5 right 1°, the risk of revision of L5 right is 0.000004% and that for L4 left is 0.0000002%. Because we also found the random intercept to have a significant effect and an enormous variance, we conclude that risk of reoperation on the screw level is still mostly influenced by the individual patient risk, that is, in some patients, all screws have a higher risk, and in some patients, all screws have a lower risk of causing a revision surgery.

Table 3  
OR and p-values of univariate LR for all outcomes on a patient level

Outcome	“Revision surgery”		“Screw loosening”		“Adjacent segment disease”	
	OR [95% CI]	p-Value	OR [95% CI]	p-Value	OR [95% CI]	p-Value
Age	0.89 [0.95;1.00]	.083+	0.97 [0.93;1.01]	.092+	0.99 [0.96;1.03]	.664
Gender	1.68 [0.98;2.87]	.060+	1.62 [0.63;4.17]	.313	2.01 [1.01;4.03]	.0475*
Number of segments	1.21 [0.82;1.78]	.329	2.10 [1.16;3.79]	.0139*	0.19 [0.02;1.47]	.111
BMI	1.05 [0.99;1.11]	.137	0.99 [0.89;1.11]	.908	1.00 [0.92;1.08]	.980
Lordosis postsurgery	0.97 [0.95;0.99]	.007*	0.98 [0.94;1.01]	.139	0.99 [0.97;1.01]	.401
Previous surgery	2.12 [1.32;3.40]	.002*	3.71 [1.78;7.72]	<.001*	1.27 [0.71;2.29]	.425
Level L5 and/or S1			0.51 [0.18;1.51]	.226		

BMI, body mass index; CI, confidence interval; OR, odds ratio.

\* Statistically significant.

Table 4  
Final model for outcome “revision surgery” and outcome “screw loosening” on a patient level

	Final model “revision surgery RO”			Final model “screw loosening SL”		
	OR estimate	OR 95% CI	p-Value	OR estimate	OR 95% CI	p-Value
Age	0.97	[0.95;1.00]	.049*	0.95	[0.91;0.99]	.019*
Gender	1.65	[0.95;2.88]	.077			
Number of segments				2.08	[1.07;4.02]	.030*
Lordosis postsurgery	0.98	[0.95;1.00]	.022*			
Previous surgery	1.93	[1.19;3.15]	.008**	3.39	[1.58;7.28]	.002**

CI, confidence interval; OR, odds ratio; RO, reoperation.

\* Statistically significant.

\*\* High statistically significant.

Table 5  
OR and p-values of univariate LR for all outcomes on a screw level

Outcome	“Revision surgery”		“Screw loosening”		“Adjacent segment disease”	
	OR [95% CI]	p-Value	OR [95% CI]	p-Value	OR [95% CI]	p-Value
Log ratio within SA	0.39 [0.14;1.04]	.059+	0.40 [0.09;1.66]	.205	0.54 [0.16;1.78]	.311
Log ratio between SA	0.24 [0.07;0.86]	.0278*	0.32 [0.05;2.04]	.227	0.24 [0.05;1.14]	.0728+
Delta within SA	0.95 [0.89;1.01]	.0828+	0.96 [0.87;1.05]	.319	0.97 [0.90;1.04]	.373
Delta between SA	0.93 [0.87;1.00]	.0621+	0.94 [0.85;1.04]	.267	0.94 [0.86;1.03]	.175
SA	0.97 [0.93;1.01]	.0892+	0.98 [0.93;1.04]	.576	0.96 [0.92;1.01]	.151
“Outer” vertebra	30.5 [10.5;88.4]	<.001*	11.5 [3.9;33.5]	<.001*		

CI, confidence interval; OR, odds ratio; SA, screw angle.

\* Statistically significant.

## Discussion

### Comparison with other dynamic and rigid stabilization cohorts

Our detailed analysis revealed age, gender, LL postsurgery, and previous surgery as main risk factors of indication for revision on the patient level. To the best of our knowledge, this is the first and largest study presenting the longitudinal reoperation rates for SL and ASD after DS of the lumbar spine. So far, only little information is available on specific risk factors for reoperation rates following dynamic pedicle screw stabilization of the lumbar spine.

On the patient level, we found an overall RO rate of 7.4% after 1 year, 15.0% after 2 years, and an overall RO rate of 22.6% after a mean follow-up of 51.4±15 months. Similarly, Payer et al. [18] found a revision rate of 7.0% for SL and 10.0% for symptomatic ASD after 2 years. They used the Dynesys DS system for single level degenerative anterolisthesis with symptomatic stenosis in 30 patients, which is a comparable cohort of patients in terms of indication. In contrast to our study, all patients with previous surgery in the lumbar spine and multilevel DS were excluded from the study. Kaner et al. [10] evaluated the Cosmic DS in 30 patients with lumbar stenosis, without degenerative spondylolisthesis and without previous surgery. In their cohort, one patient presented with SL and no revision surgery was necessary 2 years after the initial surgery [10]. In comparison to our study, the low revision rate might be explained by the narrow indication for surgery and the specific patient cohort undergoing DS.

Table 6  
Final model for outcome “revision surgery” on a screw level

	Final model “revision surgery”		
	OR estimate	OR 95% CI	p-Value
Log ratio within SA	0.01	[0.00;0.41]	.013*
Log ratio between SA	0.12	[0.00;4.22]	.241
Delta within SA	1.23	[1.01;1.49]	.036*
Delta between SA	1.13	[0.93;1.37]	.234
SA	0.93	[0.88;0.99]	.016*
“Outer” vertebra	38.3	[11.9;123]	<.001*

CI, confidence interval; OR, odds ratio; SA, screw angle.

\* Statistically significant.

Sato et al. [19] evaluated the overall revision rate for patients 5 years after surgery for degenerative lumbar stenosis. They found an overall revision rate of 6.1% after 1 year and 23.3% after 5 years independent of the surgery performed (rigid stabilization and decompression vs. decompression alone) [19]. For rigid stabilization and decompression, they found a reoperation rate of 2.2% after 1 year and 7.8% after 5 years. The difference in relation to our results might not only be due to the performed surgery technique (dynamic vs. rigid stabilization) but also depend on different inclusion criteria. In our study, all patients receiving the DS independent of previous surgery or number of stabilized levels were involved. We found the overall risk of RO was 1.9 times higher per one previous surgery. Also, for SL, the risk was 3.4 times higher per one previous surgery.

Furthermore, we found that the higher the postoperative lordosis, the lower was the risk of RO. Also, Kuo et al. [16] found that patients who failed to gain LL after DS using the Dynesys had significantly higher rates of radiological SL. Using rigid fixation, Bae et al. postulated that loss of lordosis promotes ASD [6].

Another important risk factor concerning RO was the age of the patient at the scheduled surgery. A one-unit increase in the age of a patient decreased the risk of revision surgery by 3.0%. As an example for risk prediction, using our final model on the patient level, the estimated risk of reoperation for a 35-year-old male patient, with postoperative lordosis of 15° and at least one previous surgery, is ~81%. In contrast, an 85-year-old female patient, with no previous surgery and postoperative lordosis of 50°, has an estimated risk of ~10% for reoperation.

In our study, 4.0% of all screws were revised for SL. The more segments were involved, the higher was the risk of revision for SL. Also, the risk of revision of a screw in an “outer” vertebra was 30 times higher than in an “inner” vertebra. This can be explained, as in DS force transmission will essentially be dependent on the bone-screw interface which is biomechanically more important in an outer or transition vertebra than in an inner vertebra [12]. Kuo et al. found an overall rate of radiological SL after 4 years, 8.2% per screw, and 20.4% per patient, using the Dynesys dynamic pedicle screw-based stabilization [16]. We only evaluated symptomatic SL in our study and are aware that the number of radiological

SL might be much more common as it is in radiological and symptomatic ASD. Although the SA was a significant predictor for reoperation, the mathematical and clinical importance on the screw level seemed to be low. The most important predictor was still the individual patient risk.

### Limitations

This is a retrospective analysis so all patients undergoing DS using the Cosmic system were included. Indication was due to degenerative lumbar segmental instability with or without spinal stenosis. Yet, our patient cohort is heterogeneous in relation to age, underlying pathology, and previous history. This inhomogeneous group allowed for a detailed risk analysis in relation to various factors potentially involved in revision surgery. Our detailed analysis revealed that age and previous surgery are main risk factors of indication for revision. This is important to mention as many studies involving evaluation of DS excluded previous surgery beforehand [10,13,19].

Furthermore, the retrospective analysis of all patients involved a cross-sectional follow-up to determine revision rates following DS. Revision was defined as primary end point in our analysis, so follow-up data are inhomogeneous as well. The minimum follow-up for all patients is 27 months, which is considerably long compared with most available literature. Only 12 patients (4.2%) were lost to follow-up after a mean time of 18 months after DS without revision as documented in our database. Another drawback is that information on ASD is only available for symptomatic patients because magnetic resonance imaging was performed only according to symptoms at scheduled follow-up. Adjacent segment disease can be presented in two groups, radiological ASD (involving all ASD) and symptomatic ASD (as a subgroup of all ASD). In our study, information of radiological ASD (including all ASD) was not available. Therefore, the possible impact of radiological ASD might be underestimated in our study. Corresponding to current literature, there is no strong evidence of a correlation between radiological and symptomatic ASD. Han et al. [20] found 29.03% radiological ASD after dynamic pedicle screw-based stabilization of L5/S1 after 4 years but no symptomatic ASD nor revision surgery for ASD was reported in their study.

### Risk factors

Almost two-thirds of revision surgeries in the present study are due to symptomatic ASD, but only gender was found as a predictive risk factor for revision due to ASD on the patient level. The risk of revision due to ASD was twice as high in men than in women. Also for RO, men have a 1.7 times higher overall risk than women. Sato et al. [19] also found the male gender as an independent risk factor for ASD 5 years after rigid fixation of the lumbar spine. This seems to be an important point, as it remains unclear what factors might be the reason for higher revision rates in men. In Table 7, we present

Table 7  
Gender-specific evaluation of demographics and revision surgery

	Female patients	Male patients
Age (mean, std, range)	65.4±10.4 (31–86)	65.6±10.5 (31–88)
BMI (mean, std, range)	27.2±4.5 (17.4–41.3)	27.8±4.1 (18.7–46.7)
Previous surgery (N, %)	20 (31.3%)	44 (68.7%)
Lumbar lordosis (mean, std)	46.9±14.0	46.2±12.4
Reoperation total (N, %)	32 (21.2%)	41 (31.1%)
Revision for ASD (N, %)	18 (11.9%)	27 (20.5%)
Revision for SL (N, %)	11 (7.3%)	14 (10.6%)

ASD, adjacent segment disease; BMI, body mass index; SL, screw loosening.

data in relation to gender, where RO rates obviously differ between men and women; however, no relevant covariate difference in relation to gender can be observed. Concerning gender-specific differences, further studies are necessary to shed more light on gender-specific factors possibly influencing RO and surgical outcome.

In contrast to Ou et al., we cannot confirm BMI as an independent risk factor for revision for ASD [21] nor general RO. Our analyses on the screw level found the random intercept to be the most important factor for the risk of an RO, so we presume further contributing patient-specific factors influencing the risk of revision surgery after DS of the lumbar spine. This might be in relation to pre-existing anatomical conditions such as preoperative facet joint degeneration [22], including sagittalization of the facet, laminar horizontalization [23], abnormal disc height in the adjacent segment, or imbalanced spinopelvic parameters [24].

The dynamic non-fusion pedicle-screw-rod-system combines the advantage of a pedicle screw-based fixation and a less invasive, shorter procedure with less blood loss and lower adverse event rates [25] that is biomechanically considered to be more “natural” in the lumbar spine [12,26]. Further studies are necessary to evaluate possible advantages for specific patient cohorts and underlying pathologies.

### Conclusions

The large cohort and considerably long follow-up presented in this work demonstrates that DS is a suitable option for the treatment of degenerative instability in the lumbar spine. Thus, despite no bone grafting for fusion was performed in conjunction with this DS technique, revision rates are comparable with the literature for conventional rigid instrumentation with spinal fusion. For clear clinical indication and careful evaluation of preoperative imaging data, DS is a possible option.

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