Original Article

Physical Therapy Rehabilitation Science

https://doi.org/10.14474/ptrs.2023.12.2.92
eISSN 2287-7584
pISSN 2287-7576

Phys Ther Rehabil Sci
2023, 12(2), 92-104
www.jptrs.org

Effects of Spinal Mobilization with Leg Movement and Neural Mobilization on Pain, Mobility, and Psychosocial Functioning of Patients with Lumbar Disc Herniation: A Randomized Controlled Study

Seung Jin Kim[a], Ho Young Jang[b], and Suk-Min Lee[a*]

[a]Department of Physical Therapy, College of Health and Welfare, Sahmyook University, Seoul, Republic of Korea
[b]Department of Physical Therapy, Catholic University Eunpyeong St. Mary's Hospital, Seoul, Republic of Korea

Objective: The purpose of this study was to investigate the effect of spinal mobilization with leg movement (SMWLM) and neural mobilization (NM) in patients with lumbar disc herniation (LDH) accompanied by radiating pain.

Design: Three-group pre-test–post-test control group design.

Methods: We enrolled 48 participants, whom we randomly assigned to three groups. The SMWLM group (n = 16) underwent 20 min of conventional physical therapy (CT) and 20 min of SMWLM. The NM group (n = 16) underwent 20 min of CT and 20 min of NM. The control group (n = 16) underwent 20 min of CT. These interventions in all the groups were performed three times a week for 4 weeks. Numeric pain rating score (NPRS), body grid chart score (BGCS), passive straight leg raise (PSLR), active lumbar flexion range of motion (ALFROM), korean version oswestry disability index (KODI), and korean version fear avoidance beliefs questionnaire (KFABQ) were measured pre- and post-intervention.

Results: In all three groups, the NPRS, PSLR, KODI, and KFABQ scores were significantly different pre- and post-intervention ($p < 0.05$). Significant differences were observed in BGCS and ALFROM in the SMWLM and NM groups pre- and post-intervention ($p < 0.05$). The SMWLM group showed more improvement in the NPRS of leg pain, ALFROM, and KFABQ score than that exhibited by the NM and control groups ($p < 0.05$).

Conclusions: Both SMWLM and NM were effective for improving back and leg pain, centralization of symptoms, mechanical sensitivity, lumbar mobility, lumbar functional disability, and psychosocial functioning in patients with LDH with radiating pain.

Key Words: Intervertebral Disc Displacement, Musculoskeletal Manipulation, Range of Motion, Psychosocial Functioning, Radiculopathy

Introduction

Low back pain is a heterogeneous musculoskeletal disease that affects 65–85% of the world's population [1, 2]. According to the global burden of disease in 2017, the degree of disability caused by low back pain increased by 54% worldwide between 1990 and 2015 [3], Lumbar disc herniation (LDH), the most common musculoskeletal disorder, affects approximately 10% of the world's population [4], especially young to middle-aged individuals [5, 6, 7]. Most patients with LDH have a good prognosis in terms of pain and disability. However, they have a longer recovery period than those of individuals with back pain without radiating pain, which leads to absence, burden of medical expenses, and social costs [8, 9].

LDH is defined as the displacement of the intervertebral disc space of the nucleus pulposus and annulus fibrosus

Received: Apr 3, 2023 **Revised:** May 14, 2023 **Accepted:** May 23, 2023
Corresponding author: Suk-Min Lee (**ORCID** https://orcid.org/0000-0002-6062-956X)
Department of Physical Therapy, College of Health and Welfare, Sahmyook University [01795]
Tel: +82-10-3704-5650 **Fax:** +82-2-3399-1639 **E-mail:** leesm@syu.ac.kr

of the intervertebral disc components [10]. The highest prevalence of LDH is seen in adults aged 30–50, with a male to female ratio of 2:1, and 95% of LDH occurs at the L4/L5 and L5/S1 spinal levels [6]. It mostly occurs in the posterolateral direction of the nerve root at the L4/L5 and L5/S1 spinal levels, mainly compressing the ipsilateral nerve root of the dural sac and damaging the nerve root and channels [11]. The major signs and symptoms of LDH include low back pain and radiating pain, motor disturbances, loss of sensation, paresthesia, central sensitization, limitation of trunk forward flexion, strain, and increased leg pain while coughing and sneezing [12, 13, 14, 15]. These signs and symptoms cause psychological changes and morbidity, such as disability, decreased physical and social activities, and excessive fear-avoidance behavior [8, 9, 16].

Physiological and biomechanical factors can play an important role in LDH treatment through physical therapy [17]. Non-pharmaceutical and conventional interventions are preferred as early treatment options because of their low treatment costs and less potential risks, although surgery and injection therapy remain useful options for patients with LDH and neuropathy who desire rapid recovery [18, 19]. As a physical therapy method such as traction, taping and electrotherapy are also recommended for conservative treatment [4]. Manual therapy approaches place an emphasis on application of biomechanical principles in the examination and treatment of spinal disorders [20]. These forms include joint-oriented mobilization, manipulation, traction, soft-tissue-oriented massage forms, neural-tissue-oriented neurodynamic, or mixed specific exercises [21].

The Mulligan technique was developed by Brian Mulligan and comprises active patient performance or passive intervention by a physiotherapist, combining the manual gliding of the joint with physiological and osteokinematic joint movements [22, 23]. Spinal mobilization with leg movement (SMWLM) is the application of continuous lateral gliding force to the spinous process while actively or passively performing limited peripheral joint movement [23]. The SMWLM improves pain, spinal mobility [24], and physiological and biomechanical mechanisms, such as space expansion by correcting the intervertebral disc position or opening the intervertebral foramen [4].

Neural mobilization (NM) aims to restore homeostasis inside and outside the nervous system using the nervous system itself or the structures surrounding it [25]. In 1995, Shacklock proposed the concept of neurodynamics that it can elicit physiological effects through the mechanical approach of nervous tissues and non-neural structures surrounding the nervous system through mobilization of the nervous system [26]. NM is known as the concept of mobility of the nervous system. The nervous tissues must be stretched and shortened to maintain the normal range of motion of the joints and glide in the tissues for normal movement [27]. Hypotheses for the effects of NM include promoting neural gliding, reducing nerve adherence, dispersing noxious stimulus fluids, increasing neural vascularity, and improving axoplasmic flow [28].

Previous studies have reported that manual therapy in patients with LDH has better clinical efficacy than that of conventional physical therapy, but still there were few treatments contrasting with the study subjects to support this [29]. Despite the widespread use of manual therapy in patients with LDH in clinical practice, no standardized guidelines for manual therapy for effective intervention have been established, and more treatment options are needed [28, 30]. Therefore, this study used SMWLM and NM in patients with LDH to determine possible differences among SMWLM, NM, and conventional physical therapy for improving back and leg pain, centralization of symptoms, mechanical sensitivity, lumbar mobility, lumbar functional disability, and psychosocial functioning. And this study also aimed to present a more effective clinical intervention plan.

Methods

1. Participants

This study was conducted at the W Hospital in Seoul on patients with back pain accompanied by radiating pain, who were diagnosed with LDH, and hospitalized. The inclusion criteria were diagnosis of LDH at the L4/L5 and L5/S1 levels based on magnetic resonance imaging (MRI) and aged 20–65 [28]. The exclusion criteria included a history of surgery, manual therapy within 6 months, lower-extremity vascular disease, spinal disease, tumors, spinal fractures, spinal stenosis, neurological diseases, pregnancy, rheumatoid arthritis, spinal compression fractures, and long-term steroid use [2, 28]. 48 patients were selected as subjects for this study after they have provided their informed consent. This study was approved by the Sahmyook University Institutional Review Board (SYU 2022-03-007-001) and was registered with the Korea Clinical Research Information Service (registration number: KCT0007945).

2. Procedure

This study used a pre-test–post-test control group design. The sample size of the study was calculated through statistical evaluation using the G*Power Version 3.1.9.7 (Franz Faul, University Kiel, Germany, 2020). Based on an analysis of variance (ANOVA), the main analysis method for testing the program effectiveness, the effect size was set to 0.25 for both tests, the significance level was set to 0.05, and the power was set to 0.95. The number of samples required in this study was 45; however, 54 patients were recruited considering possible dropouts during the study. As six patients dropped out, 48 patients participated in the study. A random program (https://www.graphpad.com/quickcalcs/randomize1/) was used to reduce selection bias, and the participants were classified into the SMWLM, NM, and control groups.

3. Intervention

Spinal mobilization with leg movement (SMWLM)

Two therapists formed a team. Therapist A performed continuous transverse gliding on the participant's lumbar spinous process, while therapist B assisted the participant to perform active movements within the range of movement to avoid symptom recurrence.

a. Straight leg raise (SLR) SMWLM in a side-lying position

The participants were positioned in a side-lying position on their unaffected side, close to the edge of the treatment table. The affected leg was supported by therapist B and extended with a slight abduction of 10° at the hip and a knee flexion of 45°. Therapist A applied and sustained a transverse glide of the spinous process toward the floor. The participants actively moved the leg into the SLR with therapist B’s assistance. The L4 vertebra was selected if the participant had an L4/L5 lesion. Therapist A carefully assisted the participants to perform active SLR in a gliding position with the help of therapist B to avoid symptom recurrence during movement. If pain recurred, the participant was instructed to relax and hold the position for 3 s, and then return to the starting point (Figure 1) [2, 23, 31].

b. SMWLM unilateral sustained natural apophyseal glides (SNAG)

The participants were positioned in a prone and slightly oblique position with their pelvis close to the edge of the treatment table. The affected leg was extended at the hip and knee and held by therapist B, who remained caudally on the ipsilateral side. Therapist A stood on the affected side and applied a superior cranial glide-sustained natural apophyseal glide of the transverse process. The SNAGs were sustained during the entire process, while therapist B lowered the patient’s affected leg into the SLR towards the floor, provided that there were no symptoms (Figure 2).

Figure 1. SLR SMWLM in sidelying

Figure 2. SMWLM unilateral SNAG

The SMWLM comprised three sessions in the first set and the second intervention, 6–10 times of 3–5 sets were performed for 10 min with a 30-second break between sets. According to a participant's improvement, therapist B increased the pressure within the asymptomatic range and checked for improvement in the SLR angle. As the symptoms eased, the therapist increased the range till the maximum pain-free range [2, 23, 31].

Neural mobilization (NM)

NM was performed based on the level of the nerves at which the symptoms appeared. The treatment proceeded until the location where the symptoms recurred. It was eased a few degrees at the point of symptom recurrence, and was performed with continuous mild oscillations. The slider technique was performed by repeating cervical extension to flexion during the intervention with longitudinal force at one nerve end and relaxation at the other. The tensioner technique was performed by applying tension at both nerve ends from cervical flexion to extension during the intervention. Sciatic nerve NM (L4–S2) was performed with passive SLR with the participant in supine position (Figure 3). Tibial nerve NM (L4–L5) was performed with passive NM. Knee extension or SLR was performed in knee flexion, dorsiflexion, or eversion with the patient in supine position (Figure 4). Peroneal nerve NM (L5–S1) was performed with passive NM. Knee extension was performed in hip flexion, knee flexion or plantar inversion with patients in supine position (Figure 5). Femoral nerve NM (L2–L4) was performed when symptoms recurred during prone knee bending or slump knee bending test. Passive NM involved hip extension in hip flexion or knee flexion at 90° with the patient in side-lying position (Figure 6).

Figure 3. Sciatic nerve NM

Figure 4. Tibial nerve NM

Figure 5. Peroneal nerve NM

Figure 6. Femoral nerve NM

The intervention was repeated by increasing the amplitude according to the participant's response. As the symptoms alleviated, the therapist increased the range until the maximum range was reached without pain. The slider and tensioner techniques comprised five repetitions in one set, and were performed 10 times in two sets for 10 min with 30 s of rest between sets [26, 28, 32].

Conventional physical therapy (CT)

CT included electrical stimulation therapy (Stimulator mioelectole, ITO CO., LTD, Japan), infrared (INFRALUX-300, Daekung, Korea), and laser (DR-12, DMC, Korea). The EST electrodes were fixed to the lumbar region and the lower extremities, where the participant complained of symptoms the most, stimulating the denervation of muscles and nerves. Meanwhile, laser and infrared were applied to induce pain reduction and electrophysiological effects [28, 33]

4. Measurement

Back and Leg pain

The NPRS was used to evaluate the intensity of back and leg pain. The NPRS ranged from 0 (no pain) to 10 (the worst pain imaginable), and the participants evaluated the level of back and leg pain by indicating the highest and worst pain in the current and past 24 h. The reliability of the NPRS was 0.96, and the validity was 0.86 to 0.95 [34, 35].

Centralization of symptoms

Centralization of symptoms was evaluated using BGCS. The BGCS was divided into the lower back, buttock, thigh, or distal knee from 0 points, when symptoms were not identified, to 6 points, when foot pain was observed, and the scores were measured as the farthest part where the participant's symptoms occurred by overlapping it on the participant's body chart [36]. The BGCS has good reliability at k = 0.92. When measured in the most distal symptomatic part, k value was found to be 0.92–1.0, and was high (k = 0.96) for changes in pain areas over time [36, 37, 38].

Mechanical sensitivity

The PSLR was used to evaluate mechanical sensitivity using the smartphone application, inclinometer (Peter Breitling, Version 4.9.2 (2001022) on iOS, iPhone®). The application demonstrated good reliability within the evaluator and good validity, and the intraclass correlation coefficient (ICC) was found to be 0.65–0.85 [39]. The inclinometer was positioned 5 cm distal to the tibial tuberosity, and the angle, at which the participant's radiating and neuromuscular pain recurred, was measured [40, 41]. The PSLR had a sensitivity and specificity of 0.91 and 0.26, respectively [42].

Lumbar mobility

The ALFROM was measured using a smartphone dual inclinometer to evaluate lumbar mobility. Two smartphone inclinometers were used for ALFROM measurements. The inclinometers were placed at the 12th thoracic spinous process (T12) and 15 cm below the second sacral vertebra (S2). Horizontal to the posterior superior iliac spine, the participant was positioned in a neutral position, setting the inclinometer values to 0°. The participant was instructed to bend the trunk forward as much as possible, and the angles at the thoracolumbar junction and sacroiliac joint were measured. The difference between the two angles based on the recurrence of symptoms during measurement became the final measurement value [41, 43]. In ALFROM, the inclinometer ICC had good inter-rater reliability at ≥.80 [44].

Lumbar functional disability

The KODI was used to assess lumbar functional disability. The KODI consists of 10 items including pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sex life, social life, and travel. The KODI scores range from 0 to 50 points. Each item has a maximum score of 5 points, and a higher score means more difficulty in functioning because of back pain. The participants answered the questionnaire after receiving sufficient explanation. The final score used in this study was calculated by dividing the patient's score by the total score and converting it into a percentage. The test–retest reliability (r) of KODI was 0.92 [45].

Psychosocial functioning

The KFABQ was used to evaluate psychosocial functioning. The KFABQ comprises two subscales. It consists of five measures to evaluate physical activity (FABQ-PA) and eleven measures to evaluate work (FABQ-W). Of the 16 FABQ items, five items (nos. 2, 8, 13, 14, and 16) were not used when adding up after the survey evaluation. Patients evaluated themselves for each question on a 7-point scale (0 = completely disagree, 6 = completely agree). The reliability of the KFABQ was high at 0.95 [46].

5. Data analysis

All statistical analyses in this study were performed using the Statistical Package for the Social Science (SPSS) Ver. 21.0 (SPSS Inc., USA). For general characteristics of the participants, the means and standard deviations of all variables were calculated. The normality test was conducted using the Shapiro–Wilk test, and all data were confirmed to be normally distributed. To verify the normal distribution of data among groups before intervention, the chi-square test was used for sex, Pfirmann grade, escape level, and radiating pain, and a one-way ANOVA was used for average age, height, weight, body mass index, symptom period, back and leg pain, centralization of symptoms, mechanical sensitivity, lumbar mobility, lumbar functional disability, and psychosocial functioning. The before and after differences of the groups were analyzed using a paired t-test. A one-way ANOVA was performed to analyze the differences in the amount of change among the groups. A post hoc analysis was performed using Scheffe’s test, and all statistical significance levels were set at $p < 0.05$.

Results

The general characteristics are shown in Table 1. In the preliminary examination among the SMWLM, NM, and control groups, no significant differences were observed in the data among the groups, thus making the data homogeneous. Six participants were excluded from the study because they did not meet the experimental standards, including four participants who received surgery and injection treatment and two participants, who discontinued the intervention for personal reasons. Finally, statistical analysis was conducted on 16 participants each in the SMWLM, NM, and control groups.

Back pain

The before and after changes in back pain in the three groups are presented in Table 2. A significant difference in back pain was observed, pre- and post-intervention, in all the groups ($p < 0.05$). No statistically significant difference was observed between the SMWLM and NM groups.

Table 1. General Characteristics of Participants (n = 48)

Characteristics	SMWLM group (n=16)	NM group (n=16)	CT group (n=16)	p
Sex (male / female)	7 / 9	8 / 8	8 / 8	0.920
Age (years)	38.31 (13.87)	48.06 (7.88)	40.69 (13.02)	0.064
Height (cm)	167.05 (5.87)	167.03 (10.97)	168.41 (7.45)	0.866
Weight (kg)	68.27 (11.93)	67.71 (12.71)	64.85 (14.57)	0.732
BMI (kg/m^2)	24.61 (3.34)	24.05 (3.23)	22.67 (3.68)	0.266
Pfirrmann (grade 2 / grade 3)	11 / 5	12 / 4	12 / 4	0.900
Escape level (L4-5 / L5-S1)	9 / 7	8 / 8	9 / 7	0.920
symptom period (day)	14.69 (6.98)	13.19 (7.12)	11.69 (5.88)	0.454

The values are presented mean (SD).
SMWLM: spinal mobilization with leg movement, NM: neural mobilization, CT: conventional physical therapy, BMI: body mass index.

Table 2. Comparision of NPRS, BGCS (n=48)

		SMWLM group (n=16)	NM group (n=16)	CT group (n=16)	F(p)
NPRS Back (score)	Pre	4.19 (1.32)	5.00 (1.78)	4.50 (1.54)	1.095 (0.343)
	Post	1.13 (1.02)	2.56 (1.09)	3.69 (1.44)	
	Pre-Post	3.06 (0.68)	2.43 (1.09)	0.81 (0.54)	33.134 (0.000)
	t(p)	−18.013 (0.000)	−8.916 (0.000)	−5.975 (0.000)	A, B | C
NPRS Leg (score)	Pre	5.88 (1.66)	6.06 (1.52)	5.56 (2.06)	0.327 (0.723)
	Post	1.63 (1.08)	3.06 (1.43)	4.44 (1.86)	
	Pre-Post	4.25 (1.12)	3.00 (1.09)	1.12 (0.71)	39.804 (0.000)
	t(p)	−15.105 (0.000)	−10.954 (0.000)	−6.260 (0.000)	A | B | C
BGCS (score)	Pre	5.44 (0.51)	5.50 (0.51)	5.44 (0.51)	0.079 (0.924)
	Post	3.00 (0.51)	3.56 (0.62)	5.13 (0.88)	
	Pre-Post	−2.43 (0.72)	−1.93 (0.68)	−0.31 (0.70)	40.245 (0.000)
	t(p)	−13.403 (0.000)	−11.396 (0.000)	−1.775 (0.096)	A, B | C

The values are presented mean (SD).
NPRS: numeric pain rating score, BGCS: body grid chart score, SMWLM: spinal mobilization with leg movement, NM: neural mobilization, CT: conventional physical therapy.

Leg pain

The before and after changes in leg pain in the three groups are presented in Table 2. A statistically significant difference in leg pain was observed, pre- and post-intervention, in all groups ($p<0.05$). The SMWLM was more effective than NM ($p<0.05$).

Centralization of symptoms

The before and after changes in centralization of symptoms in the three groups are summarized in Table 2. A statistically significant difference was observed in centralization of symptoms, pre- and post-intervention, in the SMWLM and NM groups ($p<0.05$), although no statistically significant difference was observed in the control group. No significant difference was observed between the SMWLM and NM groups.

Mechanical sensitivity

The before and after changes in mechanical sensitivity in the three groups are summarized in Table 3. A significant difference was observed in mechanical sensitivity, pre- and post-intervention, in all groups ($p<0.05$). No significant difference was observed between the SMWLM and NM groups.

Lumbar mobility

The before and after changes in lumbar mobility in the three groups are presented in Table 3. A statistically significant difference was observed in lumbar mobility, pre- and post-intervention, in the SMWLM and NM groups ($p<0.05$), whereas no significant difference was observed in the control group. The SMWLM was more effective than NM groups ($p<0.05$).

Lumbar functional disability

The before and after changes in lumbar functional disability in the three groups are presented in Table 3. A statistically significant difference was observed in lumbar functional disability, pre- and post-intervention, in all groups ($p<0.05$). No significant difference was observed between the SMWLM and NM groups.

Psychosocial functioning

The before and after changes in psychosocial functioning in the three groups are presented in Table 3. A statistically significant difference was observed in

Table 3. Comparision of PSLR, ALFROM, KODI, KFABQ (n=48)

		SMWLM group (n=16)	NM group (n=16)	CT group (n=16)	F(p)
PSLR (°)	Pre	49.18 (6.37)	50.43 (7.07)	48.31 (5.14)	0.467 (0.630)
	Post	72.62 (6.77)	70.31 (6.21)	53.75 (5.25)	
	Pre-Post	23.43 (4.66)	19.87 (6.48)	5.43 (4.36)	52.601 (0.000)
	t(p)	20.112 (0.000)	12.250 (0.000)	4.982 (0.000)	A, B ∣ C
ALFROM (°)	Pre	31.93 (4.12)	30.81 (5.60)	29.81 (3.60)	0.885 (0.420)
	Post	47.87 (4.54)	42.00 (4.16)	30.93 (3.49)	
	Pre-Post	15.93 (4.07)	11.18 (3.83)	1.12 (2.36)	74.463 (0.000)
	t(p)	15.649 (0.000)	11.673 (0.000)	1.904 (0.076)	A ∣ B ∣ C
KODI (score)	Pre	56.50 (9.10)	59.25 (9.11)	58.13 (8.65)	0.381 (0.686)
	Post	32.13 (5.23)	39.13 (5.46)	44.63 (6.68)	
	Pre-Post	24.37 (7.20)	20.12 (6.17)	13.50 (5.91)	11.543 (0.000)
	t(p)	−13.54 (0.000)	−13.039 (0.000)	−9.136 (0.000)	A, B ∣ C
KFABQ (score)	Pre	45.50 (5.75)	44.81 (6.84)	47.75 (7.79)	0.806 (0.453)
	Post	27.13 (3.07)	33.00 (5.09)	37.69 (6.35)	
	Pre-Post	18.37 (5.18)	11.81 (4.82)	10.06 (3.56)	14.661 (0.000)
	t(p)	−14.167 (0.000)	−9.804 (0.000)	−11.281 (0.000)	A ∣ B, C

The values are presented mean (SD).
PSLR: passive straight leg raise, ALFROM: active lumbar flexion range of motion, KODI: korean version oswestry disability index, KFABQ: korean version fear avoidance beliefs questionnaire, SMWLM: spinal mobilization with leg movement, NM: neural mobilization, CT: conventional physical therapy.

psychosocial functioning, pre- and post-intervention, in all groups ($p<0.05$). The SMWLM was more effective than NM groups ($p<0.05$).

Discussion

In this study, when SMWLM and NM were performed in 48 patients with radiating pain due to LDH, back and leg pain, centralization of symptoms, mechanical sensitivity, lumbar mobility, lumbar functional disability, and psychosocial functioning improved. Leg pain, lumbar mobility, and psychosocial functioning improved more with SMWLM than they did with NM.

LDH is a spinal disease that causes back pain accompanied by radiating pain [12]. This leads to a vicious cycle of limiting activity, reducing joint use, secondary weakening of muscle strength, and inhibiting physical function and production activities [47]. Radiculopathy in the L4, L5, and S1 regions is most commonly caused by LDH with pain in the medial foreleg, lateral thigh, lower leg, back, posterior thigh, calf, and heel [48]. In previous studies, when SMWLM and NM were performed in patients with lumbar radiculopathy, significant improvements were noted in pre- and post-intervention back and leg pain VAS scores, and SMWLM was more effective for improving leg pain than NM was [2]. In this study, the changes in NPRS of leg pain according to the application of SMWLM and NM also indicated significant improvements, pre- and post-intervention, in all groups. The SMWLM was more effective than NM in improving the parameters, and NM was more effective than the control. This causes the NM to operate the nerves at the mechanical interface pressed by the escaped intervertebral disc, distributing the tension evenly so that the tension would not increase in a specific area [49, 50], The decrease in tension may be due to its dispersion, having a positive effect on reducing back and leg pain in patients with LDH by reducing the adhesion of surrounding tissues, relieving impingement of neural structures, and increasing flexibility and blood flow [28, 51]. The SMWLM may be more effective than NM, not only in improving tension in the soft tissues damaged by mechanical deformation, but also in reducing joint compression and correcting local defects at the corresponding spinal level [49, 52].

Lumbar pathology is often related to axis pain or neurological symptoms, and this pain may lead to a decrease in lumbar mobility [53]. Pain reduces activity, and decreased muscle and joint use ultimately reduces the range of motion of the spinal joint [54]. Damage and escape of the intervertebral disc are related to joint compression, and repetitive bending and stretching movements. Even with moderate movement and a small magnitude of compression, pain can occur during repeated bending and stretching exercises. Damage and escape severity of the disc increase with increase in the size of the load pressing on the joint [55]. In this study, changes in ALFROM according to the application of SMWLM and NM demonstrated significant improvement only in the SMWLM and NM groups pre- and post-intervention. The SMWLM was more effective than NM, and NM was more effective than the control in improving the parameters. NM aims to restore balance between the nervous tissue and the surrounding structures [56], and improves musculoskeletal and peripheral nervous system extensibility [57], The combination of nerve endings in opposite directions in the tensioner technique of NM and nerve and joint movements through nerve endings in the same direction in the slider technique may have had a positive effect on improving lumbar mobility in patients with LDH [58]. The SMWLM may have a positive effect on increased lumbar mobility by limiting the mobility of the facet joint and simultaneously affecting the mobility of the surrounding intervertebral joint by assisting the gliding of the facet joint [23]. Active trunk and facet movements through biomechanical effects corrected positional faults in patients with LDH. The resulting symptomatic improvement led to a direct improvement in joint mobility, which may have a more positive effect on the lumbar mobility of patients with LDH than that associated with NM [22].

Fear of movement and activity is a major factor in the transition from acute back pain to long-term disability, and the avoidance of physical activity and work tasks leads to work loss and disability [20, 59]. Avoidance reactions may result in a decrease in physical and social activity, excessive fear avoidance behavior, long-term disability, and negative physical and psychological consequences [16]. In this study, the change in the KFABQ scores with the application of SMWLM and NM demonstrated significant improvements in all groups pre- and post-intervention. In the KFABQ score, the SMWLM was more effective than NM, and no statistically significant difference was observed between the NM and control groups. This is considered to be because the improvement of leg pain and lumbar mobility through SMWLM was more effective than NM. The SMWLM is considered to have a more positive effect than that of NM on psychological levels by inducing physiological movements in patients with LDH by combining active and additional movements [23, 60].

Other major symptoms of LDH include back pain, radiating pain, disability, and decreased physical and social activity [12, 13, 14, 16]. In this study, changes in the NPRS of back pain, BGCS, PSLR, and KODI according to the application of SMWLM and NM were confirmed. All the groups demonstrated significant improvements in all items, except for BGCS, post-intervention. The BGCS significantly improved post-intervention only in the SMWLM and NM groups. In the BGCS score, no statistically significant difference was observed between the SMWLM and NM groups, and SMWLM and NM were more effective than the control. The SMWLM and NM were confirmed to be effective for back pain, centralization of symptoms, mechanical sensitivity, and lumbar functional disability in patients with LDH.

A limitation of this study was its small size (48 participants), thus making it difficult to generalize the study results to all patients with LDH. Additionally, the 4-week study period was insufficient to determine the long-term effects of the intervention. Moreover, pain, functional disability, and psychosocial functioning were influenced by subjective factors of the participants, making it difficult to measure various factors. Considering these limitations, future studies should have a sufficient sample size and study duration. Measurements using additional tools, considering subjective factors, and research using more accurate inspection tools, such as X-rays and MRI, should be conducted.

In conclusion SMWLM and NM effectively improved back and leg pain, centralization of symptoms, mechanical sensitivity, lumbar mobility, lumbar functional disability, and psychosocial functioning in patients with LDH with radiating pain. SMWLM was more effective than NM for leg pain, lumbar mobility, and psychosocial functioning and could provide useful basic data for manual therapy for LDH patients.

Conflicts of interest

The authors declare no potential conflicts of interest regarding the research, author rights, and publication.

References

1. Ozturk B, Gunduz OH, Ozoran K, Bostanoglu S. Effect of continuous lumbar traction on the size of herniated disc material in lumbar disc herniation. Rheumatol Int. 2006;26(7):622-6.
2. Satpute K, Hall T, Bisen R, Lokhande P. The Effect of Spinal Mobilization With Leg Movement in Patients With Lumbar Radiculopathy-A Double-Blind Randomized Controlled Trial. Arch Phys Med Rehabil. 2019;100(5):828-36.
3. Collaborators G. Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990-2017: a systematic analysis for the Global Burden of Disease Study 2017. 2018.
4. Singh V, Malik M, Kaur J, Kulandaivelan S, Punia S. A systematic review and meta-analysis on the efficacy of physiotherapy intervention in management of lumbar prolapsed intervertebral disc. Int J Health Sci (Qassim). 2021;15(2):49-57.
5. Anderson PA, McCormick PC, Angevine PD. Randomized controlled trials of the treatment of lumbar disk herniation: 1983-2007. J Am Acad Orthop Surg. 2008;16(10):566-73.
6. Bono C, Wisneski R, Garfin S. Lumbar disc herniations. The Spine 5th ed Philadelphia, PA: Saunders. 2006.
7. McCulloch J, Edwards C. II, Riew KD. Lumbar microdiscectomy. Master Techniques in Orthopaedic Surgery: The Spine Philadelphia, PA: Lippincott Williams & Wilkins. 2002.
8. Khorami AK, Oliveira CB, Maher CG, Bindels PJ, Machado GC, Pinto RZ, et al. Recommendations for Diagnosis and Treatment of Lumbosacral Radicular Pain: A Systematic Review of Clinical Practice Guidelines. J Clin Med. 2021;10(11):2482.
9. Tawa N, Rhoda A, Diener I. Accuracy of clinical neurological examination in diagnosing lumbo-sacral radiculopathy: a systematic literature review. BMC Musculoskelet Disord. 2017;18(1):93.
10. Fardon DF, Williams AL, Dohring EJ, Murtagh FR, Gabriel Rothman SL, Sze GK. Lumbar disc nomenclature: version 2.0: Recommendations of the combined task forces of the North American Spine Society, the American Society of Spine Radiology and the American Society of Neuroradiology. Spine J. 2014;14(11):2525-45.
11. Koes BW, van Tulder MW, Peul WC. Diagnosis and treatment of sciatica. BMJ. 2007;334(7607): 1313-7.
12. Pourahmadi MR, Mohsenifar H, Dariush M, Aftabi A, Amiri A. Effectiveness of mobilization with movement (Mulligan concept techniques) on low back pain: a systematic review. Clin Rehabil. 2018;32(10):1289-98.
13. Schafer A, Hall T, Briffa K. Classification of low back-related leg pain--a proposed patho-mechanism-based approach. Man Ther. 2009;14(2):222-30.
14. Vroomen PC, de Krom MC, Wilmink JT, Kester AD, Knottnerus JA. Diagnostic value of history and physical examination in patients suspected of lumbosacral nerve root compression. J Neurol Neurosurg Psychiatry. 2002;72(5):630-4.
15. Vucetic N, Svensson O. Physical signs in lumbar disc hernia. Clin Orthop Relat Res. 1996(333): 192-201.
16. Fritz JM, Irrgang JJ. A comparison of a modified Oswestry low back pain disability questionnaire and the Quebec back pain disability scale. Phys Ther.

2001;81(2):776-88.
17. Warude T, Shanmugam S. The effect of Mckenzie approach and Mulligan's Mobilisation (SNAGS) in lumbar disc prolapse with unilateral radiculopathy. Int J SCI Res. 2014;39(4.89):38-93.
18. Gibson JN, Waddell G. Surgical interventions for lumbar disc prolapse: updated Cochrane Review. Spine (Phila Pa 1976). 2007;32(16):1735-47.
19. Hahne AJ, Ford JJ, McMeeken JM. Conservative management of lumbar disc herniation with associated radiculopathy: a systematic review. Spine (Phila Pa 1976). 2010;35(11):E488-504.
20. Olson KA. Manual Physical Therapy of the Spine-E-Book: Elsevier Health Sciences; 2015.
21. Kuligowski T, Skrzek A, Cieślik B. Manual therapy in cervical and lumbar radiculopathy: a systematic review of the literature. International Journal of Environmental Research and Public Health. 2021;18(11):6176.
22. Hussien HM, Abdel-Raoof NA, Kattabei OM, Ahmed HH. Effect of Mulligan Concept Lumbar SNAG on Chronic Nonspecific Low Back Pain. J Chiropr Med. 2017;16(2):94-102.
23. Mulligan BR. Manual Therapy:" nags"," snags"," mwms" Etc: Orthopedic Physical Therapy & Rehabilitation Produ; 2004.
24. Burton AK, Tillotson KM, Cleary J. Single-blind randomised controlled trial of chemonucleolysis and manipulation in the treatment of symptomatic lumbar disc herniation. Eur Spine J. 2000;9(3):202-7.
25. Coppieters MW, Butler DS. Do 'sliders' slide and 'tensioners' tension? An analysis of neurodynamic techniques and considerations regarding their application. Man Ther. 2008;13(3):213-21.
26. Shacklock M. Neurodynamics. Physiotherapy. 1995; 81(1):9-16.
27. McLellan DL, Swash M. Longitudinal sliding of the median nerve during movements of the upper limb. J Neurol Neurosurg Psychiatry. 1976;39(6): 566-70.
28. Ahmed N, Khan Z, Chawla C. Comparison of Mulligan's spinal mobilization with limb movement (SMWLM) and neural tissue mobilization for the treatment of lumbar disc herniation: a randomized clinical trial. J Nov Physiother. 2016;6(304):2.
29. Lee JH, Choi KH, Kang S, Kim DH, Kim DH, Kim BR, et al. Nonsurgical treatments for patients with radicular pain from lumbosacral disc herniation. Spine J. 2019;19(9):1478-89.
30. Danazumi MS, Bello B, Yakasai AM, Kaka B. Two manual therapy techniques for management of lumbar radiculopathy: a randomized clinical trial. J Osteopath Med. 2021;121(4):391-400.
31. Hing W, Hall T, Rivett D, Vicenzino B, Mulligan B. The Mulligan Concept of Manual Therapy-eBook: Textbook of Techniques: Elsevier Health Sciences; 2014.
32. Butler DS. The neurodynamic techniques: a definitive guide from the Noigroup team: Noigroup publications; 2005.
33. Reyes A, Aguilera MP, Torres P, Reyes-Ferrada W, Peñailillo L. Effects of neural mobilization in patients after lumbar microdiscectomy due to intervertebral disc lesion. J Bodyw Mov Ther. 2021;25:100-7.
34. Hawker GA, Mian S, Kendzerska T, French M. Measures of adult pain: Visual analog scale for pain (vas pain), numeric rating scale for pain (nrs pain), mcgill pain questionnaire (mpq), short-form mcgill pain questionnaire (sf-mpq), chronic pain grade scale (cpgs), short form-36 bodily pain scale (sf-36 bps), and measure of intermittent and constant osteoarthritis pain (icoap). Arthritis Care Res (Hoboken). 2011;63(S11):S240-S52.
35. Jensen MP, Turner JA, Romano JM. What is the maximum number of levels needed in pain intensity measurement? Pain. 1994;58(3):387-92.
36. Werneke M, Hart DL, Cook D. A descriptive study of the centralization phenomenon: a prospective analysis. Spine. 1999;24(7):676-83.
37. Cleland JA, Childs JD, Palmer JA, Eberhart S. Slump stretching in the management of non-radicular low back pain: a pilot clinical trial. Man Ther. 2006;11(4):279-86.
38. Werneke M, Hart DL. Centralization phenomenon as a prognostic factor for chronic low back pain and disability. Spine. 2001;26(7):758-64.
39. Tousignant-Laflamme Y, Boutin N, Dion AM, Vallée C-A. Reliability and criterion validity of two applications of the iPhone™ to measure cervical range of motion in healthy participants. J Neuroeng Rehabil. 2013;10(1):1-9.

40. Bueno-Gracia E, Malo-Urriés M, Borrella-Andrés S, Montaner-Cuello A, Estébanez-de-Miguel E, Fanlo-Mazas P, et al. Neurodynamic test of the peroneal nerve: Study of the normal response in asymptomatic subjects. Musculoskelet Sci Pract. 2019;43:117-21.
41. Delitto A, George SZ, Van Dillen L, Whitman JM, Sowa G, Shekelle P, et al. Low back pain: clinical practice guidelines linked to the International Classification of Functioning, Disability, and Health from the Orthopaedic Section of the American Physical Therapy Association. J Orthop Sports Phys Ther. 2012;42(4):A1-A57.
42. Devillé WL, van der Windt DA, Dzaferagic A, Bezemer P, Bouter LM. The test of Lasegue: systematic review of the accuracy in diagnosing herniated discs. Spine (Phila Pa 1976). 2000;25(9):1140-7.
43. Fletcher JP, Taylor JD, Carroll CA, Richardson MB. Comparison of Two Handheld Digital Dual Inclinometry Techniques in the Measurement of Lumbar Flexion Active Range of Motion. J Sport Rehabil. 2020;30(2):339-42.
44. Kolber MJ, Pizzini M, Robinson A, Yanez D, Hanney WJ. The reliability and concurrent validity of measurements used to quantify lumbar spine mobility: an analysis of an iphone® application and gravity based inclinometry. Int J Sports Phys Ther. 2013;8(2):129.
45. Kim D-Y, Lee S-H, Lee H-Y, Lee H-J, Chang S-B, Chung S-K, et al. Validation of the Korean version of the oswestry disability index. Spine. 2005;30(5):E123-E7.
46. Joo M-K, Kim T-Y, Kim J-T, Kim S-Y. Reliability and validity of the Korean version of the fear-avoidance beliefs questionnaire. Phys Ther Kor. 2009;16(2):24-30.
47. Choi J, Hwangbo G, Park J, Lee S. The effects of manual therapy using joint mobilization and flexion-distraction techniques on chronic low back pain and disc heights. J Phys Ther Sci. 2014;26(8):1259-62.
48. Tarulli AW, Raynor EM. Lumbosacral radiculopathy. Neurol Clin. 2007;25(2):387-405.
49. Das S, Dowle P, Iyengar R. Effect of spinal mobilization with leg movement as an adjunct to neural mobilization and conventional therapy in patients with lumbar radiculopathy: Randomized controlled trial. J Med Sci Res. 2018;6(1):11-9.
50. Lundborg G, Rydevik B. Effects of stretching the tibial nerve of the rabbit. A preliminary study of the intraneural circulation and the barrier function of the perineurium. J Bone Joint Surg Br. 1973;55(2):390-401.
51. Topp KS, Boyd BS. Structure and biomechanics of peripheral nerves: nerve responses to physical stresses and implications for physical therapist practice. Phys Ther. 2006;86(1):92-109.
52. Yadav S, Nijhawan MA, Panda P. Effectiveness of spinal mobilization with leg movement (SMWLM) in patients with lumbar radiculopathy (L5/S1 nerve root) in lumbar disc herniation. Int J Physiother Res. 2014;2(5):712-8.
53. Ruiz FK, Bohl DD, Webb ML, Russo GS, Grauer JN. Oswestry Disability Index is a better indicator of lumbar motion than the Visual Analogue Scale. Spine J. 2014;14(9):1860-5.
54. Pi T, Chung Y. Immediate Effect of Flexion-Distraction Spinal Manipulation on Intervertebral Height, Pain, and Spine Mobility in Patients with Lumbar Degenerative Disc Disease. Physical Therapy Rehabilitation Science. 2021;10(2):235-43.
55. Callaghan JP, McGill SM. Intervertebral disc herniation: studies on a porcine model exposed to highly repetitive flexion/extension motion with compressive force. Clin Biomech. 2001;16(1):28-37.
56. Díez Valdés S, Vega JA, Martínez-Pubil JA. Upper Limb Neurodynamic Test 1 in patients with Acquired Brain Injury: a cross-sectional study. Brain Inj. 2019;33(8):1039-44.
57. Saxena A, Sehgal S, Jangra MK. Effectiveness of Neurodynamic Mobilization versus Conventional Therapy on Spasticity Reduction and Upper Limb Function in Tetraplegic Patients. Asian Spine J. 2021;15(4):498.
58. Coppieters MW, Hough AD, Dilley A. Different nerve-gliding exercises induce different magnitudes of median nerve longitudinal excursion: an in vivo study using dynamic ultrasound imaging. J Orthop Sports Phys Ther. 2009;39(3):164-71.
59. Waddell G, Newton M, Henderson I, Somerville D, Main CJ. A Fear-Avoidance Beliefs Questionnaire (FABQ) and the role of fear-avoidance beliefs in

chronic low back pain and disability. Pain. 1993;52(2):157-68.
60. Exelby L. The Mulligan concept: its application in the management of spinal conditions. Man Ther. 2002;7(2):64-70.