RESEARCH | Article in Press

Effectiveness of dynamic neuromuscular stabilization exercises on clinical variables in postoperative rehabilitation of patients with lumbar disc herniation: a randomized controlled trial

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Received: 23 December 2024 / Accepted: 13 August 2026

Abstract

Purpose This study evaluates the effects of an 8-week Dynamic Neuromuscular Stabilization (DNS) program on disability, physical activity, and fear-avoidance behaviors in postoperative lumbar disc herniation (LDH) patients.

Method The study was designed as a randomized controlled trial. Participants of both sexes, aged 35–50 years, were recruited from a single-center postoperative outpatient physiotherapy setting and randomized into DNS (intervention) and standard care (control) groups. The DNS program emphasized core stability, diaphragmatic breathing, and postural alignment. Outcomes were measured at baseline and after the 8-week intervention period using validated scales for disability (ODI), pain (VAS), physical activity (MET-minutes), and fear-avoidance (FDAQ). Data were analyzed using appropriate inferential statistical methods, with statistical significance set at $p < 0.05$.

Results Baseline characteristics were comparable between groups ($p > 0.05$). Post-intervention, a significant difference was observed between groups in physical activity level categories ($p = 0.001$), with a shift toward higher activity levels in the intervention group. Physical activity (MET-min/week) was significantly higher in the intervention group at post-intervention ($p = 0.001$). Post-intervention, the intervention group demonstrated significantly lower functional disability, pain at rest, pain during activity, and fear of daily activities compared to the control group (all $p \leq 0.001$). Within-group analyses showed significant improvements in functional disability, pain, fear of daily activities, and physical activity in the intervention group (all $p < 0.001$).

Conclusion DNS demonstrated superior efficacy compared to standard care, achieving clinically meaningful improvements across all metrics. These results highlight DNS as a promising approach for enhancing functional recovery and clinical outcomes in patients with LDH.

Clinical trial number The protocol is registered with http://clinicaltrials.gov/15/August/2023, Clinical Trial, NCT06005948).

Keywords Dynamic neuromuscular stabilization · Exercise therapy · Low back pain · Lumbar disc herniation · Postoperative rehabilitation

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https://doi.org/10.1186/s12891-026-10375-1

Published online: 02 September 2026

Introduction

Lumbar disc herniation (LDH) is a prevalent musculoskeletal condition that significantly impacts the quality of life, particularly in working-age adults [1, 2]. While conservative treatments, such as physical therapy and pharmacological management, are effective for many patients, surgical intervention becomes necessary in cases of persistent radicular pain and neurological dysfunction unresponsive to these approaches [3, 4]. Although surgery alleviates nerve compression and reduces pain, residual complications such as muscle weakness, spinal instability, and sciatica frequently persist, hindering full functional recovery [5, 6].

Postoperative rehabilitation plays a critical role in mitigating these complications and promoting optimal recovery. Early rehabilitation has been shown to reduce pain, improve disability, and enhance lumbar mobility [7, 8]. However, challenges such as scar tissue formation, muscle atrophy, and impaired neural control remain barriers to effective outcomes, often leading to long-term spinal instability and compromised functional capacity [9]. These limitations underscore the need for advanced and targeted rehabilitation strategies.

Dynamic Neuromuscular Stabilization (DNS) represents a promising approach to postoperative rehabilitation. Grounded in developmental kinesiology, DNS emphasizes restoring motor control and postural stability by utilizing genetically encoded movement patterns observed in infancy [10, 11]. The approach prioritizes the activation of core stabilizing muscles, such as diaphragm, transverse abdominis, and multifidus, to achieve postural alignment and optimize spinal mechanics. Breathing exercises and functional movements within DNS protocols are designed to correct faulty motor patterns, restore joint centration, and enhance mechanical efficiency [12–14].

While DNS has demonstrated efficacy in improving outcomes for neuromuscular and musculoskeletal conditions, its specific effects in postoperative LDH rehabilitation are underexplored. Most studies focus on general benefits such as muscle strength, postural control, and pain relief, but there is limited research on how DNS impacts key metrics like disability, physical activity, and fear-avoidance behaviors in this patient population [15–17]. Furthermore, comparative analyses of DNS and other rehabilitation techniques over the long term remain scarce.

This study aims to evaluate the efficacy of an 8-week DNS-based rehabilitation program in reducing pain, improving disability, increasing physical activity levels, and decreasing fear-avoidance behaviors in patients undergoing postoperative rehabilitation for LDH.

Method

This study utilized a prospective, parallel-group, randomized controlled trial design to evaluate the efficacy of a DNS program in postoperative rehabilitation of patients with LDH. The trial was single-blind (assessor-blinded); outcome assessors were blinded to group assignment, whereas participants and intervention administrators could not be blinded due to the nature of the intervention. Assessments were conducted at baseline (pre-intervention) and after the 8-week intervention (post-intervention). This study was conducted and reported following the Consolidated Standards of Reporting Trials (CONSORT) statement [18]. Following the Helsinki Declaration, ethical approval was obtained from the Uskudar University Non-Interventional Research Ethics Committee (approval number: 61351342/December 2022). The protocol is registered with http://clinicaltrials.gov/15/August/2023, Clinical Trial, NCT06005948). All participants provided written informed consent. The study flowchart illustrating enrollment, allocation, and follow-up processes is provided in Fig. 1.

Participants and sample size

The study recruited 56 individuals aged 35–50 years with MRI-confirmed LDH at the L4–L5 or L5–S1 levels from a single-center postoperative outpatient physiotherapy clinic. Participants were randomly allocated to either the intervention (DNS exercises) or control (standard care) group using a computer-generated random sequence

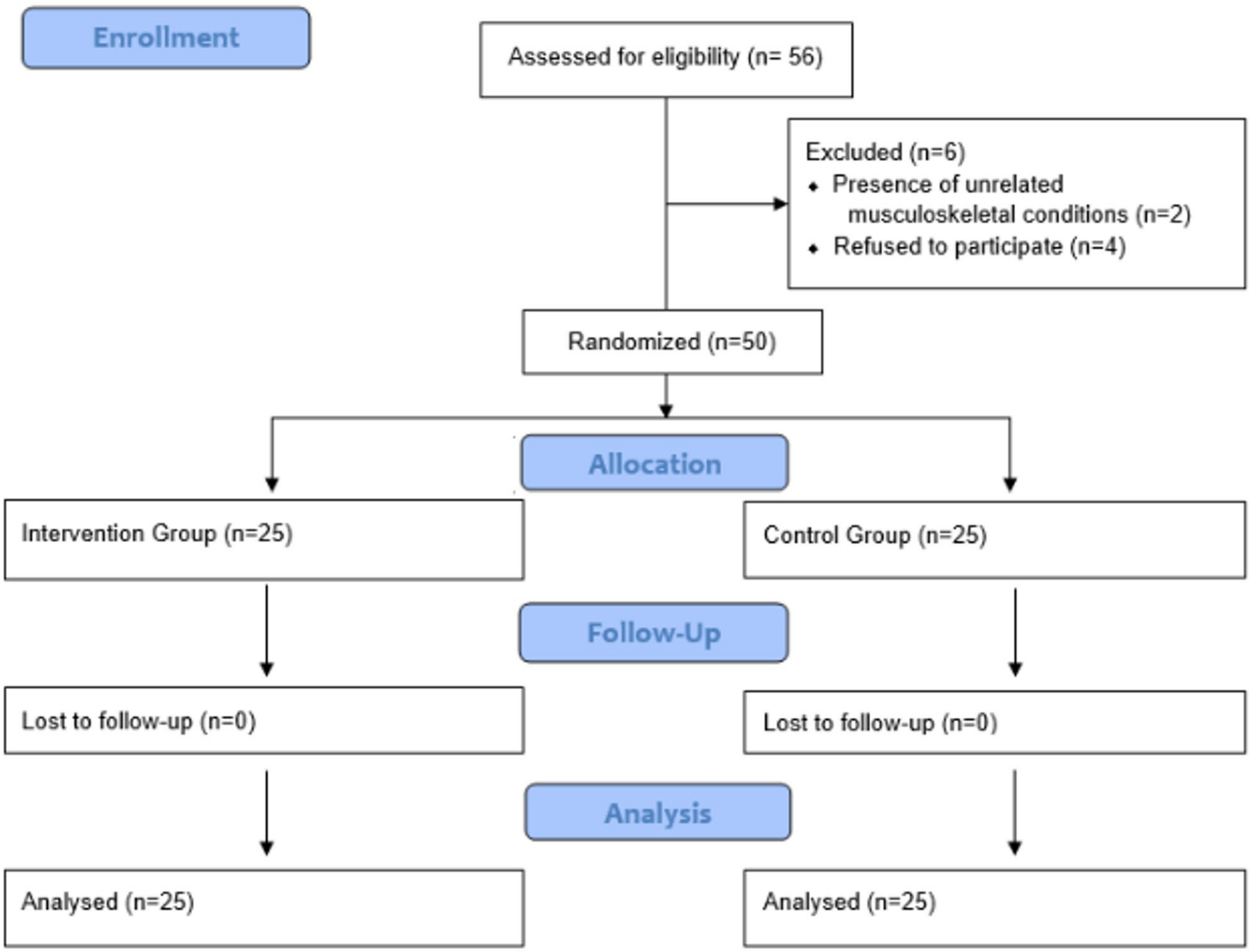

Fig. 1 Flowchart of the study

created via Random.org, with a 1:1 allocation ratio. Allocation concealment was ensured using sequentially numbered, opaque, sealed envelopes prepared by a researcher not involved in recruitment or assessment.

Due to the nature of the intervention, participants and treating therapists were not blinded; however, outcome assessments were performed by an independent assessor blinded to group assignment. The sample size was calculated using G*Power 3.1.9.4 software, based on an effect size of $f = 0.59$ ($\eta^2 = 0.26$), significance level $\alpha = 0.05$, and power $1 - \beta = 0.80$. To account for a potential 10% dropout rate, the final sample size was adjusted to 56 participants (28 per group), aligning with similar early postoperative rehabilitation studies [19].

Inclusion criteria

Participants were included if they:

- Had symptomatic LDH confirmed via MRI requiring surgical intervention.
- Were 35–50 years old and in a stable postoperative condition.
- Could follow written and verbal instructions and had access to internet-connected devices for virtual monitoring.
- Provided informed consent for participation in the study.

Exclusion criteria

Participants were excluded if they:

- Had undergone previous spinal surgery or had other spinal conditions such as spondylolisthesis, spinal stenosis, or instability unrelated to the current LDH.
- Presented with significant musculoskeletal disorders unrelated to LDH (e.g., severe osteoarthritis, fibromyalgia) [15].
- Had diagnosed neurological, rheumatological, or systemic diseases such as rheumatoid arthritis, lupus, or multiple sclerosis [7].
- Experienced functional impairments due to conditions like severe cardiovascular disease or uncontrolled diabetes.
- Reported cognitive, psychological, or mental health issues that could interfere with adherence to the protocol.
- Had medical contraindications to active exercise (e.g., recent myocardial infarction or uncontrolled hypertension) [19].
- Demonstrated unwillingness or inability to adhere to the prescribed exercise regimen.

Intervention protocol

The intervention group participated in a structured DNS-based rehabilitation program aimed at restoring motor control, core stability, and postural alignment after lumbar disc herniation surgery [11]. The intervention group participated in a structured DNS-based rehabilitation program (Table 1). The 8-week program included:

1. *Educational Phase (2 Weeks)*: Participants were introduced to safe movement techniques, postural awareness, diaphragmatic breathing, and pelvic tilts, laying the groundwork for motor control and safety before beginning active rehabilitation.
2. *Active Rehabilitation (8 Weeks)*: Sessions focused on postural stability, core muscle activation, and progressive loading [15]. Maintaining a neutral spine was emphasized to prevent compensatory movements and enhance mechanical efficiency [11]. Exercises were adjusted weekly based on individual improvements in strength and motor control [20].

The DNS intervention was conducted over an 8-week period and consisted of one supervised session per week led by a physiotherapist, complemented by home-based exercises performed five days per week. In total, participants completed eight supervised sessions and approximately 40 home-based exercise sessions during the intervention period. Each 50–60 min session was divided into three phases:

Warm-up (5–10 min): Diaphragmatic breathing and gentle mobilization exercises to activate the core and improve joint mobility.

Main exercise (40 min):

- *Core Activation*: Exercises like “Baby Rock,” “Oblique Sit,” and “Rolling” targeted the diaphragm, transverse abdominis, and multifidus.
- *Postural Control*: Closed kinetic chain exercises, including partial body-weight support movements, gradually improved stability and strength.

Cool-down (5-10 minutes): Relaxation and static stretching exercises to reduce muscle tension and facilitate recovery.

Detailed instructions, repetitions, and sets for each exercise are provided in Table 1. A physiotherapist with expertise in DNS ensured proper form during weekly supervised sessions and provided feedback for home-based

Table 1 DNS-based exercise program

Phase	Exercise	Description	Position	Repetitions/Sets	Cues/Progression	Notes for Pain or Adjustments
Warm-Up	Diaphragmatic Breathing	Deep breathing to activate the diaphragm and stabilize the core.	Supine or Seated	3 sets of 10 breaths	Focus on diaphragmatic expansion; avoid chest movement.	Stop if dizziness occurs; ensure slow, controlled breaths.
	Gentle Mobilization	Pelvic tilts and light spinal movements.	Supine	2 sets of 10 reps	Maintain a neutral spine and avoid overextension.	If lumbar pain occurs, reduce range of motion or stop.
Main Exercise	Baby Rock	Rock forward and backward on hands and knees.	Quadruped	3 sets of 12 reps	Engage the core; avoid lumbar collapse or hyperextension.	Use pillows under knees for comfort if pain occurs.
	Oblique Sit	Shift weight between sides in a side-sitting position.	Side Sitting	3 sets of 10 reps	Keep the torso upright; focus on pelvic control.	If discomfort arises, limit range or transition to supported sitting.
	Rolling	Roll from supine to prone without using limbs for leverage.	Supine	3 sets of 8 reps	Initiate movement from the core; maintain smooth, controlled rolling.	Stop if twisting causes discomfort; reduce rolling speed.
	Inclined Board	Perform partial bodyweight-supported movements.	Inclined Board	3 sets of 10 reps	Gradually increase load as tolerated; ensure core engagement.	Lower incline or reduce range if back strain is felt.
	Static Plank	Hold plank position; progress to dynamic variations.	Prone	2 sets of 20 s	Maintain alignment; avoid sagging hips or overarched back.	Use knees for support if holding full plank is too difficult or painful.
Cool-Down	Relaxation	Controlled breathing and light mobility exercises.	Supine or Seated	5 min	Focus on relaxation and diaphragmatic breathing.	Stop if any discomfort or fatigue is observed; prioritize rest.
	Static Stretching	Stretching major muscle groups (e.g., hamstrings, lumbar extensors).	Various	2 sets of 15 s	Stretch to the point of mild discomfort; avoid bouncing movements.	Modify or skip stretches that exacerbate pain; hold gentle positions.

exercises. Video tutorials and weekly logs supported adherence, with regular check-ins allowing adjustments to the intervention plan.

The control group followed standard postoperative care, which included walking and routine daily activities, without additional structured rehabilitation exercises. Participants in the control group did not receive instructional videos, structured exercise guidance, or supervised rehabilitation sessions. During the study period, they continued with usual postoperative recommendations and were contacted periodically to confirm adherence to these recommendations and to report any additional physical activities, without receiving therapeutic feedback or exercise instruction.

Outcome measures

Pain intensity

Pain was assessed using a 100-mm Visual Analog Scale (VAS). The VAS has demonstrated acceptable to excellent test–retest reliability in individuals with low back pain, with reported intraclass correlation coefficient (ICC) values ranging from 0.68 to 0.89 [21–25].

The scale ranges from 0 (“no pain”) to 100 (“worst imaginable pain”) and was administered to evaluate pain both at rest and during activity.

To determine clinical relevance, the Minimal Clinically Important Difference (MCID) was considered. In patients undergoing minimally invasive spinal surgery, the MCID corresponds to approximately 2–3 points on a 10-point scale, equivalent to 20–30 mm on the 100-mm VAS [26, 27].

 https://doi.org/10.1186/s12891-026-10375-1

Functional disability

Functional disability was assessed using the Oswestry Disability Index (ODI), a disease-specific self-reported instrument evaluating the impact of low back pain on functional status. The ODI has demonstrated excellent internal consistency (Cronbach's alpha > 0.90) and high test–retest reliability (ICC ≈ 0.92–0.94) in individuals with low back pain [28, 29].

The questionnaire consists of 10 items addressing domains such as pain intensity, personal care, lifting, walking, sitting, standing, sleeping, social life, sexual function, and traveling. Each item is scored from 0 (no disability) to 5 (maximum disability), and the total score is expressed as a percentage ranging from 0 to 100, with higher scores indicating greater disability [24, 28–30].

An MCID of 12 points was adopted based on prior studies in patients undergoing lumbar spine interventions.

Physical activity levels

Weekly physical activity was assessed using the International Physical Activity Questionnaire–Short Form (IPAQ-SF) and expressed in MET-minutes. Based on established cut-off values, participants were categorized as inactive (< 600 MET-min/week), minimally active (600–3000 MET-min/week), or highly active (> 3000 MET-min/week) [31, 32].

The IPAQ-SF has demonstrated moderate to good test–retest reliability in adult populations, with reported ICC values ranging from approximately 0.70 to 0.88 [31, 32].

Scoring was performed according to standardized procedures published on the official IPAQ website (www.ipaq.ki.se) [33].

Fear-avoidance behavior: Fear of Daily Activities Questionnaire (FDAQ)

Fear-avoidance behavior was assessed using the Fear of Daily Activities Questionnaire (FDAQ), a self-reported instrument evaluating fear related to common daily movements in individuals with chronic low back pain. Validation studies have reported good internal consistency (Cronbach's alpha > 0.85) and acceptable test–retest reliability (ICC ≈ 0.78–0.82) in low back pain populations [34, 35].

The FDAQ comprises 10 items representing activities such as lifting, bending, and sitting. Each item is rated on a 0–100 scale (0 = "no fear," 100 = "maximum fear"), and the total score is calculated as the mean of item scores, with higher values indicating greater fear-avoidance behavior [34, 35].

An MCID of 12.9 points was applied based on previous validation research [34].

Statistical analysis

All statistical analyses were performed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables were presented as mean ± standard deviation (Mean ± SD), and categorical variables as n (%). Independent Samples t-test was used to compare continuous variables (e.g., age, BMI) between the Intervention and Control groups at baseline. Chi-Square Test was applied to compare categorical variables (e.g., gender, education level, physical activity levels) between groups. For within-group comparisons (Baseline vs. Post-Intervention), the Wilcoxon Signed-Rank Test was utilized for non-normally distributed paired data. Between-group differences for non-normally distributed data were analyzed using the Mann-Whitney U Test. A p-value < 0.05 was considered statistically significant.

Results

At the beginning of the study, 56 participants were assessed for eligibility, and 6 of them were excluded due to the presence of unrelated musculoskeletal conditions ($n=2$) and refused to participate ($n=4$). Between September 2023 and December 2023, the study included 50 participants with LDH who were randomly allocated to the intervention and control groups.

Baseline characteristics

Baseline demographic and anthropometric characteristics were comparable between the intervention and control groups, with no statistically significant differences in age, height, weight, BMI, gender distribution, or educational status (all $p>0.05$) (Table 2). All participants completed the intervention period, and no dropouts or losses to follow-up were recorded during the study.

Physical activity levels

There was no significant difference between groups in baseline physical activity level distribution according to the IPAQ-Short Form ($p=0.47$).

Post-intervention, a significant difference was observed between groups in physical activity level categories ($p=0.001$), with a shift toward higher activity levels in the intervention group (Table 3).

Functional disability, pain, fear of daily activities, and physical activity (MET)

Baseline ODI, VAS (rest and activity), FDAQ, and MET values did not differ significantly between groups (all $p>0.05$).

Following the intervention, statistically significant between-group differences were observed in functional disability, pain at rest, pain during activity, fear of daily activities, and MET values (all $p\leq0.001$ except MET: $p=0.001$) (Table 4).

Table 2 Baseline socio-demographic characteristics of participants

Variables	Intervention Group Mean±SD	Control Group Mean±SD	*p*-value
Age (years)	41.20±5.36	42.20±5.69	0.54
Height (m)	1.71±0.10	1.70±0.09	0.64
Weight (kg)	78.96±16.48	80.96±14.75	0.65
BMI (kg/m²)	26.86±3.90	27.95±3.54	0.31
	n (%)	**n (%)**	
Gender			
Female	13 (52%)	14 (56%)	0.75
Male	12 (48%)	11 (44%)	
Education Level			
Basic Education	13 (52%)	11 (44%)	0.62
High School	3 (12%)	9 (36%)	
University	7 (28%)	5 (20%)	
Postgraduate	2 (8%)	0	

All values are presented as mean±standard deviation (mean±sd) or n (%)

Abbreviations BMI body mass index, *SD* standard deviation

Independent t-tests were used for continuous variables; chi-square tests were applied for categorical variables. $p < 0.05$ indicates statistical significance

Table 3 Physical activity levels (IPAQ-Short Form) baseline and post-intervention

			Intervention Group n (%)	Control Group n (%)	X^2	p-value
Physical Activity Levels (IPAQ-Short Form)	**Baseline**	Low	18 (72%)	20 (80%)	0.79	0.47
		Moderate	5 (20%)	4 (16%)		
		High	2 (8%)	1 (4%)		
	Post-Intervention	Low	0	10 (40%)	0.84	**0.001**
		Moderate	8 (32%)	12 (48%)		
		High	17 (68%)	3 (12%)		

Values are presented as n (%)

AbbreviationsIPAQ international physical activity questionnaire

Changes between groups were analyzed using the chi-square test (X^2)

$P<0.05$ indicates statistical significance

Table 4 Comparison of ODI, VAS, FDAQ, and IPAQ Scores Between Intervention and Control Groups at Baseline and Post-Intervention

Variables		Intervention Group Median (IQR)	Control Group Median (IQR)	U value	*p*-value (between groups)
Functional Disability	Baseline	71 (62–78)	70 (60–80)	298.0	0.77
	Post-Intervention	29 (27–34)	41 (35–48)	142.0	**0.0018**
	Z (within group)	-4.38	-4.21		
	p-value (within groups)	**<0.001**	**<0.001**		
Pain (Activity)	Baseline	85 (80–90)	86 (82–91)	305.5	0.66
	Post-Intervention	15 (12–20)	42 (36–48)	98.0	**<0.001**
	Z (within group)	-4.41	-4.36		
	p-value (within groups)	**<0.001**	**<0.001**		
Pain (Rest)	Baseline	84 (80–89)	85 (81–90)	312.0	0.80
	Post-Intervention	16 (12–19)	41 (35–47)	105.0	**<0.001**
	Z (within group)	-4.35	-4.29		
	p-value (within groups)	**<0.001**	**<0.001**		
Fear of Daily Activities	Baseline	83 (72–94)	85 (74–96)	301.0	0.65
	Post-Intervention	14 (5–28)	40 (22–55)	110.0	**<0.001**
	Z (within group)	-4.22	-4.18		
	p-value (within groups)	**<0.001**	**<0.001**		
Physical Activity (MET-min/week)	Baseline	500 (460–540)	512 (470–550)	280.0	0.40
	Post-Intervention	890 (850–930)	610 (560–670)	150.0	**0.001**
	Z (within group)	-4.30	-2.31		
	p-value (within groups)	**<0.001**	**0.02**		

All values are presented as median (interquartile range, IQR)

Between-group comparisons were performed using the Mann-Whitney U test. Within-group comparisons were performed using the Wilcoxon Signed-Rank test

$p<0.05$ indicates statistical significance

Within-group analyses demonstrated significant improvements in both groups for functional disability, pain (rest and activity), and fear of daily activities (all $p<0.001$).

For physical activity (MET), a significant increase was observed in the intervention group **($p<0.001$)** and a smaller but statistically significant increase in the control group ($p=0.02$) (Table 4).

Discussion

This randomized controlled trial underscores the effectiveness of an 8-week DNS program in postoperative rehabilitation for LDH patients. Both intervention and control groups exhibited significant improvements in disability (ODI), pain (VAS), and physical activity (IPAQ). However, the DNS group consistently achieved results surpassing MCID thresholds, indicating superior clinical benefits beyond natural recovery facilitated by standard care. These findings highlight DNS as an effective method for addressing postoperative recovery challenges.

Current evidence on early postoperative rehabilitation is mixed. While Millisdotter et al. [19] emphasized neuromuscular stabilization training benefits for early recovery, concerns about risks such as inflammation and re-injury persist [36]. This study adds to the literature by demonstrating that DNS, with its progressive and controlled methodology, mitigates these risks while enhancing core muscle activation and postural stability. These results validate DNS as a structured and cautious early rehabilitation approach.

The absence of baseline differences between groups strengthens the internal validity of the study. Additionally, the inclusion of participants with higher body mass indices provides clinically relevant insight, as excess weight may negatively influence spinal mechanics and postoperative pain [9]. DNS appears to address these biomechanical challenges through targeted core activation and optimization of postural control [14], thereby supporting functional restoration in a population often considered at greater risk for delayed recovery.

Improvements in physical activity observed in the intervention group further underscore the rehabilitative impact of DNS in the postoperative period. Restoration of activity participation is a central goal of lumbar disc herniation rehabilitation, as insufficient activity may delay functional recovery. These results align with prior research demonstrating the efficacy of motor control exercises in enhancing activity levels [20]. In this context, the present findings suggest that DNS, through its emphasis on coordinated trunk stabilization and postural control, may represent an effective strategy for facilitating functional reintegration after surgery.

The DNS group demonstrated greater pain reduction compared to the control group, indicating an enhanced analgesic effect beyond standard postoperative care. This finding is consistent with previous studies reporting that interventions targeting deep trunk stabilizers and postural control contribute to improved spinal alignment and decreased nociceptive input [11, 13]. Unlike conventional rehabilitation protocols that primarily emphasize general strengthening and mobility, DNS specifically integrates diaphragmatic breathing with segmental stabilization strategies. Such neuromuscular integration may reduce compensatory muscle overactivity and mechanical stress on spinal structures, thereby supporting more effective postoperative pain modulation. These results suggest that DNS offers a mechanism-based approach to pain management in lumbar disc herniation rehabilitation.

Functional disability outcomes were more favorable in the intervention group compared to standard care. This finding is consistent with previous reports emphasizing the contribution of postural control and joint centration to functional recovery in patients with lumbar spine conditions [15]. Given that DNS specifically targets neuromuscular coordination and segmental stabilization, the observed improvements may be associated with enhanced movement control during daily activities. These results support the potential role of DNS within postoperative rehabilitation programs.

Fear-avoidance levels were more favorably reduced in the intervention group. This finding is consistent with existing literature identifying fear-avoidance as a key contributor to persistent pain and functional limitation in lumbar spine conditions [34]. Interventions that combine controlled movement exposure with postural stabilization strategies have been shown to positively influence movement-related anxiety [12, 14]. In this context, the structured and stabilization-focused nature of DNS may have supported both physical and behavioral aspects of recovery. These findings suggest that DNS may contribute to postoperative rehabilitation by addressing factors beyond purely mechanical impairment.

High adherence observed in this study represents a methodological strength. Previous reports have noted notable drop-out rates in early postoperative rehabilitation programs, often related to pain exacerbation or logistical challenges [7]. In contrast, participant retention in the present study was favorable, which may be associated with the structured format combining supervised and home-based DNS sessions. Although adherence can be influenced by multiple factors, these findings suggest that DNS may be a feasible and well-tolerated option in the postoperative rehabilitation setting.

By addressing existing gaps in the literature, the findings of this study suggest that DNS may represent a promising rehabilitation approach in postoperative LDH. However, given the single-center design and relatively short follow-up period, further multicenter studies with longer follow-up are required before DNS can be recommended as a standard protocol.

Limitations and future directions

This study's high adherence rate, with no dropouts, underscores the feasibility of DNS exercises in clinical practice. The combination of supervised and home-based sessions likely contributed to this success. While the results are promising, several limitations warrant consideration. First, the study's follow-up period was limited to 8 weeks, preventing assessment of long-term outcomes. Future research should include extended follow-up to evaluate the sustainability of DNS benefits. Additionally, the reliance on self-reported measures, such as the IPAQ, introduces potential biases related to subjective reporting. Incorporating objective measures, such as accelerometry, could strengthen the validity of these findings. Lastly, while DNS demonstrated superiority to standard care, direct comparisons with other rehabilitation approaches, such as Pilates or core stabilization exercises, remain unexplored and warrant further investigation.

Conclusion

This study provides compelling evidence for the integration of DNS-based exercises in postoperative rehabilitation for LDH patients. The significant improvements observed in physical activity, pain, functional disability, and fear-avoidance behaviors suggest that DNS offers a comprehensive and effective approach to optimizing recovery. While natural recovery during the postoperative period likely contributed to the improvements seen in the control group, the DNS group consistently achieved superior outcomes in clinically relevant measures, underscoring the added value of this intervention. By addressing common postoperative complications such as pain, disability, and fear-avoidance behavior, DNS demonstrates its potential as a structured, safe, and reliable rehabilitation strategy. Further research is warranted to establish DNS as a standard component of postoperative care, assess its long-term benefits, and evaluate its comparative effectiveness against alternative interventions.

Acknowledgements Not applicable.

Authors' contributions B.B.: Conceptualization, Investigation, Methodology, Writing – original draft, Writing- review & editing. B.A.: Formal analysis, Investigation, Methodology. E.E.S. Conceptualization, Formal Analysis, Investigation, Methodology, Supervision, Validation, Writing- review & editing. Ö.Ş. : Data curation, Formal analysis, Investigation, Supervision, Validation.

Funding Not applicable.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate The Non-Interventional Research Ethics Committee of Uskudar University granted ethical approval following Helsinki Declaration (approval number: 61351342/December 2022). All participants provided written informed consent.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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