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The efficacy of minimally invasive discectomy compared with open discectomy: a meta-analysis of prospective randomized controlled trials

Hormuzdiyar H. Dasenbrock, M.D.¹, Stephen P. Juraschek, B.A.^{4,6}, Lonni R. Schultz, Ph.D.⁵, Timothy F. Witham, M.D.^{2,3,4}, Daniel M. Sciubba, M.D.^{2,3,4}, Jean-Paul Wolinsky, M.D.^{2,3,4}, Ziya L. Gokaslan, M.D.^{2,3,4}, and Ali Bydon, M.D.^{2,3,4}

¹Department of Neurosurgery, Brigham and Women's Hospital/Children's Hospital of Boston/Harvard Medical School, Boston, Massachusetts ²Spinal Column Biomechanics and Surgical Outcomes Laboratory, Johns Hopkins University, Baltimore, Maryland ³Department of Neurosurgery, Johns Hopkins University, Baltimore, Maryland ⁴School of Medicine, Johns Hopkins University, Baltimore, Maryland ⁵Department of Biostatistics and Research Epidemiology and Neuroscience Institute, Henry Ford Hospital, Detroit, Michigan ⁶Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland

Abstract

Object—Advocates of minimally invasive discectomy (MID) have promoted this operation as an alternative to open discectomy (OD), arguing that there may be less injury to the paraspinal muscles, decreased postoperative pain, and a faster recovery time. However, a recently published large randomized controlled trial (RCT) comparing these approaches reported inferior relief of leg pain in patients undergoing MID. The authors conducted a meta-analysis to evaluate complications and improvement in leg pain in patients with radiculopathy enrolled in RCTs comparing OD to MID.

Methods—The authors performed a literature search using Medline and EMBASE of studies indexed between January 1990 and January 2011. Predetermined RCT eligibility included the usage of tubular retractors during MID, a minimum follow-up duration of 1 year, and quantification of pain with the visual analog scale (VAS). Trials that only evaluated patients with recurrent disc herniation were excluded. Data on operative parameters, complications, and VAS scores of leg pain were extracted by 2 investigators. A meta-analysis was performed assuming random effects to determine the difference in mean change for continuous outcomes and the risk ratio for binary outcomes.

Results—Six trials comprising 837 patients (of whom 388 were randomized to MID and 449 were randomized to OD) were included. The mean operative time was 49 minutes during MID and

Address correspondence to: Ali Bydon, M.D., Department of Neurosurgery, Johns Hopkins University, 600 North Wolfe Street, Meyer 5-109, Baltimore, Maryland 21287. abydon1@jhmi.edu.

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Disclosure

Author contributions to the study and manuscript preparation include the following. Conception and design: Bydon. Acquisition of data: Dasenbrock, Schultz. Analysis and interpretation of data: Bydon, Dasenbrock, Schultz. Drafting the article: Dasenbrock, Juraschek, Schultz. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Bydon. Statistical analysis: Juraschek, Schultz. Administrative/technical/material support: Bydon. Study supervision: Bydon, Witham, Sciubba, Wolinsky, Gokaslan.

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44 minutes during OD; this difference was not statistically significant. Incidental durotomies occurred significantly more frequently during MID (5.67% compared with 2.90% for OD; RR 2.05, 95% CI 1.05–3.98). Intraoperative complications (incidental durotomies and nerve root injuries) were also significantly more common in patients undergoing MID (RR 2.01, 95% CI 1.07–3.77). The mean preoperative VAS score for leg pain was 6.9 in patients randomized to MID and 7.2 in those randomized to OD. With long-term follow-up (1–2 years postoperatively), the mean VAS score improved to 1.6 in both the MID and OD cohorts. There was no significant difference in relief of leg pain between the 2 approaches with either short-term follow-up (2–3 months postoperatively, 0.81 points on the VAS, 95% CI –4.71 to 6.32) or long-term follow-up (2.64 on the VAS, 95% CI –2.15 to 7.43). Reoperation for recurrent herniation was more common in patients randomized to the MID group (8.50% compared with 5.35% in patients randomized to the OD group), but this difference was not statistically significant (RR 1.56, 95% CI 0.92–2.66). Total complications did not differ significantly between the operations (RR 1.50, 95% CI 0.97–2.33).

Conclusions—The current evidence suggests that both OD and MID lead to a substantial and equivalent long-term improvement in leg pain. Adequate decompression, regardless of the operative approach used, may be the primary determinant of pain relief—the major complaint of many patients with radiculopathy. Incidental durotomies occurred significantly more frequently during MID, but total complications did not differ between the techniques.

Keywords

Discectomy; incidental durotomy; lumbar spine; meta-analysis; tubular discectomy; sciatica

Sciatica is a major cause of morbidity worldwide. Recent prospective RCTs have found a benefit of surgery for patients with lumbar disc herniation–induced sciatica that persists despite conservative management.^{6,12,13,33,35,75,78,105,108–111} Although OD performed with or without an operating microscope (known as microdiscectomy) remains the standard approach to the lumbar disc,^{24,39,48,63,79,100} tubular retractor system–based MID has been increasingly performed

^{1–3,11,14,17,18,20,21,23,31,42,44,45,47,50,51,53,57–61,66,67,69,72,73,77,81,85,87–90,95,103,104,106,112–114}

Potential benefits to this technique include less muscle damage,^{9,52,91–93} decreased pain,^{32,37} and faster recovery period after surgery.^{71,115} However, before MID becomes more widely adopted, its efficacy compared with OD must be systematically evaluated.

While RCTs provide high-quality evidence, occasionally different trials investigating a similar question do not reach the same conclusions. Several recent prospective RCTs have compared OD to tubular retractor–based MID.^{7,8,16,30,38,43,82–84,86,101} Most studies concluded that the 2 procedures lead to an equivalent improvement in leg pain postoperatively,^{43,82,83,86} but these studies were relatively small ($n = 22$ – 200 patients), and they were underpowered to detect some potentially clinically relevant differences between the operations. In the largest trial to date ($n = 328$ patients),^{8,10} Arts et al.^{7,8} found significantly greater leg pain relief using the Roland-Morris Disability Questionnaire in patients randomized to OD; thus, the authors concluded that patients undergoing MID have less favorable outcomes.

Assessing the efficacy of MID compared with OD is important because an estimated 300,000 discectomies are performed annually in the US alone.⁴ Additionally, there is a strong interest in minimally invasive spine surgery in the lay community.²⁹ In fact, the majority of patients in the 2 most recently published RCTs comparing OD and MID expressed a preference for MID.^{7,101} We report a meta-analysis examining the improvement in leg pain and complications (including incidental durotomies and reoperation for recurrent

disc herniation) in patients with radiculopathy enrolled in prospective RCTs comparing open discectomy to minimally invasive discectomy utilizing a tubular retractor system.

Methods

Study Selection Criteria

Study eligibility was based on predefined criteria. The inclusion criteria were as follows: 1) an RCT of OD compared with MID in which a tubular retractor was used in patients with disc herniation; 2) quantification of the intensity of leg pain with the VAS; and 3) a minimum follow-up period of 1 year. Studies were excluded if they only examined patients undergoing surgery for recurrent disc herniation. There were no external sources of funding for the meta-analysis.

Literature Search and Data Sources

On January 5, 2011, we searched MEDLINE and EMBASE databases for articles indexed between January 1990 and January 2011. Given that the first endoscopic discectomy was reported in 1993,⁶² articles published before 1990 were not evaluated. The initial key word used was “discectomy,” with the search limited to “randomized controlled trial.” Other key words that were used (without any search limitations) were “minimally invasive discectomy,” “tubular retractor discectomy,” and “microendoscopic discectomy.” Review was restricted to abstracts published in English. A search of bibliographies of pertinent reviews was also performed for additional studies. Articles that did not definitively meet the exclusion criteria based on the abstract were obtained in full. The results of unpublished studies were not sought.

Methodological Evaluation and Data Extraction

Assessment of methodological quality and determination of study inclusion was performed independently by multiple investigators; any differences were determined by consensus at the conclusion of full text review. The quality of individual RCTs was assessed at the study level using the Jadad Scale.⁴⁶ However, studies were not stratified or differentially weighted according to these characteristics. Data were extracted by 2 investigators (H.H.D. and L.R.S.), and any discrepancies were later reconciled. The following data were extracted from the trials: number of patients; average age and sex of the patients; spinal levels; operative time; estimated intraoperative blood loss; intraoperative incidental durotomies; nerve root injuries; surgical site infections; recurrent disc herniation requiring another operation; and VAS scores preoperatively and in the short-term (2–3 months) and long-term (1–2 years) postoperatively. If studies reported VAS score on a 10-point scale, the scores were converted to the 100-point scale.

Data Synthesis and Statistical Analysis

For short-term and long-term VAS scores, the difference in end-baseline VAS score between the MID and OD group (MID-OD) was calculated.⁶⁴ If not provided, the variance for the end-baseline difference in VAS score was calculated assuming a correlation coefficient of 0.7. A sensitivity analysis was also conducted using a correlation coefficient of 0.5, yielding nearly identical results (data not shown). For operative time, the difference in end-trial values was calculated by $E_M - E_O$, where E is the time of the operation for MID (M) and OD (O).²⁵

The risk ratio was used to estimate discrete outcomes, as calculated with the corresponding variance on the logarithmic scale from the reported number of events and patients in each group. For 1 study,⁸² medians, ranges, and p values from Wilcoxon tests were provided, but

for this analysis the medians were treated as means, and variance was estimating from p values, assuming 2-sample t -tests.

The Cochran test (Q -statistic) and the I^2 statistic⁴¹ were used to evaluate heterogeneity. Due to differences in the design of the trials evaluated, random effects were assumed for all outcomes measures. Trials were weighted by inverse variance. A sensitivity analysis using an inverse-weighted random-effects model yielded very similar results (data not shown). Publication bias was assessed graphically using funnel plot analysis and statistically using both the Begg rank correlation test and Egger linear regression test.²⁵ Statistical analyses were performed using Stata 8.2 (StataCorp).

Results

Search Results

After accounting for duplicates, 271 abstracts were screened, the majority of which were excluded because they were not RCTs. Thirteen trials were retrieved in full (Fig. 1).^{7,8,16,19,30,36,40,43,62,82–84,86,101} Of these trials, 6 with a total of 837 patients (388 randomized to MID and 449 randomized to OD) were included.^{7,8,43,82,83,86,101} The remaining trials were excluded because they only evaluated patients with recurrent disc herniations,⁸⁴ the follow-up was too short,¹⁶ or they used older minimally invasive techniques that have largely been replaced by the tubular retractor system.^{19,30,36,40,62}

Study Characteristics

The study characteristics of the 6 trials that were included in the meta-analysis are summarized in Tables 1 and 2. For the open approach, 3 trials used an operating microscope,^{7,83,86} 2 trials did not use an operating microscope,^{43,82} and in another trial patients were randomized to 1 of 3 techniques—MID or OD performed either with or without an operating microscope.¹⁰¹ For the minimally invasive treatment group, 3 studies used microendoscopic discectomy,^{43,82,101} 2 used the operating microscope with the tubular retractor system,^{7,86} and another used full endoscopy.⁸³

Operative Parameters

The pooled average operative time was 49 minutes for MID and 44 minutes for OD; operative time was not significantly different (7.62 minutes, 95% CI –10.02 to 25.27) (Fig. 2). However, operative time demonstrated significant heterogeneity between trials ($I^2 = 98\%$, $Q = 322.2$, $p < 0.01$). Due to the different methods (categorical and continuous) of reporting estimated blood loss, data on this parameter were not pooled. Estimated blood loss was reported in 5 of the 6 studies. In 4 trials, EBL was lower in the MID group,^{7,43,83,86} whereas in 1 study it was lower in the OD group.⁸²

Incidental Durotomies

Rates of incidental durotomies were reported in all of the included studies (although there were no cases in either operative group in 1 study),⁸³ and statistical heterogeneity was not significant between studies ($I^2 = 0\%$, $Q = 2.89$, $p = 0.58$). Incidental durotomies were significantly more common in patients randomized to undergo MID (5.67% compared with 2.90% in the OD group [RR 2.05, 95% CI 1.05–3.98]). Although postoperative sequelae of the intraoperative incidental durotomies were rare, there were 5 cases of persistent CSF leakage, in 3 of which (all OD treated) subsequent operative repair was performed.

Nerve Root Injury and Surgical Site Infections

Intraoperative injury to the proximal nerve root is another potential complication of discectomy. Three studies did not report data on this complication.^{43,82,86} in 1 study there were no cases of nerve root injury;⁸³ in a second there were 3 cases in each treatment group;⁷ and in the third there were 2 cases during MID and none during OD.¹⁰¹ Surgical site infections are a relatively rare complication of lumbar discectomy.^{70,96} Two studies did not report any data on this complication.^{82,86} The largest study did not detect any wound infections in either treatment group;⁷ 3 other studies found slightly higher rates of surgical site infections in individuals who underwent OD.^{43,83,101} However, data on intraoperative nerve root injury and surgical site infections were not reported in all of the studies, making it impossible to determine if this was because the complication did not occur or if it was not reported. Thus, data on these 2 parameters were not pooled individually.

Long-Term Outcomes: Leg Pain and Recurrent Herniation

The pooled mean VAS leg pain score preoperatively was 6.9 and 7.2 in the MID and OD groups, respectively. Postoperatively, in both groups there a substantial decrease in the VAS score with long-term follow-up—to 1.6 points in the MID and OD cohorts. There was no significant intergroup difference in pain relief with either short-term follow-up (VAS score 0.81, 95% CI -4.71 to 6.32) or long-term follow-up (VAS score 2.64, 95% CI -2.15 to 7.43). Statistical heterogeneity was significant between studies for the VAS scores postoperatively with both short-term ($I^2 = 90\%$, $Q = 31.2$, $p < 0.01$) and long-term ($I^2 = 83\%$, $Q = 28.6$, $p < 0.01$) follow-up.

Subsequent reoperation for recurrent disc herniation was more common in patients randomized to MID (8.50%) than OD (5.35%). However, the pooled relative risk was not significantly different (RR 1.56, 95% CI 0.92–2.66), nor was statistical heterogeneity ($I^2 = 3\%$, $Q = 4.14$, $p = 0.39$).

Composite Variables: Total Intraoperative Complications and Total Complications

Two composite variables were analyzed: total number of intraoperative complications (incidental durotomies or nerve root injuries) and total number of complications (incidental durotomies, nerve root injuries, surgical site infections, and reoperation for recurrent disc herniation). Intraoperative complications were significantly more common in patients randomized to receive MID (6.96%) than OD (3.56%) (RR 2.01, 95% CI 1.07–3.77), and heterogeneity was not significant ($I^2 = 3\%$, $Q = 4.14$, $p = 0.39$). Total complications did not differ significantly between MID and OD (16.5% and 11.1%, respectively; RR 1.50, 95% CI 0.97–2.33), and heterogeneity between studies was also not significant ($I^2 = 19\%$, $Q = 6.14$, $p = 0.29$).

Publication Bias

No publication bias was detected for any of the outcome measures that were pooled when assessed graphically or statistically ($p > 0.05$ [data not shown]).

Discussion

The modification of the OD with the use of an operating microscope, which became known as the microdiscectomy,⁷⁹ led some investigators to evaluate even less invasive approaches to the lumbar discs.^{27,33,94} In 1993, Mayer and Brock⁶² first reported endoscopic surgery for a herniated disc. Subsequently, modifications were described in which either an endoscope or an operating microscope was used in conjunction with a tubular retractor system.²⁸

Advocates of MID highlight many of its potential benefits, including a smaller incision and less paraspinal muscle injury,^{9,93} which may lead to reduced postoperative pain, a shorter hospital stay, and a faster recovery.^{32,37,71} There may also be a lower rate of surgical site infections,⁷⁰ which may make this technique useful in obese patients.^{23,74,103} Other surgeons, however, have cautioned against the adoption of newer approaches without high-level evidence in support of its benefit.²⁹ Potential limitations to MID include a steep learning curve,^{55,68,73,77} limited visualization (especially with endoscopy),^{76,101} and a restricted ability to extend the approach if necessary.⁸³ Given that the findings of recent RCTs comparing OD to MID did not agree in their entirety,^{7,16,30,43,82–84,86,101} pooling their results in a meta-analysis is merited.

Incidental Durotomy

In this meta-analysis, incidental durotomies occurred significantly more often during MID. This difference may be due to the limited visualization and poor depth perception,¹⁰¹ but it may also be due to the learning curve–associated tubular retraction.^{73,77,107} Many of the incidental durotomies that occurred during MID were reported in the double-blinded study, in which, to facilitate patient blinding, the MID was performed using a midline incision.⁸ However, this is a slight modification to MID, as the incision is typically approximately 1.5 cm from the midline, which may have compromised intraoperative visualization.²⁹ Additionally, the K-wire used in the tubular approach may have led to additional durotomies.⁸

Incidental durotomies are a potential complication of any spine operation.⁹⁹ Those that occur during minimally invasive spine surgery are typically managed intraoperatively by placing fibrous glue or adhesive substances over the dura mater, tight closure of the fascia and the skin, and occasional bed rest.^{22,102} Although primary repair of an incidental durotomy through the tubular retractors is difficult, the successful closure of the dura has been reported using a laparoscopic knot pusher,²² as well as by placing a self-closing U-Clip device.⁹⁸ Incidental durotomies are important, as they may lead to spinal headaches, herniation of the nerve roots through the dural opening, a pseudomeningocele, or a CSF fistula, the latter of which may predispose to meningitis.¹⁰² Moreover, persistent CSF fistulas and pseudomeningoceles may require operative repair. Although in most cases incidental durotomies do not have sequelae, in the pooled studies there were 5 cases of persistent postoperative CSF leakage.

Other Perioperative Parameters

There has been a trend toward the performance of discectomy (both MID and OD) on an ambulatory basis.^{15,26,34,71} Thus, the length of hospital stay was not examined due to its limited clinical significance. Although many of the potential benefits to MID, including decreased postoperative pain and faster mobilization, manifest during the initial postoperative period, few studies reported data on these parameters during this time period. The only study to report immediate postoperative pain found that VAS scores 12 hours postoperatively were significantly lower in the OD cohort;⁸² the only study to evaluate time to mobilization found no difference between the 2 treatment groups.⁷

Leg Pain

Severe leg pain is the primary complaint of many patients who present with lumbar radiculopathy. The VAS is a commonly used outcome measure that assesses the intensity of a patient's pain on a scale of 0–10 (or 0–100), with a higher score indicating more severe pain, and the VAS was used in all included trials. Other outcome measures quantifying pain or disability, including the 36-Item Short Form Health Survey, the Oswestry Disability Index, and the Roland-Morris Disability Questionnaire, were not used by all of the trials.

There was no statistically significant difference in either short-term or long-term leg pain relief when comparing patients randomized to MID or to OD. The goal of a discectomy is the relief of the nerve root compression caused by the herniated fragment.³³ The primary determinant of long-term pain relief may be the ability to decompress the appropriate nerve root. Thus, the approach that is selected to reach the spinal canal—either subperiosteal or paraspinal—may be a less important determinant of the long-term outcomes, given that the approaches provide an equivalent ability to excise the herniated disc.⁵ Both procedures provide a substantial improvement in preoperative leg pain, and the current evidence suggests that they do so equivalently.

Recurrent Disc Herniation

Disc herniation may recur after discectomy, with the reported recurrence rates ranging from 3.5% to 20%.^{4,49,54,56,63,65,84,97} Higher, but not statistically significantly different, rates of recurrent herniation were seen in patients randomized to MID. Some authors have hypothesized that patients undergoing MID may have a higher rate of recurrence due to a limited surgical exposure that leads to difficulty in extracting the entirety of the herniated fragment of the disc.⁹ However, the difference in reoperation rates may also be due to differential experience of surgeons with minimally invasive approaches.⁷³ Nonetheless, the lack of a statistically significant difference limits the ability to draw conclusions about this parameter.

Limitations

There are several limitations of this meta-analysis. Some authors have suggested that surgeons' experience with MID may have differed among the various studies.⁸⁰ There may be a steep learning curve associated with MID,^{9,73} which has been shown to be correlated with a shorter operative time and fewer complications, including incidental durotomies.^{30,55,68} However, it was difficult to adjust for this potentially important confounder, as few studies provided data on the individual surgeon's experience with MID. Additionally, not all of the studies used the same technique for OD or MID, but for this meta-analysis, the different open and the minimally invasive techniques were assumed to be similar.

Conclusions

Data from 6 prospective RCTs comparing minimally invasive to open discectomy (with a total of 837 patients) were pooled in a meta-analysis. Incidental durotomies were reported significantly more frequently during MID, which may be due to limited visualization or the learning curve associated with this procedure. However, the total incidence of complications did not differ between the approaches. The current evidence suggests that both open and minimally invasive discectomy lead to a substantial and equivalent degree of short- and long-term improvement in leg pain, the primary symptom of many patients with lumbar radiculopathy.

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Abbreviations used in this paper

MID	minimally invasive discectomy
OD	open discectomy
RCT	randomized controlled trial
VAS	visual analog scale

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Fig. 1. Flow diagram depicting the literature search strategy used to retrieve the prospective RCTs evaluating the improvement in leg pain in patients with radiculopathy undergoing minimally invasive compared with open discectomy.

Fig. 2.

Forest plots evaluating the long-term pain relief measured by the VAS score, short-term pain relief measured by the VAS score, operative time, total complications, rates of incidental durotomies, and reoperation for recurrent disc herniation in patients randomized to MID compared with those randomized to OD.

TABLE 1

Comparison of the design and methods of the RCTs published between 2005 and 2008 and included in the meta-analysis *

Factor	Study		
	Huang et al., 2005	Righesso et al., 2007	Ryang et al., 2008
no. of patients			
overall	22	40	60
MI group	10	21	30
open group	12	19	30
no. of centers	1	1	1
mean age of participants (yrs)			
MI group	39	42	38
open group	40	46	30
sex			
MI group			
male	6	10	13
female	4	11	17
open group			
male	9	13	19
female	3	6	11
major inclusion criteria	1) symptoms refractory to 3 mos of conservative Tx; 2) 1–2 wks of intractable pain refractory to bed rest	1) sciatica refractory to 4–8 wks of conservative Tx; 2) posterolateral disc herniation on MRI	1) 1-level disc herniation; 2) sciatica; 3) failure of 8–12 wks of conservative Tx or CES
major exclusion criteria	1) motor deficits; 2) bowel & bladder dysfunction	1) prior LS op; 2) age >60 yrs; 3) additional LS pathology; 4) extraforaminal disc herniation; 5) workers' comp	1) prior LS op; 2) other LS pathology; 3) extraforaminal disc herniation; 4) chronic pain; 5) workers' comp
level affected			
MI group			
L1–2	0	0	0
L2–3	0	1	0
L3–4	1	1	0
L4–5	8	11	12
L5–S1	1	8	18
open group			
L1–2	0	0	0
L2–3	0	0	0
L3–4	0	0	0
L4–5	9	11	14
L5–S1	3	8	16
treatment groups			
open	open discectomy	open discectomy	open discectomy
MI	microendoscopic discectomy	microendoscopic discectomy	minimal-access trocar microdiscectomy

Factor	Study		
	Huang et al., 2005	Righesso et al., 2007	Ryang et al., 2008
outcome measures	VAS	VAS, ODI	VAS, ODI, SF-36
mean follow-up (mos)	18.9	24	16
method of randomization	NS	NS	NS
blinding?	NS	NS	NS
attrition (%)	NS	NS	NS
intention-to-treat?	yes	yes	Yes

* CES = cauda equina syndrome; comp = compensation; LS = lumbar spine; MI = minimally invasive; NS = not specified; ODI = Oswestry Disability Index; SF-36 = 36-Item Short Form Health Survey; Tx = therapy.

TABLE 2

Comparison of the design and methods of the RCTs published between 2008 and 2010 and included in the meta-analysis *

Factor	Study			
	Ruetten et al., 2008	Arts et al., 2009	Teli et al., 2010	
no. of patients	200 [†] (MI: 100; open: 100)	328 (MI: 166; open: 159)	212 (MI: 70; open: 142)	
no. of centers	1	7	1	
mean age of participants (yrs)	MI: not reported; open: not reported	MI: 42; open: 41	MI: 39; open: 40	
sex breakdown	MI: not reported; open: not reported	MI: 84 M, 82 F; open: 88 M, 71 F	MI: 45 M, 25 F; open: 94 M, 45 F	
major inclusion criteria	1) radicular symptoms or neurological deficits; 2) "standard indications for surgery"	1) age 18–70 yrs; 2) pain for >6–8 wks & failure of conservative Tx; 3) disc herniation on MRI	1) symptomatic disc herniation; 2) age 18–65 yrs; 3) failure of >6 wks of conservative Tx	
major exclusion criteria	none listed	1) small herniation (<1/3 of spinal canal); 2) prior surgery; 3) other LS pathology or CES; 4) psychiatric disease	1) prior LS op; 2) extraforaminal herniation or CES; 3) additional LS pathology; 4) rheumatic disease	
affected levels	MI [‡]	MI	MI	Open
L1–2	2	0	0	0
L2–3	7	0	0	0
L3–4	20	5	1	3
L4–5	33	67	29	56
L5–S1	38	94	40	83
treatment groups	open: open microdiscectomy; MI: full-endoscopic discectomy	open: open microdiscectomy; MI: tubular discectomy	open: open microdiscectomy & open discectomy; MI: micro-endoscopic discectomy	
outcome measures	VAS, ODI, NASS instrument score	RDQ, VAS, SF-36	VAS, ODI, SF-36	
mean follow-up (mos)	24	24	24	
method of randomization	alternating	computer-generated block schedule	computer-aided	
blinding?	no	yes	no	
attrition (%)	11	10	9	
intention-to-treat?	yes	yes	yes	

* NASS = North American Spine Society; RDQ = Roland-Morris Disability Questionnaire.

[†]Number of patients and levels involved reflect the patients who were randomized, but which patients were lost to follow-up is not specified.