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Can Exercise Therapy Improve the Outcome of Microdiscectomy?

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Study Design. A prospective randomized controlled trial of exercise therapy in patients who underwent microdiscectomy for prolapsed lumbar intervertebral disc. Results of a pilot study are presented.

Objective. To determine the effects of a postoperative exercise program on pain, disability, psychological status, and spinal function.

Summary of Background Data. Microdiscectomy is often used successfully to treat prolapsed lumbar intervertebral disc. However, some patients do not have a good outcome and many continue to have low back pain. The reasons for this are unclear but impairment of back muscle function due to months of inactivity before surgery may be a contributing factor. A postoperative exercise program may improve outcome in such patients.

Methods. Twenty patients who underwent lumbar microdiscectomy were randomized into EXERCISE and CONTROL groups. After surgery, all patients received normal postoperative care that included advice from a physiotherapist about exercise and a return to normal activities. Six weeks after surgery, patients in the EXERCISE group undertook a 4-week exercise program that concentrated on improving strength and endurance of the back and abdominal muscles and mobility of the spine and hips. Assessments of spinal function were performed in all patients during the week before surgery and at 6, 10, 26, and 52 weeks after. The assessment included measures of posture, hip and lumbar mobility, back muscle endurance capacity and electromyographic measures of back muscle fatigue. On each occasion, patients completed questionnaires inquiring about pain, disability and psychological status.

Results. Surgery improved pain, disability, back muscle endurance capacity and hip and lumbar mobility in both groups of patients. After the exercise program, the EXERCISE group showed further improvements in these measures and also in electromyographic measures of back muscle fatigability. All these improvements were maintained 12 months after surgery. The only further improvement showed by the CONTROL group between 6 and 52 weeks was an increase in back muscle endurance capacity.

Conclusion. A 4-week postoperative exercise program can improve pain, disability, and spinal function in patients who undergo microdiscectomy. [Key words: electromyogram median frequency, exercise therapy, intervertebral disc prolapse, microdiscectomy, randomized controlled trial, spinal function. **Spine 2000;25:1523–1532**

Microdiscectomy is often used in the treatment of prolapsed intervertebral disc to relieve the associated leg pain. Its success rate compares favorably with that of other surgical techniques.[5,44,45] However, between 5% and 20% of patients do not have a satisfactory short-term outcome,[5,17,27,32] and many in whom surgery is deemed successful continue to have some degree of low back pain. This may explain why a recent review of 3,544 patients who had undergone lumbar disc surgery found that only 70% were fit to resume work within 12 months of operation.[14] The costs of such unsatisfactory outcomes are substantial, both to the patient in terms of quality of life and lost income and to employers, insurers, and health service providers in terms of the financial costs of work loss and subsequent treatment. In the United Kingdom, a report by the Clinical Standards Advisory Group[6] indicated that approximately 1% of the National Health Service budget was spent on treating low back pain in 1993, and results of a recent survey indicate that approximately 80% of the costs are accounted for by the small number of patients who progress to chronic back pain.[57]

The reasons some people have persistent pain after surgery remain unclear, although results of recent studies indicate that microdiscectomy is less successful for protruding discs than for extruded or sequestrated discs.[5,27,32] Other investigators have shown that a long duration of work incapacity before surgery is significantly associated with a poor outcome.[14,29] This could reflect the negative consequences of a longer period of nerve root compression. However, impairment of back muscle function due to months of continuing pain and inactivity before surgery may also be a contributing factor, especially in the United Kingdom, where waiting lists for surgery are particularly long.

Prolonged periods of inactivity due to pain may cause muscle atrophy,[7,26] and in patients with prolapsed intervertebral disc, such atrophy may become marked in the back muscles.[42] Atrophied muscles are excessively weak and fatigable, and fatigued back muscles allow increased bending stresses on the intervertebral discs and ligaments.[11] As well as causing inactivity, pain may lead to reflex inhibition of muscle, and this may contribute fur-

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ther to back muscle atrophy and weakness.[55] Pain may also lead to abnormal use of certain muscles, perhaps to splint and protect a painful part of the spine, and this may cause chronic fatigue in the affected muscles and increased loading of the underlying spine. Postural changes may also occur, especially in people with unilateral pain, and small changes in posture have a large effect on stress distributions within the intervertebral discs[1,2] and apophysial joints.[15] The result of these changes may be repeated small injuries that tend to exacerbate the original problem and prevent a good recovery.

Changes in muscle structure and function are unlikely to be corrected by surgery. On the contrary, surgery can cause muscle and/or nerve damage resulting in postoperative muscle atrophy.[50,51] Some investigators have reported persistent impairment of spinal mobility and muscle strength after surgery,[43] and in one case, postoperative impairment of muscle strength was directly related to the time of muscle retraction during surgery and the severity of low back pain in the follow-up period.[19] These factors may explain why treatment of the disc problem alone does not always lead to a good clinical outcome, and why a large percentage of patients who undergo disc surgery have residual back pain.[16]

Exercise has been shown to improve pain and disability in patients with nonspecific chronic low back pain,[18,24,30,35,54] and it may also benefit patients recovering from disc surgery. As well as improving spinal function in the short-term, a controlled exercise program may increase patients' confidence in their ability to exercise and perform manual work, and this could be of additional benefit in the longer term.

The purpose of the current study was to evaluate the effects of an early postoperative exercise program in patients who had undergone microdiscectomy, and to determine whether any reduction in pain and disability was associated with improvements in spinal function. This is a report of preliminary results based on the first 20 patients.

■ Materials and Methods

Subjects. Twenty-one patients aged between 18 and 60 years (18 men, 3 women) participated in the study. Patients were admitted if they had radiologic evidence of disc prolapse that was associated with sciatica of less than 12 months' duration that showed a typical nerve root distribution. Exclusion criteria included inflammatory disease, tumor, infection, and prior spinal surgery. All patients provided informed consent to participate in the study, which was approved by the Local Research Ethics Committee. (One patient withdrew from the study at 6 weeks, before the exercise program, and he was therefore excluded from all analyses.) The physical characteristics of the remaining 20 patients and the surgical levels are given in Table 1.

Table 1. Physical Characteristics and Operated Disc Levels for the Subjects Participating in the Study

	n	Age (years)	Height (cm)	Weight (kg)	Operated Discs Level
Exercise	9 (9m)	39.2 (9.4)	179.4 (3.8)	86.9 (11.6)	L4–5 (2); L5–S1 (7)
Control	11 (8m:3f)	42.7 (10.1)	173.2 (7.5)	79.5 (15.3)	L4–5 (3); L5–S1 (8)

For age, height, and weight, values are the mean (±STD). m = male; f = female.

Experimental Protocol. On entry into the study, all patients were blindly randomized into an EXERCISE or CONTROL group. During the week before surgery, they underwent an assessment of spinal function that included measurements of posture, mobility, and back muscle fatigability. During the first 6 weeks after surgery, all patients received normal postoperative care that included advice from a physiotherapist about exercise and a return to normal activities. At the end of this time, patients underwent a further spinal assessment, after which patients in the EXERCISE group embarked on a 4-week exercise program. Patients in the CONTROL group received no further treatment. Subsequent assessments of spinal function were performed 10, 26, and 52 weeks after surgery. Before each functional assessment, patients completed questionnaires inquiring about pain, disability, and psychological status, so that these clinical outcome measures could be compared with objective measures of spinal function.

Assessment of Pain, Disability, and Psychological Status. Pain was assessed using two methods: a visual analog scale (VAS) completed the day before each assessment on which usual levels of pain are scored between 0 and 100 mm, where 0 is no pain and 100 is the worst pain imaginable, and a pain diary completed four times each day during the week before each assessment, scored between 0 and 5, where 0 is no pain and 5 is intense, incapacitating pain.

Disability was measured using the Low Back Outcome Score.[23] This questionnaire is used to assess a wide range of factors, each scored on a 4-point scale to avoid an average option. Overall outcome is scored between 0 and 75 and is categorized as excellent (65–75), good (50–64), fair (30–49), or poor (0–29).

Psychological status was assessed using a series of psychometric questionnaires including the Multidimensional Health Locus of Control (HLC), the Modified Somatic Perception Questionnaire (MSPQ), and the Zung Depression Scale (ZUNG). The HLC[56] is an assessment of beliefs and attitudes about health and sickness, which are scored in three separate categories: the internal locus (IHLC; personal control of health); chance locus (CHLC; chance plays a large part in determining health); powerful others locus (PHLC; other individuals such as physicians and family play a large part in determining health). Each locus is scored between 6 and 36, with high scores indicating a strong belief in that category. The MSPQ[33] assesses heightened somatic perception and is scored between 0 and 39, with higher scores indicating higher levels of somatic awareness. The ZUNG[58] is used to measure anxiety and depression and is scored between 0 and 60, with higher scores indicating increased levels of depression.

Posture and Mobility Measurements. These were made using an electromagnetic tracking device, the 3-Space Isotrak (Polhemus, Colchester, VT, USA),[9] which consists of a source and a sensor of electromagnetic waves. The three-dimensional orientation and position of the sensor relative to the source can be recorded at either 28 or 60 Hz. The sacral angle was measured as shown in Figure 1, by attaching the Isotrak source to

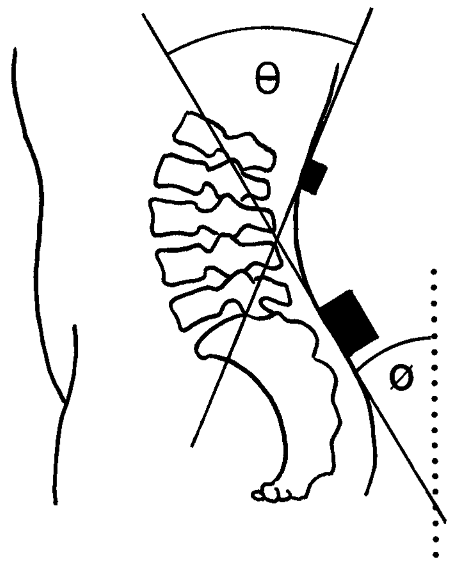


Figure 1. The angle between the vertical and the tangent to the skin surface at S1–S2 was termed the sacral angle (ø), and the angle between the tangent to the skin surface at L1 and the tangent at S1–S2 was termed the lumbar curvature (Θ).

the skin overlying the sacrum at the S1 spinous process, and placing the sensor on a vertical post near the subject. Patients stood in a relaxed position with legs straight, arms by the side, and head erect, with a horizontal line of sight. The angle between source and sensor in the sagittal plane then indicated the sacral angle in standing. This was measured on four occasions at 1-minute intervals and a mean value determined.

The sacral angle in flexion was measured while patients stood and flexed forward as far as they could. The difference in sacral angle between standing and full flexion indicated the range of hip flexion movement. This range of movement was measured in a similar manner when patients sat and attempted to touch their toes, and the greater of the two values was taken as the patient's hip range of flexion. The hip range of extension was similarly defined from changes in the sacral angle when patients attempted to bend backward as far as they could, both in standing with legs straight and when lying prone.

Lumbar curvature between L1 and S1 was determined by attaching the sensor to the skin overlying the L1 spinous process and measuring the angle between sensor and source in the sagittal plane (Figure 1). Measurements of lumbar curvature in relaxed standing, forward flexion, and backward bending were measured as described for the sacral angle. In addition, measurements of lateral flexion were made while patients stood and bent as far as they could to each side while keeping their legs straight and their feet placed firmly on the floor. In these latter tests, the angle in the frontal plane was measured and used as a measure of maximal right and left side flexion.

The ranges of lumbar flexion and extension were determined by subtracting the mean lumbar curvature in standing from the peak value in each movement. The range of lateral bending was determined as the range of movement between full right- and left-side flexion.

Electromyography. Surface electromyography was used to record the electrical activity of the paraspinal muscles, as described previously.[10] Pairs of disposable electrodes (Biotrace; MSB, Marlborough, UK) were attached bilaterally to the skin at T10 and L3, approximately 5 cm from the midline, and a reference electrode was placed over the sternum. Before the electrodes were attached, the skin was abraded and cleaned with alcohol until the impedance between the reference and recording electrodes was less than 10 kΩ. This procedure ensures a good signal-to-noise ratio and reduces the problem of movement artifact.

Assessment of Back Muscle Fatigue. Fatigue was assessed during the Biering-Sorensen test[4] in which patients lay prone on an examination couch with the ankles and hips firmly secured, and the upper body, above the level of the iliac crest, overhanging the edge. Patients were asked to keep the unsupported upper body horizontal for as long as possible. Throughout the test, the electromyographic activity of the paraspinal muscles, and the lumbar curvature were recorded.[37] The time at which the subject could no longer maintain the horizontal position was recorded as the subject's endurance time.

Frequency Analysis of Electromyographic Signal. The raw electromyographic signal recorded during the fatigue test was filtered with a band-pass of 5–300 Hz, A/D converted at 1024 Hz, and stored on a microcomputer.[12] Subsequently, 1.0-second epochs of the raw data were subjected to fast Fourier analysis to express the frequency content of the electromyographic signal in terms of a power spectrum. The median frequency of the power spectrum declines as muscle fatigues, and the rate at which this occurs is often used as a measure of muscle fatigability. In the paraspinal muscles, the rate of decline is acceptably linear,[12] and linear regression was therefore used to determine the initial median frequency (IMF) at each muscle site and its rate of decline during the test (the median frequency gradient: MFG). The most rapid rate of decline at any site (MFG_{max}) was also determined, because it best reflects the endurance capacity of the muscle.[37] The IMF indicates the frequency components of the active motor units at the beginning of the fatigue test and is thought by some researchers to be related to the fiber type composition of the muscle.[20,21]

Exercise Program. The exercise program consisted of two 1-hour sessions per week for 4 weeks, beginning 6 weeks after surgery. The exercise class was run by an experienced physiotherapist, and patients were allowed to progress at their own pace. The program consisted of general aerobic exercises, including treadmill walking, step-ups, and dumbbell lifts; stretching exercises to improve mobility, including side bends, knees to chest, and extension exercises for the back and hips, and also a series of exercises designed to improve the strength and endurance of the back and abdominal muscles, including abdominal curls, straight leg raises, pelvic lifts, back lifts, and a back endurance test (the Biering-Sorensen test.[4]

Statistical Analysis. Comparisons between patients in the EXERCISE and CONTROL groups were made using group *t* tests. Changes over time within each of the groups were assessed using repeated-measures analysis of variance. Estimates of the Pearson product correlation coefficient were used to identify significant correlations between measures of pain, disability, psychological status, and spinal function. Significance was accepted at the 5% level.

Table 2. Mean Values and 95% Confidence Intervals (CI) for Various Physical and Psychological Measures in 403 Healthy Subjects With No Previous History of Low Back Pain

	Female Subjects (n = 371)		Male Subjects (n = 32)	
Variable	Mean	95% CI	Mean	95% CI
IHLC	25.4	16.8–33.9	26.9	17.9–35.8
PHLC	12.7	5.1–20.3	13.5	4.7–22.2
CHLC	16.5	7.3–25.8	14.1	5.1–23.1
MSPQ	3.0	0.0–8.5	2.7	0.0–7.4
ZUNG	11.8	0.0–24.4	9.7	1.8–17.5
MSPQ + ZUNG	14.8	0.0–29.9	12.4	3.1–21.6
Hip ROF (deg)	77.9	51.3–104.6	72.8	50.5–95.1
Hip ROE (deg)	16.3	1.8–30.8	20.7	6.4–34.9
Lumbar ROF (deg)	56.8	38.2–75.4	53.1	35.9–70.2
Lumbar ROE (deg)	32.8	6.4–59.2	28.9	4.4–53.4
Lumbar ROLB (deg)	52.8	33.9–71.7	49.6	31.4–67.9
Endurance time (sec)	150.4	32.2–268.6	135.3	12.7–257.9
MFI: T10 (Hz)	66.0	45.6–86.5	64.3	42.1–86.6
MFI: L3 (Hz)	62.6	41.3–84.0	66.4	40.4–92.4
MFG: T10 (%/sec)	−0.24	−0.02–−0.47	−0.33	0.06–−0.72
MFG: L3 (%/sec)	−0.25	−0.01–−0.49	−0.43	−0.03–−0.83
MFG: max (%/sec)	−0.28	−0.05–−0.52	−0.45	−0.06–−0.84

See Tables 3 and 4 and Figure 5 for explanation of abbreviations.

Results

The EXERCISE and CONTROL groups were compared before and 6 weeks after surgery to ensure that the randomization procedure had not introduced any bias that might influence the outcome of the study. No significant differences were found in any of the parameters at these two time points, with the exception of hip range of flexion, which, at 6 weeks, was significantly higher in the CONTROL group because of the larger ranges of hip flexion in the women. In all other respects, the groups could be considered equivalent before the exercise program. Excluding the female data for hip flexion did not affect the significance of the changes during the follow-up period, and therefore the female data have been included throughout.

Changes over time within each group of patients are presented below. With the exception of the pain and disability scores, all parameters had been measured previously in 403 healthy volunteers with no history of low back pain. Comparison of the initial patient data with this database of normal values indicated the extent of any psychological abnormality and functional impairment at the time of entry into the study. It also enabled improvements over the course of the study to be considered in relation to normal values. The normative data used for this purpose (mean values and 95% confidence limits) are shown in Table 2.

Differences between the EXERCISE and CONTROL groups from 10 weeks onward are presented in the appropriate sections in those instances in which they reached significance.

Pain

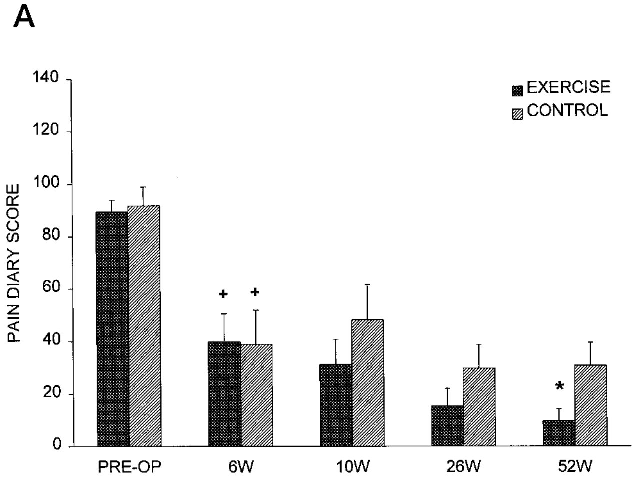
Pain diary scores and VAS scores are shown in Figure 2. Before surgery, both groups reported high levels of pain on both scales, but 6 weeks after surgery, pain diary scores were reduced by 55% and 58% in the EXERCISE ($P < 0.0001$) and CONTROL ($P < 0.0001$) groups, respectively. The VAS scores showed a similar level of reduction (EXERCISE, $P < 0.0001$; CONTROL, $P < 0.01$). Four patients in the EXERCISE group and five in the CONTROL group reported persistent back pain after surgery, compared with six in the EXERCISE group and four in the CONTROL group who reported persistent leg pain. After completing the exercise program, the EXERCISE group showed further reductions in pain diary and VAS scores, which reached significance at 12 months. The CONTROL group, however, showed no further significant decrease in either of the pain scores.

Comparisons between the two groups at 12 months showed that pain diary scores were significantly lower in the EXERCISE group than in the CONTROL group ($P < 0.05$) but the difference in VAS scores barely failed to reach significance ($P = 0.08$).

Disability

Low-Back Outcome Scores before and after surgery are shown in Figure 3. Both groups reported high levels of disability before surgery with mean (±SD) scores of 23 ± 16 and 23 ± 14 in the EXERCISE and CONTROL groups, respectively. Six weeks after surgery, significant improvements in disability were reported by both groups, with scores increasing to 54 ± 21 in the EXERCISE group ($P < 0.002$) and 50 ± 25 in the CONTROL group ($P < 0.01$). The EXERCISE group showed further increases in Low Back Outcome Score, which reached significance at 12 months when compared with the 6-week value, whereas the CONTROL group showed no further significant improvement.

Based on the classification system given earlier, both groups showed a good outcome 6 weeks after surgery. However, at 12 months, the Low Back Outcome Score was significantly higher in the EXERCISE group ($P < 0.05$) in which all but one person obtained a score of 74



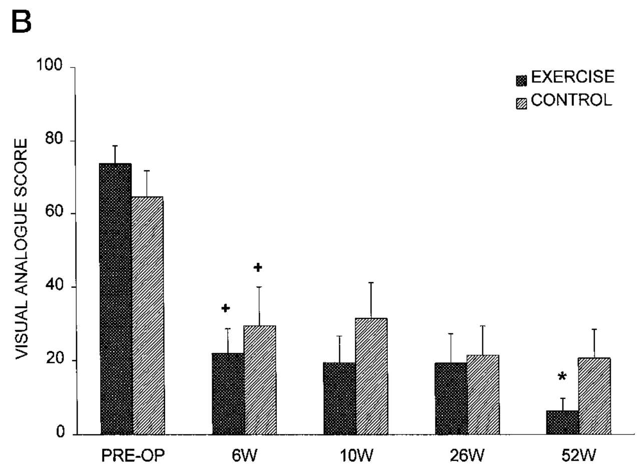


Figure 2. Pain diary scores (**A**) and visual analog scales scores (**B**) in the EXERCISE and CONTROL groups, before surgery (preop) and at 6, 10, 26, and 52 weeks after. Bars, SEM. Significant differences within each group are indicated compared with presurgery values (+) and with values 6 weeks after surgery (*).

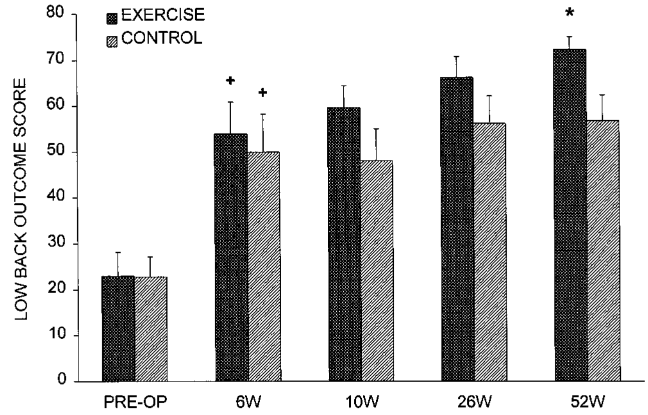


Figure 3. Low Back Outcome Scores in the EXERCISE and CONTROL groups, before surgery (preop) and at 6, 10, 26, and 52 weeks after. Bars, SEM. Significant differences within each group are indicated compared with presurgery values (+) and with values 6 weeks after surgery (*).

or 75, indicating an excellent outcome. In the CONTROL group, the average score of 57 at 12 months indicated a good outcome for the group as a whole, although there was considerable variation between patients, with three categorized as excellent, two as good, five as fair, and one as poor.

Psychometric Scores

Scores for the Health Locus of Control (IHLC, PHLC, CHLC), MSPQ, and ZUNG are shown in Table 3. All three HLC scores before surgery were similar to those obtained in healthy subjects (Table 2). These scores showed little change in either group 6 weeks after surgery or during the follow-up period. The only exceptions were a small decrease in PHLC in the CONTROL group at 12 months and an increase in IHLC in the EXERCISE group at 6 and 12 months. The MSPQ, ZUNG, and MSPQ+ZUNG scores before surgery were slightly higher than in healthy subjects (Table 2) but 6 weeks after surgery were reduced in both groups to normal levels. Thereafter, both scores showed little further change.

Posture and Mobility

Measures of sacral angle and lumbar curvature in standing, and of hip and lumbar ranges of motion are shown in Table 4. Before surgery, hip and lumbar ranges of flexion were greatly reduced and lay outside the normal range of values obtained in healthy subjects (Table 2). Other measures were within the normal range, but most were well below average values. Six weeks after surgery, both groups showed large and significant increases in hip and lumbar ranges of flexion (Figure 4), although all other measures remained unchanged. At 10 weeks, the EXERCISE group showed further significant increases in hip and lumbar ranges of flexion that were maintained up to 12 months after surgery. Patients in the EXERCISE group also showed a significant improvement in lumbar range of lateral bending at 6 and 12 months compared with values before and 6 weeks after surgery. Patients in the CONTROL group showed no further significant changes beyond those observed at 6 weeks.

Measures of Back Muscle Endurance and Fatigue

Endurance time, IMF, and MFG during the performance of the Biering-Sorensen test are shown for both groups in Figure 5. For conciseness, IMF values have been shown for a single muscle only, but these were typical of the four sites assessed. For MFG, the maximum value attained at any of the four sites (MFG_{max}) is shown, because this best correlates with the endurance capacity of the paraspinal muscle group.

Before surgery, endurance times were low compared with those of healthy subjects (Table 2) but these were improved 6 weeks after surgery, reaching significance in the EXERCISE group ($P < 0.05$) but not in the CONTROL group (Figure 5A). Ten weeks after surgery, both groups showed further improvements in endurance time, although again these reached significance only in the EXERCISE group. At 6 and 12 months, endurance time was significantly improved in both groups compared with values before and 6 weeks after surgery.

Table 3. MSPQ, Zung, and Health Locus of Control Scores Before Surgery (Pre-Op) and at 6, 10, 26, and 52 Weeks After

	Pre-op	6 W	10 W	26 W	52 W
Exercise					
MSPQ	3.0 (2.1)	1.3 (1.0)	1.2 (1.6)	1.3 (1.8)	1.5 (2.1)
ZUNG	18 (11)	11 (8)	8 (6)*	7 (6)*	7 (3)*
MSPQ + ZUNG	21 (13)	13 (8)*	9 (7)*	9 (8)*	8 (3)*
IHLC	23 (4)	24 (6)	24 (6)	26 (4)*†‡	27 (4)*†‡
PHLC	12 (3)	12 (4)	12 (3)	10 (2)	11 (4)
CHLC	16 (10)	17 (7)	16 (7)	17 (7)	17 (8)
Control					
MSPQ	5.7 (6.4)	1.0 (1.1)*	1.0 (0.9)*	1.3 (1.8)*	1.5 (1.5)*
ZUNG	16 (6)	9 (6)*	7 (5)*	9 (8)*	8 (5)*
MSPQ + ZUNG	22 (5)	10 (6)*	8 (5)*	10 (8)*	9 (6)*
IHLC	26 (5)	25 (6)	26 (3)	26 (4)	25 (6)
PHLC	16 (7)	15 (7)	15 (9)	15 (7)	12 (4)*
CHLC	19 (2)	19 (5)	19 (7)	19 (6)	17 (7)

IHLC = internal locus; PHLC = powerful others locus; CHLC = chance locus.
Mean (STD) values are shown for each group. (Significant differences within each group are indicated compared to *presurgery values, and to values †6 weeks, and ‡10 weeks after surgery.)

Initial median frequency values were lower than normal before surgery (Table 2) and showed no significant change in either group 6 weeks after (Figure 5B). At 10 weeks, the EXERCISE group showed a significant increase in IMF at two of the four recording sites on the paraspinal muscles, and at 6 and 12 months all sites showed a significant increase compared with 6 weeks. The CONTROL group, in contrast, showed no significant change in IMF at any site throughout the follow-up period.

The MFG before surgery was lower than normal in the lumbar region but higher than normal in the thoracic region, and as a result, MFG_{max} values were similar to those of healthy controls (cf. Figure 5C and Table 2). Six weeks after surgery, there was no change in MFG at any muscle site or in MFG_{max} in either group of patients (Figure 5C). At 10 weeks, the EXERCISE group showed a significant reduction in MFG in the left thoracic region and a reduction in MFG_{max}. By 6 months, the reduction was also significant in the left lumbar region. The CONTROL group showed no significant change in MFG at any site throughout the follow-up period.

Correlations Between Pain, Disability, Psychological Status, and Spinal Function

Mean values of Low Back Outcome Score before and after surgery were highly correlated with VAS scores ($r > 0.97$) and pain diary scores ($r = 0.99$) in both groups of patients. The VAS scores and pain diary scores were also highly correlated with one another ($r = 0.97$). Correlations between these clinical outcome measures and psychometric and functional measures were greatest for

Table 4. Posture and Mobility Measurements Before Surgery (Pre-Op) and at 6, 10, 26, and 52 Weeks After

	Pre-op	6 W	10 W	26 W	52 W
Exercise					
SA: standing	15.0 (4.1)	13.9 (5.4)	15.0 (5.2)	17.0 (4.4)†	17.4 (5.4)†
Hip ROF	28.8 (19.9)	42.4 (18.1)*	54.9 (21.9)*†	54.4 (14.6)*†	57.6 (17.2)*†
Hip ROE	22.9 (9.5)	23.6 (3.9)	25.7 (4.9)	24.5 (10.3)	24.5 (7.7)
LC: standing	25.4 (8.0)	25.3 (8.8)	25.2 (8.7)	27.1 (6.7)	29.7 (11.3)
Lumbar ROF	26.9 (13.3)	33.9 (8.3)	40.6 (8.5)*	43.9 (5.4)*†	45.9 (8.2)*†
Lumbar ROE	12.9 (9.0)	15.9 (8.3)	18.6 (14.3)	20.2 (12.4)	19.2 (8.4)
Lumbar ROLB	45.3 (9.8)	46.1 (4.2)	47.1 (5.1)	51.9 (6.0)*†	52.6 (4.4)*†
Control					
SA: standing	14.8 (8.8)	16.0 (9.0)	15.6 (7.4)	13.9 (5.5)	16.4 (6.0)
Hip ROF	39.5 (14.1)	60.8 (14.4)*	64.8 (16.3)*	69.0 (16.5)*	69.1 (14.2)*
Hip ROE	20.0 (8.9)	18.6 (6.4)	24.1 (2.7)	22.2 (7.0)	22.8 (8.6)
LC: standing	19.6 (9.7)	20.8 (10.7)	22.8 (9.4)	21.4 (7.1)	24.3 (9.3)
Lumbar ROF	34.9 (10.0)	40.9 (8.7)*	44.3 (11.4)*	43.0 (9.2)*	45.4 (11.0)*
Lumbar ROE	17.0 (13.1)	15.4 (10.2)	12.4 (12.8)	17.9 (13.2)	18.3 (16.8)
Lumbar ROLB	42.5 (10.7)	46.6 (8.6)	43.4 (8.2)	45.8 (8.0)	46.0 (7.1)

Mean (STD) values are shown for each group.
SA = sacral angle; LC = lumbar curvature; ROF = range of flexion; ROE = range of extension; ROLB = range of lateral bending.
(Significant differences within each group are indicated compared to presurgery values,* and to values 6 weeks after surgery†.)

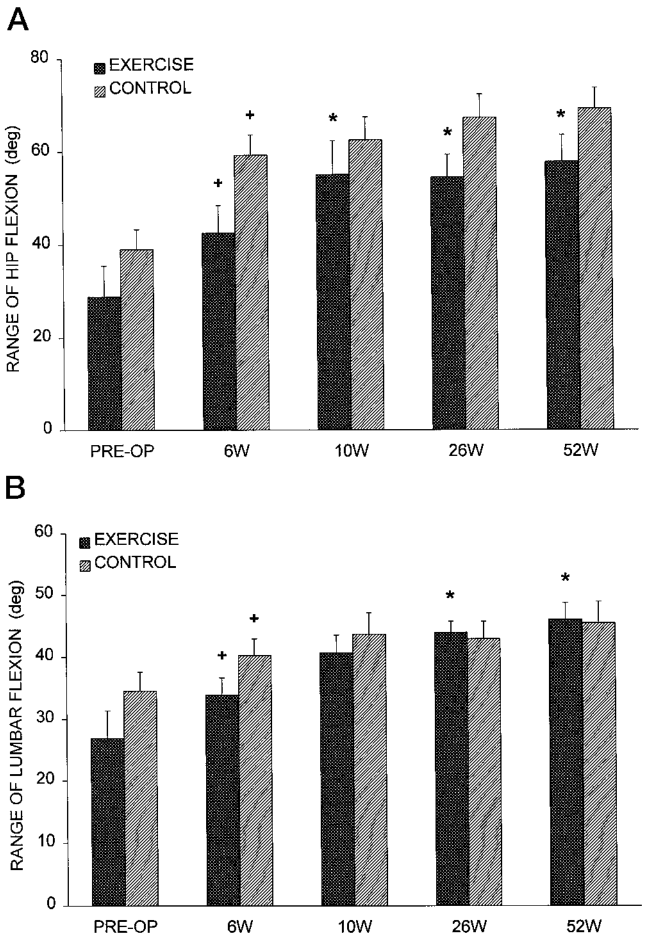


Figure 4. Ranges of hip (**A**) and lumbar (**B**) flexion in the EXERCISE and CONTROL groups, before surgery (pre-op) and at 6, 10, 26, and 52 weeks after. Bars, SEM. Significant differences within each group are indicated compared with presurgery values^{+} and with values 6 weeks after surgery*.

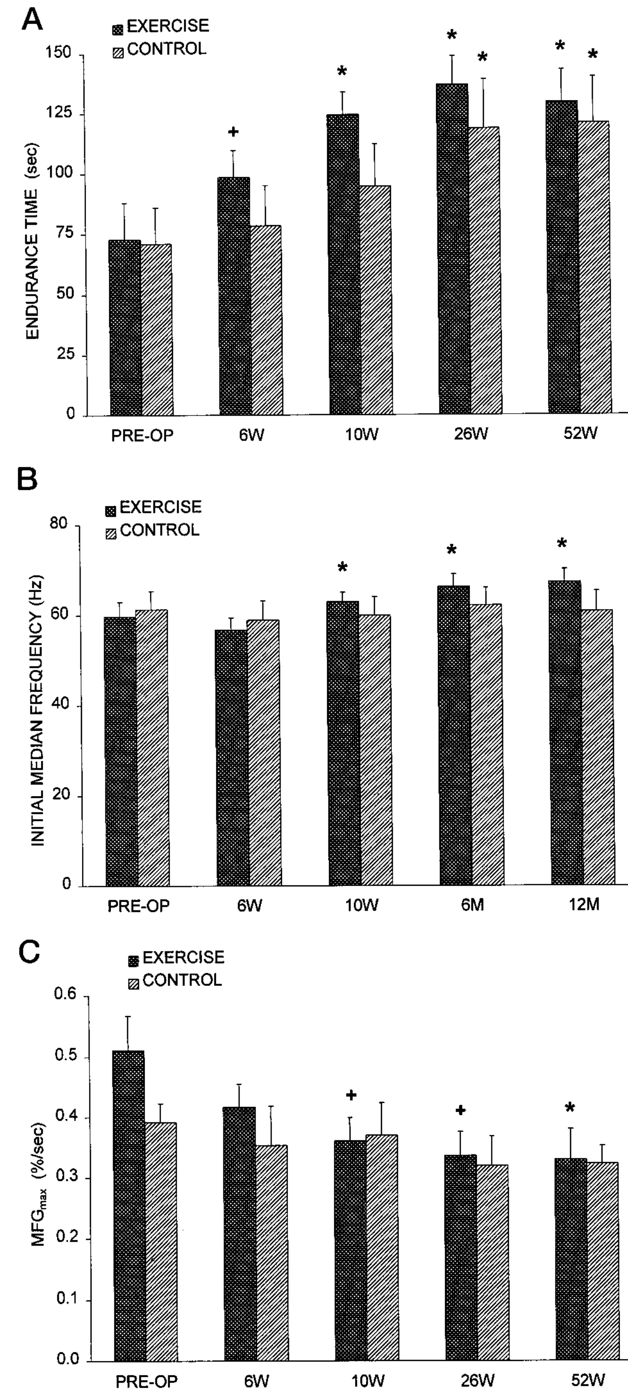


Figure 5. Endurance time (**A**), initial median frequency for the left lumbar region (**B**), and maximum rate of decline in median frequency (MFG_{max}) over the four muscle sites (**C**), during the performance of the Biering-Sorensen fatigue test. Values are shown for the EXERCISE and CONTROL groups, before surgery (pre-op) and at 6, 10, 26, and 52 weeks after. Bars, SEM. Significant differences within each group are indicated compared with presurgery values^{+} and with values 6 weeks after surgery*.

MSPQ ($r = 0.93$), ZUNG ($r = 0.97$), and hip ($r = 0.92$) and lumbar ($r = 0.88$) ranges of flexion, if all time points were included in the comparison. However, if presurgery values were excluded, then correlation coefficients declined for the psychometric factors and increased for the functional factors, particularly in the EXERCISE group in which the highest correlations were observed for lumbar ranges of flexion and lateral bending, and for IMF and MFG. In the EXERCISE group, these functional measures were more highly correlated with pain diary scores than VAS scores, but the converse was often true for the CONTROL group.

Discussion

The purpose of this study was to determine whether a postoperative exercise program could improve outcome in patients who undergo microdiscectomy for prolapsed intervertebral disc. The results indicate that there were significant improvements in many of the outcome measures as a result of surgery and that the EXERCISE group showed further improvements during the 12-month follow-up period that were generally not observed in the CONTROL group, showing that the exercise program was effective. In the following discussion, the validity of the techniques and the outcome measures are evaluated first, after which the study's findings are discussed and their applicability to other patient groups assessed.

Validity of Outcome Measures and Assessment Techniques

The methods used to assess pain, disability, and psychological status were designed for use by nonspecialists. All of them are well-validated[22,23,28,34,39] and have been used previously in the assessment of patients with low back pain, and this justified their use in the current study.

The techniques used to measure spinal function were developed in the authors' laboratory, and these have also been evaluated and validated previously. Isotrak measurements of posture and range of motion show good reproducibility,[9] and range of flexion measurements obtained with the Isotrak are very similar to those obtained using bilateral radiographs, indicating that there are no large systematic errors in the measurements.[13] The Biering-Sorensen fatigue test is well accepted by patients with back pain, and in a previous study of healthy volunteers a significant correlation was observed between endurance time and the rate of decline in median frequency in the test.[37] However, endurance time is influenced by psychological factors that affect motivation,[39] and in patients it may also be affected by pain or fear of pain. For this reason, the decline in median frequency was also measured to provide a more objective measure of fatigue. These electromyographic techniques have been extensively validated in a number of studies in which results have shown that the median frequency has high test–retest reliability for its initial value and its rate of decline.[12,37] The rate of decline in median frequency correlates highly with loss of maximal force-generating capacity by the muscle and thereby provides a reliable measure of the rate of muscle fatigue.[38]

Discussion of Results

Patients in this study had high levels of pain, disability, and functional impairment before surgery that were considerably greater than those observed in patients with acute low back pain.[8] Higher values of MFG in thoracic muscles and lower values in lumbar muscles, when compared with those in healthy subjects, may be an indication that thoracic muscles were used in preference to lumbar muscles, perhaps because of reflex inhibition in the painful lumbar region of the spine.

After surgery, pain and disability were greatly reduced, although levels in both patient groups at 6 weeks remained above those in patients with acute back pain.[8] Equal numbers of patients reported some back or leg pain after surgery, and in each group this number represented 40–60% of the study population. Although the numbers in this study are small, these results are not dissimilar to those reported previously in a large group of patients who had undergone lumbar discectomy.[16] In addition to improvements in pain and disability, surgery also increased hip and spinal mobility. These initial improvements were probably due to simple removal of the nerve root compression and the associated pain rather than to any true changes in the flexibility of spinal tissues, although some local loss of stiffness in the surgically treated disc may have occurred as a result of surgery.[49] On average, lumbar and hip flexion at 6 weeks had increased to values equivalent to 60–80% of those obtained in healthy subjects, which is slightly better than the results reported after open discectomy.[43]

Improvements in endurance time in the Biering-Sorensen test after surgery were not accompanied by any improvements in the rate of decline in median frequency, suggesting that they may have been due to improvements in pain and/or motivation rather than to true improvements in muscle fatigability. This is supported by the fact that endurance times before surgery were much lower than expected based on the rate of decline in median frequency,[37] indicating that patients were limited by pain or fear of pain rather than by the endurance properties of their back muscles. The beneficial effect of surgery on the ZUNG and MSPQ scores, which decreased to values below those of healthy control subjects, indicates that high scores before surgery were the result of severe pain and not the cause of it.

If the effects of surgery alone are considered, then at 6 weeks they produced a good outcome, on average, in both groups of patients. However, the exercise program brought about further improvements in spinal function that were associated with further reductions in pain and disability. In fact, eight of the nine patients in the EXERCISE group reported no disability at 12 months. These improvements in pain and disability after completion of the exercise program were highly correlated with improvements in a number of the functional measures including hip and lumbar ranges of flexion, IMF, and MFG. Although this does not prove causality, the time course of the changes indicates that the functional improvements that were generally significant immediately after the program (Figures 4 and 5) preceded the improvements in pain and disability (Figures 2 and 3) and may therefore have contributed to them.

In contrast to the improvements in endurance time after surgery, subsequent improvements from 6 weeks onward were mirrored by an accompanying reduction in the rate of decline in median frequency, indicating possible real improvements in muscle fatigability. Several studies have shown that muscle fiber type influences the rate of decline in median frequency, so that muscles with a high proportion[47] or high percentage area[25,40] of Type I fibers show a slower decline in the mean or median frequency with fatigue. This indicates that the exercise program in the current study may have caused Type I fiber hypertrophy. This may seem surprising, given that patients with chronic low back pain often show selective atrophy of Type II fibers. However, nerve root compression after disc prolapse may lead to denervation and therefore to a more generalized atrophy of the spinal musculature. Exercises such as those used in the current study could then be expected to stimulate hypertrophy of all fiber types, and because Type I fibers predominate in the paraspinal muscles, the overall effect may be to improve fatigability and reduce the rate of median frequency decline. However, the accompanying increase in IMF is more difficult to explain. The IMF is thought to reflect the average conduction velocity of the active muscle fibers[3,53] and has been shown to increase with the percentage of Type II fibers in lower limb muscles,[20,21,46] but not in the erector spinae muscles.[40] That there is no association with muscle fiber type in the erector spinae may be explained by the fact that Type I fibers in this muscle are usually as large or larger than Type II fibers[41,48,52] and for this reason may have equivalent or slightly higher conduction velocities and initial median frequencies. The increases in IMF in the current study may therefore reflect hypertrophy of one or more fiber types, but at present there is too little information to indicate which.

Regardless of the precise cause of the functional improvements observed in the current study, the 4-week exercise program brought about measurable changes in back muscle function that appear to have improved patient outcome. Other investigators have reported improvements in pain, disability, and various aspects of spinal function as a result of an early, active exercise program after lumbar discectomy.[31,36] In these earlier studies, the active exercise program, similar to that in the current study, included specific exercises to improve strength, endurance, and mobility of the trunk muscles but also included some exercises for cardiovascular fitness. In both studies, the active program was compared with a less active program, and regardless of whether the program was home based[31] or hospital based,[36] patients in the active group showed significant short-term improvements in pain, disability, and spinal function when compared with the less active group. These findings show that an exercise program involving both aerobic exercise and specific exercises for the trunk muscles, when undertaken fairly soon after surgery, can bring about rapid improvements in pain, disability, and spinal function after lumbar discectomy.

Of particular interest in the current study is the longer term data that show that the short-term benefits of the exercise program were maintained or even enhanced 12 months after surgery. It seems unlikely that these improvements were the direct result of a 4-week exercise program. A more likely explanation is that the patients who undertook the program gained increased confidence in their ability to exercise, which may have lead them to become more active in their daily lives and perhaps to have continued the exercises after the formal program was over. Although there are no specific data to support this suggestion, the EXERCISE group showed a significant increase in the IHLC over the follow-up period. This indicates that they believed more strongly that they could control their health by their own efforts, and it may have led them to continue such efforts after the exercise program was completed.

These encouraging results indicate that a short postoperative exercise program may offer a cost-effective way of improving the outcome of surgery for patients with prolapsed intervertebral disc. However, these results are based on small numbers of patients who had sciatica of less than 12 months' duration, and therefore generalizations regarding their effectiveness in other groups of patients can only be speculative at this stage. The full value of the exercise program will only become evident with longer term follow-ups on larger numbers of patients with varying length and severity of symptoms; these are currently being performed in the authors' laboratory. However, the results of this and other studies show that certain exercise interventions can improve spinal function and may be able to break the vicious circle of pain and dysfunction that probably leads to chronic low back pain.

■ Conclusions

Microdiscectomy brought about significant improvements in pain, disability, and hip and lumbar mobility in patients with sciatica of less than 12 months' duration. A 4-week postoperative exercise program designed predominantly to strengthen back and abdominal muscles brought about further significant improvements in spinal function. The improvements in spinal function were associated with improvements in pain and disability that were maintained or further enhanced 12 months after surgery.

■ Key Points

- Approximately 20% of patients do not have a good short-term outcome after microdiscectomy for prolapsed intervertebral disc, and many continue to have some low back pain.
- Back muscle function is often impaired in patients awaiting surgery for prolapsed intervertebral disc.
- Surgery does not correct back muscle dysfunction and may make it worse.
- The results showed that a 4-week postoperative exercise program improved pain, disability, and spinal function in patients after microdiscectomy.

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