

Effects of Clinical Pilates on Ankle Proprioception and Sensorimotor Function in Middle-Aged Women With Chronic Lumbar Disc Herniation: A Randomized Controlled Trial

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Research Article

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Abstract

Background

Clinical Pilates is widely used in the rehabilitation of chronic low back disorders; however, its effects on distal sensorimotor function in individuals with chronic lumbar disc herniation (LDH) remain insufficiently investigated. This study aimed to investigate the effects of an 8-week clinical Pilates program on ankle proprioception, tibialis anterior muscle strength, dynamic balance, functional mobility, and pain intensity in middle-aged women with chronic LDH.

Methods

Thirty women with chronic LDH were randomly allocated to a clinical Pilates group ($n = 15$) or a control group ($n = 15$). The clinical Pilates group participated in 60-minute sessions twice weekly for 8 weeks, while the control group maintained their usual daily activities. The primary outcome was ankle proprioception, assessed as absolute angular repositioning error using an active joint repositioning test in a functional weight-bearing standing position. Secondary outcomes were tibialis anterior muscle strength, dynamic balance, functional mobility, and pain intensity.

Results

Ankle joint repositioning error significantly decreased at all measurement points in the clinical Pilates group (all $p \leq 0.003$). Tibialis anterior muscle strength increased bilaterally (both $p < 0.001$), functional reach increased in all directions (all $p \leq 0.001$), Timed Up and Go performance improved ($p < 0.001$), and pain intensity decreased ($p = 0.001$). Post-intervention between-group differences favored the clinical Pilates group for tibialis anterior muscle strength, functional reach, Timed Up and Go performance, pain intensity, and selected ankle proprioception measurements ($p < 0.05$).

Conclusions

An 8-week clinical Pilates program improved ankle proprioception and several sensorimotor and functional outcomes and reduced pain intensity in middle-aged women with chronic LDH. Assessment of ankle proprioception under functional weight-bearing conditions suggests that clinical Pilates may have relevance beyond symptom management and may contribute to sensorimotor-focused rehabilitation.

Trial registration:

ClinicalTrials.gov, NCT07515287. Registered 31 March 2026; retrospectively registered.

1. Introduction

Lumbar disc herniation (LDH) is a common musculoskeletal disorder characterized by displacement of intervertebral disc material beyond its normal anatomical boundaries, which may result in nerve root

compression and clinical manifestations including low back and lower-extremity pain, sensory disturbances, and functional limitations [1, 2]. In chronic LDH, persistent symptoms may be accompanied by impaired lumbopelvic motor control, structural and functional alterations in deep stabilizing muscles such as the multifidus, and reduced functional performance [3, 4]. In addition, chronic low back pain has been associated with alterations in motor control and sensorimotor processing, which may influence the integration of somatosensory information and postural control [5–7].

Postural control depends on the integration of visual, vestibular, and somatosensory information to maintain body orientation and stability during both static and dynamic tasks. The lumbopelvic region represents an important kinetic link between the trunk and lower extremities and contributes to the coordinated transmission of movement and force throughout the body [8]. Impairments in lumbopelvic control may therefore influence sensorimotor function in distal segments. In particular, alterations in ankle proprioception and lower-extremity muscle performance may contribute to impaired dynamic balance and functional movement performance [8–11]. These relationships are clinically relevant in individuals with chronic LDH, in whom altered movement strategies and impaired sensorimotor control may affect the performance of weight-bearing and locomotor activities.

Clinical Pilates has increasingly been incorporated into the rehabilitation of individuals with chronic low back disorders, with an emphasis on activation of the deep trunk musculature, controlled breathing, movement awareness, and postural control [8, 12, 13]. Previous studies have suggested that Pilates-based exercise may improve proprioceptive performance, trunk control, physical function, and pain-related outcomes [8, 9, 12, 13]. However, research in individuals with LDH has predominantly focused on pain, trunk muscle performance, disability, and quality of life, whereas the potential effects of Pilates on distal sensorimotor function remain insufficiently investigated.

Ankle proprioception is particularly relevant to postural control because accurate information regarding joint position contributes to the regulation of lower-limb alignment and balance during weight-bearing activities. Nevertheless, ankle proprioception has commonly been assessed under non-weight-bearing conditions, such as sitting, in previous studies [9, 11]. This may not fully reflect the sensory demands encountered during standing, walking, and other functional activities. Importantly, proprioceptive accuracy can be influenced by the testing position. Previous research has demonstrated differences in joint position sense according to body position, while weight-bearing conditions have also been associated with more accurate and reliable assessment of joint position sense in comparison with non-weight-bearing conditions [14, 15]. Therefore, assessment of ankle proprioception in a functional weight-bearing standing position may provide clinically relevant information regarding sensorimotor performance under conditions that more closely resemble everyday functional demands.

Despite the established effects of Pilates on trunk-related outcomes, evidence regarding its potential influence on distal sensorimotor function, particularly ankle proprioception assessed under weight-bearing conditions, remains limited in individuals with chronic LDH. Addressing this gap may provide

additional insight into whether an exercise approach primarily targeting lumbopelvic control is accompanied by changes in distal sensorimotor performance.

Therefore, the aim of this study was to investigate the effects of an 8-week clinical Pilates program on ankle proprioception, tibialis anterior muscle strength, dynamic balance, and functional mobility in middle-aged women with chronic LDH. We hypothesized that clinical Pilates would improve ankle proprioception, tibialis anterior muscle strength, and dynamic balance, in addition to reducing pain, thereby contributing to improved sensorimotor and functional performance.

2. Methods

2.1. Study Design and Ethical Approval

This study was designed as a randomized controlled trial to investigate the effects of a clinical Pilates exercise program on sensorimotor function in middle-aged women with chronic lumbar disc herniation (LDH). The study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Hasan Kalyoncu University Non-Interventional Research Ethics Committee (Approval No. 2026/046; Date: March 6, 2026). The study was conducted at the Special Healthy Life Center between April and August 2026. Before enrollment, all participants were informed in detail about the purpose of the study, study procedures, and potential risks. Written informed consent was obtained from all participants before participation. The trial was registered with ClinicalTrials.gov (NCT07515287).

2.2. Participants and Randomization

Women aged 45–60 years with an imaging-confirmed diagnosis of lumbar disc herniation (LDH) at the L4–L5 level, L5–S1 level, or both levels, established at least 1 year before enrollment, were eligible for participation. Participants were required to have no history of participation in a therapeutic exercise program during the previous year and no surgical intervention within the previous 6 months. Individuals who declined to participate or had a history of systemic diseases that could affect ankle muscle strength or proprioception, including diabetes mellitus and rheumatic diseases, or neuromuscular disorders were excluded.

An a priori power analysis was performed using G*Power version 3.1.9.4. Ankle proprioception, assessed based on angular repositioning error, was defined as the primary outcome measure of the study. The effect size was calculated based on the pre- and post-intervention mean and standard deviation values for ankle proprioception reported by Chatutain et al. (2019), who investigated the effects of walking meditation on ankle proprioception and balance in older adults. Based on an independent-samples t-test, an alpha level of 0.05, 95% power, and an effect size of $d = 1.30$, the required sample size was calculated as 30 participants, with 15 participants allocated to each group (11).

A total of 35 individuals were initially assessed for eligibility. Participants who met the eligibility criteria and provided written informed consent were randomly allocated in a 1:1 ratio to either the clinical Pilates

group or the control group using a computer-generated simple randomization sequence. Allocation concealment was ensured using sequentially numbered, opaque, sealed envelopes. Following randomization, 30 participants were included in the final study sample, with 15 participants assigned to the clinical Pilates group and 15 to the control group (Fig. 1).

The intervention and all outcome assessments were conducted by the same physiotherapist, who was experienced in clinical Pilates. Participants and the physiotherapist delivering the intervention were not blinded to group allocation because of the nature of the exercise intervention. To minimize analytical bias, all statistical analyses were performed independently by a researcher who was not involved in participant enrollment, intervention delivery, or outcome assessment. Participants assigned to the clinical Pilates group were required to attend at least 80% of the scheduled exercise sessions to be considered adherent to the intervention protocol [16].

2.3. Intervention Protocol

Following randomization, participants were allocated to either the clinical Pilates group or the control group. Participants in the clinical Pilates group completed an 8-week mat-based Pilates exercise program consisting of two 60-minute sessions per week, with an emphasis on core stabilization. All exercise sessions were supervised by the same physiotherapist with experience in clinical Pilates. Adherence to the intervention protocol was monitored throughout the study, and participants who attended at least 80% of the scheduled exercise sessions were considered adherent to the intervention protocol.

Any adverse events occurring during the intervention period were recorded.

2.4. Outcome Measures

All outcome assessments were performed at baseline and repeated after the 8-week intervention period. The primary outcome was ankle proprioception, assessed as absolute angular repositioning error. Secondary outcomes were tibialis anterior muscle strength, dynamic balance, functional mobility, and pain intensity. Demographic and clinical characteristics, including age, height, body weight, body mass index (BMI), dominant side, and smoking status, were recorded at baseline. Pain intensity was assessed using the Visual Analog Scale (VAS; 0–10 cm), a widely used and clinically practical measure of pain intensity [17]. Tibialis anterior muscle strength was assessed during a maximal voluntary isometric contraction in the sitting position using a handheld muscle testing device (Lafayette Instrument Co., Lafayette, IN, USA) [18].

Ankle joint position sense was assessed in a functional weight-bearing standing position. Markers were placed according to the anatomical landmarks corresponding to the goniometric axis. Participants were passively positioned at target ankle angles of 0° and 10° and were instructed to reproduce each target angle actively. The reproduced position was photographed, and the absolute angular error between the target angle and the reproduced angle was calculated using the MB-Ruler computer software (MB-Software Solutions, Germany) [19]. Lower angular error values indicated greater joint position sense

accuracy. Functional mobility and dynamic balance were assessed using the Timed Up and Go (TUG) test and the Functional Reach Test (FRT) [20]. For the FRT, participants stood with their feet in a fixed position and reached forward as far as possible without moving their feet. The maximum reach distance was measured in centimeters using a wall-mounted measuring tape.

2.5. Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version 24.0 (IBM Corp., Armonk, NY, USA). The normality of continuous variables was assessed using the Kolmogorov–Smirnov test. Normally distributed continuous variables were presented as mean $\pm$ standard deviation, whereas non-normally distributed variables were presented using the median. Categorical variables were expressed as frequencies and percentages.

Within-group changes were assessed using the paired-samples t-test for normally distributed continuous variables and the Wilcoxon signed-rank test for VAS scores. Between-group comparisons were performed using the independent-samples t-test. Categorical variables were compared using Fisher's exact test. Effect sizes were calculated using Cohen's d and interpreted as small (0.20), moderate (0.50), or large (≥ 0.80). Statistical significance was set at $p < 0.05$.

Use of generative AI

During the preparation of this manuscript, the authors used the free version of ChatGPT (OpenAI; model version not available to the authors) for language editing, proofreading, and improving clarity and readability. The tool was not used for data generation, statistical analysis, or scientific interpretation. All AI-assisted output was critically reviewed and edited by the authors, who take full responsibility for the final content of the manuscript.

3. Results

3.1. Participant Characteristics

A total of 30 women were included in the study, with 15 participants in the clinical Pilates group and 15 in the control group. No adverse events or exercise-related side effects were observed during the intervention period. All participants completed the study according to the planned protocol. No statistically significant between-group differences were observed in age, body mass index, or dominant side distribution at baseline (all $p > 0.05$) (Table 1).

Table 1
Demographic and Clinical Characteristics of Participants

Variable	Pilates Group (n = 15) $\bar{X} \pm SS$	Control Group (n = 15) $\bar{X} \pm SS$	p
Age (years)	52.27 $\pm$ 5.47	52.13 $\pm$ 5.45	0.947
BMI (kg/m ²)	28.72 $\pm$ 4.47	30.74 $\pm$ 4.71	0.240
Dominant Side (Right/Left), n (%)	6 (40%) / 9 (60%)	7 (46.7%) / 8 (53.3%)	0.717*
<i>$\bar{X}$: Mean; SD: Standard deviation; BMI: Body mass index. Independent-samples t-test was used for continuous variables, and Fisher's exact test was used for the categorical variable. A $p < 0.05$ was considered statistically significant.</i>			

3.2. Proprioceptive Function

Ankle joint repositioning error significantly decreased at all measurement points in the clinical Pilates group (right 0°, right 10°, left 0°, and left 10°; all $p \leq 0.003$). In the control group, a significant increase in repositioning error was observed for the left-sided measurements, whereas changes in the right-sided measurements did not reach statistical significance. Post-intervention between-group differences were statistically significant for the right 10° and left 10° measurements (Table 2).

Table 2
Within-group ve Between-group Pre-test–Post-test Comparisons

Variable	Group	Pre-test ($\bar{X} \pm SS$)	Post-test ($\bar{X} \pm SS$)	Within-group p	Effect Size (Cohen's d)
VAS (0–10 cm)	Pilates	6.27 $\pm$ 1.16	2.80 $\pm$ 1.01	0.001†	3.79
	Control	5.07 $\pm$ 1.83	4.93 $\pm$ 1.75	0.317†	0.26
TUG (sn)	Pilates	9.04 $\pm$ 1.93	6.40 $\pm$ 0.98	< 0.001	1.58
	Control	7.30 $\pm$ 1.22	9.34 $\pm$ 1.37	0.001	-1.09
Tibialis Anterior Muscle Strength – Right (kg)	Pilates	7.76 $\pm$ 1.77	12.89 $\pm$ 2.45	< 0.001	-2.67
	Control	6.89 $\pm$ 1.15	8.50 $\pm$ 1.74	0.011	-0.76
Tibialis Anterior Muscle Strength – Left (kg)	Pilates	7.27 $\pm$ 1.39	12.11 $\pm$ 2.29	< 0.001	-1.82
	Control	9.55 $\pm$ 1.57	7.47 $\pm$ 1.26	0.001	1.02
Functional Reach – Right Anterior (cm)	Pilates	23.73 $\pm$ 5.56	29.53 $\pm$ 3.46	< 0.001	-1.17
	Control	21.47 $\pm$ 5.98	21.60 $\pm$ 5.05	0.869	-0.04
Functional Reach – Right Lateral (cm)	Pilates	13.07 $\pm$ 3.62	18.73 $\pm$ 3.90	0.001	-1.04
	Control	13.00 $\pm$ 4.16	12.47 $\pm$ 3.04	0.527	0.17
Functional Reach – Left Anterior (cm)	Pilates	21.67 $\pm$ 5.33	29.00 $\pm$ 5.67	< 0.001	-1.46
	Control	19.67 $\pm$ 3.77	20.13 $\pm$ 5.17	0.559	-0.15
Functional Reach – Left Lateral (cm)	Pilates	12.20 $\pm$ 2.73	17.53 $\pm$ 3.50	0.001	-1.13

$\bar{X}$: Mean; SD: Standard deviation; TUG: Timed Up and Go Test; VAS: Visual Analog Scale. Paired-samples t-test was used for within-group comparisons, and the Wilcoxon signed-rank test was used for the variable marked with † (VAS). Independent-samples t-test was used for between-group comparisons. Effect sizes were calculated as Cohen's d and presented as absolute values.

	Control	12.73 ± 3.37	11.87 ± 2.26	0.343	0.25
Proprioception – Right 0°	Pilates	12.41 ± 5.98	5.77 ± 5.50	< 0.001	1.21
	Control	7.05 ± 4.63	9.81 ± 6.92	0.077	-0.49
Proprioception – Right 10°	Pilates	13.20 ± 5.42	7.38 ± 6.74	< 0.001	1.40
	Control	11.40 ± 4.37	12.90 ± 4.29	0.058	-0.53
Proprioception – Left 0°	Pilates	13.81 ± 9.03	6.77 ± 7.35	0.001	1.12
	Control	7.47 ± 7.32	9.88 ± 6.19	0.018	-0.69
Proprioception – Left 10°	Pilates	12.67 ± 5.67	8.90 ± 7.42	0.003	0.91
	Control	12.31 ± 6.43	14.54 ± 5.90	0.003	-0.93
<i> $\bar{X}$: Mean; SD: Standard deviation; TUG: Timed Up and Go Test; VAS: Visual Analog Scale. Paired-samples t-test was used for within-group comparisons, and the Wilcoxon signed-rank test was used for the variable marked with † (VAS). Independent-samples t-test was used for between-group comparisons. Effect sizes were calculated as Cohen's d and presented as absolute values. </i>					

Table 3
8-Week Clinical Pilates Exercise Protocol

Phase	Exercise	First 3 Weeks (Basic Level)	Second 3 Weeks (Intermediate Level)	Last 2 Weeks (With Theraband)
Warm-up Phase	Spine Roll Down	<i>Applied in all warm-up sessions throughout the 8-week program:</i> • Spine Roll Down • Weight Transfer and Body Awareness • Upper Extremity Exercises • Scapular Stabilization Exercise • Footwork Series • Side Bend with Stretch		
	Weight Transfer and Body Awareness			
	Upper Extremity Exercises			
	Scapular Stabilization Exercise			
	Footwork Series			
	Side Bend with Stretch			
Main Exercise Phase	Spine Twist	Spine Twist	Spine Twist	Advanced Theraband Protocol:
	Abdominal Taps	Level 1 (5 reps)	Level 1–2	• Mermaid
	Single Leg Stretch	Level 1	Level 2	• Spine Twist
	Double Leg Stretch	Level 1	Level 2	• Single Leg Stretch
	Shoulder Bridge (Series)	Level 1	Level 2	• Abdominal Taps (Level 3)
	Swan Dive	Level 1	Level 2	• Shoulder Bridge Series
	Quadruped Swimming	Level 1	Level 2	• Swan Dive
	Clamshell	Level 1	Level 2	• Quadruped Swimming
	Hip Twist / Circles	Level 1	Level 2	• Hip Twist (Level 3)
				• Side Kick
				• Side Plank

Intervention: Clinical Pilates program performed twice weekly for 8 weeks, with each session lasting 60 minutes (10-minute warm-up, 40-minute main exercise phase, and 10-minute cool-down). Sessions were individually supervised by the same physiotherapist. Exercise progression was based on participants' tolerance and performance. During Weeks 4–6, elastic resistance (TheraBand®) was incorporated to increase exercise intensity. During Weeks 7–8, more advanced exercise variations emphasizing lumbopelvic stability, neuromuscular control, and functional movement quality were introduced. Exercises in the warm-up and cool-down phases were performed consistently in every session without modification throughout the entire program.

Phase	Exercise	First 3 Weeks (Basic Level)	Second 3 Weeks (Intermediate Level)	Last 2 Weeks (With Theraband)	
	Side Kick (Series)	Level 1	Level 2	• Spine Roll Down	
	Chest Opening	Level 1	Level 2	• Cobra	
Cool-down Phase	Chest Stretch	Applied in all cool-down sessions throughout the 8-week program:			
	Cleopatra				• Chest Stretch
	Spine Alignment				• Cleopatra
	Breathing Exercises and Awareness				• Spine Alignment
	Stretching Exercises				• Breathing Exercises and Awareness
	Mermaid				• Stretching Exercises
		• Mermaid			
Intervention: Clinical Pilates program performed twice weekly for 8 weeks, with each session lasting 60 minutes (10-minute warm-up, 40-minute main exercise phase, and 10-minute cool-down). Sessions were individually supervised by the same physiotherapist. Exercise progression was based on participants' tolerance and performance. During Weeks 4–6, elastic resistance (TheraBand®) was incorporated to increase exercise intensity. During Weeks 7–8, more advanced exercise variations emphasizing lumbopelvic stability, neuromuscular control, and functional movement quality were introduced. Exercises in the warm-up and cool-down phases were performed consistently in every session without modification throughout the entire program.					

3.3. Muscle Strength

Tibialis anterior muscle strength increased significantly on both the right and left sides in the clinical Pilates group (both $p < 0.001$). In the control group, a modest increase was observed on the right side, whereas a significant decrease was observed on the left side ($p = 0.001$). Post-intervention between-group differences were statistically significant for both sides (Table 2).

3.4. Dynamic Balance and Functional Mobility

TUG completion time significantly decreased in the clinical Pilates group ($p < 0.001$), whereas it significantly increased in the control group ($p = 0.001$). The post-intervention between-group difference was statistically significant ($p < 0.001$). Similar patterns were observed across all four directions of the Functional Reach Test. Reach distance increased significantly in all directions in the clinical Pilates group (all $p \leq 0.001$), whereas no statistically significant changes were observed in the control group. Post-intervention between-group differences were statistically significant in all directions (Table 2).

3.5. Pain Intensity

After the 8-week intervention, VAS scores significantly decreased in the clinical Pilates group ($p = 0.001$), whereas no statistically significant change was observed in the control group ($p = 0.317$). The post-intervention between-group difference was statistically significant ($p < 0.001$) (Table 2).

4. Discussion

This study investigated the effects of an 8-week clinical Pilates program on sensorimotor function in middle-aged women with chronic lumbar disc herniation (LDH), with particular emphasis on ankle proprioception assessed under a functional weight-bearing condition. The findings indicate that clinical Pilates was associated with improvements in ankle joint position sense, tibialis anterior muscle strength, dynamic balance, and functional mobility, accompanied by a reduction in pain intensity. Notably, ankle repositioning error decreased across all measurement conditions in the clinical Pilates group, whereas increases in repositioning error were observed for the left-sided measurements in the control group. These findings suggest that clinical Pilates may have beneficial effects extending beyond symptom reduction to sensorimotor performance under functional loading conditions. However, given the passive nature of the control condition, these findings should be interpreted as evidence of an association with the Pilates intervention rather than definitive evidence of a Pilates-specific effect.

Ankle Proprioception and the Clinical Relevance of Functional Assessment

One of the most notable findings of the present study was the improvement in ankle joint position sense following clinical Pilates when proprioception was assessed in a weight-bearing standing position. Previous studies investigating ankle proprioception have predominantly used seated or non-weight-bearing assessment conditions [9, 11]. However, proprioceptive accuracy may be influenced by the testing position. Preuss et al. [14] reported lower repositioning error for lumbar joint position sense during standing compared with sitting, whereas Stillman and McMeeken [15] demonstrated greater accuracy and reliability of knee joint position sense under weight-bearing conditions. Accordingly, assessment of ankle proprioception during functional weight-bearing may provide information that is more closely related to the sensorimotor demands encountered during standing and other functional activities.

During functional standing, postural control is supported not only by afferent information from joint and muscle mechanoreceptors but also by sensory input from plantar cutaneous receptors [21]. Therefore, the weight-bearing assessment used in the present study may provide greater functional relevance than non-weight-bearing assessments by incorporating sensory information generated during contact with the support surface. The reduction in ankle repositioning error at both target positions in the clinical Pilates group suggests that the intervention may have improved the accuracy of ankle joint position reproduction under functional loading conditions. Nevertheless, because the present study did not separately assess the contribution of plantar cutaneous input, muscle spindle activity, or other sensory components, the specific sensory mechanisms underlying this improvement cannot be determined [22].

Previous research has reported beneficial effects of Pilates-based exercise on proprioceptive function at the trunk level. Suner-Keklik et al. [8] reported improvements in trunk position sense following clinical Pilates, suggesting that Pilates may influence proprioceptive processing through improvements in trunk control. The present findings extend this observation by suggesting that improvements associated with a proximal stabilization-oriented exercise program may also be reflected in distal sensorimotor performance. One possible explanation is that improvements in lumbopelvic motor control may facilitate more coordinated movement strategies throughout the kinetic chain. However, this proposed proximal-to-distal mechanism remains hypothetical, as the present study did not directly assess changes in lumbopelvic proprioception, neuromuscular activation, or intersegmental coordination.

The increase in repositioning error observed in the left-sided measurements of the control group is also noteworthy [23]. A similar deterioration in ankle proprioceptive performance in individuals who did not receive an exercise intervention has previously been reported by Chatutain et al. [11]. However, the present findings should be interpreted cautiously. The observed changes may reflect temporal variation in sensorimotor performance rather than progression of the underlying LDH pathology, particularly given the relatively small sample size and passive control design. Nevertheless, the concurrent changes observed in ankle proprioception and tibialis anterior strength highlight the potential relevance of maintaining sensorimotor function in individuals with chronic LDH.

The reduction in tibialis anterior strength observed on the left side in the control group provides further context for these findings. Chronic low back pain has been associated with changes in central motor processing, somatosensory integration, and muscle activation strategies [5–7]. Such adaptations may contribute to altered motor performance in individuals with persistent spinal pain. In contrast, clinical Pilates emphasizes trunk stabilization, controlled movement, and neuromuscular coordination, which may support the maintenance or improvement of sensorimotor performance. The concurrent improvement in ankle proprioception and tibialis anterior strength observed following the intervention is therefore consistent with a potential beneficial effect of Pilates on sensorimotor function, although the underlying neurophysiological mechanisms require further investigation.

Functional Mobility and Dynamic Balance

In the present study, the improvements observed in dynamic balance and functional mobility following clinical Pilates training, considered together with the positive changes in ankle proprioception and tibialis anterior muscle strength, support the holistic effects of clinical Pilates on sensorimotor performance. Similarly, Surbala et al. [24] reported that Pilates exercises improved dynamic balance in different populations. Our findings suggest that this effect may also be observed in middle-aged women with chronic lumbar disc herniation.

Dynamic balance depends on the integrated functioning of effective postural control, adequate muscle strength, and accurate proprioceptive feedback [25]. The emphasis of clinical Pilates on trunk stabilization and lumbopelvic motor control may have contributed to functional performance by supporting coordinated force transfer between the upper and lower extremities. This may be one of the

potential mechanisms explaining the improvement in functional performance, particularly during weight transfer, walking, and other activities of daily living.

Taken together, these findings suggest that clinical Pilates may contribute to improvements in functional mobility and sensorimotor performance in individuals with chronic lumbar disc herniation.

Effects on Pain Intensity

This finding is consistent with previous studies reporting reductions in pain following clinical Pilates in individuals with chronic lumbar disc herniation [12, 13].

Therefore, clinical Pilates may be considered not only as an exercise approach aimed at symptom management but also as a component of a comprehensive rehabilitation strategy targeting sensorimotor and functional performance in individuals with chronic lumbar disc herniation.

LIMITATIONS

This study has several limitations. First, the relatively small sample size and the inclusion of only middle-aged women limit the generalizability of the findings. Second, the use of a passive control group makes it difficult to distinguish the effects specific to clinical Pilates from those attributable to general exercise effects. In addition, the absence of objective neuromuscular assessment methods, such as electromyography or imaging, and the lack of long-term follow-up data limit the evaluation of the underlying mechanisms of the observed improvements and the sustainability of these effects. Future studies involving larger and more heterogeneous samples, active comparison groups, objective neuromuscular assessments, and long-term follow-up are warranted to provide a more comprehensive understanding of the effects of clinical Pilates on sensorimotor function in individuals with chronic lumbar disc herniation.

An important strength of this study is that ankle proprioception was assessed in a weight-bearing functional position reflecting activities of daily living. This approach may contribute to a more functional perspective in the assessment of sensorimotor function in clinical rehabilitation. Furthermore, the simultaneous assessment of proprioception, tibialis anterior muscle strength, dynamic balance, and functional mobility enabled a multidimensional evaluation of the effects of clinical Pilates on sensorimotor function.

5. CONCLUSION

The novel contribution of this study is the assessment of ankle proprioception in a weight-bearing functional position and the finding that improvements following a proximal stabilization-focused clinical Pilates program were accompanied by changes in distal sensorimotor function.

The unfavorable changes observed in sensorimotor performance in the control group may support the potential importance of active rehabilitation approaches in individuals with chronic lumbar disc

herniation. Based on these findings, clinical Pilates may be considered a complementary exercise approach in the rehabilitation of chronic lumbar disc herniation, targeting not only symptom management but also the improvement of sensorimotor function. Nevertheless, larger, multicenter randomized controlled trials incorporating active comparison groups and long-term follow-up assessments are needed to confirm these findings and improve their generalizability.

Abbreviations

BMI

Body mass index

FRT

Functional Reach Test

LDH

Lumbar disc herniation

TUG

Timed Up and Go

VAS

Visual Analog Scale

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Hasan Kalyoncu University Non-Interventional Research Ethics Committee (Approval No. 2026/046; Date: March 6, 2026). Written informed consent was obtained from all participants before participation.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

AU: Conceptualization, Methodology, Investigation, Writing – original draft. YY: Conceptualization, Supervision, Formal analysis, Review and editing.

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Data Availability

Data Availability Statement The datasets generated or analyzed during the current study are available from the corresponding author on reasonable request.

Clinical Trial Registration: ClinicalTrials.gov, NCT07515287

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Figures

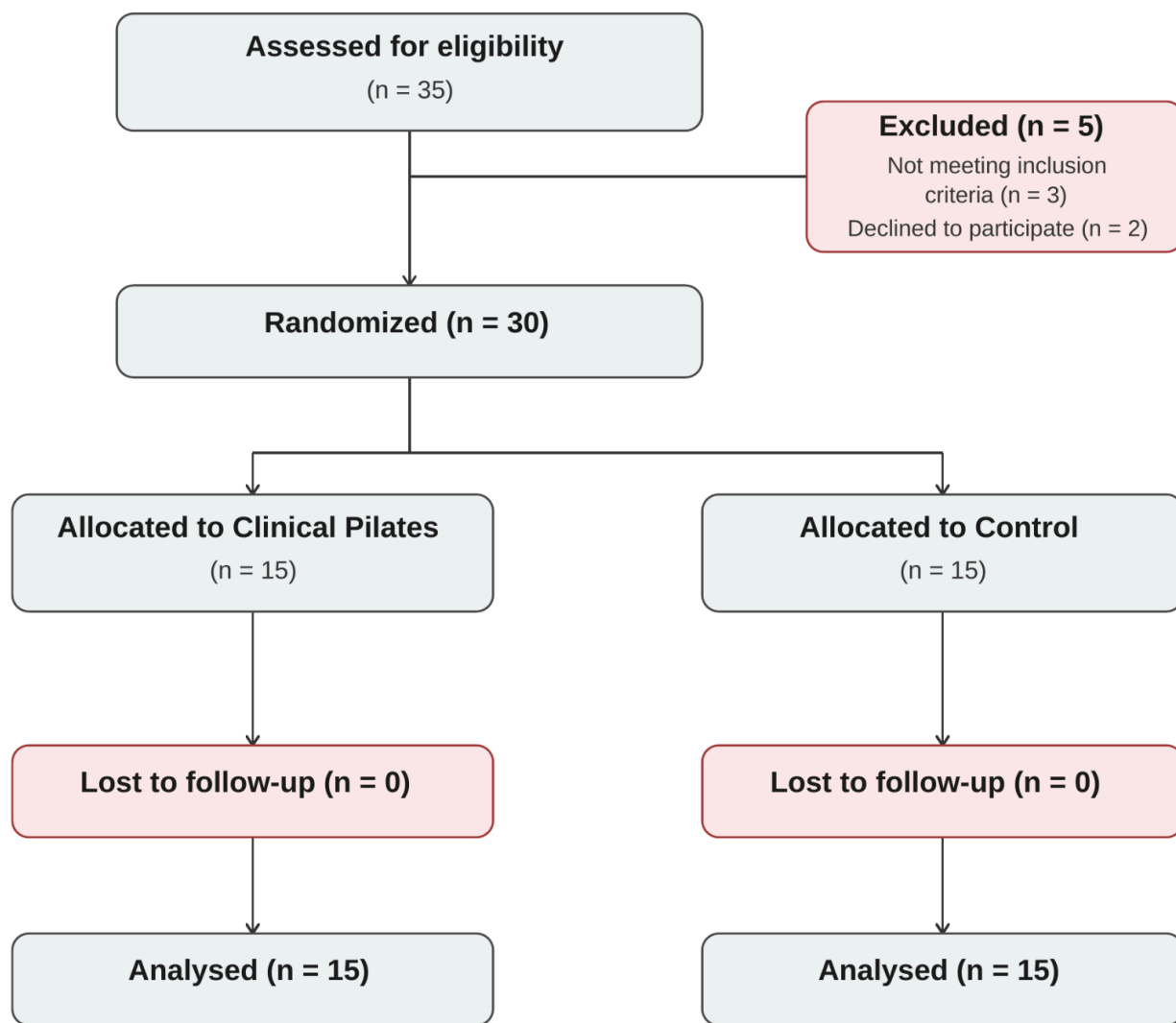


Figure 1

CONSORT 2010 Flow Diagram

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