



# Exercise Tolerance Test as a Predictor of Functional Status and Surgical Outcomes in Symptomatic Spinal Stenosis Patients Undergoing Decompressive Lumbar Laminectomy

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## Abstract

**Aim:** The aim of our study is to demonstrate the effectiveness of total laminectomy, a less invasive technique compared to fusion procedures. Additionally, we aim to evaluate preoperative and postoperative functional mobility using the treadmill exercise test.

**Material and Method:** This clinical study includes 16 patients who underwent their first surgery for pure spinal stenosis at the Bakırköy Mental and Neurological Diseases Hospital, Neurosurgery Clinic III. All patients underwent an exercise tolerance test using a treadmill device preoperatively and at the third postoperative month. Prior to these tests, electrocardiography and chest radiography were performed.

**Results:** Preoperative exercise tolerance test results indicated that initial symptoms appeared at an average of 1.42 minutes, while severe symptoms preventing test continuation emerged at an average of 6.09 minutes. At the 3-month postoperative follow-up, the exercise tolerance test results demonstrated significant improvement. The average time to the onset of initial symptoms increased to 5.39 minutes, and the onset of severe symptoms was delayed to 11.08 minutes.

**Conclusion:** This study demonstrates that fusionless decompression techniques remain an effective treatment option. Additionally, preoperative and postoperative treadmill exercise tests can be utilized to assess disease status and severity. Moreover, these tests serve as an objective tool for evaluating the effectiveness of surgical treatment.

**Keywords:** Decompressive lumbar laminectomy, surgical outcomes, exercise tolerance test

## INTRODUCTION

Degenerative lumbar stenosis refers to the pathological narrowing of the lumbar canal, lateral recess, and intervertebral foramina, resulting in a reduction in their area and volume beyond a critical threshold (1). Progressive degenerative changes in the spine, including the lumbar intervertebral discs, facet joints, ligamentum flavum, and other connective tissues, are thought to play a key role in the development of lumbar stenosis over time (2-4).

The human lumbar spine segment, composed of an intervertebral disc and two facet joints, serves as a distinct and structurally complex example (5). The lower lumbar spine segments exhibit greater torsional and lateral bending movements compared to the upper lumbar segments, whereas the upper lumbar segments demonstrate more

pronounced flexion and extension movements than the lower segments, highlighting the spine's unique biomechanics (5).

Degenerative lumbar stenosis is a progressive condition that impacts all motion segments of the spine while simultaneously limiting mobility (6). Clinical symptoms include worsening leg pain during walking, increased discomfort with prolonged standing, fatigue, lower extremity discomfort, and sensory loss (4,7). Degeneration of the intervertebral discs, collapse or reduction in disc height, facet joint hypertrophy, ligamentum flavum thickening and degeneration, and calcification within the lumbar canal contribute to spinal stenosis, ultimately leading to the compression of structures such as blood vessels and nerves (2,7,8). Stenosis impairs both vascular and neural structures, hindering their ability to perform physiological functions (2,4,7).

## CITATION

Erhan Sofuoglu OE, Tacyildiz AE. Exercise Tolerance Test as a Predictor of Functional Status and Surgical Outcomes in Symptomatic Spinal Stenosis Patients Undergoing Decompressive Lumbar Laminectomy. Med Records. 2025;7(3):584-90. DOI:1037990/medr.1647600

Received: 03.03.2025 Accepted: 22.03.2025 Published: 29.07.2025

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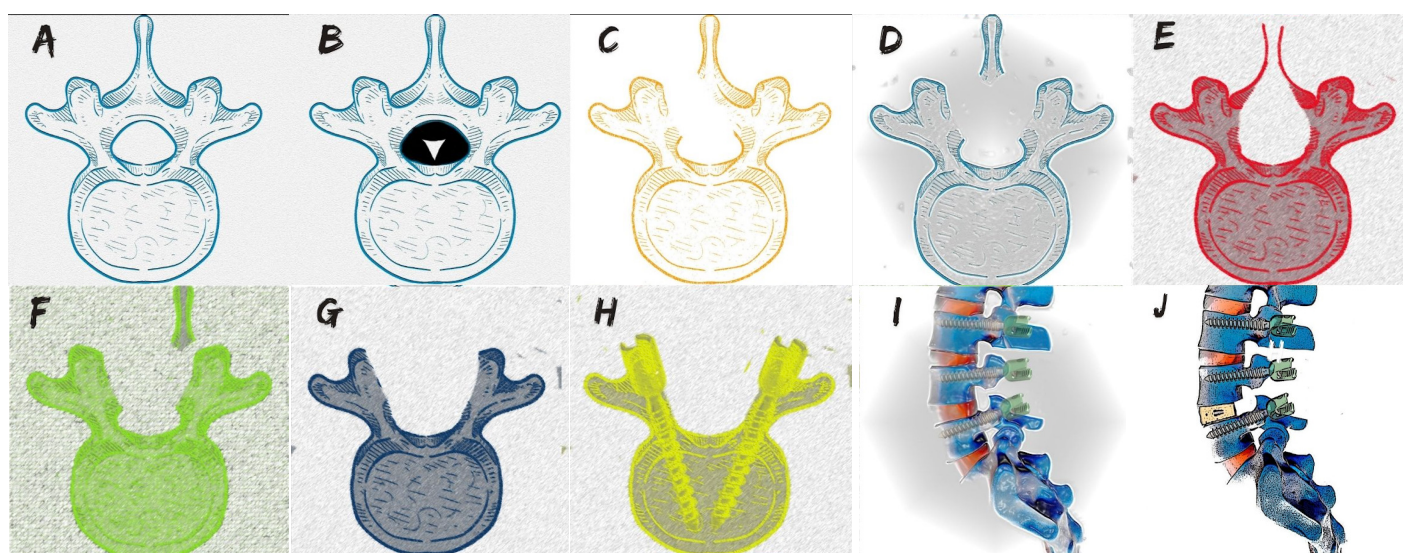
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Studies have shown that surgical treatments are more effective than non-surgical approaches for lumbar spinal stenosis (9). Lumbar spinal stenosis becomes more prevalent with age and is more commonly observed in women, with scientific studies reporting a prevalence ranging from 7% to 38% (2,10-13). Diagnostic evaluation involves imaging modalities and tests such as radiography, magnetic resonance imaging (MRI), computed tomography (CT), and electromyography (EMG) (2).

Non-surgical treatment options for lumbar spinal stenosis include bed rest, nonsteroidal anti-inflammatory drugs (NSAIDs), corticosteroids, epidural steroid injections, and physical therapy (2). Severe gait disturbances affecting daily life, neurogenic claudication limiting walking to 5–10 meters, muscle weakness, rapidly progressing neurological deficits, and loss of bladder and bowel control are generally considered indications for surgical intervention.

In lumbar spinal stenosis (Figure 1), both fusion and non-fusion surgical approaches are available (14, 15). Traditional minimally invasive techniques, open surgical approaches, single-port and dual-port endoscopic techniques, fluoroscopy- and navigation-guided minimally invasive screw placement, as well as microsurgical laminectomy, microdiscectomy, and open discectomy, are employed in the surgical management of lumbar spinal stenosis (14-17).

In lumbar stenosis, clinical and physical examinations, along with walking tests and fall-related assessments, are used to evaluate both the current condition and postoperative functional status (2,18,19). Our study aims to assess the effectiveness of total laminectomy, a less invasive alternative to fusion procedures. Additionally, we aim to evaluate preoperative and postoperative functional mobility using the treadmill exercise test.



**Figure 1.** Illustration of lumbar decompression techniques; (A) Normal spine, (B) Spinal stenosis, (C) Unilateral laminotomy, (D) Bilateral laminotomy, (E) Split laminectomy, (F) Spinous process osteotomy, (G) Total laminectomy, (H, I, J) Fusion surgeries

## MATERIAL AND METHOD

This clinical study includes 16 patients who underwent their first surgery for pure spinal stenosis at the Bakırköy Mental and Neurological Diseases Hospital, Neurosurgery Clinic III, between 1996 and 1997. The surgical procedure performed was decompressive laminectomy. All patients presented with neurogenic intermittent claudication, and radiological examinations confirmed the diagnosis of spinal stenosis. This study is a single-center, non-randomized, prospective, and observational study. Ethical approval for the present study was obtained in 1997 from the Department of Neurosurgery at Bakırköy Mental and Neurological Diseases Hospital, under the authority of Head of Department, Op. Dr. Halil Toplamaoğlu.

Preoperative and postoperative MRI examinations were conducted on all patients at the third month using a 1.5 Tesla ACSNT Philips Gyroscan MRI device. Standard imaging sequences included sagittal T1, sagittal T2, axial T2, and axial views. During these examinations, the anteroposterior

and transverse diameters of the entire lumbar canal were measured. All patients underwent the same surgical procedure, consisting of decompressive laminectomy and bilateral foraminotomy at the stenotic level.

Only patients who underwent lumbar laminectomy were included in the study. Patients who underwent instrumentation and fusion were excluded. Additionally, patients who underwent decompression for lumbar vertebral fractures were not included. Patients with severe comorbid conditions, including heart failure, were also excluded from the study.

### Treadmill Test Protocol

All patients underwent an exercise tolerance test using a treadmill device preoperatively and at the third postoperative month. Prior to these tests, electrocardiography and chest radiography were performed. Additionally, internal medicine consultations were conducted to assess any contraindications for the exercise tests. These contraindications are summarized in Table 1.

| Table 1. Summarize of contraindications for exercise tests |                                                        |
|------------------------------------------------------------|--------------------------------------------------------|
| 1                                                          | Recent-onset unstable angina accompanied by chest pain |
| 2                                                          | Untreated cardiac arrhythmias                          |
| 3                                                          | Decompensated congestive heart failure                 |
| 4                                                          | Advanced atrioventricular block                        |
| 5                                                          | Acute myocarditis or pericarditis                      |
| 6                                                          | Critical aortic stenosis                               |
| 7                                                          | Severe hypertrophic obstructive cardiomyopathy         |
| 8                                                          | Uncontrolled hypertension                              |
| 9                                                          | Acute systemic illnesses                               |

The exercise tolerance test was conducted using a Morishima Exercise Equipment Motorized Treadmill at a speed of 2.8 km/h with zero incline. The test was terminated upon the emergence of severe symptoms. If the patient's symptoms were milder, the test continued for a maximum duration of 15 minutes. The speed of 2.8 km/h was selected based on previous studies, which indicated that higher speeds could induce cardiopulmonary symptoms before the onset of neurological symptoms (20).

The onset time of initial symptoms was recorded as the moment the patient first reported discomfort after starting the exercise (e.g., low back pain, leg pain, mild numbness, etc.). The onset time of severe symptoms was defined as the point at which the patient developed symptoms severe enough to prevent the continuation of the exercise test

(e.g., severe low back and leg pain, weakness, dragging of the legs, significant numbness, etc.).

Patients were instructed to maintain an upright posture on the treadmill. During the treadmill exercise test, the following data were recorded:

- Time of initial symptom onset,
- Time of severe symptom onset, preventing continuation of the test,
- Type of symptoms (e.g., low back pain, hip pain, leg pain, numbness, etc.).

For statistical analysis, the Wilcoxon signed-rank test was used to compare preoperative and postoperative results. A p-value of <0.05 was considered statistically significant.

RESULTS

The demographic and clinical characteristics of the 16 patients included in the study are summarized in Table 2. The cohort consisted of six males and ten females, with a mean age of 51.7 years (range: 32–64 years). The average symptom onset occurred 7.8 before surgery. During the preoperative period, all patients received medical treatment, including nonsteroidal anti-inflammatory drugs and muscle relaxants, along with bed rest. Additionally, six patients underwent physical therapy before surgery. While these interventions provided temporary symptom relief, all patients later reported recurrence.

| Table 2. The treadmill test results are being monitored |                     |                                                 |                               |                                                  |
|---------------------------------------------------------|---------------------|-------------------------------------------------|-------------------------------|--------------------------------------------------|
| Patient                                                 | Canal diameter (mm) | Preoperative treadmill test durations (minutes) | Type of surgery               | Postoperative treadmill test durations (minutes) |
| 1                                                       | 57                  | Initial symptom: 1:30<br>Severe symptom: 12     | L4-L5 total laminectomy       | Initial symptom: 2:30<br>Severe symptom: None    |
| 2                                                       | 58                  | Initial symptom: 1:40<br>Severe symptom: 4:50   | L3-L4 total laminectomy       | Initial symptom: 4:10<br>Severe symptom: 11      |
| 3                                                       | 60                  | Initial symptom: 0:30<br>Severe symptom: 5:10   | L4-L5 total laminectomy       | Initial symptom: 3:20<br>Severe symptom: 11:30   |
| 4                                                       | 53                  | Initial symptom: 2:40<br>Severe symptom: 13     | L2-L3-L4 total laminectomy    | Initial symptom: 5:20<br>Severe symptom: None    |
| 5                                                       | 78                  | Initial symptom: 1:30<br>Severe symptom: 10:15  | L3-L4-L5 total laminectomy    | Initial symptom: 7<br>Severe symptom: 13         |
| 6                                                       | 63                  | Initial symptom: 0:25<br>Severe symptom: 1:30   | L3-L4 total laminectomy       | Initial symptom: 2:20<br>Severe symptom: 3:50    |
| 7                                                       | 47                  | Initial symptom: 0:30<br>Severe symptom: 8:45   | L5 total laminectomy          | Initial symptom: 4:40<br>Severe symptom: None    |
| 8                                                       | 88                  | Initial symptom: 0:50<br>Severe symptom: 6:15   | L4-L5 total laminectomy       | Initial symptom: 3:40<br>Severe symptom: 8:00    |
| 9                                                       | 48                  | Initial symptom: 6:25<br>Severe symptom: 9:30   | L3-L4-L5 total laminectomy    | Initial symptom: 10:00<br>Severe symptom: None   |
| 10                                                      | 53                  | Initial symptom: 0:45<br>Severe symptom: 3:50   | L3-L4-L5 total laminectomy    | Initial symptom: None<br>Severe symptom: None    |
| 11                                                      | 88                  | Initial symptom: 3:20<br>Severe symptom: 8:20   | L4 total laminectomy          | Initial symptom: 6:30<br>Severe symptom: 8:10    |
| 12                                                      | 64                  | Initial symptom: 1:15<br>Severe symptom: 2:40   | L3-L4 total laminectomy       | Initial symptom: 3:15<br>Severe symptom: 9:00    |
| 13                                                      | 38                  | Initial symptom: 0:50<br>Severe symptom: 2:10   | L2-L3-L4-L5 total laminectomy | Initial symptom: 1:10<br>Severe symptom: 11:20   |
| 14                                                      | 47                  | Initial symptom: 2:20<br>Severe symptom: 9:00   | L5 total laminectomy          | Initial symptom: 3:30<br>Severe symptom: 8:10    |
| 15                                                      | 40                  | Initial symptom: 0:30<br>Severe symptom: 0:30   | L3 total laminectomy          | Initial symptom: 7:30<br>Severe symptom: None    |
| 16                                                      | 58                  | Initial symptom: 2:10<br>Severe symptom: 6:25   | L4-L5 total laminectomy       | Initial symptom: 6:20<br>Severe symptom: None    |

Preoperative exercise tolerance test results indicated that initial symptoms appeared at an average of 1.42 minutes, while severe symptoms preventing test continuation emerged at an average of 6.09 minutes. At the 3-month postoperative follow-up, exercise tolerance test results demonstrated significant improvement. The average time to the onset of initial symptoms increased to 5.39 minutes, and the onset of severe symptoms was delayed to 11.08 minutes. Notably, while no patients were able to complete the maximum test duration of 15 minutes preoperatively, seven patients successfully completed the full test

postoperatively without experiencing severe symptoms. Four patients underwent decompressive laminectomy and bilateral foraminotomy at a single level, seven at two levels, four at three levels, and one at four levels. Patients were categorized by age, and their preoperative and postoperative exercise tolerance test results were analyzed (Table 3). The younger group (<49 years) demonstrated significantly better exercise tolerance both preoperatively and postoperatively compared to the older group (≥49 years) (p<0.05).

| Table 3. Comparison by age groups                                                                                 |     |                                                 |                               |                                                  |
|-------------------------------------------------------------------------------------------------------------------|-----|-------------------------------------------------|-------------------------------|--------------------------------------------------|
| Age groups                                                                                                        | Age | Preoperative treadmill test durations (minutes) | Type of surgery               | Postoperative treadmill test durations (minutes) |
| 30–39 Age group                                                                                                   | 38  | I.S: 0.45<br>S.S: 3.50                          | L3-L4-L5 total laminectomy    | I.S: None<br>S.S: None                           |
|                                                                                                                   | 32  | I.S: 3.20<br>S.S: 8.20                          | L4 total laminectomy          | I.S: 6.30<br>S.S: 8.10                           |
| 40–49 Age group                                                                                                   | 45  | I.S: 1.30<br>S.S: 12                            | L4-L5 total laminectomy       | I.S: 2.30<br>S.S: None                           |
|                                                                                                                   | 42  | I.S: 0.50<br>S.S: 6.15                          | L4-L5 total laminectomy       | I.S: 3.40<br>S.S: 8.00                           |
|                                                                                                                   | 44  | I.S: 0.30<br>S.S: 0.30                          | L3 total laminectomy          | I.S: 7.30<br>S.S: None                           |
|                                                                                                                   | 41  | I.S: 2.10<br>S.S: 6.25                          | L4-L5 total laminectomy       | I.S: 6.20<br>S.S: None                           |
| 50–59 Age group                                                                                                   | 55  | I.S: 1.40<br>S.S: 4.50                          | L3-L4 total laminectomy       | I.S: 4.10<br>S.S: 11.00                          |
|                                                                                                                   | 54  | I.S: 6.25<br>S.S: 9.30                          | L3-L4-L5 total laminectomy    | I.S: 10<br>S.S: None                             |
|                                                                                                                   | 56  | I.S: 1.15<br>S.S: 2.40                          | L3-L4 total laminectomy       | I.S: 3.15<br>S.S: 9.20                           |
|                                                                                                                   | 56  | I.S: 0.50<br>S.S: 2.10                          | L2-L3-L4-L5 total laminectomy | I.S: 1.10<br>S.S: 11.20                          |
|                                                                                                                   | 52  | I.S: 2.20<br>S.S: 9                             | L5 total laminectomy          | I.S: 3.30<br>S.S: 8.10                           |
| 60–69 Age group                                                                                                   | 60  | I.S: 0.30<br>S.S: 5.10                          | L4-L5 total laminectomy       | I.S: 3.20<br>S.S: 11.30                          |
|                                                                                                                   | 63  | I.S: 2.40<br>S.S: 13                            | L2-L3-L4 laminectomy          | I.S: 5.20<br>S.S: None                           |
|                                                                                                                   | 64  | I.S: 1.30<br>S.S: 10.15                         | L3-L4-L5 total laminectomy    | I.S: 7.00<br>S.S: 13.00                          |
|                                                                                                                   | 61  | I.S: 0.30<br>S.S: 8.45                          | L5 total laminectomy          | I.S: 4.40<br>S.S: None                           |
|                                                                                                                   | 63  | I.S: 0.25<br>S.S: 1.30                          | L3-L4 total laminectomy       | I.S: 2.20<br>S.S: 3.50                           |
| I.S: time of onset of initial symptoms, S.S: time of onset of severe symptoms preventing continuation of the test |     |                                                 |                               |                                                  |

Among the eight patients with a preoperative canal diameter of <59 mm, six successfully completed the full 15-minute test postoperatively. In contrast, those with a relatively wider preoperative canal diameter (>70 mm) had less favorable exercise tolerance outcomes (Table 2).

DISCUSSION

Our study demonstrated that total laminectomy enhanced exercise tolerance test outcomes in 16 patients with lumbar spinal stenosis (Table 2, Table 3). Previous studies from the 1990s reported good to excellent surgical outcomes in 60% to 64% of patients with lumbar stenosis (21,22). Our findings align with previous research (Table 2, Table 3). In a

study by Herno et al., long-term follow-up at 7 and 13 years showed predominantly positive outcomes in patients with lumbar spinal stenosis, with unfavorable results reported in only 9.3% of cases (23). Deen et al. assessed bladder function in patients with symptomatic spinal stenosis (24). They reported improvements in bladder function tests, including increased maximum urinary flow rate and reduced post-void residual urine volume (24). Surgery is currently recommended for patients with lumbar spinal stenosis who do not respond to conservative treatment and experience reduced quality of life, paresthesia, muscle weakness, or gait disturbances (2). The primary goal is to decompress neural and vascular

structures (25). Various techniques are employed to achieve decompression, including endoscopic procedures, minimally invasive approaches, open decompression, and microscopic decompression (3, 26-28). Katz et al. reported that recovery rates were comparable between patients who underwent lumbar laminectomy alone and those who underwent lumbar decompression with fusion (3). Först et al. similarly reported that at 2- and 5-year follow-ups, clinical outcomes were comparable between the decompression-only group and the decompression-plus-fusion group (27). Our study, which demonstrated improvements in exercise tolerance test outcomes among patients who underwent laminectomy without fusion, aligns with previous literature (Table 2, Table 3). Furthermore, the decompression-plus-fusion group had higher complication rates, including increased blood loss, infection, longer hospital stays, and greater costs. (3, 27). Hermansen et al. compared minimally invasive techniques, including unilateral laminotomy with crossover, bilateral laminotomy, and spinous process osteotomy (28). The recovery outcomes of these three minimally invasive surgical techniques were found to be comparable based on the Oswestry Disability Index (28). In our patient series, traditional non-fusion total laminectomy, a less invasive approach than fusion surgeries, led to improvements in treadmill test results, a key indicator of neurogenic claudication (Tables 2 and 3). Similarly, a multicenter prospective study conducted in Switzerland found that clinical outcomes were comparable between decompression surgery with and without fusion (29). More importantly, the need for revision surgery was similar between the two groups and did not reach statistical significance (29). In surgeries for degenerative lumbar stenosis, decompression alone (Table 2, Table 3) appears to be a sufficient treatment option (27-29). Our findings, consistent with the literature (Table 2, Table 3), demonstrate improved treadmill exercise tolerance in patients who underwent laminectomy alone.

Försth et al. also assessed surgical outcomes in both groups using a walking test (27). The 6-minute walking test results for the fusion and non-fusion decompression groups were similar; however, they did not provide preoperative walking test results (27). In our study, the exercise test duration was 15 minutes. We compared preoperative and postoperative exercise test results and reported the improvement rates (Table 2, Table 3).

Deen et al. evaluated the surgical outcomes of patients with lumbar spinal stenosis using a treadmill test (30). They found that the average time to the onset of initial symptoms was 2.68 minutes, while the average time to the onset of severe symptoms was 5.47 minutes (30). In our study, preoperative exercise tolerance test results showed that the average time to the onset of initial symptoms was 1.42 minutes, while the average time to the onset of severe symptoms preventing test continuation was 6.09 minutes (Table 2, Table 3). These findings are consistent with those reported by Deen et al (30). Deen et al. reported that, after surgery, the average time to the onset of initial symptoms increased to 11.12 minutes, while the average time to the

onset of severe symptoms reached 11.81 minutes (30). In our study, postoperative (3rd month) exercise tolerance test results showed that the average time to the onset of initial symptoms was 5.39 minutes, while the average time to the onset of severe symptoms preventing test continuation was 11.08 minutes (Table 2, Table 3). When comparing our postoperative findings with those of Deen et al. (Table 2, Table 3), the time to the onset of severe symptoms after surgery appears to be comparable (30). However, a discrepancy exists between the two studies regarding the time to the onset of initial symptoms. Deen et al. reported an average of 11.12 minutes, whereas our study found a shorter duration of 5.39 minutes (Table 2, Table 3) (30). This discrepancy may be attributed to several factors, including differences in the timing of the postoperative test (Deen et al.: 2nd month; our study: 3rd month), test speed settings (Deen et al.: 1.93 km/h; our study: 2.8 km/h), surgical techniques, and patient-related factors. The treadmill test is a safe and practical tool for assessing initial functional status and objectively evaluating surgical outcomes (30, 31). Our study findings align with the literature (Table 2, Table 3). Moreover, the treadmill test demonstrates high reliability for both initial and repeat assessments (32). McIlroy et al. compared the preoperative and postoperative walking ability of patients who underwent lumbar laminectomy at up to two levels (33). They reported that patients' walking capacity continued to improve up to the 12th month following fusionless decompression surgery (33). They also stated that advanced preoperative age (>70 years), high body mass index (>35), severe leg pain, greater disability levels, and lower quality of life were associated with poorer walking ability and capacity at the 12-month follow-up (33). They also identified preoperative long walking capacity and higher education level as predictive factors for better walking capacity and walking distance at the 12-month postoperative follow-up (33). In our patient groups undergoing treadmill testing, we also observed better preoperative and postoperative outcomes in the younger group (Table 3). Our findings regarding age are consistent with those of McIlroy.

Additionally, a study conducted in Japan (which included patients who underwent fusion surgery) demonstrated that active elderly individuals who underwent spinal stenosis surgery were more capable of performing activities such as stretching and low-intensity exercises, walking, muscle-strengthening exercises, and home and garden maintenance tasks. (34). The GLFS-25 (25-Question Geriatric Locomotive Function Scale) is a tool used to assess physical pain and limitations in activities of daily living (ADL) in patients (35). The GLFS-25 test, which measures locomotive dysfunction, is a valuable tool for preoperative decision-making, assessing disease severity, and evaluating functional surgical outcomes in patients with lumbar spinal stenosis (35). An association has been identified between improvements in GLFS-25 scores and pain reduction (35). In our study, we also demonstrated an increase in exercise tolerance following surgery (Table 2, Table 3). The treadmill test used in our study can serve

as a valuable tool for preoperative decision-making and assessment, as well as for evaluating the therapeutic effects of surgery postoperatively (Table 2, Table 3). Our findings are consistent with the existing literature.

Recent studies have shown that patients who engage in appropriate postoperative exercise experience better spinal recovery compared to those who remain inactive (36). Appropriate postoperative exercises have been reported to improve pain levels, disability status, analgesic use, and psychological factors such as depression, anger, and mood disorders (37).

Endoscopic lumbar decompression is a safe and effective surgical technique for transforaminal and interlaminar procedures (38). In elderly patients for whom general anesthesia poses a risk, it is an ideal approach due to its minimal tissue damage, shorter hospital stay, and lower costs (39). The most common complication associated with endoscopic decompression is durotomy (40). This technique is not suitable for cases of pure low back pain without neurogenic symptoms, instability or deformities requiring stabilization, transforaminal decompression in the presence of central stenosis, or complex foraminal stenosis (38).

Our study has several limitations. It is based on a relatively outdated dataset, and patients' magnetic resonance imaging (MRI) scans were not recorded in the electronic database. Additionally, the sample size is small, and preoperative and postoperative quality of life or disability scores were not assessed. Due to technical limitations, certain aspects of the statistical analysis remain unclear in the preoperative and postoperative comparisons.

## CONCLUSION

Our study primarily demonstrates that fusionless decompression techniques remain an effective treatment option. Additionally, preoperative and postoperative treadmill exercise tests can be utilized to assess disease status and severity before surgery. Moreover, these tests serve as an objective tool for evaluating the effectiveness of surgical treatment postoperatively.

**Financial disclosures:** The authors declared that this study has received no financial support.

**Conflict of interest:** The authors have no conflicts of interest to declare.

**Ethical approval:** In our country, the first regulation on non-drug clinical research was published in the Official Gazette on March 11, 2010 (Issue No. 27518). Permission for this study was granted in 1997 by the Head of the Neurosurgery Department, Op. Dr. Halil Toplamaoğlu, at Bakırköy Mental and Neurological Diseases Hospital.

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