Journal of Pain Research
Dovepress
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ORIGINAL RESEARCH

The Impact of Preoperative Adaptive Training on Postoperative Outcomes in Lumbar Spine Fusion Surgery for Lumbar Disc Herniation: A Retrospective Analysis

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Purpose: Lumbar disc herniation, often treated with surgical decompression when conservative measures fail, presents challenges due to prolonged prone positioning in surgeries. This retrospective study evaluates the benefits of preoperative adaptive training to mitigate post-surgical physiological changes.

Patients and Methods: A review of medical records from June 2021 to March 2023 identified 170 patients unresponsive to conservative treatments. Grouped into adaptive training and control groups based on historical data, the former had undergone exercises to prepare for surgery and postoperative changes. Vital signs and VAS scores were extracted from patient records to assess training impact.

Results: The adaptive training group demonstrated stabilized vital signs intraoperatively, with a notable improvement in surgical exposure compared to the control group. However, there were no significant differences in operative time or blood loss between the groups. Additionally, postoperative VAS scores showed no significant improvement in the adaptive training group at follow-up intervals of 14 days, 1 month, and 3 months post-operation, compared to the control group.

Conclusion: Our study reveals that preoperative adaptive training stabilizes intraoperative blood pressure fluctuations in lumbar disc herniation surgeries. However, this stabilization does not significantly impact long-term postoperative pain management. This highlights the need for further research to explore comprehensive strategies that effectively combine preoperative training with post-operative care.

Keywords: lumbar surgery, preoperative education, adaptive training, retrospective analysis

Introduction

For patients diagnosed with lumbar disc herniation who have not responded to conservative treatments, surgical decompression is often the recommended course of action.[1] The posterior decompression approach is a commonly employed method for lumbar surgeries.[2] Lumbar procedures typically have extended durations, necessitating the patient's back soft tissues to endure prolonged traction in the prone position to clearly expose the surgical site.[3] This traction process frequently results in fluctuations in the patient's blood pressure and additional intraoperative bleeding.[4] Moreover, standard posterior decompression surgery often requires the insertion of intervertebral fusion devices, pedicle screws, and rods to achieve immediate postoperative stability.[5] Consequently, patients often experience postoperative lumbar swelling and pain.[6] Current research reports indicate that postoperative lumbar sacral pain and discomfort, resulting from the insertion of internal fixations, are primary complications following lumbar posterior decompression and fixation surgery.[7]

Received: 20 October 2023
Accepted: 30 December 2023
Published: 5 January 2024

”The term ‘adaptive training,’ originally associated with military training, is now being increasingly applied in the medical field, particularly in preparing patients for spinal surgery. Soldiers, for instance, often spend time in different climates to adapt to varying environmental conditions.[8,9] Similarly, we propose that patients undergoing lumbar surgery could benefit from acclimatizing in advance to the surgical process and its postoperative repercussions. This could potentially alleviate the discomfort caused by the physiological changes experienced after surgery.[10]

In Shanghai, preoperative training for spinal surgery is a long-established practice. For instance, patients undergoing anterior cervical decompression surgery are educated about tracheal shift exercises to reduce postoperative cervical edema and pain, a method supported by existing literature.[11] Extending this concept, adaptive training for lumbar spine surgery can be specifically designed according to the surgical approach and the patient’s condition. For traditional open lumbar surgeries, such training may include exercises to improve flexibility and strengthen the muscles around the lumbar spine. This can help patients prepare for the postoperative recovery phase, potentially reducing recovery time and enhancing pain management.

With the advent of minimally invasive spine surgery (MISS), the nature of preoperative adaptive training has evolved. MISS techniques, known for smaller incisions and reduced tissue disruption, inherently lessen postoperative pain and speed up recovery.[12–21] However, the role of adaptive training remains crucial, albeit with a modified focus. In the context of MISS, preoperative training can be more targeted towards educating patients about postoperative care, mobility, and self-care techniques. This includes exercises to maintain muscle tone and flexibility without exerting undue stress on the operated area. Such tailored training, attuned to the specificities of the surgical approach, holds the potential to optimize surgical outcomes and enhance overall patient well-being.

Based on the aforementioned research findings and the authors’ clinical observations, this retrospective study postulated that the factors contributing to discomfort in lumbar posterior surgery included prolonged prone positioning, tension in the back soft tissues, intraoperative soft tissue traction, and changes in lumbar curvature following internal fixation. While preoperative adaptive training for lumbar surgery had a longstanding history and had been practiced in certain hospitals in Shanghai for a long history, historical research on the benefits of such training remained scarce. Therefore, by reviewing patients’ vital signs and VAS scores preoperatively, intraoperatively, and postoperatively, we aimed to evaluate the impact of preoperative adaptive training on postoperative outcomes in lumbar surgery patients.

Materials and Methods

Ethics Statement

The retrospective review and analysis of this study received approval from the Institutional Review Board of Shanghai East Hospital, Shanghai, China. In adherence to the principles outlined in the Declaration of Helsinki, all research activities were conducted ethically within our country. Written informed consent was obtained from every participant, ensuring their voluntary participation and understanding of the study’s purpose and procedures. This study fully complies with the ethical standards set forth in the Declaration of Helsinki for medical research involving human subjects.

Patient Population

This study reviewed a total of 170 patients, comprising 84 females and 86 males, admitted from June 2021 to March 2023. The inclusion criteria were patients exhibiting degeneration in 1–2 lumbar segments, specifically in the L4-L5, L5-S1, or L4-S1 regions, which are commonly affected segments in lumbar degenerative diseases. The primary symptoms observed in these patients included numbness, pain in the lower limbs, or muscle weakness. All participants had not responded to non-surgical treatments and had no prior history of lumbar surgery. Exclusion criteria were comprehensive, including patients with adjacent segment disease post-lumbar surgery, lumbar tumors, lumbar spinal stenosis, ankylosing spondylitis, and systemic autoimmune diseases such as rheumatoid arthritis, Parkinson’s disease, amyotrophic lateral sclerosis, diabetes, and heart disease. After confirming lumbar degeneration and the specific segments for surgery through physical examinations and auxiliary tests such as CT and MRI, the patients were allocated into two groups: a stretch group and a control group. The division into groups was managed through a computer-generated randomization process. To clarify, the study did not initially create a randomization table for all 170 patients.

Instead, the process was iterative. We initially set up the program to generate a randomization table for 80 patients, with 40 patients per group. Once this initial cohort of 80 patients was included and their treatment was underway, we generated a subsequent randomization table for another 80 patients, also divided into two groups of 40. This staggered approach in patient inclusion and group allocation explains why the total number of patients eventually reached 170. It's important to note that this method of randomization was designed to ensure a balanced and unbiased distribution of patients between the groups, considering the gradual accrual of participants over the study period.

Pre-Operation Training and Evaluation

Patients in the adaptive training group received education on the day of admission. Patients were positioned prone on the bed with a pillow placed under their chest. They dorsiflexed their back muscles and maintained the position with upper limbs (Figure 1). The exercise sequence was as follows: patients performed 20 repetitions of the dorsiflexion exercise, doing these at a measured pace of 5 repetitions per minute. This pace was chosen to ensure that the exercises were both manageable and effective, considering the patients' physical condition pre-surgery. Upon completing these 20 repetitions, constituting one set, patients were advised to remain in the prone position for a rest period of 10 minutes. This rest interval allowed for muscle recovery and minimized the risk of strain. Each "large set" comprised four of these individual sets, interspersed with the 10-minute rest periods.

To prevent fatigue and overexertion, patients had a significant rest period of 2–3 hours between each large set. In total, approximately three large sets were conducted daily, striking a balance between adequate exercise and necessary rest. It's essential to note that the exercise regimen was not meant to exhaust the patients but to engage them in a productive activity during their hospital stay. In cases where patients experienced immediate pain in the lower limbs or back following the exercises, the regimen was promptly halted. Patients were then allowed to rest in the prone position until the pain subsided, after which they could continue the exercises at their discretion. This approach ensured patient safety and comfort while providing adequate physical preparation for the upcoming surgery. The exercise regimen began 3 days before surgery and ceased on the evening one day prior to the operation. Between the first and third day of exercise, vital signs such as blood pressure, heart rate, blood oxygen saturation, and respiratory rate were measured. Patients in the control group did not undergo the related training but had the same vital sign measurements taken during their hospital stay.

After the adaptive training group patients completed their exercises, the posterior lumbar decompression surgery proceeded as planned. Three surgeons from the same treatment group performed the posterior lumbar decompression fusion surgery on the patients. During the surgical procedure, an anesthesiologist monitored and recorded the vital signs of the patients, including blood pressure, blood oxygen saturation, and respiratory rate.

Follow-Up Evaluation

Clinical outcomes for patients in both groups were evaluated using the visual analogue scale (VAS) for back and leg pain. Assessments were made pre-operation and at follow-up intervals of 14 days, 1 month and 3 months post-operation.

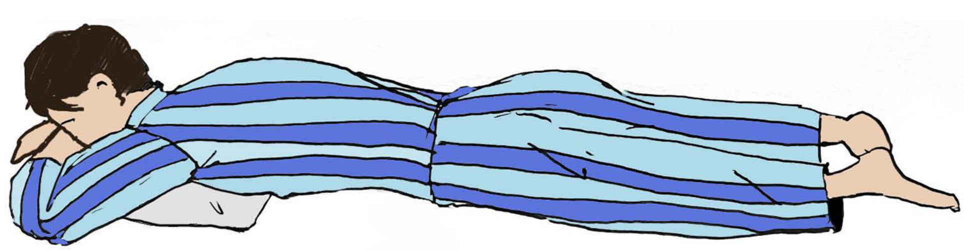

Figure 1 Adaptive training method. The patient was in prone position on the bed with a pillow placed under chest in rest. Dorsiflexed the back and maintain the position with upper limbs for seconds.

Statistical Analysis

Statistical analyses were performed using statistical software R 4.1.2 Differences between the averages of various indices during exercise and surgery were determined. Paired *t*-tests assessed the impact of TSE on the variances of blood pressure, respiratory rate, VAS, and blood oxygen saturation in the stretched group. The same method was applied to analyze intraoperative changes of the indices after skin incision and before and after trachea retraction in both groups. Data for blood pressure, respiratory rate, and blood oxygen saturation were presented as x±s. To evaluate the statistical significance of postoperative improvements in outcome scores for each treatment group, 2-way ANOVA tests were utilized. A P-value of less than 0.05 was considered statistically significant.

Results

Patient Characteristics

All patients (84 females, 86 males) completed the follow-up assessments, with an average age of 64 years (range, 48–84 years). Data on age, gender, and surgical segments were analyzed for all patients. No significant differences were observed between the adaptive training group and the control group (Table 1). Besides, there was also no significant intergroup difference in other vital signs such as blood pressure, respiratory rate, and back pain VAS score.

Analysis of Vital Signs at the Beginning and End of Training in the Training Group

In the stretched group, during the initial exercise, there was a notable increase in blood pressure, heart rate, and respiratory fluctuations. The variations observed were 15 (±8.1) mm Hg for systolic blood pressure, 3.7 (±5.1) mm Hg for diastolic blood pressure, and 4.1 (±1.8) times/min for the respiratory rate. By the conclusion of the final exercise, the variations of systolic blood pressure were 7.7 mm Hg (±5.1), diastolic blood pressure were 1.9 mm Hg (±1.3) and respiratory rate were 2.2 (±1.1) times/min. The observed reductions in these vital signs from the beginning to the end of the training were statistically significant ($p<0.001$, as shown in Table 2).

Analysis of Vital Signs Between Stretch and Control Groups During the Surgery

The fluctuation in blood pressure in the Stretched group were significantly smaller than those in the control group ($p<0.01$). However, the intraoperative respiratory and blood oxygen saturation showed no significant difference between groups ($p>0.05$, Table 3). A key observation made during the surgeries was the enhanced surgical exposure in the

Table 1 Grouping and Demographic Data of the Patients

	Control (N=83)	Stretch (N=87)	Overall (N=170)
Age			
Mean (SD)	63 (8.7)	65 (8.3)	64 (8.5)
Gender (%)			
Female	43 (52%)	41 (47%)	84 (49%)
Male	40 (48%)	46 (53%)	86 (51%)
Segments (%)			
One level	46 (55%)	43 (49%)	89 (52%)
Two level	37 (45%)	44 (51%)	81 (48%)

Table 2 Mean Fluctuation in Blood Pressure, Heart Rate and Respiratory in the Stretched Group During the First and Last Exercise

Vital Signs Mean (SD)	First Exercise (N=87)	Last Exercise (N=87)	P-value
Systolic blood pressure (mm Hg)	15 (&±8.1)	7.7 (±5.1)	<0.001
Diastolic blood pressure (mm Hg)	3.7 (±2.0)	1.9 (±1.3)	<0.001
Respiratory rate (times/min)	4.1 (±1.8)	2.2 (±1.1)	<0.001

Table 3 Mean Fluctuation in Intraoperative Blood Pressure, Heart Rate, Respiratory and Blood Oxygen Saturation in Both Group

Vital Signs Mean (SD)	Stretched (N=83)	Control (N=87)	P-value
Systolic blood pressure (mm Hg)	2.3 (±1.1)	6.4 (±0.59)	<0.001
Diastolic blood pressure (mm Hg)	5.1 (±2.7)	8.7 (±1.5)	<0.001
Respiratory rate (times/min)	1.7 (±1.2)	2.1 (±1.5)	0.0526
Blood oxygen saturation (%)	1.3 (±0.94)	1.2 (±0.89)	0.401

Stretched group. Surgeons conducting the procedures noted better exposure and more relaxed soft tissue conditions in these patients compared to those in the control group. This qualitative assessment, based on the surgeons' observations, indicates a possible benefit of preoperative adaptive training on the ease of surgical access. It is important to note, however, that despite these observations, no significant differences were found in measurable surgical outcomes such as total operative time and blood loss between the two groups. This result highlights that while preoperative adaptive training may influence certain intraoperative conditions, such as surgical exposure, it does not necessarily translate into quantifiable differences in these specific operative metrics.

Surgical Outcomes and Follow-Up Analysis

On the 14th postoperative day, no significant differences in VAS score improvements were observed between the training and control groups. Similarly, VAS score results showed no significant differences between the two groups during the 1-month and 3-month postoperative follow-ups (Figure 2).

Discussion

Posterior lumbar decompression fusion surgery is one of the mainstream surgical options for treating lumbar disc herniation.[2] However, this procedure requires blunt dissection near the lamina to access the target area for decompression and fusion.[22] This inevitably causes traction and damage to the patient's soft tissues. Current complications associated with posterior lumbar decompression surgery mainly include postoperative lumbar tissue soreness and swelling.[23,24] It is also important to note that pain is a major factor causing blood pressure fluctuations in patients during the postoperative period.[25] Effective management of postoperative pain is thus crucial, as uncontrolled pain can lead to abnormal blood pressure, which in turn increases the risk of stroke, particularly in elderly patients.[26] There have also been reports of secondary cardiovascular risk events in patients after lumbar surgery.[27] Furthermore, although reperfusion injuries, such as muscle tissue necrosis and swelling, rarely occur after lumbar surgery due to prolonged traction, they have been documented.[28] We believe that the main reasons for postoperative soft tissue swelling and the inability to tolerate and

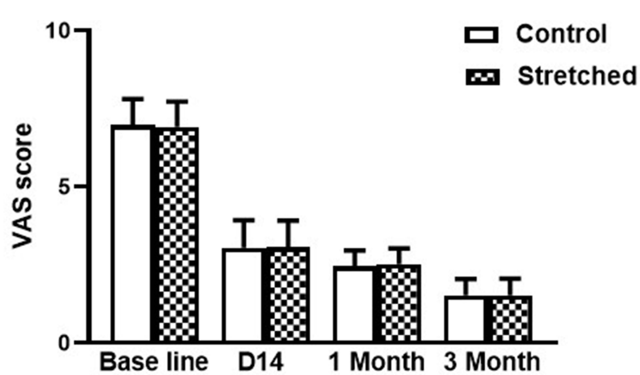

Figure 2 The improvement of the visual analogue scale for back pain score at different follow-up time points.

endure postoperative pain are the traction on the surgical area's soft tissue and the prolonged prone position during lumbar surgery.[9]

Adaptive training is an essential aspect of preparation for various spinal surgeries, helping patients to acclimate to the changes and demands of both the surgical procedure and postoperative recovery.[29] This training involves educating patients about specific preoperative functional exercises that are tailored to their upcoming surgery. These exercises are designed to aid in adapting to the physical changes and challenges that may occur post-surgery.[6]

In the context of anterior cervical surgery, for instance, we guide patients through tracheal traction training to facilitate surgical exposure and minimize postoperative cervical edema and discomfort.[7] Similarly, for lumbar surgery patients, our hospital has a long-standing practice of providing preoperative lumbar adaptive training. This specialized training focuses on exercises specific to the lumbar region, preparing patients for the particular requirements of lumbar procedures.[8,10]

Additionally, for patients with compromised lung function, exercises such as balloon-blowing are recommended to enhance cardiopulmonary function, which is crucial for meeting the requirements of anesthesia.[30] Although this exercise is not a part of the lumbar adaptive training regimen, it exemplifies the broader principle that various types of preoperative exercises can be beneficial in enhancing the overall surgical experience and recovery. Our study's findings contribute valuable insights into the role of preoperative adaptive training in lumbar surgery. While the training demonstrated a significant effect in stabilizing intraoperative blood pressure fluctuations, this did not translate into long-term improvements in postoperative pain, as measured by the Visual Analog Scale (VAS) scores at 14 days, 1 month, and 3 months postoperatively. This suggests that while preoperative adaptive training can enhance certain intraoperative outcomes, its impact on long-term postoperative recovery, particularly in terms of pain management, may be limited.

Notably, during lumbar surgery, the traction and manipulation of soft tissues can have significant effects on a patient's intraoperative vital signs. Cardiovascular events related to blood pressure changes are a concern, and our findings indicate that preoperative lumbar adaptive training effectively mitigates these risks by maintaining the stability of patients' blood pressure and respiratory rates during the surgical procedure. Surgeons reported smoother operative exposure and progression in the stretch group compared to the control group, which could potentially facilitate surgical efficiency. However, it is important to note that this did not result in statistically significant differences in operative time or blood loss.

The lack of significant difference in postoperative VAS scores between the preoperative adaptive training group and the control group at all postoperative time points indicates that factors beyond the scope of preoperative training may play a more dominant role in long-term pain management. This might include the extent of soft tissue damage, changes in spinal sequence due to lumbar internal fixation, and individual patient responses to surgery and postoperative care.

Our study underscores the need for a comprehensive approach to preoperative preparation that not only focuses on physical exercises to improve functional aspects relevant to the surgery but also considers the broader context of postoperative care and pain management strategies. The potential benefits of preoperative adaptive training on immediate intraoperative parameters are clear, yet its impact on long-term postoperative outcomes, particularly pain, requires further exploration to understand the full scope of its efficacy. Future studies may focus on integrating adaptive training with other postoperative rehabilitation strategies to enhance overall patient recovery following lumbar surgery.

Considering recent meta-analyses, our study's findings gain additional relevance by situating preoperative adaptive training within a broader continuum of perioperative care. These analyses underscore the crucial role of structured postoperative exercises in enhancing recovery, particularly focusing on pain management, functional outcomes, and psychosocial aspects of patient care. This evidence aligns with our findings, suggesting that while preoperative preparation is essential, it should be part of a more comprehensive care approach that also encompasses structured postoperative rehabilitation programs.

Such postoperative programs could integrate various forms of physical therapy, including strengthening, stabilization, and aerobic exercises, which have been shown to offer additional advantages in terms of disability scores and functional recovery in the short to medium term. Notably, relaxation, stretching, and mobilization training are also emphasized for their beneficial effects post-lumbar decompression surgery. Furthermore, cognitive therapy elements, a significant focus in some studies, have demonstrated benefits in managing long-term disability and kinesiophobia, particularly when combined with exercise interventions.[31–41]

For instance, one meta-analysis revealed that cognitive therapy, when added to exercise programs, yields better outcomes in lumbar fusion surgery compared to exercise alone, particularly in terms of long-term disability and kinesiophobia.[42] Another study highlighted the effectiveness of exercise training on physical function, bodily pain, and social function, demonstrating moderate-degree evidence of its efficacy in improving quality of life parameters post-lumbar decompression surgery.[43]

These insights indicate the importance of a holistic approach to spinal surgery recovery, where preoperative adaptive training is just one component of a multifaceted rehabilitation strategy. Our study, while focusing on the immediate postoperative phase, opens the door for future research to explore the synergistic effects of combining preoperative training with structured postoperative rehabilitation to optimize patient outcomes in lumbar surgery.

This study presents several strengths that contribute significantly to the understanding of preoperative adaptive training in lumbar surgery. A primary strength lies in its focused examination of the immediate effects of preoperative training on postoperative outcomes, particularly emphasizing improvements in VAS scores. The systematic approach to patient selection, rigorous adherence to exercise protocols, and meticulous monitoring of outcomes provide robust data supporting the efficacy of preoperative adaptive training. Additionally, the study's design, which includes a control group for comparison, lends credibility to the findings by minimizing biases and allowing for a clearer interpretation of the training's impact.

However, the study is not without its limitations, which offer avenues for future research. The primary limitation is the short-term follow-up period, which restricts our understanding of the long-term effects of preoperative adaptive training on patient recovery and quality of life. Furthermore, the study primarily focuses on quantitative measurements such as VAS scores and vital signs, potentially overlooking qualitative aspects such as patient satisfaction, psychological well-being, and long-term functional capacity. Another limitation is the study's single-center design, which may limit the generalizability of the findings to broader populations with diverse demographics and healthcare settings. Addressing these limitations in future studies could provide a more comprehensive understanding of the role of preoperative adaptive training in enhancing long-term outcomes for lumbar surgery patients.

Conclusion

This study sheds light on the role of preoperative adaptive training in lumbar surgery, with a specific focus on its impact on intraoperative parameters. While our results demonstrated that such training significantly stabilizes intraoperative blood pressure fluctuations, it did not translate into noticeable improvements in postoperative pain outcomes, as indicated by the VAS (Visual Analog Scale) scores at various follow-up intervals (14 days, 1 month, and 3 months postoperatively). This finding suggests that while preoperative adaptive training can enhance certain aspects of the surgical process, its influence on longer-term postoperative pain management is limited.

Our research, primarily concentrating on short-term follow-up and vital sign monitoring, indicates the need for further investigation into the long-term effects of preoperative adaptive training on overall surgical outcomes. Future research is required to fully understand the spectrum of benefits and limitations of such training, particularly in the context of patient recovery and pain management over an extended postoperative period.

In conclusion, our study contributes to the existing knowledge on preoperative preparation for lumbar surgery, highlighting the immediate intraoperative benefits of adaptive training. However, it also points to the necessity for a more comprehensive approach in preoperative care, integrating physical training with a broader strategy encompassing post-operative pain management and rehabilitation. The significance of our findings lies in their implication for future research and the refinement of surgical preparation protocols to optimize patient outcomes in lumbar surgery.

Disclosure

The authors report no conflicts of interest in this work.

References

1. Demirel A, Yorubulut M, Ergun N. Regression of lumbar disc herniation by physiotherapy. Does non-surgical spinal decompression therapy make a difference? Double-blind randomized controlled trial. *J Back Musculoskelet Rehabil*. 2017;30(5):1015–1022. doi:10.3233/BMR-169581
2. Kim SK, Lee SC, Park SW, Kim ES. Complications of lumbar disc herniations following trans-sacral epiduroscopic lumbar decompression: a single-center, retrospective study. *J Orthop Surg Res*. 2017;12(1):187. doi:10.1186/s13018-017-0691-z
3. Chen BL, Guo JB, Zhang HW, et al. Surgical versus non-operative treatment for lumbar disc herniation: a systematic review and meta-analysis. *Clin Rehabil*. 2018;32(2):146–160. doi:10.1177/0269215517719952
4. Kim HS, Yun DH, Huh KY. Effect of spinal decompression therapy compared with intermittent mechanical traction in lumbosacral disc herniation. *J Korean Acad Rehabilit Med*. 2008;32(3):319–323.
5. Chen KT, Choi KC, Song MS, Jabri H, Lokanath YK, Kim JS. Hybrid Interlaminar endoscopic lumbar decompression in disc herniation combined with spinal stenosis. *Oper Neurosurg*. 2021;20(3):E168–E174. doi:10.1093/ons/opaa360
6. Hellinger S. Treatment of contained lumbar disc herniations using radiofrequency assisted micro-tubular decompression and nucleotomy: four year prospective study results. *Int J Spine Surg*. 2014;8:24. doi:10.14444/1024
7. Toyone T, Tanaka T, Kato D, Kaneyama R. Low-back pain following surgery for lumbar disc herniation: a prospective study. *JBJS*. 2004;86 (5):893–896. doi:10.2106/00004623-200405000-00001
8. Lurie JD, Tosteson TD, Tosteson AN, et al. Surgical versus nonoperative treatment for lumbar disc herniation: eight-year results for the spine patient outcomes research trial. *Spine*. 2014;39(1):3–16. doi:10.1097/BRS.0000000000000088
9. Best NM, Sasso RC. Outpatient lumbar spine decompression in 233 patients 65 years of age or older. *Spine*. 2007;32(10):1135–1139; discussion 1140. doi:10.1097/01.brs.0000261486.51019.4a
10. Saraçoğlu İ, Kaya İ, Cingözi D, Emre Aydın H. Preoperative pain neurophysiology education for lumbar radiculopathy: a randomized-controlled trial. *Turk J Phys Med Rehabil*. 2021;67(3):328–335. doi:10.5606/tftrd.2021.5495
11. Zhang Y, Tian L, Zhao X, et al. Effect of preoperative tracheal stretch exercise on anterior cervical spine surgery: a retrospective study. *J Spinal Disord Tech*. 2015;28(10):E565–E570. doi:10.1097/BSD.0000000000000039
12. Zairi F, Arikat A, Allaoui M, Marinho P, Assaker R. Minimally invasive decompression and stabilization for the management of thoracolumbar spine metastasis. *J Neurosurg Spine*. 2012;17(1):19–23. doi:10.3171/2012.4.SPINE111108
13. Kerimbayev TT, Tuigynov ZM, Aleinikov VG, et al. Minimally invasive posterolateral approach for surgical resection of dumbbell tumors of the lumbar spine. *Front Surg*. 2022;9:792922. doi:10.3389/fsurg.2022.792922
14. Kumar N, Malhotra R, Maharajan K, et al. Metastatic spine tumor surgery: a comparative study of minimally invasive approach using percutaneous pedicle screws fixation versus open approach. *Clin Spine Surg*. 2017;30(8):E1015–E1021. doi:10.1097/BSD.0000000000000400
15. Hudak EM, Perry MW. Outpatient minimally invasive spine surgery using endoscopy for the treatment of lumbar spinal stenosis among obese patients. *J Orthop*. 2015;12(3):156–159. doi:10.1016/j.jor.2015.01.007
16. Miscusi M, Polli FM, Forcato S, et al. Comparison of minimally invasive surgery with standard open surgery for vertebral thoracic metastases causing acute myelopathy in patients with short- or mid-term life expectancy: surgical technique and early clinical results. *J Neurosurg Spine*. 2015;22(5):518–525. doi:10.3171/2014.10.SPINE131201
17. Park J, Ham DW, Kwon BT, Park SM, Kim HJ, Yeom JS. Minimally invasive spine surgery: techniques, technologies, and indications. *Asian Spine J*. 2020;14(5):694–701. doi:10.31616/asj.2020.0384
18. Camacho JE, Usmani MF, Strickland AR, Banagan KE, Ludwig SC. The use of minimally invasive surgery in spine trauma: a review of concepts. *J Spine Surg*. 2019;5(Suppl 1):S91–S100. doi:10.21037/jss.2019.04.13
19. Gandham EJ, Uvaraj NR, Eum JH. Unilateral biportal percutaneous transforaminal endoscopic lumbar foraminal decompression and discectomy: a technical note. *Neurol India*. 2022;70(2):510–514. doi:10.4103/0028-3886.344669
20. Imada AO, Huynh TR, Drazin D. Minimally invasive versus open laminectomy/discectomy, transforaminal lumbar, and posterior lumbar interbody fusions: a systematic review. *Cureus*. 2017;9(7):e1488. doi:10.7759/cureus.1488
21. Patel PD, Canseco JA, Houlihan N, Gabay A, Grasso G, Vaccaro AR. Overview of minimally invasive spine surgery. *World Neurosurg*. 2020;142:43–56. doi:10.1016/j.wneu.2020.06.043
22. Benz RJ, Garfin SR. Current techniques of decompression of the lumbar spine. *Clin Orthop Relat Res*. 2001;384(384):75–81. doi:10.1097/00003086-200103000-00010
23. Kleeman TJ, Hiscoe AC, Berg EE. Patient outcomes after minimally destabilizing lumbar stenosis decompression: the “Port-Hole” technique. *Spine*. 2000;25(7):865–870. doi:10.1097/00007632-200004010-00016
24. Nerland US, Jakola AS, Giannadakis C, et al. The risk of getting worse: predictors of deterioration after decompressive surgery for lumbar spinal stenosis: a multicenter observational study. *World Neurosurg*. 2015;84(4):1095–1102. doi:10.1016/j.wneu.2015.05.055
25. Cheung PWH, Fong HK, Wong CS, Cheung JPY. The influence of developmental spinal stenosis on the risk of re-operation on an adjacent segment after decompression-only surgery for lumbar spinal stenosis. *Bone Joint J*. 2019;101-b(2):154–161. doi:10.1302/0301-620X.101B2.BJJ-2018-1136.R2
26. Garcia RM, Messerschmitt PJ, Furey CG, Bohlman HH, Cassinelli EH. Weight loss in overweight and obese patients following successful lumbar decompression. *J Bone Joint Surg Am*. 2008;90(4):742–747. doi:10.2106/JBJS.G.00724
27. Pritchett JW. Lumbar decompression to treat foot drop after Hip arthroplasty. *Clin Orthop Relat Res*. 1994;303:173–177.
28. Rosen DS, O’Toole JE, Eichholz KM, et al. Minimally invasive lumbar spinal decompression in the elderly: outcomes of 50 patients aged 75 years and older. *Neurosurgery*. 2007;60(3):503–509; discussion 509–510. doi:10.1227/01.NEU.0000255332.87909.58
29. Spratt KF, Keller TS, Szpalski M, Vandeputte K, Gunzburg R. A predictive model for outcome after conservative decompression surgery for lumbar spinal stenosis. *Eur Spine J*. 2004;13(1):14–21. doi:10.1007/s00586-003-0583-2
30. Sedighi M, Haghnegahdar A. Lumbar disk herniation surgery: outcome and predictors. *Global Spine J*. 2014;4(4):233–244. doi:10.1055/s-0034-1390010
31. Divya PA, Nuhmani S, Hussain Khan M, Hussain Khan M, Hussain Khan M. Effect of lumbar stabilization exercises and thoracic mobilization with strengthening exercises on pain level, thoracic kyphosis, and functional disability in chronic low back pain. *J Complement Integr Med*. 2020;18(2):419–424. doi:10.1515/jcim-2019-0327

32. Kim S, Kim H, Chung J. Effects of spinal stabilization exercise on the cross-sectional areas of the lumbar multifidus and psoas major muscles, pain intensity, and lumbar muscle strength of patients with degenerative disc disease. *J Phys Ther Sci*. 2014;26(4):579–582. doi:10.1589/jpts.26.579
33. Kim GY, Kin SH. Effects of push-ups plus sling exercise on muscle activation and cross-sectional area of the multifidus muscle in patients with low back pain. *J Phys Ther Sci*. 2013;25(12):1575–1578. doi:10.1589/jpts.25.1575
34. Koumantakis GA, Watson PJ, Oldham JA. Trunk muscle stabilization training plus general exercise versus general exercise only: randomized controlled trial of patients with recurrent low back pain. *Phys Ther*. 2005;85(3):209–225. doi:10.1093/ptj/85.3.209
35. You JH, Kim SY, Oh DW, Chon SC. The effect of a novel core stabilization technique on managing patients with chronic low back pain: a randomized, controlled, experimenter-blinded study. *Clin Rehabil*. 2014;28(5):460–469. doi:10.1177/0269215513506231
36. Sung PS. Multifidi muscles median frequency before and after spinal stabilization exercises. *Arch Phys Med Rehabil*. 2003;84(9):1313–1318. doi:10.1016/S0003-9993(03)00139-4
37. Bayraktar D, Guclu-Gunduz A, Lambeck J, Yazici G, Aykol S, Demirci H. A comparison of water-based and land-based core stability exercises in patients with lumbar disc herniation: a pilot study. *Disabil Rehabil*. 2016;38(12):1163–1171. doi:10.3109/09638288.2015.1075608
38. Moon HJ, Choi KH, Kim DH, et al. Effect of lumbar stabilization and dynamic lumbar strengthening exercises in patients with chronic low back pain. *Ann Rehabil Med*. 2013;37(1):110–117. doi:10.5535/arm.2013.37.1.110
39. Demir S, Dulgeroglu D, Cakci A. Effects of dynamic lumbar stabilization exercises following lumbar microdiscectomy on pain, mobility and return to work. Randomized controlled trial. *Eur J Phys Rehabil Med*. 2014;50(6):627–640.
40. Carli F, Zavorsky GS. Optimizing functional exercise capacity in the elderly surgical population. *Curr Opin Clin Nutr Metab Care*. 2005;8 (1):23–32. doi:10.1097/00075197-200501000-00005
41. Holmgren T, Oberg B, Sjöberg I, Johansson K. Supervised strengthening exercises versus home-based movement exercises after arthroscopic acromioplasty: a randomized clinical trial. *J Rehabil Med*. 2012;44(1):12–18. doi:10.2340/16501977-0889
42. Özden F. The effectiveness of physical exercise after lumbar fusion surgery: a systematic review and meta-analysis. *World Neurosurg*. 2022;163: e396–e412. doi:10.1016/j.wneu.2022.03.143
43. Özden F. The effect of exercise interventions after lumbar decompression surgery: a systematic review and meta-analysis. *World Neurosurg*. 2022;167:e904–e921. doi:10.1016/j.wneu.2022.08.103