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ORIGINAL ARTICLE - SPINE DEGENERATIVE

Risk factors for early reherniation after lumbar discectomy with or without annular closure: results of a multicenter randomized controlled study

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Abstract

Background Reherniation after lumbar discectomy is classified as a failure and occurs in 3 to 18% of cases. Various risk factors for reherniation such as age, sex, body mass index, smoking, and size of annular defect have been reported. The aim of this study was to identify risk factors for early reherniation after one-level lumbar discectomy with or without annular closure within 3 months after surgery.

Methods This study is based on data analysis of a prospective, multicenter randomized controlled trial in Europe. Patients included underwent standard lumbar discectomy—with or without implantation of an annular closure device (ACD). Enrollment of 554 patients in 21 centers in Europe (Germany, Switzerland, Austria, Belgium, The Netherlands, and France) started in 2010 and was completed in October 2014. A total of 276 patients were randomized to the ACD group (ACG) and 278 patients to the control group (CG).

Results Four (1.5%) symptomatic reherniations occurred in the ACG and 18 (6.5%) in the CG. In the overall population, a significant correlation was found with recurrent herniation for disc degeneration (Pfirrmann $p = 0.009$) and a trend for current smoker status ($p = 0.07$). In CG, age ≥ 50 years ($p = 0.05$) and disc degeneration (Pfirrmann $p = 0.026$, Kellgren and Lawrence $p = 0.013$) were predictive factors for reherniation.

Conclusion In the current study, risk factors for early recurrent disc herniation after lumbar discectomy were age ≥ 50 years and moderate disc degeneration. The annular closure device reduced the risk of early reherniation.

Trial registration Clinicaltrials.gov NCT01283438

Keywords Annulus fibrosus · Disc herniation · Annular closure device · Lumbar discectomy · Risk factors · Reherniation

This article is part of the Topical Collection on *Spine degenerative*

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Introduction

Lumbar disc herniation is the most common spinal degenerative pathology, and discectomy is the most frequently performed spinal surgery [7, 13, 14]. Reherniation after lumbar discectomy (RLD) is a known frequent failure and has been described extensively in the literature [5, 9, 10, 12, 20, 23, 30, 31, 53]. The reported reherniation rate after lumbar discectomy ranges from 3 to 18% [3, 41, 55]. RLD is defined as recurrence of symptoms after a postoperative pain-free period caused by a new disc herniation at the same ipsilateral level [43]. If RLD is diagnosed, reoperation may be required. The SPORT study described reoperation rates of 2% at 90 days, 4% at 1 year, and 10% after 4 years post-surgery [54]. Moreover, only 78% patient satisfaction was reported

at 1 year post-surgery in the Swedish Spine Registry [46]. The reoperation rate after 3 years in our current trial was 19.3% in the control group and 11% in the group with annular closure device implantation [21].

Many risk factors have already been reported, such as age, sex, body mass index (BMI), smoking, type and size of annular defect, amount of removed disc volume, grade of disc degeneration, disc height, and range of motion [1, 8, 25, 26, 32–35, 42, 51]. In the study by Meredith et al., obese patients were 12 times more likely to suffer RLD compared with non-obese patients [33]. Several authors have confirmed the findings that smoking and increasing age are associated with RLD [1, 22, 25, 32, 34, 42]. A Finnish study found no difference between genders concerning risk for reoperation [20]. Carragee et al. demonstrated a trend towards higher reherniation rates with limited discectomy compared with the more aggressive discectomy group [9]. This was confirmed in a review article by Watters et al. which described a significant increase in RLD rate following conservative versus aggressive discectomy [52]. Furthermore, it was shown that patients with annular defects > 6 mm account for most of the clinically relevant reherniations [8]. Kim et al. recently acknowledged the correlation between a wider defect and a higher reherniation rate [25]. Moreover, a larger mean annular defect area (46 mm ± 18 mm^2) and a lower percentage of removed disc volume were obtained in patients with reherniations in the study by McGirt et al. [33].

A recently introduced annular closure device (Barricaid®, Intrinsic Therapeutics, Inc., Woburn, MA) was developed to occlude the annular defect and prevent reherniation [56]. It has been reported that Barricaid® might reduce the risk of reherniation in high-risk patients. These findings were observed in two prospective, single-arm trials with a total of 75 patients. A low rate (1.4%) of symptomatic RLD was reported, and Barricaid® use was associated with a good overall outcome [6]. The 2- and 3-year follow-up results of a European prospective, multicenter randomized controlled trial including 554 patients in 21 centers have already been published [21, 50]. The frequency of symptomatic reherniation after 2 years was lower in the annular closure device group compared with the control group (12% vs. 25%, $p < 0.001$) [50]. Similar results have been reported for the 3-year follow-up (14.8% vs. 29.5%) [21].

The aim of the present data analysis was to identify factors associated with very early reherniation within the first 3 months after surgery in patients undergoing one-level lumbar discectomy, with or without annular closure.

Methods

Trial design

This study includes data of a post-marketing, prospective, multicenter, randomized controlled trial (RCT) of limited discectomy—with and without use of an annular closure device (Clinicaltrials.gov NCT01283438). The study protocol was published previously [27].

Table 1 Preoperative demographic characteristics

	All patients ($n = 545$)	AC ($n = 267$)	CG ($n = 278$)	Recurrent group ($n = 22$)	Non-recurrent group ($n = 523$)
Preoperative demographic characteristics					
Age (mean, range)	43.5 (22–74)	42.9 (22–71)	44.0 (23–74)	46.3 (27–72)	43.4 (22–74)
Sex (female)	40.2%	41.9%	38.5%	54.5%	39.6%
BMI (mean)	26.3	26.3	26.3	26.9	26.3
Smoking (yes)	44.4%	44.6%	44.2%	63.6%	43.6%
VAS leg (mean)	80.9	81	80.8	87.0	80.6
VAS back (mean)	56.1	56.6	55.7	65.5	55.8
ODI (mean)	58.7	59.2	58.2	61.1	58.6
Working status (yes)	21.1%	19.9%	22.3%	18.2%	21.2%
Homemaker, retired, student, unable to find work, not working by choice	8.6%	7.9%	9.4%	9.1%	8.6%
Preoperative duration of symptoms (median months)	5.6	5.5	5.6	5.6	5.6
Level of disc herniation					
L2/3	0.6%	0.7%	0.4%	0.0%	0.6%
L3/4	2.4%	3.0%	1.8%	0.0%	2.5%
L4/5	40.7%	45.3%	36.3%	50.0%	40.3%
L5/S1	56.3%	50.9%	61.5%	50.0%	56.6%

For smoking, "yes" means the percentage of active smokers, and for working status, "yes" includes the percentage of patients working before surgery.
VAS Visual Analog Scale, *ODI* Oswestry Disability Index

Participants

This European study included 554 patients in 21 centers located in Germany, Switzerland, Austria, Belgium, The Netherlands, and France from 2010 to 2014 and was conducted in compliance with the Ethics Committee, GCP, and ISO requirements. A total of 276 patients were randomized to ACG and 278 patients to CG. Only 267 patients in the ACG with a device implanted (no implantation $n = 4$, failures to implant $n = 5$, implantation on second attempt $n = 3$) were included in our analysis. Informed consent was obtained for all patients. Study oversight regarding safety was provided by an independent data safety monitoring board.

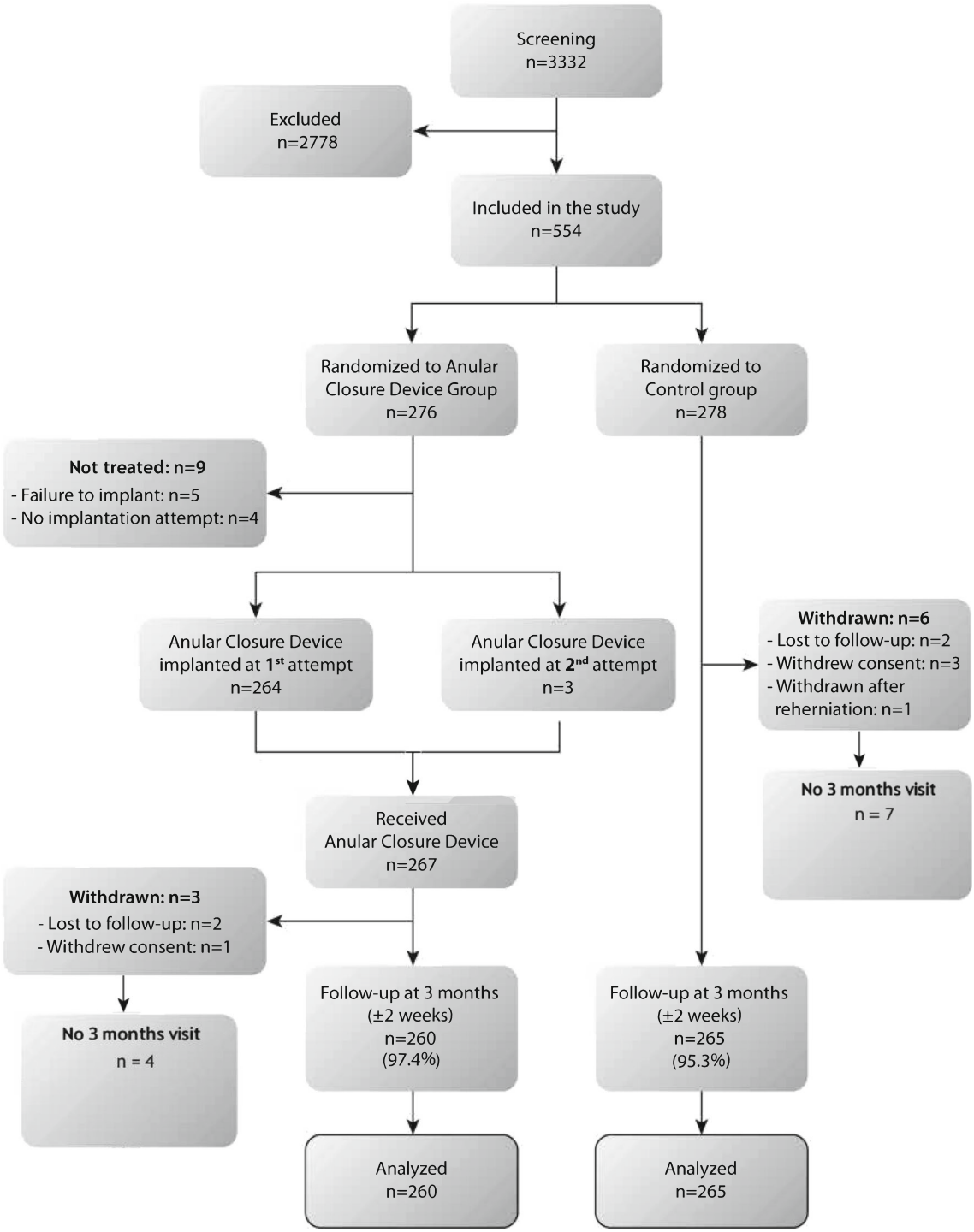

Fig. 1 Flow diagram of randomization and patient follow-up

Randomization and masking

Patients were randomized web-based intraoperatively 1:1 to either standard discectomy (control group, CG) or standard discectomy with implantation of an annular closure device (annular closure group, ACG). The main criteria for study enrollment were an annular defect of 4 to 6 mm in height and 6 to 10 mm in width. Neither the surgeons nor the participants were blinded for the treatment allocation.

Early reherniation after lumbar discectomy

RLD was reported as adverse event in the RCT. RLD was reported as ipsi- or contralateral new disc herniation at index level and had to be confirmed by either magnetic resonance imaging (MRI) or during reoperation.

Annular closure device

The ACD (Barricaid®, Intrinsic Therapeutics, Inc., Woburn, MA, USA) was developed to prevent reherniation after lumbar discectomy, through closure of the annular defect. European Conformity (CE) marking was received in 2009 and FDA approval in 2019. The device consists of a flexible mesh, a mechanical barrier to the annular defect, and a bone anchor.

Surgical technique

The majority of surgeons preferred intraoperative microscopy. A limited nucleotomy described by Spengler [45] was performed. The volume of removed disc material varied according to the surgeon's implementation of limited discectomy and was measured in cubic centimeters. The height and width of the annular defect were measured using sizing paddles. Randomization occurred after discectomy. No further nucleus removal was allowed thereafter. Device implantation and correct alignment were verified by intra- and X-ray.

Follow-up

Clinical examination and X-ray were performed at the consultation after 6 weeks and 3 months. Assessment included Visual analog Scale (VAS) leg (LP-VAS) and low back pain (BP-VAS), Oswestry Disability Index (ODI), and Medical Outcomes Short Form-36 (SF-36) physical and mental component summary scales [15, 37].

Radiographic assessment

Preoperative imaging of the lumbar spine included anterior-posterior /lateral X-ray with extension/flexion, computed tomography (CT), and MRI. Analysis of the images was performed by a team of independent radiologists.

An MRI was performed in cases with clinical evidence of early RLD. Disc degeneration was graded according to Kellgren and Lawrence (K-L) [18] and Pfirrmann [38].

Statistical analysis

Descriptive statistics was used for demographic characteristics, intraoperative findings, and pain scores. Univariate logistic regression analysis was applied to investigate correlation between potential risk factors and early RLD in three different populations: (1) all subjects, (2) subjects implanted with the ACD, and (3) control subjects.

The multivariate logistic regression analysis was applied on the "all subjects" population only. Any variable with a p value < 0.1 in the univariate regression analysis was utilized in a multivariate logistic regression, stepwise, backward

Table 2 Disc degeneration according to Pfirrmann's and Kellgren and Lawrence classification—with the corresponding reherniation rates

Pfirrmann and Kellgren and Lawrence classification of disc degeneration and reherniation rate									
		All patients	ACG	CG			All patients	ACG	CG
Pfirrmann grade	I	0	0	0	Kellgren-Lawrence classification	None	5	2	3
	Reherniation rate	n/a	n/a	n/a		Reherniation rate	0%	0%	0%
	II	2	2	0		Doubtful	235	109	126
	Reherniation rate	0%	0%	n/a		Reherniation rate	2.55%	2.75%	2.38%
	III	423	205	218		Minimal	229	122	107
	Reherniation rate	2.8%	1.0%	4.6%		Reherniation rate	4.8%	0.82%	9.35%
	IV	100	47	53		Moderate	67	29	38
	Reherniation rate	9%	4.3%	13.2%		Reherniation rate	7.46%	0%	13.16%
	V	1	1	0		Severe	5	3	2
	Reherniation rate	0	0	n/a		Reherniation rate	0%	0%	0%

Table 3 Herniation type, annular defect type, surgical approach, defect geometry, and annular defect size at initial surgery

Herniation type				Annular defect type				Surgical approach		Defect geometry				Defect size and amount of nucleus removed				
	Contained fragment	Extruded fragment	Sequestered fragment	Bulge/ weakness	Fissure	Full thickness defect	None	Through existing defect	New defect	Puncture/ slit	Cruciate	Box	None	Defect size (mm^2, mean, range)	Defect width (mm, mean, range)	Defect height (mm, mean)	Defect ≥ 54 mm^2	Nucleus removed (ml, mean, range)
All patients	27.0% (147)	36.1% (197)	36.9% (201)	30.1% (164)	18.2% (99)	51.4% (280)	0.4% (2)	62.4% (340)	37.6% (205)	27.7% (151)	5.3% (29)	62.6% (341)	4.4% (24)	38.8 (24–60)	7.9 (6–10)	4.9	7.0% (38/545)	1.3 (0.1–8.0)
ACG	26.6% (71)	35.2% (94)	38.2% (102)	29.6% (79)	16.5% (44)	53.9% (144)	0.0% (0)	64.0% (171)	36.0% (96)	22.8% (61)	4.1% (11)	68.2% (182)	4.9% (13)	38.2 (24–60)	7.8 (6–10)	4.9	6.0% (16/267)	1.3 (0.1–8.0)
CG	27.3% (76)	37.1% (103)	35.6% (99)	30.6% (85)	19.8% (55)	48.9% (136)	0.7% (2)	60.8% (169)	39.2% (109)	32.4% (90)	6.5% (18)	57.2% (159)	4.0% (11)	39.3 (24–60)	8.0 (6–10)	4.9	7.9% (22/278)	1.3 (0.1–4.3)
Recurrent group	31.8% (7)	40.9% (9)	27.3% (6)	31.8% (7)	22.7% (5)	45.5% (10)	0.0% (0)	68.2% (15)	31.8% (7)	31.8% (7)	13.6% (3)	54.5% (12)	0.0% (0)	40.0 (24–60)	8.4 (6–10)	N/A	13.6% (3/22)	1.2 (0.4–3.2)
Non-recurrent group	26.8% (140)	35.9% (188)	37.3% (195)	30.0% (157)	18.0% (94)	51.6% (270)	0.4% (2)	62.1% (325)	37.9% (198)	27.5% (144)	5.0% (26)	62.9% (329)	4.6% (24)	38.7 (24–60)	7.9 (6–10)	N/A	6.7% (35/523)	1.3 (0.1–8.0)

elimination. At each step, the variable with the highest insignificant p value was dropped, until all p values were less than 0.05.

Results

Preoperative demographic characteristics

There were no significant differences between the groups (Table 1). Follow-up rates at 3 months were 97.4% for ACG and 95.3% for CG. Ten patients (CG $n = 6$, ACG $n = 4$) withdrew from the study before their 3-month visit (Fig. 1).

Preoperative radiological findings

The majority of patients had a Pfirrmann grade III (423 patients, 76.3%) or IV (100 patients, 18%) disc degeneration (DD). In comparison, DD classified according to Kellgren and Lawrence presented mostly as doubtful (235 patients, 42.4%) or minimal (229 patients, 41.3%) changes (Table 2). There was no significant difference in Pfirrmann grades ($p = 0.398$) or Kellgren and Lawrence classification ($p = 0.441$) between ACG and CG groups. Average disc height was 8.9 ± 2.1 mm (ACG: 8.9 ± 2.1 mm, CG: 8.8 ± 2.2 mm), translational range of motion (ROM) 0.4 ± 1.5 mm (ACG: 0.5 ± 1.4 mm, CG: 0.3 ± 1.6 mm) and angular ROM − 4.2 ± 4.5° (ACG: − 4.0 ± 4.5°, CG: − 4.4 ± 4.5°).

Intraoperative findings

A full thickness defect was present in 51.4% of patients. Approach through the existing annular defect was used in 62.4% of patients. The overall mean defect size was 38.8 mm^2, and the mean amount of nucleus removed was 1.3 mL (Table 3).

Postoperative clinical outcome

We observed postoperative at the 3-month follow-up a significant improvement in VAS leg pain, VAS back pain, and ODI in ACG and CG compared with the preoperative baseline (< 0.0001).

Risk factors for RLD

Twenty-two patients (4%) suffered a symptomatic index level reherniation during the first 3 months, 4 (1.5%) occurred in ACG and 18 (6.5%) in CG. Type of RLD is shown in Table 4. RLD occurred ipsilateral in 91% (ACG 75%, CG 94%). Ipsilateral reherniations in ACG were found lateral to the device mesh. RLD due to device malfunction did not occur. No patient described an event that precipitated the recurrence. Reoperation due to RLD was necessary in 12 patients ($n = 3$ ACG, $n = 9$ CG). Median time from pain recurrence to reoperation was 17 days (1 day ACG, 20 days CG).

Regarding risk factors for RLD, a significant correlation was found for age ≥ 50 years and DD. Control subjects ≥ 50 years of age were more likely to have a symptomatic reherniation (CG $p = 0.051$, OR = 2.61) (Table 5). In CG, reherniation rate of patients aged < 50 years was 4.6% compared with 9.9% for patients aged ≥ 50 years. In ACG, all RLD occurred in patients < 50 years. Disc degeneration according to the K-L classification was a predictor for RLD in CG (CG $p = 0.013$, OR = 2.15). The RLD rate in CG was 13.2% for moderate degeneration. Pfirrmann grade IV degeneration showed a reherniation rate of 9% overall and 13.2% in CG. In summary, subjects with a 1 point higher Pfirrmann grade were 3.2 times more likely to have a symptomatic RLD.

All other variables including sex, BMI, smoking status, amount of nucleus removed, herniation or defect type, defect size, surgical approach, and radiological data—including range of motion and disc height—were not significant in the uni- and multivariate logistic regression analysis.

Smokers had a trend for a higher symptomatic RLD rate overall ($p = 0.07$, OR = 2.26). Although sex was not a significant predictor for reherniation, the RLD rate for females in CG was higher (F: 7.5% vs. M: 5.9%), and all reherniations in ACG occurred in females.

Implantation of ACD correlated with an overall reduction of symptomatic RLD ($p = 0.007$, OR = 0.23). In the multivariate logistic regression model, the following three variables remained after use of backward stepwise elimination: current smoker ($p = 0.049$, OR = 2.57), Pfirrmann grade ($p = 0.010$, OR = 3.26), and implantation of ACD ($p = 0.007$, OR = 0.23). Reherniation rate was 0.9% for non-smokers with grade III degeneration and implantation of ACD, compared with 19.2% for smokers with grade IV degeneration and no ACD device. In summary, the multivariate

Table 4 Recurrent herniation type

	Contained fragment		Extruded fragment		Sequestered fragment		Protrusion		Not specified	
All patients	2	9%	6	27%	9	41%	1	5%	4	18%
ACG	0	0%	2	50%	2	50%	0	0.%	0	0%
CG	2	11%	4	22%	7	39%	1	6%	4	22%

Table 5 Multivariate analysis of predictors for early symptomatic reherniation

Predictors for early symptomatic reherniation	All Patients			ACG			CG		
	p value	Odds ratio (95% CI)	Reherniation rate	*p* value	Odds ratio (95% CI)	Reherniation rate	*p* value	Odds ratio (95% CI)	Reherniation Rate
Age ≥ 50	0.157	1.88 (0.78–4.49)	No: 3.3% (13/395) vs. Yes: 6.0% (9/150)	n/a (all reherniations < 50)		No: 2.0% (4/198) vs. Yes: 0.0% (0/69)	0.051	2.61 (1.00–6.84)	No: 4.6% (9/197) vs. Yes: 11.1% (9/81)
Sex: male	0.166	0.55 (0.23–1.29)	No: 5.5% (12/219) vs. Yes: 3.1% (10/326)	n/a (all reherniations female)		No: 3.6% (4/112) vs. Yes: 0.0% (0/155)	0.592	0.77 (0.29–2.01)	No: 7.5% (8/107) vs. Yes: 5.9% (0/171)
Current smoker	0.071	2.26 (0.93–5.49)	No: 2.5% (8/303) vs. Yes: 5.8% (14/242)	0.250	3.80 (0.39–37.03)	No: 0.7% (1/148) vs. Yes: 2.5% (3/119)	0.143	2.08 (0.78–5.53)	No: 4.5% (7/155) vs. Yes: 8.9% (11/123)
BMI > 25 kg/m^2	0.430	1.43 (0.59–3.46)	No: 3.3% (8/243) vs. Yes: 4.6% (14/302)	0.434	2.48 (0.25–24.14)	No: 0.8% (1/120) vs. Yes: 2.0% (3/147)	0.637	1.27 (0.48–3.37)	No: 5.7% (7/123) vs. Yes: 7.1% (11/155)
Defect size ≥ 54 mm^2	0.221	2.20 (0.62–7.80)	No: 3.8% (19/507) vs. Yes: 7.9% (3/38)	n/a (all reherniations with defect area < 54 mm^2)		No: 1.6% (4/251) vs. Yes: 0.0% (0/16)	0.168	2.54 (0.67–9.54)	No: 5.9% (15/256) vs. Yes: 13.6% (3/22)
Removed nucleus < 1 ml	0.745	0.86 (0.35–2.06)	No: 4.4% (9/205) vs. Yes: 3.8% (13/340)	0.583	0.57 (0.08–4.15)	No: 2.0% (2/98) vs. Yes: 1.2% (2/169)	0.971	0.98 (0.37–2.62)	No: 6.5% (7/107) vs. Yes: 6.4% (11/171)
Defect type	0.650	0.90 (0.56–1.44)	Bulge/weakness: 4.3% (7/164) Fissure: 5.1% (5/99) Full thickness: 3.6% (10/280) None: 0.0% (0/2)	0.128	0.37 (0.11–1.33)	Bulge/weakness: 2.5% (2/79) Fissure: 4.6% (2/44) Full thickness: 0.0% (0/144) None: n/a	0.693	1.12 (0.65–1.93)	Bulge/weakness: 5.9% (5/85) Fissure: 5.5% (3/55) Full thickness: 7.4% (10/136) None: 0.0% (0/2)
Surgical approach: created new defect	0.568	0.77 (0.31–1.91)	No: 4.4% (15/340) vs. Yes: 3.4% (7/205)	0.649	0.59 (0.06–5.75)	No: 1.8% (3/171) vs. Yes: 1.0% (1/96)	0.598	0.76 (0.28–2.09)	No: 7.1% (12/169) vs. Yes: 5.5% (6/109)
Disc degeneration (Kellgren-Lawrence)	0.086	1.61 (0.94–2.78)	0: 0.0% (0/5) 1: 2.6% (6/235) 2: 4.8% (11/229) 3: 7.5% (5/67) 4: 0.0% (0/5)	0.207	0.32 (0.05–1.90)	0: 0.0% (0/2) 1: 2.8% (3/109) 2: 0.8% (1/122) 3: 0.0% (0/29) 4: 0.0% (0/3)	0.013	2.15 (1.18–3.94)	0: 0.0% (0/3) 1: 2.4% (3/126) 2: 9.4% (10/107) 3: 13.2% (5/38) 4: 0.0% (0/2)
Pfirrmann grade	0.009	3.16 (1.34–7.46)	1: 0.0% (0/2) 2: 2.8% (12/423) 3: 9.0% (9/100) 4: 0.0% (0/1)	0.149	3.72 (0.62–22.17)	1: 0.0% (0/2) 2: 1.0% (2/205) 3: 4.3% (2/47) 4: 0.0% (0/1)	0.026	3.17 (1.14–8.75)	1: n/a 2: 4.6% (10/218) 3: 13.2% (7/53) 4: n/a
Angular ROM (quartiles)	0.199	1.30 (0.87–1.94)	Q1: 2.4% (3/127) Q2: 3.9% (5/127) Q3: 4.7% (6/127) Q4: 5.5% (7/127)	0.139	2.62 (0.73–9.35)	Q1: 0.0% (0/57) Q2: 0.0% (0/59) Q3: 3.0% (2/66) Q4: 2.9% (2/69)	0.379	1.22 (0.78–1.90)	Q1: 4.3% (3/70) Q2: 7.4% (5/68) Q3: 6.6% (4/61) Q4: 8.6% (5/58)
Translational ROM (quartiles)	0.921	0.98 (0.66–1.45)	Q1: 3.9% (5/127) Q2: 4.7% (6/127) Q3: 3.9% (5/127) Q4: 3.9% (5/127)	0.841	0.91 (0.37–2.24)	Q1: 0.0% (0/52) Q2: 3.2% (2/63) Q3: 3.0% (2/67) Q4: 0.0% (0/69)	0.769	1.07 (0.69–1.65)	Q1: 6.7% (5/75) Q2: 6.3% (4/64) Q3: 5.0% (3/60) Q4: 8.6% (5/58)
Disc height (quartiles)	0.198	0.77 (0.51–1.15)	Q1: 5.3% (7/131) Q2: 4.6% (6/130) Q3: 3.8% (5/131) Q4: 2.3% (3/131)	0.200	0.50 (0.17–1.44)	Q1: 1.6% (1/63) Q2: 4.6% (3/66) Q3: 0.0% (0/61) Q4: 0.0% (0/66)	0.446	0.84 (0.54–1.31)	Q1: 8.8% (6/68) Q2: 4.7% (3/64) Q3: 7.1% (5/70) Q4: 4.6% (3/65)
Use of ACD	0.007	0.22 (0.07–0.66)	No: 6.5% (18/278) vs. Yes: 1.5% (4/267)	n/a					

OR odd ratios, *n/a* not available, *BMI* body mass index, *K-L* Kellgren and Lawrence disc degeneration classification, *ROM* range of motion, *ACD* annular closure device. For angular and translational ROM, as well as disc height, each subject has been assigned to a quartile group based on the quartiles (Q) for all subjects

model predicts that a smoker with one point worse Pfirrmann grade without ACD is 36.4 (2.57 × 3.26 × 1/0.23) times more likely to suffer a symptomatic reherniation within 3 months.

Discussion

In our multicenter randomized controlled trial, the early RLD rate until the 3-month follow-up was 4% overall. These rates are in line with the literature [9, 20, 23, 30, 31, 49]. Implantation of an ACD was a significant predictor for RLD risk reduction in the overall population.

The median interval until RLD in the study by Moliterno et al. [35] and Wera et al. [55] was 3 and 2.8 month, respectively; McGirt et al. identified two postoperative time periods when RLD most frequently occurred, < 4 months or > 11 months after surgery [32].

In our current study, RLD reoperation rate was 2.2% within 3 months. The reported reoperation rate was 2% at 90 days in the SPORT trial [54] and 4.9% at 3 months after discectomy in the study by Kim et al. [23], where 46% of reoperations were performed within half a year. In Aizawa et al.'s trial, reoperation for RLD was performed significantly more often within the first 6 months [2].

Patients with grade IV Pfirrmann DD in CG and overall had the highest reherniation rate. Several authors found that patients with low to moderate DD were at increased risk of RLD [1, 11, 26]. Dora et al. presented a reduced RLD rate for each Pfirrmann grade increase [11].

A trend for RLD and increasing age has been reported [1, 23, 24, 32]. We confirmed these findings with a significant correlation between age ≥ 50 years and RLD in CG. Martin et al. presented results showing older age associated with higher short-term and lower long-term reoperation risk [31].

Our study identified smoking as a risk factor for RLD. Earlier studies have also shown that smokers have a higher recurrence rate [4, 19, 26, 34, 42, 47]. The lumbar disc space is known to be an avascular structure and absorbs all nutrients by diffusion [16, 17]. It was proposed that smoking-associated hypoxia inhibits closure of the discogenic and ligamentous defect after discectomy [28, 29, 34, 36, 44].

Similar to our findings, Martin et al. noted that female sex was associated with a higher risk for RLD and reoperation [31]. In contrast, Suk et al. reported male sex to be a risk factor for RLD [47]. However, other studies showed no difference between the genders [20, 33, 35, 48].

As with other studies [39, 40, 57], BMI did not prove to be a risk factor for RLD in our trial. However, patients with a BMI greater than 40 kg/m^2 were excluded, and the mean BMI was 26.3 kg/m^2. Several other authors have found higher BMIs to be associated with RLD rates [1, 24, 33, 42]. In contrast, Moliterno et al. found that patients with RLD had on average significantly lower BMIs [35].

It was shown by Carragee et al. that patients with large annular defects (> 6 mm wide) account for most of the clinically significant RLD [8]. Kim et al. [25] confirmed these results in a patient cohort of 467 patients, whereby large annular defect (> 6 mm) was a risk factor for RLD.

McGirt et al. [32] observed a greater mean annular defect area for patients with symptomatic RLD. In patients with early RLD (within 4 months), mean annular defect was larger compared with patients with RLD at a later time point [32]. An annular defect size of > 54 mm^2 correlated with an 18% RLD rate, which is 4 times higher compared with 4.7% rate for patients with defect size of 36 mm^2 [32].

A minimum of 6 mm and maximum of 10-mm defect width were necessary for our study enrollment. This might explain why we did not observe correlation between RLD and defect size. Awareness of a maximum allowed width and height made the surgeons more careful in their incision of the annulus. Only a small number (7%) of patients in our study had a defect size of ≥ 54 mm^2, and the RLD rate in this group was 7.9%.

We were not able to observe any correlations between removed nucleus amount, disc height, type of herniation, sagittal ROM, and RLD rate.

Conclusion

Significant risk factors for early recurrent disc herniation after lumbar microdiscectomy in this study included age ≥ 50 years (OR = 2.6) and moderate disc degeneration (OR = 3.2). The annular closure device was a predictive factor that significantly reduced the risk of early reherniation. These results suggest that implantation of an ACD can prevent early reherniation after lumbar discectomy.

Compliance with ethical standards

This study was approved by the local EC (Ethikkommission Nordwest- und Zentralschweiz, EKNZ, Nr. 2012-036). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study was supported by the Intrinsic Therapeutics, Inc., Woburn MA, USA. None of the authors received financial compensation for the work related to the study. The coauthor G.J. Bouma has received research grants from the Intrinsic Therapeutics. All other authors declared that they have no conflict of interest.

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