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Effects of neural mobilization on sciatic nerve excursion, symptoms, and regional function in individuals with nerve-related low back pain

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Abstract

Introduction. Low back pain is one of the most common musculoskeletal disorders. Neural mobilization was usually rendered as a treatment for nerve-related low back pain (N-LBP) but warrants more support for its effectiveness and outcomes. The study aimed to find the effect of neural mobilization in improving nerve mobility and symptoms among N-LBP individuals.

Methods. An experimental study was conducted in a physiotherapy outpatient department with 23 subjects, divided with simple random allocation into 2 groups: experimental (n = 13) and control (n = 10). A standardized musculoskeletal evaluation was performed prior to the treatment to quantify pain (numeric pain rating scale), lumbar range (bubble inclinometer), sciatic nerve mobility (ultrasonogram), and regional function (Oswestry Disability Index). The participants received therapy for pain modulation and spinal conditioning exercises with or without neural mobilization for 10 sessions spread over 3 weeks. The pre- and post-treatment data were analysed with non-parametric testing with significance assumed at $p < 0.05$.

Results. Between-group analyses provided the following observations: pain intensity: $p < 0.047$; lumbar range: flexion: $p < 0.555$, extension: $p < 0.294$; nerve mobility: $p < 0.001$; Oswestry Disability Index: $p < 0.617$. Significant differences were noted only in pain intensity and nerve mobility. In turn, within-group analyses revealed a statistical and clinical significance for all the above post-treatment variables in both groups.

Conclusions. Neural mobilization improves nerve mobility (sciatic nerve excursion) and alleviates symptoms. It can be rendered as a treatment in individuals with N-LBP.

Key words: nerve-related low back pain, neural mobilization, ultrasonogram

Introduction

Low back pain is one of the most common musculoskeletal disorders, contributing greatly to disability [1]. Nerve-related low back pain (N-LBP) can arise from a lesion involving the sciatic nerve, and leg pain is a frequent accompanying symptom [2, 3]. Increased neural mechano-sensitization is proposed as one of the predominating pathomechanisms for this feature. The nervous tissue must undergo elongation and sliding, and withstand compression during normal mechanical loading. If this elongation, sliding, and compression withstanding ability decreases, the nervous tissue becomes vulnerable to neural oedema, ischemic fibrosis, and hypoxia [4, 5].

Adverse neural tension results from impaired nerve mobility during static and dynamic functions. Compression of the nerve could occur at many proximal locations owing to several pathologies, leading to pain down the extremity, with or without secondary weakness. To achieve a pain-free range of motion and clinical improvement, the normal biomechanics of spine and surrounding structures, like intervertebral discs, spinal cord, and facet joint, needs to be optimized [6].

Neural mobilization is an intervention which, when applied as a passive manoeuvre or in the form of active self-exercise, improves peripheral nerve movement and decreases the associated symptoms [7]. The expected benefits include facilitation of sciatic nerve gliding, reduction of nerve adherence, and improvement in the physiological function [8, 9]. However, these benefits require robust validation and evidence.

Neural mobilization exercise, like slump and straight leg raise (SLR) mobilization targeting sciatic nerve, was strongly recommended for N-LBP [10–12], but the studies which support these recommendations had low, as well as high risk of bias, questioning their clinical reliability [13]. Further, the clinical application of neural mobilization was augmented only by measuring pain, disability, and regional function in few studies relating nerve mobility with the symptoms among patient population. It is thought that the reason for the lack of nerve-movement-related outcome measure was that no research has utilized a tool to quantify peripheral nerve movement, which is well evident from the systematic reviews [13]. Hence, in this study, an attempt was made to objectively measure sciatic nerve movement in individuals with N-LBP and to determine if decreased nerve mobility was the prime cause and if its increase reduced pain and facilitated function. Such observations would add clarity in the management of N-LBP with neural mobilization and pave way for future research regarding the dosage, self-exercise, and outcome.

The sciatic nerve moves in both longitudinal and transverse direction during nerve mobility exercise; the range and pattern of nerve excursion was different for different types of exercise [14]. However, very limited information is available about reduction in nerve mobility, increased mechano-sensitivity, its effect on symptom production, and patient

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prognosis. We think that the lacunae regarding the objective measurement of peripheral nerve mobility, faulty mechanosensitivity as a standalone cause, and natural recovery warrant a control group during the study conduct.

Ultrasound imaging was widely used to measure nerve movement in vivo and in real time by using grey scale imaging [15, 16]. When ultrasound penetrates human tissues, a series of rapid images are displayed, depicting tissue motions, which allows echo creation, imaging, and virtually real-time analysis [15, 17]. It is not clear whether ultrasonogram can be used to measure the sciatic nerve excursion among N-LBP participants.

The objective of this study was to find the effect of neural mobilization in improving nerve mobility and symptoms when rendered as a lesion-specific management. The clinical possibility to objectively measure nerve movement using ultrasonogram was verified in addition to other clinical outcomes.

Subjects and methods

Methodology

A non-randomized controlled study with purposive sampling was conducted in the physiotherapy outpatient department, Faculty of Physiotherapy, Sri Ramachandra Institute of Higher Education and Research.

Inclusion criteria

The study involved individuals visiting the outpatient department aged 18–65 years with the first episode low back pain within the previous 3 months, with radiating pain distal to knee in one extremity. Positive slump and SLR were considered for inclusion in the study by a therapist with 15 years of experience.

Exclusion criteria

Patients with a history of low back pain who had received neural mobilization, with the diagnosis of a systemic inflammatory disease, ankylosing spondylitis, malignancy, spinal cord lesion, or fractures involving the spine and lower limbs were excluded.

Initial evaluation

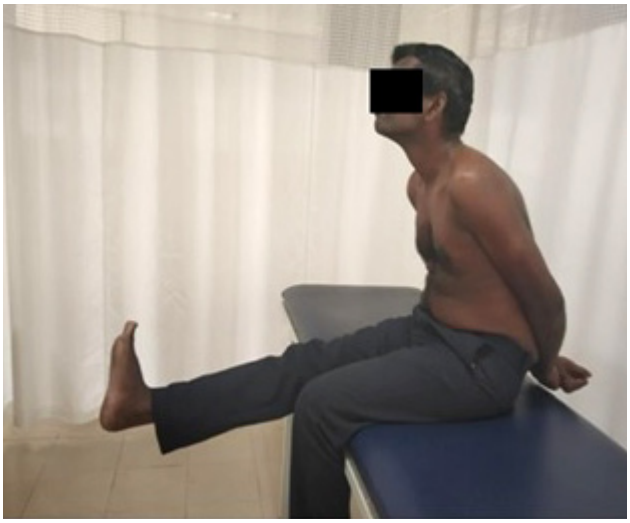
The subjects who met the eligibility criteria were included in the study. The sample size was derived by considering an improvement of 2 points in the numeric pain rating scale (NPRS) (standard deviation: 1.01–1.78), error 5%, power of 80%; a sample of 10–12 in each group was obtained. A standardized musculoskeletal assessment was performed prior to the treatment to quantify pain, lumbar range, sciatic nerve mobility, and regional function. Pain intensity was measured with NPRS, lumbar range – with a bubble inclinometer, sciatic nerve mobility – with ultrasonogram, and regional function – with the Oswestry Disability Index (ODI). The selected outcome variables of NPRS (γ = 0.75), bubble inclinometer score (γ = 0.86), and ODI (γ: 0.74–0.82) were found to have good validity and reliability in the specific population.

In addition to the above evaluations, the participants were asked to clearly document the location and intensity of their pain in the lower limb on a body chart before and after completion of the 10 sessions of treatment.

Allocation and intervention

The enrolled patients were divided into 2 groups by using simple random allocation. The experimental group (n = 13) received therapy for pain modulation, spinal conditioning exercises, and neural mobilization, whereas the control group (n = 10) received therapy to modulate pain and spinal conditioning exercises. Both groups underwent 10 sessions of therapy, spread over 3 weeks. The treatment was provided by an associate professor in physiotherapy and a post-graduate with 20 and 5 years of clinical experience, respectively.

Neural mobilization exercises, consisting of both sliders and tensioners, were provided as follows. The patient was positioned in high sitting, with the hands clasped behind and in slouched posture as base position. They performed neck extension and knee extension for the sliding technique, and neck flexion with knee extension for the tensioning technique (Figure 1 a, b). The movement range was determined by the severity of symptoms and patient tolerance. The nerve sliding technique was applied for 20–30 repetitions in 2–3 sets per day for 10 sessions, and the nerve tensioning technique was implemented in addition for 15–25 seconds in 5–7 repetitions in sessions 8–10.



a) slider technique

b) tensioner technique

Figure 1. Neural mobilization exercises

The participants in both groups received therapy to modulate pain with interferential therapy over the painful area in the low back region, by using the bipolar method, for 20 minutes. Spinal conditioning exercises targeted abdominals and deep lumbar flexors for strengthening and lumbar extensors and hamstrings for flexibility. Strengthening exercises were performed in 10 repetitions per set, 2–3 sets per day; stretching exercises were performed in 10 repetitions per set, 2 sets per day, with a 30-second hold. On completing 10 sessions of treatment, a post-treatment measurement was taken by a therapist blinded to the group allocation to determine the effectiveness of the technique. The subjects were asked to perform follow-up exercises for 12 weeks as a home program.

Ultrasonogram measurement and analysis

Grey scale ultrasonography was performed in all participants by using a GE LOGIQ P5 sonography instrument with a 12-MHz linear array probe by a sonologist who had more than 15 years of clinical experience and was blinded to group allocation. Initially, the patient was lying in prone position and the probe was positioned in the posterior lateral thigh transversely at a distance of 12–24 cm from the greater trochanter and 21–30 cm from the lateral condyle of the femur, as per individual need, aligning with the sciatic nerve course.

Once localized, the patient was made to lie on the non-symptomatic side with their trunk and hip in neutral position, and sciatic nerve movement was scanned in the longitudinal plane. Peripheral nerves appear as hypoechoic tubes when viewed longitudinally and hypoechoic round/oval sections when viewed transversely (Figure 2). A video of sciatic nerve movement was recorded while the participant performed knee flexion and extension slowly till 90° and 0°, respectively, and the same was extracted for analysis.

The video clip was investigated with the use of the Tracker video analysis and modelling tool, version 5.0.7. The video loop was converted into a succession of digital frames which show the nerve movement from start to end at the rate of 40 frames per second; a speckle was marked on the nerve as point mass. To measure the relative movement of the point in each frame, a key frame or area of reference was created and a template was matched to the speckle. A cross-correlational frame by frame analysis of the speckle was tracked to depict the nerve movement as the speckle shifted by one point every frame. The cumulative pixel shift provided the actual distance or nerve movement (Figure 3).

Both the bubble inclinometer and the ultrasonogram device exhibit good to moderate validity and reliability to measure the lumbar range and nerve excursion in the specific population (inclinometer $\gamma = 0.86$, ultrasonogram intraclass correlation coefficient: 0.77–0.99).

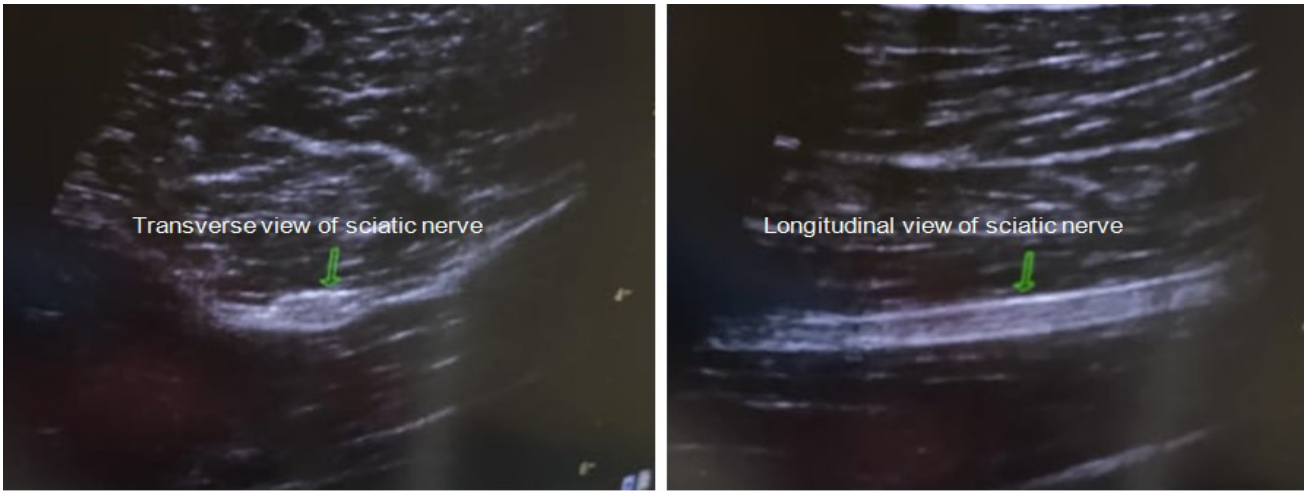


Figure 2. Ultrasonogram transverse and longitudinal view of sciatic nerve

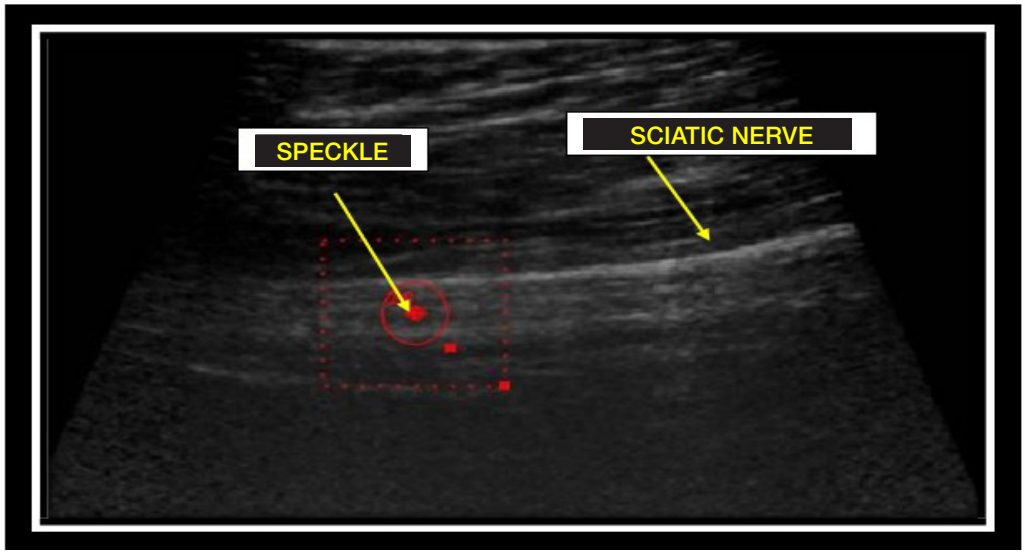


Figure 3. Tracking of nerve movement

Statistical analysis

After the completion of treatment, all the pre-measured parameters were obtained again and both the pre- and post-treatment data were subjected to analysis with the IBM SPSS Statistics for Windows software, version 22.0 (IBM Corp., Armonk, NY, USA). To describe the demographic and baseline data, mean and standard deviation were used. To find out significant differences within and between the experimental and control groups, the Wilcoxon signed-rank and Mann-Whitney *U* tests were applied, respectively. Fisher's exact test served to analyse the significance in symptom centralization.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Ethics Committee of Sri Ramachandra Institute of Higher Education and Research (REF: CSP/18/NOV/74/317).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

Both pre- and post-treatment data obtained from the 23 subjects were analysed to establish the improvement in nerve mobility and effectiveness of neural mobilization. The demographic and baseline data were comparable between the groups, with no significant difference (Table 1). The longitudinal analysis of pain intensity, lumbar range, nerve mobility, and disability alleviation exposed significant differences in both groups, with greater improvement observed in the experimental group (Table 2). The cross-sectional analysis of both groups revealed that only pain intensity ($p = 0.047$) and nerve mobility ($p < 0.001$) improvement attained significance (Table 2). As for the centralization of symptoms, the improvement in both groups ($p = 0.685$) was not significant (Table 3). The nerve mobility improvement was greater in the experi-

Table 1. Demographic and baseline data of the experimental and the control group

Variables		EG (*n* = 13)	CG (*n* = 10)	*p**
Age (years), mean (*SD*)		41.1 (8.3)	40.2 (6.2)	0.996
Gender (%)	Male	30.77	40	
	Female	69.23	60	
Symptom duration (*n*)	< 1 month	2	1	
	> 1 to < 2 months	5	4	
	> 2 to < 3 months	6	5	
NPRS, mean (*SD*)		6.08 (0.76)	6.00 (0.67)	0.802
ODI, mean (*SD*)		36.62 (2.53)	36.40 (1.58)	0.812
Lumbar range (cm), mean (*SD*)	Flexion	2.85 (0.31)	2.90 (0.21)	0.196
	Extension	1.30 (0.43)	1.30 (0.43)	0.202
Nerve mobility (mm), mean (*SD*)		12.06 (1.76)	12.14 (1.89)	0.919

EG – experimental group, CG – control group, NPRS – numeric pain rating scale, ODI – Oswestry Disability Index; * unpaired *t*-test

Table 2. Within- and between-group comparison of pain intensity (NPRS), lumbar range, disability score (ODI), and nerve mobility in the experimental and the control group

Variables		Within-group analysis						Between-group analysis		
		EG (*n* = 13)			CG (*n* = 10)			Between-group mean difference		*p***
		Pre	Post	*p**	Pre	Post	*p**	EG	CG	
NPRS, mean (*SD*)		6.08 (0.76)	3.61 (1.32)	< 0.001	6.00 (0.67)	4.50 (0.71)	< 0.005	2.47	1.5	0.047
Lumbar range (cm), mean (*SD*)	Flexion	2.85 (0.31)	3.85 (0.55)	< 0.001	2.90 (0.21)	3.85 (0.34)	< 0.005	1	0.95	0.555
	Extension	1.30 (0.43)	2.35 (0.42)	< 0.001	1.30 (0.43)	2.50 (0.53)	< 0.005	1.05	1.2	0.294
ODI, mean (*SD*)		36.62 (2.53)	17.92 (1.89)	< 0.001	36.40 (1.58)	20.30 (4.42)	< 0.005	18.7	16.1	0.617
Nerve mobility (mm), mean (*SD*)		12.06 (1.76)	16.21 (1.39)	< 0.001	12.14 (1.89)	13.62 (2.09)	< 0.005	4.15	1.48	< 0.001

EG – experimental group, CG – control group, NPRS – numeric pain rating scale, ODI – Oswestry Disability Index
* Wilcoxon signed-rank test, ** Mann-Whitney *U* test

Table 3. Number of individuals with and without improvement in symptom centralization in the experimental and the control group

Variable	Experimental group		Control group		*p**
	Improved	Not improved	Improved	Not improved	
Centralization	8	5	5	5	0.685

* Fisher's exact test

mental group (Table 2); its correlation with other variables resulted in a significant decrease in pain intensity only in the experimental group. The lumbar range and regional function improvement was similar in both groups and did not correlate with the above improvement.

Discussion

On analysing the pre- and post-treatment values of outcome measures, we found that neural mobilization was effective in bringing out clinically meaningful and statistically significant improvement (in pain and nerve mobility) among the participants with N-LBP, without exacerbating the symptoms. The observations of this study support the suggestion of a previous review that clinical outcomes can be improved when treatment is targeted at subgroups of patients with N-LBP [12]. The post-treatment mean difference for NPRS in the experimental and the control group was 2.47 and 1.50, respectively (Table 2). While there was a statistically significant improvement in both groups, the score change exceeded the minimal clinically important difference value of 2 for NPRS only in the experimental group (Table 2). Neural mobilization could have been the cause for this greater improvement as it has been claimed to exert an immediate endogenous hypoalgesic and sympatho-excitatory influence [18]. Neural mobilization can induce analgesia by the facilitation of nerve gliding, reduction of nerve adherence, dispersion of noxious fluids, increase of neural vascularity, improvement of axoplasmic flow, and reduction of mechanosensitivity [8, 19, 20].

Limited information is available in the literature about the normative values of sciatic nerve excursion among N-LBP patients. When sciatic nerve excursion was studied until recently during neural mobilization with its different techniques, the longitudinal excursion of the sciatic nerve identified in posterior lateral thigh was 17.8 ± 5.2 mm in a similar test position [14]. The mean pre-treatment value of sciatic nerve excursion for all participants included in the present study was 12.09 mm, which reflects reduced nerve excursion among this specific population (Table 1). The pre-exercise ultrasonogram observation revealed that the sciatic nerve appeared as a hypoechoic tube when viewed longitudinally and was moving very slowly during knee flexion and extension. With frame by frame cross-sectional analysis of the video clip from the ultrasonogram by using a video tracker, peripheral nerve movement objective measurement was possible and can be considered as one of the outcome measures.

The sciatic nerve excursion improved by 4.15 mm and 1.48 mm, with more gain in the experimental than the control group, substantiating the effect of neural mobilization (Table 2). More free and fast movement was observed in the ultrasonogram of the sciatic nerve after the exercise. The above measurement was taken in the sliding manoeuvre, which resulted in greater nerve excursion [14]. Regained nerve excursion could have decreased the neural strain and tension development, leading to symptom reduction; this was very evident in the current study [21, 22]. The longitudinal excursion of the sciatic nerve was found to differ depending on the spinal posture, and seated neural mobilization exercises with different postures were recommended for N-LBA [23]; this further supports this study observation.

Nerve mobility improved well in the experimental group after neural slider and tensioner application. However, the observed improvement is cumulative and cannot be attributed to the individual techniques, as this was not studied in the current research.

The participants in both groups experienced centralization of the symptoms, without a significant difference (Table 3). Centralization was reported by the subjects: they were asked to mark it on a body chart as proximal migration and reduced pain intensity are considered as prognostic signs [24, 25]. This is, however, a subjective method and a more objective way of monitoring this is warranted. The inference from this lack of significant improvement was that neural mobilization could not be considered as a standalone treatment for subjects with N-LBP and central lesions could yield better results on incorporating movement-based treatment to cause centralization of symptoms. As implementing segmental stabilization exercise along with neural mobilization has led to good results in the N-LBP population [26], such addition could improve the outcome.

The ODI score improved by more than 10 points in both groups and did not show significance in between-group analysis. A possible reason for this is that the patients were followed over a short period and the data were collected on completion of 10 treatment sessions at 3 weeks. A randomized controlled trail conducted recently also revealed that adding neurodynamic treatment and advice to remain active did not alleviate leg pain and disability at 2 weeks [27–29]. In turn, neural mobilization when compared with extracorporeal shock wave therapy resulted in good improvement by 6 weeks [30]. Hence, if participants are observed for a longer time through a proper follow-up, more information can be attained, and no conclusions can be derived from the current study in this regard.

Limitations

The nerve movement measurement was taken in a different position and movement than SLR and slump mobilization, which could be more appropriate in terms of provocation. Post-treatment neural tension testing response was not included in the analysis. The speed of leg movement during ultrasonography was not controlled in the current study, and only the short-term effect of neural mobilization was investigated.

Implications for further research

Future studies can be conducted to determine the effects of various individual techniques in alleviating symptoms among N-LBP patients. An accelerometer can be used to ensure a constant speed of limb motion. To reflect the long-term effect, participants should be followed up for a longer time. Involving and analysing numerous patient subgroups would help reveal the effectiveness of individual techniques (slider and tensioner) and standardize the treatment.

Conclusions

Neural mobilization improves nerve mobility (sciatic excursion) and alleviates symptoms. It can be rendered as a specific treatment in individuals with N-LBP. Different exercises can be studied to identify the activity of maximum benefit and more subgroups can be observed to enhance the understanding of clinical utility.

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Conflict of interest

The authors state no conflict of interest.

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References

1. Wu A, March L, Zheng X, Huang J, Wang X, Zhao J, et al. Global low back pain prevalence and years lived with disability from 1990 to 2017: estimates from the Global Burden of Disease Study 2017. Ann Transl Med. 2020; 8(6):299; doi: 10.21037/atm.2020.02.175.
2. Kavlak Y, Uygur F. Effects of nerve mobilization exercise as an adjunct to the conservative treatment for patients with tarsal tunnel syndrome. J Manipulative Physiol Ther. 2011;34(7):441–448; doi: 10.1016/j.jmpt.2011.05.017.
3. Schäfer A, Hall T, Briffa K. Classification of low back-related leg pain – a proposed patho-mechanism-based approach. Man Ther. 2009;14(2):222–230; doi: 10.1016/j.math.2007.10.003.
4. Butler DS. The sensitive nervous system. Adelaide: Noigroup; 2000.
5. Shacklock M. Neurodynamics. Physiotherapy. 1995; 81(1):9–16; doi: 10.1016/S0031-9406(05)67024-1.
6. Shacklock M. Clinical applications of neurodynamics. In: Shacklock M (ed.), Moving in on pain. London: Butterworth-Heinemann; 1995; 123–131.
7. Nee RJ, Jull GA, Vicenzino B, Coppieters MW. The validity of upper-limb neurodynamic tests for detecting peripheral neuropathic pain. J Orthop Sports Phys Ther. 2012;42(5):413–424; doi: 10.2519/jospt.2012.3988.
8. Shacklock M. Clinical neurodynamics. A new system of musculoskeletal treatment. London: Butterworth-Heinemann; 2005.
9. Gifford L. Neurodynamics. In: Pitt-Brooke J (ed.), Rehabilitation of movement. Theoretical basis of clinical practice. London: WB Saunders; 1998; 159–195.
10. Kaur G, Sharma S. Effect of passive straight leg raise sciatic nerve mobilization on low back pain of neurogenic origin. Indian J Physiother Occup Ther. 2011;5(3): 179–184.
11. Schäfer A, Hall T, Müller G, Briffa K. Outcomes differ between subgroups of patients with low back and leg pain following neural manual therapy: a prospective cohort study. Eur Spine J. 2011;20(3):482–490; doi: 10.1007/s00586-010-1632-2.
12. Neto T, Freitas SR, Marques M, Gomes L, Andrade R, Oliveira R. Effects of lower body quadrant neural mobilization in healthy and low back pain populations: a systematic review and meta-analysis. Musculoskelet Sci Pract. 2017;27:14–22; doi: 10.1016/j.msksp.2016.11.014.
13. Basson A, Olivier B, Ellis R, Coppieters M, Stewart A, Mudzi W. The effectiveness of neural mobilization for neuromusculoskeletal conditions: a systematic review and meta-analysis. J Orthop Sports Phys Ther. 2017; 47(9):593–615; doi: 10.2519/jospt.2017.7117.
14. Coppieters MW, Andersen LS, Johansen R, Giskegjerde PK, Høivik M, Vestre S, et al. Excursion of the sciatic nerve during nerve mobilization exercises: an in vivo cross-sectional study using dynamic ultrasound imaging. J Orthop Sports Phys Ther. 2015;45(10):731–737; doi: 10.2519/jospt.2015.5743.
15. Beekman R, Schoemaker MC, Van Der Plas JPL, Van Den Berg LH, Franssen H, Wokke JHJ, et al. Diagnostic value of high-resolution sonography in ulnar neuropathy at the elbow. Neurology. 2004;62(5):767–773; doi: 10.1212/01.wnl.0000113733.62689.0d.
16. Dilley A, Summerhayes C, Lynn B. An in vivo investigation of ulnar nerve sliding during upper limb movements. Clin Biomech. 2007;22(7):774–779; doi: 10.1016/j.clinbiomech.2007.04.004.
17. Beekman R, Visser LH. High-resolution sonography of the peripheral nervous system – a review of the literature. Eur J Neurol. 2004;11(5):305–314; doi: 10.1111/j.1468-1331.2004.00773.x.
18. Beneciuk JM, Bishop MD, George SZ. Effects of upper extremity neural mobilization on thermal pain sensitivity: a sham-controlled study in asymptomatic participants. J Orthop Sports Phys Ther. 2009;39(6):428–438; doi: 10.2519/jospt.2009.2954.
19. Coppieters MW, Alshami AM. Longitudinal excursion and strain in the median nerve during novel nerve gliding exercises for carpal tunnel syndrome. J Orthop Res. 2007;25(7):972–980; doi: 10.1002/jor.20310.
20. Schmid AB, Elliott JM, Strudwick MW, Little M, Coppieters MW. Effect of splinting and exercise on intraneural edema of the median nerve in carpal tunnel syndrome – an MRI study to reveal therapeutic mechanisms. J Orthop Res. 2012;30(8):1343–1350; doi: 10.1002/jor.22064.
21. Harringe ML, Nordgren JS, Arvidsson I, Werner S. Low back pain in young female gymnasts and the effect of specific segmental muscle control exercises of the lumbar spine: a prospective controlled intervention study. Knee Surg Sports Traumatol Arthrosc. 2007;15(10): 1264–1271; doi: 10.1007/s00167-007-0289-9.
22. Jeong U-C, Kim C-Y, Park Y-H, Hwang-Bo G, Nam C-W. The effects of self-mobilization techniques for the sciatic nerves on physical functions and health of low back pain patients with lower limb radiating pain. J Phys Ther Sci. 2016;28(1):46–50; doi: 10.1589/jpts.28.46.
23. Ellis R, Osborne S, Whitfield J, Parmar P, Hing W. The effect of spinal position on sciatic nerve excursion during seated neural mobilisation exercises: an in vivo study using ultrasound imaging. J Man Manip Ther. 2017; 25(2):98–105; doi: 10.1179/2042618615Y.0000000020.
24. McKenzie R, May S. The lumbar spine. Mechanical diagnosis and therapy, vol. 2. Waikanae: Spinal Publications; 2003.
25. Donelson R, Silva G, Murphy K. Centralization phenomenon. Its usefulness in evaluating and treating referred pain. Spine. 1990;15(3):211–213.
26. Fritz JM, Whitman JM, Childs JD. Lumbar spine segmental mobility assessment: an examination of validity for determining intervention strategies in patients with low back pain. Arch Phys Med Rehabil. 2005;86(9): 1745–1752; doi: 10.1016/j.apmr.2005.03.028.
27. Butler DS, Shacklock MO, Slater H. Treatment of altered nervous system mechanics. In: Boyling JD, Palastanga N (eds.), Grieve's modern manual therapy: the vertebral column, 2nd ed. Edinburgh: Churchill Livingstone; 1994; 693–703.
28. Ferreira G, Stieven F, Araujo F, Wiebusch M, Rosa C, Plentz R, et al. Neurodynamic treatment did not improve pain and disability at two weeks in patients with chronic nerve-related leg pain: a randomised trial. J Physiother. 2016;62(4):197–202; doi: 10.1016/j.jphys.2016.08.007.
29. Hall T, Coppieters MW, Nee R, Schäfer A, Ridehalgh C. Neurodynamic treatment improves leg pain, back pain,

function and global perceived effect at 4 weeks in patients with chronic nerve-related leg pain. J Physiother. 2017;63(1):59; doi: 10.1016/j.jphys.2016.09.001.
30. Alatawi SF. Effectiveness of neural mobilization in the management of chronic low back pain with radiculopathy: a randomized controlled trial. Int J Physiother. 2019; 6(5):217–223; doi: 10.15621/ijphy/2019/v6i5/186844.