

COMPARATIVE EFFECTS OF MULLIGAN TRACTION AND SLUMP STRETCH ON PAIN AND AUTONOMIC FUNCTION IN CHRONIC LUMBAR RADICULOPATHY

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Abstract

Background: Chronic lumbar radiculopathy is a prevalent musculoskeletal condition characterized by persistent pain, restricted mobility, functional disability, and impaired quality of life. Neural mobilization techniques, including traction-based leg raise therapy and slump stretching, are commonly incorporated into physiotherapy rehabilitation; however, their comparative effects on pain and autonomic function remain insufficiently established.

Objective: To compare the effects of traction-based leg raise therapy and slump stretch therapy on pain intensity, neural mobility, and autonomic cardiovascular function in adults with chronic lumbar radiculopathy.

Methods: This randomized controlled trial included 60 adults aged 18–60 years who met the predefined eligibility criteria. Participants were randomly allocated into two groups. Group A received traction-based leg raise therapy combined with lumbar stabilization exercises, whereas Group B received slump stretch therapy combined with lumbar stabilization exercises. Both interventions were administered three times weekly for 12 weeks. Pain intensity was assessed using the Visual Analogue Scale (VAS), while autonomic function was evaluated through heart rate variability (HRV), resting heart rate, and blood pressure. Straight leg raise performance was also assessed as an indicator of neural mobility. Paired-samples and independent-samples t-tests were used for within- and between-group comparisons, respectively.

Results: Both groups demonstrated significant reductions in pain intensity following the intervention ($p < 0.001$). Mean VAS scores decreased from 6.39 ± 1.08 to 2.91 ± 1.25 in the traction-based leg raise group and from 6.47 ± 1.15 to 3.83 ± 1.36 in the slump stretch group. The reduction in pain was significantly greater in the traction-based leg raise group than in the slump stretch group (3.49 ± 0.74 vs. 2.64 ± 0.63 , $p < 0.001$). Both interventions also produced significant improvements in straight leg raise, HRV parameters, resting heart rate, and blood pressure ($p < 0.001$); however, the between-group differences in these outcomes were not statistically significant.

Conclusion: Both traction-based leg raise therapy and slump stretch

therapy, when combined with lumbar stabilization exercises, were effective in reducing pain and improving neural mobility and autonomic cardiovascular function in individuals with chronic lumbar radiculopathy. However, traction-based leg raise therapy demonstrated superior efficacy in reducing pain intensity.

1. INTRODUCTION

Chronic lumbar radiculopathy (LRP) is a neurological condition characterized by radiating lower-limb pain resulting from irritation or compression of lumbar nerve roots, commonly associated with intervertebral disc herniation, degenerative disc disease, and spinal stenosis [1]. Patients may experience pain, paresthesia, numbness, and muscle weakness, leading to considerable limitations in mobility, physical function, and daily activities [2]. LRP represents a substantial clinical burden, with reported prevalence of approximately 3.7% in women and 5.3% in men, particularly among individuals aged 35–50 years [3]. Mechanical compression can impair neural conduction and local circulation, while inflammatory mediators may further sensitize neural tissues and contribute to persistent neuropathic pain [2, 4, and 5].

Chronic LRP can significantly affect walking, sitting, bending, lifting, occupational participation, and quality of life [6]. Persistent pain may also contribute to sleep disturbance, psychological distress, anxiety, depression, and increased socioeconomic burden [7]. In recent years, increasing attention has been directed towards autonomic dysfunction associated with chronic pain. The autonomic nervous system regulates cardiovascular and other involuntary functions, and persistent neural irritation may influence autonomic regulation [8, 9]. Changes in heart rate variability (HRV) and other cardiovascular parameters may therefore reflect alterations in sympathetic-parasympathetic balance in individuals experiencing chronic pain [8].

Conservative management of LRP commonly includes physiotherapy, therapeutic exercise, manual therapy, and pharmacological interventions [9]. However, persistent or recurrent symptoms indicate the need for effective rehabilitation strategies targeting both pain and neural dysfunction [10]. Mulligan traction is a manual therapy technique based on

the Mobilization with Movement concept, combining sustained traction with active or passive movement. It is proposed to reduce mechanical stress on neural structures, improve joint mechanics, and produce neurophysiological pain inhibition [11]. These effects may facilitate pain-free movement and improve functional mobility.

Slump stretching is a neurodynamic technique designed to improve neural mobility and reduce neural mechanosensitivity through controlled loading of the spinal and lower-limb neural structures [12]. Its proposed mechanisms include enhancing neural gliding, reducing restrictions around neural tissues, and improving tolerance to mechanical stress. Neurodynamic techniques have demonstrated potential benefits for pain and functional recovery in nerve-related musculoskeletal conditions [12]. Thus, both Mulligan traction and slump stretching may provide clinically meaningful benefits for individuals with chronic LRP, although they differ in their primary therapeutic mechanisms.

Despite the use of both techniques in clinical practice, limited evidence directly compares Mulligan traction with slump stretching, particularly in relation to autonomic cardiovascular function. Previous research has predominantly focused on pain, mobility, and functional outcomes, while HRV and related autonomic measures have received comparatively less attention. Therefore, the present randomized controlled trial was designed to compare the effects of Mulligan traction and slump stretching on pain and autonomic function in individuals with chronic lumbar radiculopathy, providing evidence that may assist clinicians in selecting appropriate rehabilitation strategies.

PROBLEM STATEMENT AND OBJECTIVES

Chronic lumbar radiculopathy is a prevalent musculoskeletal and neurological condition

affecting approximately 3–5% of adults and is associated with persistent radiating pain, impaired neural mobility, functional limitations, and reduced quality of life. Although Mulligan traction and neurodynamic techniques such as slump stretching are commonly used in physiotherapy and have demonstrated beneficial effects on pain and functional outcomes, evidence regarding their comparative effectiveness remains inconsistent. Furthermore, existing research has primarily focused on symptomatic and functional outcomes, with limited investigation of autonomic responses and cardiovascular regulation. The absence of standardized comparative studies assessing both pain and autonomic function represents an important gap in the current literature. Therefore, the present study aimed to evaluate the effects of Mulligan Traction Straight Leg Raise and Slump Stretch on pain and autonomic function in patients with chronic lumbar radiculopathy and to compare the effectiveness of both interventions. Changes in heart rate variability and cardiovascular parameters, including resting heart rate and blood pressure, were also assessed following the intervention.

2. CRITICAL ANALYSIS OF THE LITERATURE

Current evidence supports both Mulligan traction and neurodynamic techniques for lumbar radiculopathy, but their comparative effectiveness remains uncertain. Randomized controlled trials by Mishra et al. [1], Rajesh et al. [13], Iqbal et al. [17], Nagrale et al. [12], Cleland et al. [16], and Danazumi et al. [18] provide relatively stronger evidence, whereas studies by Irshad et al. [2] and Hayat et al. [14] used less rigorous quasi-experimental designs. Mulligan traction has demonstrated favorable effects on pain, disability, and neural mobility, particularly when combined with stabilization exercises [1–3, 13]. Conversely, Iqbal et al. [17], Narelle et al. [12], Cleland et al. [16], and Mansuri and Shah [15] reported substantial improvements following slump-based neurodynamic interventions in pain, disability, neural mobility, and functional outcomes. These contrasting findings indicate that treatment effects may depend on the outcome assessed and

the clinical characteristics of participants. Mechanistically, Mulligan traction may reduce mechanical stress around the nerve root and facilitate pain-free spinal movement, whereas slump stretching primarily targets neural excursion and mechanosensitivity [11, 12]. Thus, Mulligan traction may have greater effects on mechanical restrictions, while neurodynamic stretching may provide greater benefits through improved neural mobility and tolerance to mechanical loading.

Interpretation of these findings is complicated by considerable methodological heterogeneity. Treatment duration varied from very short protocols, such as the six-day intervention of Mishra et al. [1], to longer interventions and follow-up periods reported by Nagrale et al. [12] and Danazumi et al. [18]. Short studies may primarily capture immediate analgesic effects, whereas longer follow-up provides greater insight into sustained recovery. Furthermore, many studies combined the primary intervention with lumbar stabilization, mobilization, traction, TENS, or thermotherapy [2, 11, 12, 14, 15], making it difficult to determine the independent contribution of Mulligan traction or slump stretching. Shafique et al. [11] and Danazumi et al. [18] demonstrated that combining mechanical and neurodynamic approaches may produce synergistic effects; however, multimodal protocols reduce the ability to establish comparative superiority. Small sample sizes, often involving only 26–60 participants [1, 2, 17], further limit statistical power and generalizability. In addition, inconsistent reporting of randomization, allocation concealment, and blinding in some studies [2, 14] increases the risk of selection and measurement bias, particularly when subjective outcomes such as pain and disability are used.

A major gap in the literature is the limited assessment of physiological outcomes beyond pain, disability, and neural mobility. Although Rajesh et al. [13] incorporated quality of life, most studies have focused on conventional clinical outcomes [1, 2, 12–17], with little attention to neurophysiological or autonomic changes. Importantly, none of the reviewed studies directly evaluated autonomic function using objective cardiovascular measures such as

heart rate variability (HRV). This is clinically relevant because chronic pain and persistent neural irritation may influence sympathetic-parasympathetic regulation, and reduction in pain does not necessarily indicate restoration of autonomic function. Moreover, the limited long-term follow-up in most studies makes the sustainability of treatment effects uncertain, although Danazumi et al. [18] provided comparatively stronger evidence through nine-month follow-up. Overall, the literature suggests that both Mulligan traction and slump stretching are beneficial, but evidence regarding their relative superiority remains inconclusive because of heterogeneous interventions, small samples, mixed populations, co-interventions, and restricted outcome assessment. Therefore, a standardized randomized controlled trial directly comparing these techniques while assessing both pain and autonomic cardiovascular function is warranted. The present study addresses this gap by evaluating the comparative effects of Mulligan traction and slump stretching in individuals with chronic lumbar radiculopathy.

3. METHOD AND MATERIAL

3.1 Study Design, Setting and Population

The study was conducted as a randomized controlled trial (RCT) to evaluate the efficacy of selected physiotherapy interventions in patients diagnosed with chronic lumbar radiculopathy. The study population consisted of male and female adults aged 18–60 years. Participants were recruited from the Physiotherapy OPD and IPD of Lahore General Hospital (LGH), Horizon Hospital, Bahria Hospital, and Farooq Hospital, Lahore, using a convenience sampling technique.

3.2 Sample Size, Randomization and Blinding

A total of 60 participants were recruited and randomly allocated into two equal groups of 30 participants each. The sample size was calculated using a standard formula for comparing two means, with a 95% confidence level, 80% power, an assumed difference of 2 units in pain scores, and a standard deviation of 2.5 units. The calculated sample size was 25 participants per group and was increased to 30 per group considering a 15% anticipated

dropout rate. Group A received traction-based leg raise therapy (Mulligan-type) with lumbar stabilization, while Group B received slump stretch therapy with lumbar stabilization. Randomization was performed using the chit-draw method, with equal numbers of group-designated chits placed in a sealed box. The study was single-blinded, with the outcome assessor unaware of participants' group allocation. Blinding of participants and treating physiotherapists was not possible because of the nature of the interventions.

3.3 Study Duration and Intervention

The study was conducted over a period of six months, including participant recruitment, screening, baseline assessment, intervention, post-intervention assessment, data entry, statistical analysis, and interpretation of results. The intervention was administered for 12 weeks, with participants receiving physiotherapy treatment three times per week. Baseline measurements were recorded before the intervention, while post-intervention measurements were obtained after completion of the 12-week intervention period.

3.4 Selection Criteria

Participants were included if they had lumbar radiculopathy affecting the pelvic area, were aged 18–60 years, had a positive Straight Leg Raise (SLR) test, reported pain between 2 and 6 on the VAS, had an early diagnosis of pain radiating along the sciatic nerve, and were willing to participate in the study. Participants were excluded if they had undergone spinal surgery within the previous six months, had knee or ankle problems limiting movement, were pregnant or had a pacemaker, had serious spinal conditions such as fractures, tumors, or osteoporosis, were unable to perform the slump stretching position, or had cervical headache, spinal deformity, or ankylosing spondylitis.

3.5 Study Variables

The independent variables were Mulligan traction straight leg raise and slump stretch. The primary dependent variables were heart rate variability, resting heart rate, blood pressure, and autonomic function, while pain intensity was considered a secondary dependent variable.

3.6 Outcome Measurement Tools

Heart rate variability (HRV) was assessed using a 5-minute resting ECG recording obtained with participants in the supine position. The HRV parameters included standard deviation of normal-to-normal intervals (SDNN), root mean square of successive differences (RMSSD), percentage of successive normal intervals differing by more than 50 ms (pNN50), high-frequency (HF) power, and the low-frequency/high-frequency (LF/HF) ratio. These measures provide objective indicators of cardiac autonomic regulation, with higher HRV generally reflecting greater parasympathetic modulation, whereas reduced HRV may indicate sympathetic predominance. The LF/HF ratio was considered an indicator of sympathovagal balance. Reported test-retest reliability for HRV parameters ranges from ICC 0.80–0.95, with correlation coefficients greater than 0.85 [19, 20].

Resting blood pressure and pulse rate were measured using a validated digital sphygmomanometer and pulse-rate monitor. Participants remained seated during assessment, and the average of two readings was recorded for analysis. Blood pressure was assessed as systolic and diastolic pressure, with values below 120/80 mmHg considered normal, 120–129/<80 mmHg classified as elevated, and $\geq 130/80$ mmHg indicative of hypertension. Validated digital devices have demonstrated good measurement reliability, with reported ICC values of approximately 0.85–0.95 [21].

Resting pulse rate was also recorded objectively, with a normal adult resting range of approximately 60–100 beats/min and reported reliability of ICC >0.90 . Changes in blood pressure and pulse rate were considered supportive indicators of alterations in autonomic cardiovascular regulation [21, 22].

Pain intensity was assessed using a 10-cm Visual Analog Scale (VAS) before and after the intervention. Participants marked the point corresponding to their perceived pain intensity, with 0 representing no pain and 10 representing the worst possible pain. For interpretation, scores of 1–4 were considered mild pain, 5–7 moderate pain, and 8–10 severe pain. The VAS demonstrates excellent test-retest reliability, with an ICC of approximately 0.97, and good construct validity, with reported correlation coefficients ranging from 0.62–0.91 [23, 24]. The pre- and post-intervention scores were recorded to determine changes in pain intensity following Mulligan traction and slump stretch therapy.

3.7 Intervention Protocols

Both intervention groups received treatment three times per week for 12 weeks, with each session lasting approximately 40–50 minutes. Exercises were progressively advanced according to individual tolerance and functional improvement, while pain during exercise was maintained at $\leq 4/10$ on the VAS. HRV, blood pressure, and pulse rate were assessed at baseline, 6 weeks, and 12 weeks.

Table 1 Intervention Protocol for Group A: Traction-Based Leg Raise Therapy (Mulligan-Type) with Lumbar Stabilization

Week	Intervention	Sets/Repetitions	Progression/Grading	Rationale
1–2	Passive traction-assisted leg raises	2–3 $\times$ 10	Gentle mobilization within a pain-free range	Reduction of nerve-root compression and improvement of hip flexibility
3–4	Active-assisted leg raises with lumbar stabilization and bridging	3 $\times$ 12	Range gradually increased; bridge held for 5–10 s	Improvement of core stability while maintaining neural mobility
5–6	Active leg raises with 0.5–1 kg resistance and plank hold	3 $\times$ 10	Resistance and stabilization duration progressively increased	Enhancement of neuromuscular control and spinal support
7–8	Resisted leg raises	3 $\times$ 12	Repetitions and dynamic	Strengthening of

	with dynamic bridging and alternating leg lifts		stabilization progressively increased	paraspinal musculature while maintaining neural mobility
9-10	Leg raises with stabilization on a foam pad	3 × 12-15	Instability progressively introduced to challenge core control	Improvement of proprioception and postural control
11-12	Leg raises with advanced core exercises, including side plank and bird-dog	3 × 12-15	Full pain-tolerated range; holds increased to 20-30 s	Maximization of functional core strength and neural mobilization

Note. The protocol was based on previously reported Mulligan traction and lumbar stabilization approaches [2, 13, and 26].

Table 2 Intervention Protocol for Group B: Slump Stretch Therapy with Lumbar Stabilization

Week	Intervention	Sets/Repetitions	Progression/Grading	Rationale
1-2	Seated slump stretch with gentle knee extension	2-3 sets; 10-15-s hold	Performed within a pain-free range	Reduction of neural tension and initiation of neural gliding
3-4	Slump stretch with ankle dorsiflexion and gentle cervical flexion	3 sets; 15-s hold	Distal neural tension gradually increased	Improvement of sciatic nerve mobility
5-6	Slump stretch with seated hip flexion and repeated knee extension	3-4 sets; 15-20-s hold	Stretch duration gradually increased with active participation	Enhancement of neural excursion and flexibility
7-8	Supine slump stretch with straight leg raise	3 × 10	Neural mobilization combined with hip and knee movements	Improvement of neural tolerance and reduction of mechanosensitivity
9-10	Dynamic slump stretch with alternating limb movements	3 × 10-12	Movement variability progressively introduced	Enhancement of neural tolerance and functional mobility
11-12	Slump stretch with active lumbar stabilization and bridging	3 × 12-15	Full pain-tolerated range with active core engagement	Integration of neural mobility with spinal stability and functional recovery

Note. The protocol was adapted from previously described neurodynamic and slump-stretch approaches [1, 17, and 27].

3.8 Ethical Considerations

Ethical approval was obtained from the Institutional Review Board before commencement of the study, and permission was obtained from the administrations of Lahore General Hospital, Horizon Hospital,

Bahria Hospital, and Farooq Hospital, Lahore. Written informed consent was obtained from all participants after explaining the study objectives, procedures, potential risks, and benefits. Participant privacy and confidentiality were maintained throughout, and participants

were informed of their right to withdraw from the study at any time without consequences.

3.9 Data Collection Procedure

A total of 60 eligible participants with chronic lumbar radiculopathy, aged 18–60 years, were recruited from the Physiotherapy OPD/IPD of the selected hospitals. After informed consent, baseline VAS, HRV, blood pressure, and pulse rate measurements were recorded. Participants were randomly allocated to Group A or Group B using the chit-draw method, while the outcome assessor remained blinded to group allocation. Group a received traction-based leg raise therapy with lumbar stabilization, whereas Group B received slump stretch therapy with lumbar stabilization, three times weekly for 12

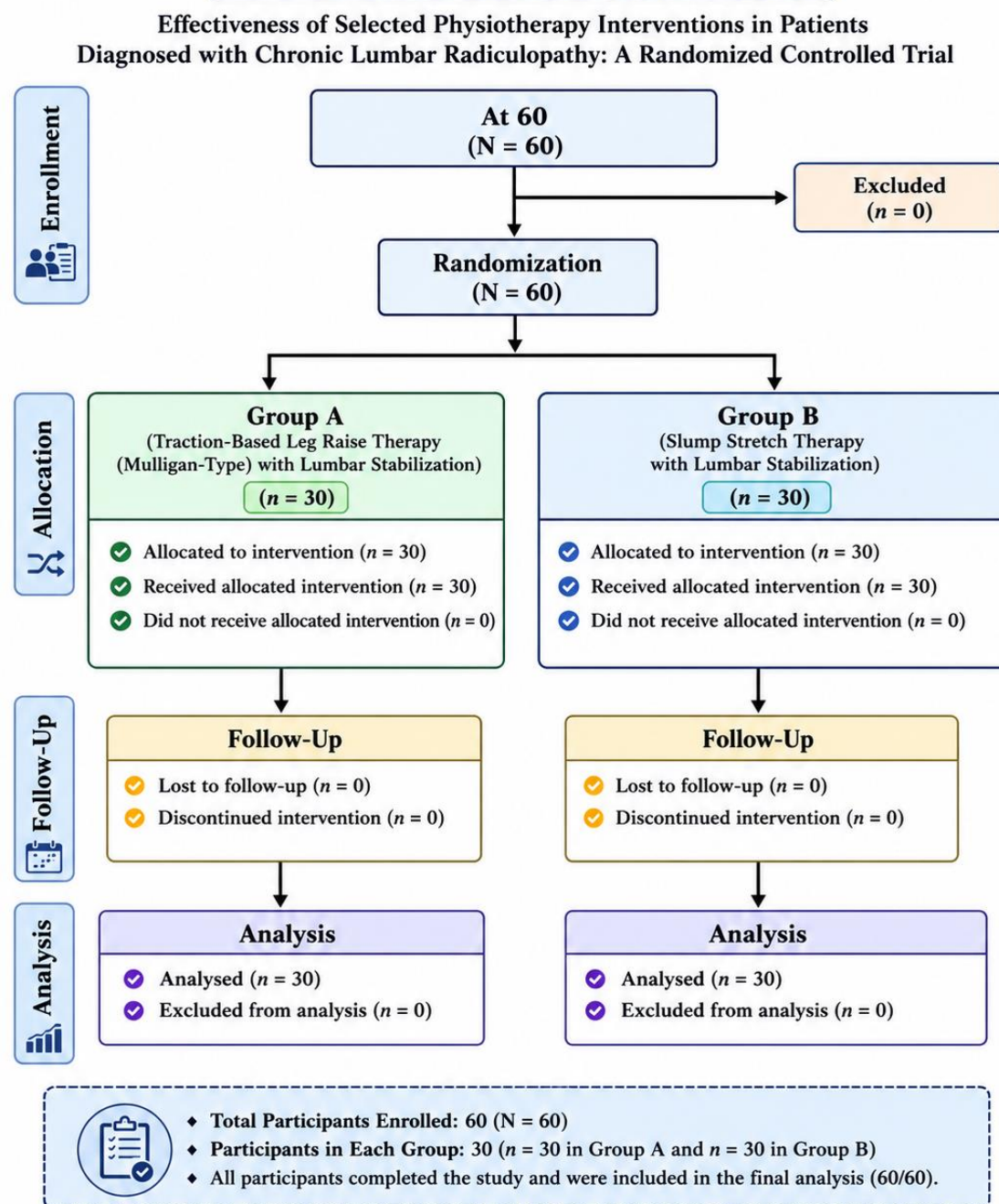
weeks. Following completion of the intervention, all outcome measures were reassessed using the same standardized procedures, and data were coded to maintain confidentiality.

3.10 Data Analysis

Data were analyzed using SPSS version 26.0. Descriptive statistics, including mean, standard deviation, frequency, and percentage, were used to summarize the data. The Shapiro–Wilk test was applied to assess normality. For normally distributed data, paired-samples t-tests were used for within-group comparisons and independent-samples t-tests for between-group comparisons. Statistical significance was set at $p \leq 0.05$, and findings were presented in tabulated form.



CONSORT FLOW DIAGRAM



4. DATA ANALYSIS AND RESULTS

4.1 Participant Characteristics

The demographic characteristics of the participants included age, gender, and hospital

of recruitment. A total of 60 participants were included, with 30 participants allocated to each intervention group. The overall distribution of these characteristics is presented in Table 3.

Table 3 Demographic Characteristics and Recruitment Distribution of Participants

Variable	Category	Mulligan Traction Straight Leg Raise (n = 30)	Slump Stretch (n = 30)
Age	Mean ± SD	35.97 ± 10.48	41.37 ± 12.17

(years)			
Gender	Male, n (%)	16 (53.3)	9 (30.0)
	Female, n (%)	14 (46.7)	21 (70.0)
Hospital	Lahore General Hospital (LGH), n (%)	6 (20.0)	3 (10.0)
	Horizon Hospital, n (%)	8 (26.7)	10 (33.3)
	Bahria Hospital, n (%)	8 (26.7)	10 (33.3)
	Farooq Hospital, n (%)	8 (26.7)	7 (23.3)

Note. SD = standard deviation; n = number of participants; % = percentage.

4.2 Comparison of Pain and Neural Mobility Outcomes

Table 4 presents the pre- and post-intervention VAS scores of participants in both treatment

groups. Both groups demonstrated a reduction in pain intensity following the intervention, with a greater reduction observed in the Mulligan Traction Straight Leg Raise group.

Table 4 Comparison of Pre- and Post-Intervention VAS Scores

Group	Pre-intervention Mean $\pm$ SD	Post-intervention Mean $\pm$ SD
Mulligan Traction Straight Leg Raise	6.39 $\pm$ 1.08	2.91 $\pm$ 1.25
Slump Stretch	6.47 $\pm$ 1.15	3.83 $\pm$ 1.36

Table 5 presents the pre- and post-intervention SLR ranges in both groups. Both interventions

resulted in an increase in SLR range, indicating improvement in neural mobility following treatment.

Table 5 Comparison of Pre- and Post-Intervention Straight Leg Raise Range

Group	Pre-intervention Mean $\pm$ SD (°)	Post-intervention Mean $\pm$ SD (°)
Mulligan Traction Straight Leg Raise	53.30 $\pm$ 11.52	74.13 $\pm$ 15.71
Slump Stretch	54.67 $\pm$ 11.63	74.40 $\pm$ 13.16

4.3 ECG-Based Heart Rate Variability (HRV)

Table 6 presents the pre- and post-intervention values of the HRV parameters, including SDNN, RMSSD, pNN50, HF, and LF/HF ratio,

for both the Mulligan Traction Straight Leg Raise and Slump Stretch groups. Both groups demonstrated favorable changes in HRV parameters following the 12-week intervention, indicating improved autonomic regulation.

Table 6 Comparison of Pre- and Post-Intervention Heart Rate Variability Parameters

HRV parameter	Group	Before intervention, M $\pm$ SD	After intervention, M $\pm$ SD
SDNN (ms)	Mulligan Traction Straight Leg Raise	34.17 $\pm$ 6.66	47.50 $\pm$ 8.57
	Slump Stretch	31.20 $\pm$ 7.74	43.33 $\pm$ 9.83
RMSSD (ms)	Mulligan Traction Straight Leg Raise	24.27 $\pm$ 5.49	35.87 $\pm$ 6.28
	Slump Stretch	25.37 $\pm$ 5.89	36.93 $\pm$ 7.66
pNN50 (%)	Mulligan Traction Straight Leg Raise	11.60 $\pm$ 5.61	20.87 $\pm$ 6.66
	Slump Stretch	11.67 $\pm$ 5.42	21.30 $\pm$ 6.85

HF (ms ²)	Mulligan Traction Straight Leg Raise	459.27 ± 154.28	737.30 ± 201.97
	Slump Stretch	451.93 ± 162.76	747.47 ± 209.25
LF/HF ratio	Mulligan Traction Straight Leg Raise	3.20 ± 0.64	1.97 ± 0.78
	Slump Stretch	3.30 ± 0.78	2.08 ± 0.97

Note. M = mean; SD = standard deviation; HRV = heart rate variability; SDNN = standard deviation of normal-to-normal intervals; RMSSD = root mean square of successive differences; pNN50 = percentage of successive normal-to-normal intervals differing by more than 50 ms; HF = high-frequency power; LF/HF = low-frequency to high-frequency ratio.

4.4 Digital Sphygmomanometer / Pulse Rate Monitor

Table 7 presents the pre- and post-intervention resting heart rate (RHR), systolic blood pressure (SBP), and diastolic blood pressure (DBP) of

participants in both treatment groups. Both groups demonstrated reductions in resting cardiovascular parameters following the intervention.

Table 7 Comparison of Pre- and Post-Intervention Cardiovascular Parameters

Parameter	Group	Before Intervention, M ± SD	After Intervention, M ± SD
RHR (bpm)	Mulligan Traction Straight Leg Raise	86.10 ± 6.92	77.37 ± 7.02
	Slump Stretch	83.57 ± 8.01	75.77 ± 9.01
SBP (mmHg)	Mulligan Traction Straight Leg Raise	132.07 ± 7.74	124.47 ± 8.53
	Slump Stretch	131.27 ± 9.14	124.20 ± 11.20
DBP (mmHg)	Mulligan Traction Straight Leg Raise	83.53 ± 5.19	78.03 ± 6.08
	Slump Stretch	84.13 ± 4.63	78.57 ± 4.14

Note. M = mean; SD = standard deviation; RHR = resting heart rate; bpm = beats per minute; SBP = systolic blood pressure; DBP = diastolic blood pressure; mmHg = millimeters of mercury.

4.5 Inferential Analysis of Study Outcomes

The inferential analysis was performed to determine the within-group changes and between-group differences in pain, straight leg raise, heart rate variability, resting heart rate, and blood pressure. A paired-samples *t*-test was used to assess pre- to post-intervention changes within each group, whereas an independent-samples *t*-test was used to compare the mean changes between the Mulligan Traction Straight Leg Raise and Slump Stretch groups. Statistical significance was considered at *p* ≤ .05.

Table 8 demonstrates significant improvements in all assessed outcomes following intervention in both groups. VAS scores decreased significantly in the MTSLR group from 6.39 ± 1.08 to 2.91 ± 1.25 and in the Slump Stretch group from 6.47 ± 1.15 to 3.83 ± 1.36 (both *p* <

0.001), indicating substantial reductions in pain intensity. SLR range increased significantly in both groups, from 53.30 ± 11.52° to 74.13 ± 15.71° in the MTSLR group and from 54.67 ± 11.63° to 74.40 ± 13.16° in the Slump Stretch group (both *p* < 0.001), suggesting improved neural mobility. HRV parameters also improved significantly after both interventions. SDNN, RMSSD, and pNN50 increased in both groups, while HF power increased substantially, indicating improved cardiac autonomic modulation. Conversely, the LF/HF ratio decreased significantly in both groups, suggesting a shift towards improved autonomic balance. Cardiovascular parameters also demonstrated significant changes, with resting heart rate decreasing from 86.10 ± 6.92 to 77.37 ± 7.02 bpm in the MTSLR group and from

83.57 $\pm$ 8.01 to 75.77 $\pm$ 9.01 bpm in the Slump Stretch group. Similarly, significant reductions were observed in both systolic and diastolic blood pressure in both groups (all $p < 0.001$). Overall, both MTSLR and Slump Stretch, when combined with lumbar stabilization exercises, produced significant improvements in pain, neural mobility, cardiac autonomic parameters, and resting cardiovascular measures.

Table 9 presents the between-group comparison of changes in outcomes following intervention. A statistically significant difference was observed only for VAS scores. The MTSLR group demonstrated a greater reduction in pain intensity (3.49 $\pm$ 0.74) compared with the Slump Stretch group (2.64 $\pm$ 0.63), with a statistically significant between-group difference ($t = 4.74$, $p < 0.001$), indicating that MTSLR was more effective in reducing pain.

For SLR, the mean improvement was slightly greater in the MTSLR group (20.83 $\pm$ 6.04°) than in the Slump Stretch group (19.73 $\pm$ 6.88°);

however, the difference was not statistically significant ($t = 0.66$, $p = 0.513$). Similarly, no significant between-group differences were found for SDNN ($p = 0.368$), RMSSD ($p = 0.976$), pNN50 ($p = 0.750$), HF power ($p = 0.599$), or LF/HF ratio ($p = 0.987$). These findings indicate that both interventions produced comparable improvements in cardiac autonomic measures.

Likewise, the changes in resting HR, SBP, and DBP did not differ significantly between groups ($p = 0.186$, 0.556 , and 0.919 , respectively). Although both interventions significantly improved these cardiovascular parameters within groups, neither intervention demonstrated superior effects over the other.

Overall, MTSLR was significantly superior to Slump Stretch only for reducing pain, whereas both interventions produced comparable improvements in neural mobility, cardiac autonomic function, and cardiovascular parameters.

Table 8 Within-group comparison of outcomes before and after intervention

Outcome	MTSLR Before	MTSLR After	p value	Slump Stretch Before	Slump Stretch After	p value
VAS	6.39 $\pm$ 1.08	2.91 $\pm$ 1.25	<0.001	6.47 $\pm$ 1.15	3.83 $\pm$ 1.36	<0.001
SLR (°)	53.30 $\pm$ 11.52	74.13 $\pm$ 15.71	<0.001	54.67 $\pm$ 11.63	74.40 $\pm$ 13.16	<0.001
SDNN (ms)	34.17 $\pm$ 6.66	47.50 $\pm$ 8.57	<0.001	31.20 $\pm$ 7.74	43.33 $\pm$ 9.83	<0.001
RMSSD (ms)	24.27 $\pm$ 5.49	35.87 $\pm$ 6.28	<0.001	25.37 $\pm$ 5.89	36.93 $\pm$ 7.66	<0.001
pNN50 (%)	11.60 $\pm$ 5.61	20.87 $\pm$ 6.66	<0.001	11.67 $\pm$ 5.42	21.30 $\pm$ 6.85	<0.001
HF (ms ²)	459.27 $\pm$ 154.28	737.30 $\pm$ 201.97	<0.001	451.93 $\pm$ 162.76	747.47 $\pm$ 209.25	<0.001
LF/HF ratio	3.20 $\pm$ 0.64	1.97 $\pm$ 0.78	<0.001	3.30 $\pm$ 0.78	2.08 $\pm$ 0.97	<0.001
Resting HR (bpm)	86.10 $\pm$ 6.92	77.37 $\pm$ 7.02	<0.001	83.57 $\pm$ 8.01	75.77 $\pm$ 9.01	<0.001
SBP (mmHg)	132.07 $\pm$ 7.74	124.47 $\pm$ 8.53	<0.001	131.27 $\pm$ 9.14	124.20 $\pm$ 11.20	<0.001
DBP (mmHg)	83.53 $\pm$ 5.19	78.03 $\pm$ 6.08	<0.001	84.13 $\pm$ 4.63	78.57 $\pm$ 4.14	<0.001

Note: Values are presented as mean $\pm$ SD. p values are from paired-sample t -tests. MTSLR = Mulligan Traction Straight Leg Raise; VAS = Visual Analogue Scale; SLR = Straight Leg Raise; SDNN = Standard Deviation of NN intervals; RMSSD = Root Mean Square of Successive Differences; pNN50 = percentage of successive NN intervals differing by >50 ms; HF = high-frequency power; LF/HF = low-frequency/high-frequency ratio; HR = heart rate; SBP = systolic blood pressure; DBP = diastolic blood pressure.

Table 9 Between-group comparison of changes in outcomes

Outcome	MTSLR Change	Slump Stretch Change	t value	p value
VAS	3.49 $\pm$ 0.74	2.64 $\pm$ 0.63	4.74	<0.001
SLR (°)	20.83 $\pm$ 6.04	19.73 $\pm$ 6.88	0.66	0.513

SDNN (ms)	13.33 ± 5.71	12.13 ± 4.46	0.91	0.368
RMSSD (ms)	11.60 ± 3.84	11.57 ± 4.67	0.03	0.976
pNN50 (%)	9.27 ± 4.18	9.63 ± 4.67	-0.32	0.750
HF (ms ²)	278.03 ± 128.66	295.53 ± 127.87	-0.53	0.599
LF/HF ratio	1.23 ± 0.36	1.23 ± 0.43	0.02	0.987
Resting HR (bpm)	8.73 ± 2.55	7.80 ± 2.85	1.34	0.186
SBP (mmHg)	7.60 ± 3.54	7.07 ± 3.43	0.59	0.556
DBP (mmHg)	5.50 ± 2.57	5.57 ± 2.49	-0.10	0.919

Note: Values represent absolute pre-to-post changes. MTSLR = Mulligan Traction Straight Leg Raise; VAS = Visual Analogue Scale; SLR = Straight Leg Raise; SDNN = Standard Deviation of NN intervals; RMSSD = Root Mean Square of Successive Differences; pNN50 = percentage of successive NN intervals differing by >50 ms; HF = high-frequency power; LF/HF = low-frequency/high-frequency ratio; HR = heart rate; SBP = systolic blood pressure; DBP = diastolic blood pressure.

5. DISCUSSION

The present randomized controlled trial compared Mulligan Traction Straight Leg Raise (MTSLR) and Slump Stretch, both combined with lumbar stabilization exercises, for pain, neural mobility, and autonomic function in patients with chronic lumbar radiculopathy. Both interventions produced significant within-group improvements in all measured outcomes, while the between-group analysis demonstrated a significantly greater reduction in VAS scores with MTSLR. These findings suggest that both approaches are beneficial, although MTSLR may provide greater pain relief.

Pain intensity decreased significantly in both groups ($p < 0.001$), with a greater mean reduction in the MTSLR group (3.49 ± 0.74) than in the Slump Stretch group (2.64 ± 0.63 ; $p < 0.001$). This finding is consistent with Irshad et al., who reported lower post-treatment pain in patients receiving Mulligan traction leg raise compared with Slump Stretch [28]. The greater effect of MTSLR may be attributed to the combination of longitudinal traction and active leg movement, which may reduce mechanical loading around the nerve root, improve neural excursion, and decrease pain sensitivity.

Both groups also demonstrated significant improvements in SLR range. The MTSLR group increased from $53.30 \pm 11.52^\circ$ to $74.13 \pm 15.71^\circ$, while the Slump Stretch group increased from $54.67 \pm 11.63^\circ$ to $74.40 \pm 13.16^\circ$ ($p < 0.001$). However, the between-group difference was not significant ($p = 0.513$). Similarly, Iqbal et al. reported significant improvements in SLR following both interventions, although their

between-group findings favored Slump Stretch [29]. The improvement may be explained by reduced neural mechanosensitivity, enhanced nerve excursion, and improved flexibility of the posterior kinetic chain following repeated neural mobilization.

Regarding autonomic function, both interventions significantly increased SDNN, RMSSD, pNN50, and HF power, while the LF/HF ratio significantly decreased ($p < 0.001$). These changes indicate an overall shift towards greater vagal modulation and improved cardiac autonomic regulation. Similar improvements in SDNN following physiotherapy have been reported in patients with low back pain [30], while previous research has also demonstrated changes in RMSSD and other HRV indices following physiotherapy interventions [31,32]. The present findings therefore support the potential of movement-based and manual physiotherapy to influence cardiac autonomic function.

The increase in HF power observed in both groups is consistent with previous research reporting favorable changes in frequency-domain HRV following treatment for chronic low back pain [33]. The simultaneous reduction in the LF/HF ratio is also compatible with evidence that chronic musculoskeletal pain is associated with altered autonomic regulation and that HRV can reflect changes in autonomic function [34]. These effects may result from reduced pain-related sympathetic activation, improved neuromuscular regulation, and repeated exposure to controlled therapeutic movement.

Both interventions also significantly reduced resting heart rate. The MTSLR group decreased from 86.10 ± 6.92 to 77.37 ± 7.02 bpm, while the Slump Stretch group decreased from 83.57 ± 8.01 to 75.77 ± 9.01 bpm ($p < 0.001$). These findings are comparable with previous research showing reductions in resting heart rate following physical interventions in individuals with chronic low back pain [35]. The reduction may reflect decreased sympathetic drive and enhanced parasympathetic activity associated with reduced pain and improved physical conditioning.

Similarly, SBP and DBP decreased significantly in both groups ($p < 0.001$). SBP decreased from 132.07 ± 7.74 to 124.47 ± 8.53 mmHg in the MTSLR group and from 131.27 ± 9.14 to 124.20 ± 11.20 mmHg in the Slump Stretch group. DBP decreased from 83.53 ± 5.19 to 78.03 ± 6.08 mmHg and from 84.13 ± 4.63 to 78.57 ± 4.14 mmHg, respectively. Previous studies have similarly reported favorable cardiovascular and hemodynamic responses following physiotherapy and exercise-based interventions for chronic low back pain [36, 37]. These changes may be related to reduce pain-induced sympathetic activity, increased parasympathetic influence, and improved cardiovascular regulation following repeated therapeutic exercise.

Overall, both MTSLR and Slump Stretch combined with lumbar stabilization produced significant improvements in pain, SLR range, HRV parameters, resting heart rate, and blood pressure [38]. However, MTSLR demonstrated a significantly greater reduction in pain, whereas no significant between-group differences were observed for SLR range or autonomic outcomes. These findings suggest that both interventions may be effective physiotherapeutic approaches for patients with chronic lumbar radiculopathy, with MTSLR potentially offering an additional advantage for pain reduction [39].

5.1 CONCLUSION

Mulligan Traction Straight Leg Raise and Slump Stretch, when combined with lumbar stabilization exercises, significantly improved pain intensity, straight leg raise range, heart rate variability, resting heart rate, and blood pressure in patients with chronic lumbar radiculopathy.

Both interventions demonstrated comparable effects on neural mobility and autonomic cardiovascular outcomes. However, MTSLR produced a significantly greater reduction in pain intensity than Slump Stretch. Therefore, both interventions may be considered effective physiotherapeutic approaches for the management of chronic lumbar radiculopathy, with MTSLR showing an additional benefit for pain reduction.

5.2 LIMITATIONS

This study had several limitations. The relatively small sample size and recruitment from a limited number of clinical settings may restrict the generalizability of the findings. The 12-week intervention period did not allow assessment of the long-term persistence of treatment effects. In addition, functional, psychosocial, and quality-of-life outcomes were not included, which may have provided a broader assessment of clinical recovery. Individual participant characteristics may also have contributed to variability in treatment responses. Finally, only MTSLR and Slump Stretch were investigated; therefore, the findings cannot necessarily be generalized to other NE urodynamic or manual therapy techniques.

5.3 RECOMMENDATIONS

Future studies should recruit larger and more diverse samples from multiple clinical settings to improve the generalizability of the findings. Long-term follow-up is recommended to determine whether the observed improvements are sustained after treatment. Further research should also incorporate functional disability, quality of life, and psychosocial outcomes. Comparative trials involving other NE urodynamic and manual therapy techniques, as well as combinations of NE urodynamic interventions with different exercise-based rehabilitation programmers, are warranted to establish optimal treatment strategies for chronic lumbar radiculopathy.

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