Motor Recovery Depends on Timing of Surgery in Patients With Lumbar Disk Herniation

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BACKGROUND: Although approximately half of the patients undergoing lumbar disk surgery present with motor deficits, timing of surgery for radicular weakness is largely unclear.
OBJECTIVE: To evaluate the impact of surgical timing on motor recovery in patients with lumbar disk herniation (LDH) and to identify an ideal time window for intervention.
METHODS: In a single-center observational trial, 390 patients with LDH-associated motor deficits were prospectively followed for a minimum of 12 months after nonelective microscopic disk surgery. The duration of motor deficit before surgery was documented. Motor function was graded according to the Medical Research Council (MRC) scale. Statistical analysis of motor recovery applied unbiased recursive partitioning conditional inference tree to determine cutoff times for optimal surgical intervention. The slope of recovery calculated as the change of the MRC grade over time served as the primary outcome.
RESULTS: A preoperative motor deficit of MRC ≤2/5 and the duration of paresis were identified as the most important predictors of recovery ($P < .001$). Surgery within 3 days was associated with a better recovery for both severe and moderate/mild deficits ($P = .017$ for MRC ≤ 2/5; $P < .001$ for MRC > 2/5; number needed to treat [NNT] <2). A sensitivity analysis in mild motor deficits indicated a cutoff of 8 days.
CONCLUSION: Timing of surgery is crucial for motor recovery in LDH-associated deficits. Immediate diagnosis, imaging, and referral should be aimed for to allow disk surgery within 3 days in patients with severe and moderate radicular weakness. If functionally disabling, even mild deficits may warrant decompression within a week.

KEY WORDS: Diskectomy, Lumbar disk herniation, Motor deficit, Paresis, Recovery, Surgical timing

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Lumbar disk herniation (LDH) constitutes the most common indication for lumbar spine surgery,[1] with more than 480 000 diskectomies performed per year in the United States alone.[2] LDH-associated motor deficits occur in 30% to 50% of these patients.[1,3] In case of cauda equina syndrome, decompressive disk surgery is performed as an emergency within 48 h.[4] In patients with radicular motor deficits, however, timing of disk surgery is largely unclear and recovery rates vary widely in the literature.[5-7] Surgical decompression within days after onset of paresis has not been adequately studied, particularly for individuals with mild motor deficits, who tend to improve with conservative care.[1,8,9] Consequently, primary care givers and neurologists commonly initiate conservative care first even in case of radicular weakness. Although delaying disk surgery is ill-advised in major radicular motor deficits[10] and the severity of preoperative paresis has been identified as a negative predictor for motor recovery,[6,7] recommendations on the urgency of diagnostic imaging and surgical decompression are lacking.[4,11-13]

In everyday practice, a significant proportion of patients do not regain full strength after disk surgery,[5] and these persistent motor deficits often impose a dramatic functional, psychosocial, and economic impact commonly on young patients. Preliminary data suggested timing to be crucial for recovery just like in cauda equina syndrome,[13] but long-term outcome data are not available.

The aim of this study was, therefore, to evaluate the impact of surgical timing on motor recovery in patients with LDH and to identify an ideal time window for surgical intervention.

ABBREVIATIONS: LDH, lumbar disk herniation; **MRC,** Medical Research Council; **URP,** unbiased recursive partitioning; **URP-CTREE,** unbiased recursive partitioning conditional inference tree.

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METHODS

Trial Design

This investigator-initiated, observational study was performed in accordance with the Declaration of Helsinki and approved by our institutional research ethics board (1004/2020, AN2021-1004). The trial was funded by the Department of Neurosurgery, Medical University Innsbruck, Innsbruck, Austria, with no industry involvement. Patients were recruited retrospectively while follow-up examinations were performed prospectively after obtaining informed consent. The authors vouch for the completeness and accuracy of the data.

Enrollment

Adult patients presenting nonelectively to the outpatient clinic or emergency department with an LDH-associated radicular motor deficit and advancing to surgery were consecutively enrolled between January 2013 and December 2015. LDH was confirmed by magnetic resonance imaging and/or computed tomography. Flexion/extension views were taken in case of a symptomatic recurrence or present spondylolisthesis to rule out instability. Imaging was either performed before neurosurgical consultation or initiated as an emergency procedure on-site. The indication for surgery was based on clinical parameters and correlating imaging results. Patients without motor deficits, with extraforaminal disk herniations, and subjects not qualifying for anesthesia or denying surgery were excluded from this study. Patients were treated with analgesics and re-examined to diminish the effect of pain-induced weakness.

Patient Characteristics

Detailed information including demographics, medical history, surgical details, and radiographic data plus neurological signs and symptoms were collected.

Surgical Procedure

Surgery involved a standard microscopic disk operation with fragmentectomy only in most cases using an interlaminar speculum-based approach. If a large annular defect was present, a microdiskectomy was performed. As a departmental routine, patients with LDH-associated motor deficits were acutely presented to anesthesia for unscheduled surgical intervention.

Outcome (Dependent Variables)

Motor deficits were graded by manual and functional muscle testing according to the Medical Research Council (MRC) scale, where grade 0 represents no activity in the muscle and grade 5 is full strength/normal. The MRC scale was assessed before surgery and on follow-up at discharge, 6 and 12 wk, and 1 to 5 yr. These tests were performed by a neurosurgical resident or fellow and, in succession, a board-certified neurosurgeon.

Predictors (Independent Variables)

Main predictor variables of interest included preoperative muscle strength and timing of surgical decompression relative to the onset of paresis. The duration of the motor deficit before surgery was documented based on a detailed history and outpatient records. The time interval could be exactly determined in hours in some cases but was mostly assessed in days after onset. Depending on emergency triage and operating room availability, surgery may have been possible immediately or may have been scheduled for the next day. This ultimately means that the duration of paresis depended mainly on extramural factors, that is, the time until patient presentation to the Department of Neurosurgery and to some (lesser) extent on operating room availability. Other assessed covariates included sex, age, body mass index, and surgical level of decompression.

Statistics

Unbiased recursive partitioning (URP) conditional inference tree (CTREE) was applied to examine the relationship between surgical timing and the recovery of muscle strength. In brief, URP is a tree-based model that tests the independence of predictors and a prespecified outcome.[14] URP follows 2 fundamental steps, which repeat after each split from the original heterogeneous population. In the first step, if at least one of the predictors is significantly associated with the outcome, the algorithm selects a "split" of the predictor variable at a cutoff value yielding the smallest *P* value (adjusted for Bonferroni correction). If there is no significant association between predictors and outcome, the algorithm stops. In the second step, after a significant split, URP then calculates another possible split from the new subset created. These steps are repeated until all possible interactions are evaluated. A variable not included in the "tree" has no association with the outcome. Among benefits of URP is the provision of unbiased cutoff values for clinical decision making.[15-17]

To account for the longitudinal nature of our study, MRC was characterized for each subject by estimating a recovery slope. This was performed using all available data for a given subject by using a linear mixed model with random effects. Higher slope of MRC recovery indicates a combination of faster and greater total muscle strength achieved (see **Supplemental Figure**, http://links.lww.com/NEU/A962). Based on the cutoff time(s) established by URP for the slope of recovery, we examined changes in MRC between preoperation and last follow-up at 1 or 5 yr. To this end, subjects were categorized as "unchanged," "improved," or "fully recovered." To account for the impact of initial motor weakness severity, this procedure was performed separately for patients with "mild" (MRC = 4/5), "moderate" (MRC = 3/5), and "severe" (MRC ≤ 2/5) preoperative deficits.

For our URP analysis, $P < .05$ was set as statistically significant. All analyses were performed using *R Statistical Software* (R Core Team, GNU GPL). R package "party" was used for URP, and R package "lme4" was used for the linear mixed-effects analysis. All analyses are available at https://rpubs.com/AnhKhoaVo/627829.

Sensitivity Analysis of Mild Motor Weakness

A sensitivity analysis of individuals with mild motor weakness was performed to further examine surgical timing. This involved URP of the last follow-up MRC in individuals with a preoperative score of 4 (dependent variable), with surgical timing included as the predictor (independent variable). This was performed in response to our primary analysis for the purpose of determining whether surgery could be delayed in mild cases.

RESULTS

A total of 390 patients with motor deficits related to LDH underwent microscopic disk surgery between 2013 and 2015. The follow-up rate was 99.7% (389/390 patients) at the last visit (ie, 1-5 yr). The mean follow-up was 43.4 ± 19.7 mo (12-73 mo).

Within this cohort, 161 (41.3%) were female and the mean age was 50.6 ± 14.7 yr. Preoperatively, 118 (30.3%), 191 (49.0%), and 81 (20.8%) patients presented with mild (MRC 4/5), moderate (MRC 3/5), and severe motor deficits (MRC ≤ 2/5), respectively. The segment L4/L5 was the most common level of disk herniation, followed by L5/S1 and L3/L4 (Table).

Analysis of Muscle Strength Recovery

Severity of paresis was the most important predictor indicating worse outcome for MRC ≤ 2/5 ($P < .001$). URP muscle strength recovery clearly demonstrated the benefits of early surgical decompression and identified a time limit of 3 days. For individuals with more severe preoperative deficit (ie, ≤ 2/5), surgical decompression within 3 days of motor weakness onset was associated with better outcomes (ie, higher slopes; $P = .022$). Early decompression surgery within 3 days of motor weakness onset also benefited individuals with less severe preoperative motor weakness (ie, >2/5; $P < .001$). The URP "tree" for muscle strength recovery is shown in Figure 1A.

Based on the identified 3-day cutoff, changes in MRC between preoperation and last follow-up revealed benefits of early decompression (Figure 1B). For example, in patients with severe preoperative muscle weakness operated within 3 days, 61% achieved full muscle strength at last follow-up (MRC 5/5). Comparatively, no patients with severe preoperative muscle weakness operated after 3 days achieved full recovery of muscle weakness (**Supplemental Table**, http://links.lww.com/NEU/A963).

Sensitivity Analysis

Timing of surgical intervention remained significantly predictive of MRC at long-term follow-up in patients with mild preoperative motor weakness. Decompression surgery within 8 days yielded >90% of patients achieving full recovery (Figure 2).

DISCUSSION

In a study of 390 consecutive patients with motor deficits resulting from LDH, recovery of muscle strength was associated with preoperative impairment and surgical timing. The importance of surgical timing was evidenced in an unbiased statistical analysis that identified 3 days as a critical cutoff for full motor recovery. This time window may revolutionize everyday management of disk patients with motor weakness.

Conservative treatment is indicated in most of the patients with LDH, with only approximately 20% requiring surgical intervention because of persistent pain after 6 to 12 wk.[18,19] Surgery, however, favors better short-term outcomes for sciatica, back pain, and neurological deficits compared with conservatively treated patients.[5,20-22] Better outcomes and recovery have been reported for surgery associated with cauda equina symptoms, with a recommended critical window of 48 h.[4,11] To this point, evidence concerning the optimal time window for nerve root decompression in cases with motor weakness is limited. In theory, susceptibility to compression should not differ between all cauda equina nerve roots and single-motor nerve roots, with Wallerian degeneration being related to the degree of compression.[23]

Key Results

According to our unbiased statistical analysis, preoperative motor function is the most important predictor for complete functional recovery. The critical cutoff value for MRC was 2, with patients preoperatively scoring at or below this value achieving worse outcomes. An inverse correlation between the degree of recovery of motor function and preoperative severity has been previously described.[6,7,24] Most other studies are, however, limited by small numbers or delayed treatment.[6,25]

This study demonstrates significantly better outcomes in early treated patients (≤3 days after onset), independent of the degree of motor deficits ($P < .001$). Higher slopes of recovery for early treated patients indicate a greater total and higher recovery rate, shortening the recuperation process. Furthermore, motor strength at 3 months strongly correlates with final outcome ($r = 0.96$), indicating early recovery and allowing predictions at short-term follow-up.

Interpretation

Superior motor recovery has been shown in patients treated within 48 h supporting the importance of a timely patient management.[4,13] Early surgery in patients with associated moderate or severe motor impairment would have a number needed to treat of 1.4 or 1.6, respectively, to prevent incomplete recovery. Delayed surgical intervention did not positively alter the outcome in a recent study comparing medically and surgically treated patients with a moderate or severe (≤3/5 MRC) paresis.[26] Furthermore, recovery rates below 20% have been reported in patients with high-degree paresis of ankle dorsiflexion. These results are comparable with delayed treated patients of this study because the earliest time point of surgery was 4 days after onset.[5]

Our data strongly indicate better outcomes in early treated patients with severe and/or moderate paresis, as 61% and 97.4%, respectively, recovered if treated within 3 days. Based on the very early decompression, these recovery rates are superior to previous studies.[4-6,24,26] Hence, these patients should be triaged as a medical emergency by the attending general practitioner or neurological specialist. A prompt surgical consultation is key to increase the likelihood of neurological recovery. These findings support a patient management comparable with those presenting with cauda equina syndrome, which would dramatically affect everyday care of patients with LDH.

Lumbar disk surgery is usually not performed immediately in patients with mild deficits. Indeed, conservative management in these cases often yields acceptable levels of recovery.[8] In our center, the decision for surgery is made on the basis of whether the mild impairment is functionally debilitating. Oftentimes, this is related to motor weakness in knee extensors, which ultimately limits ambulation. The question raised from our primary analysis

TABLE. Summary of Individuals' Demographics, Deficits, and Time-Dependent Motor Outcomes

Patients' characteristics	≤3 days (n = 212)	>3 days (n = 178)	Overall (n = 390)
Level			
L2/L3	12 (5.7%)	3 (1.7%)	15 (3.8%)
L3/L4	23 (10.8%)	25 (14.5%)	48 (12.3%)
L4/L5	120 (56.6%)	101 (56.7%)	221 (56.7%)
L5/S1	57 (26.9%)	49 (28.3%)	106 (27.2%)
Sex			
Female	83 (39.2%)	78 (43.8%)	161 (41.3%)
Male	129 (60.8%)	100 (56.2%)	229 (58.7%)
Age			
Mean (SD)	48.8 (14.5)	52.9 (14.6)	50.6 (14.7)
Median [min, max]	46.7 [20.9, 86.9]	52.1 [22.0, 91.7]	48.9 [20.9, 91.7]
BMI			
Mean (SD)	25.9 (4.48)	26.1 (4.09)	26.0 (4.30)
Median [min, max]	25.0 [17.9, 46.6]	25.7 [16.8, 40.8]	25.3 [16.8, 46.6]
Missing	1 (0.5%)	0 (0%)	1 (0.3%)
Preoperative motor deficit			
Severe (MRC ≤ 2/5)	41 (19.3%)	40 (22.5%)	81 (20.8%)
Moderate (MRC 3/5)	115 (54.3%)	76 (42.7%)	191 (49%)
Mild (MRC 4/5)	56 (26.4%)	62 (34.8%)	118 (30.2%)
Slope			
Mean (SD)	0.328 (0.0230)	0.272 (0.0580)	0.302 (0.0509)
Median [min, max]	0.338 [0.197, 0.354]	0.284 [0.113, 0.338]	0.332 [0.113, 0.354]
Motor deficit at 3 months follow-up			
Severe	3 (1.4%)	31 (17.4%)	34 (8.7%)
Moderate	5 (2.4%)	33 (18.5%)	38 (9.7%)
Mild	15 (7.1%)	28 (15.7%)	43 (11%)
Recovered	168 (79.2%)	47 (26.4%)	215 (55.1%)
Missing	21 (9.9%)	39 (21.9%)	60 (15.4%)
Motor deficit at last follow-up			
Severe	1 (0.7%)	17 (9.6%)	18 (4.6%)
Moderate	15 (7%)	49 (27.5%)	64 (16.4%)
Mild	4 (1.8%)	47 (26.4%)	51 (13%)
Recovered	192 (90.5%)	64 (36%)	256 (65.6%)
Missing	0 (0%)	1 (0.6%)	1 (0.4%)

BMI, body mass index; MCR, Medical Research Council; SD, standard deviation.

was whether surgical intervention could be delayed beyond 3 days in mild cases. A sensitivity analysis confirmed the importance of timing but shifted the critical time window from ≤3 (ie, all subjects) to ≤8 days without sacrificing the likelihood of achieving full recovery. Early surgery in patients with mild motor deficits would have a number needed to treat of 4.4 to prevent incomplete recovery, supporting the importance of early action in cases of debilitating deficits. Furthermore, no secondary deterioration was observed in those patients supporting the safety of this surgical intervention.

Limitations

This study has limitations that warrant discussion. First, because of its observational nature, patients were not randomized to early and late intervention, which may introduce potential confounding effects and bias. However, randomizing patients to delayed treatment would represent a major ethical challenge. Second, a conservative control group was not included. This limits the interpretation of our results only to patients who ultimately undergo surgical intervention, although it may be hypothesized that conservative management should at best approach the results of delayed surgical care. Third, this study and subsequent analysis reflect enrollment at a single center, which limits generalizability. In addition, mild paresis (MRC 4/5) can represent a range of motor dysfunctions from minimal weakness to a truly debilitating deficit hindering ambulation. Finally, the exact onset of motor impairment might remain uncertain in case of a mild course of disease.

Generalizability

This study was performed at a third-level clinic, which leads to some selection bias, because many patients are referred to our department for acute treatment in case of (moderate to severe) neurological deficits. A large number of consecutively enrolled

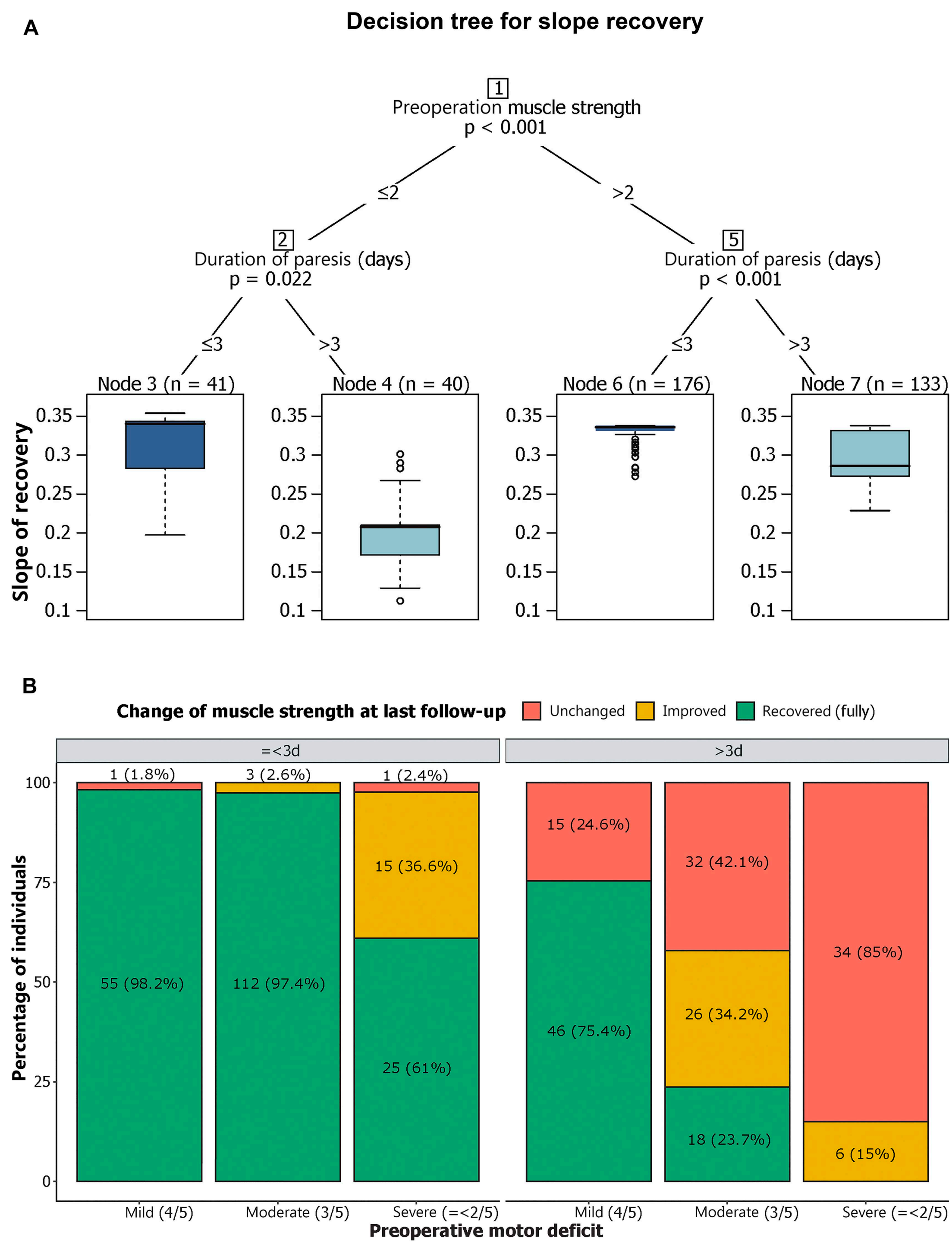

FIGURE 1. *Recovery of muscle strength after disk surgery for LDH-associated motor deficit.* **A**, *URP-CTREE revealed preoperative muscle strength and duration of paresis as predictors for recovery. A time interval of 3 days was identified as an unbiased cutoff for recovery.* **B**, *Bar graph illustrating the percentage of patients with mild, moderate, or severe motor deficit recovering fully (green), improving (orange) or staying unchanged (red). Excellent recovery after surgery within 3 days (left) contrasts poor recovery particularly for moderate and severe deficits after delayed decompression (>3 days, right). LDH, lumbar disk herniation; URP-CTREE, unbiased recursive partitioning conditional inference tree.*

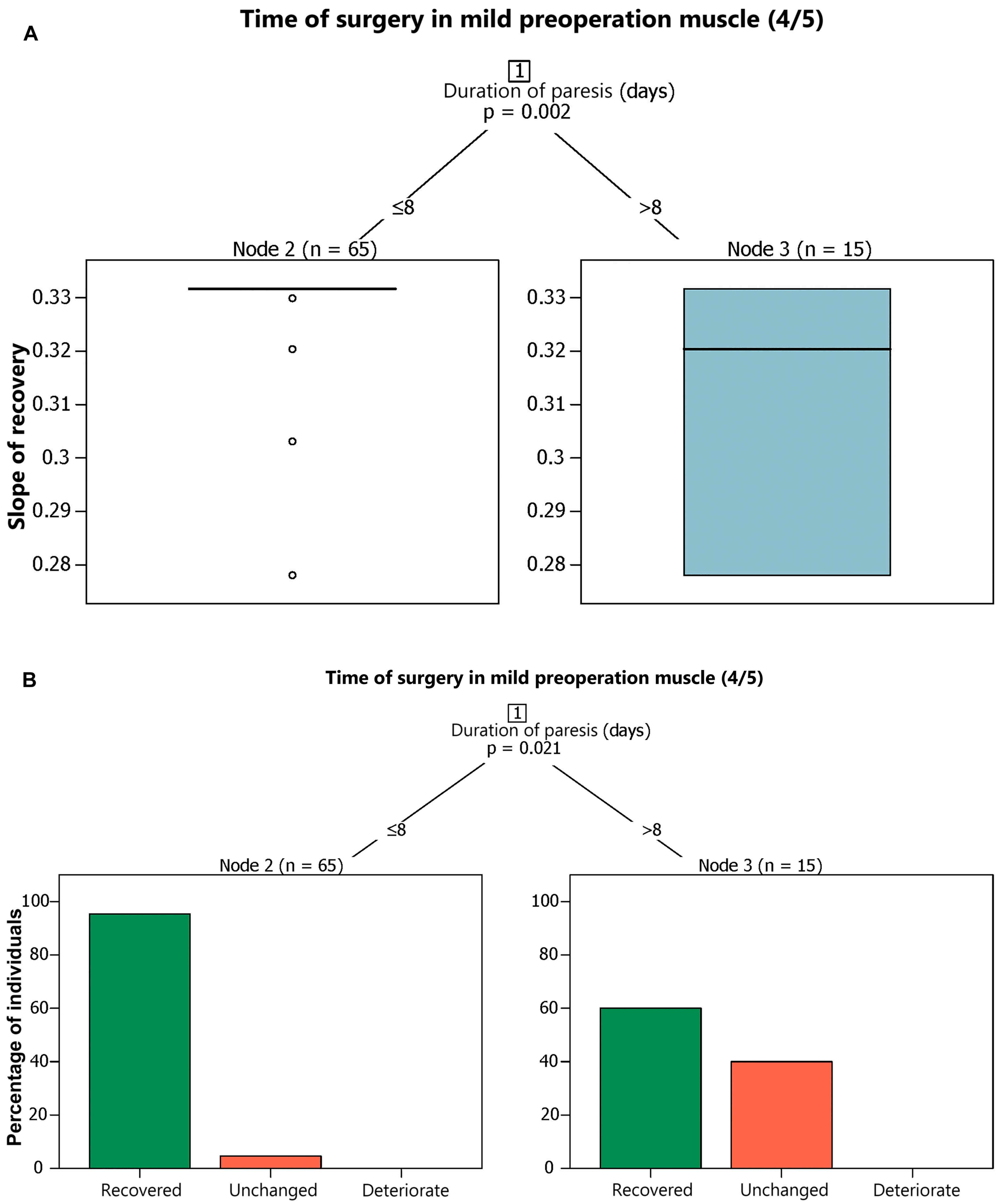

FIGURE 2. *Recovery of muscle strength after disk surgery in the subgroup of mild LDH-associated motor deficit.* **A**, *URP-CTREE identified a cutoff of 8 days as a predictor for recovery.* **B**, *Bar graph illustrating the percentage of patients recovering to normal function (green) vs those remaining with a mild deficit (red) or secondarily deteriorating after surgical intervention (not applicable) depending on the timing of surgery. LDH, lumbar disk herniation; URP-CTREE, unbiased recursive partitioning conditional inference tree.*

patients and a 99% follow-up to a long-term time point (ie, 1-5 yr postsurgery) represent major strengths of this study. Therefore, our data can be applied for counseling patients on whether to proceed with (early) surgery. To the best of our knowledge, we are the first to apply a data-driven approach to determine critical cutoffs for timing of surgical intervention for LDH. The advantage here is that we avoided a priori assumptions regarding the importance of surgical timing, thereby generating unbiased results. Compared with other statistical techniques, our results also provide discrete cutoffs that could be readily introduced into clinical practice.

CONCLUSION

The severity of LDH-associated paresis (MRC ≤2/5) significantly affects recovery rates. Early surgery within 3 days after onset should be offered to patients with a moderate and/or severe motor deficit because postponing treatment significantly decreases the likelihood of regaining full strength. Patients with mild weakness show acceptable recovery rates in case of delayed surgical intervention, but disk surgery within 8 days ensures recovery.

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Supplemental Figure. Exemplary illustration of the slope of recovery per patient calculated as change of muscle strength (MRC grade) over time from preoperatively (T1) to long-term follow-up at 1 to 5 yr after disk surgery (T5). MRC, Medical Research Council

Supplemental Table. Motor outcome depending on preoperative motor deficit and surgical timing of decompression