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EFFECT OF NEURODYNAMIC MOBILISATION PLUS CORE STABILITY ON PAIN AND MOTOR NERVE CONDUCTION VELOCITY IN ATHLETES WITH LUMBAR RADICULOPATHY

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Abstract

Introduction. Lumbar radiculopathy (LR) is a common debilitating disorder of neuromuscular origin that affects athletes. **Material and Methods.** This study was a parallel group design and a total of 24 clinically diagnosed athletes with LR were recruited for the study and randomly assigned to one of the two groups, i.e. neurodynamic mobilisation plus core stability group (NDS plus CS) and core stability group only (CS). NDS plus CS underwent neural mobilisation of the tibial nerve and core stability exercises, while CS group performed core stability for a total of 14 sessions on alternate days. The outcome measures of motor nerve conduction velocity (m NCV) of the tibial nerve and pain intensity were recorded before the start of the intervention, at midpoint (7th session) and at the end of the intervention (14th session). **Results.** Baseline scores of pain and m NCV (NDS plus CS: 6.75 ± 0.62 , 38.10 ± 7.21 and CS: 6.58 ± 0.79 , 38.92 ± 6.37) were non-significant. The outcome measures improved significantly during treatment in NDS plus CS group (baseline to 7th session, 7th to 14th session and overall mean change for pain and m NCV was found to be 4.74 ± 0.37 and -6.43 ± 3.08 , respectively. Non-significant improvement was reported for CS group. Two-way repeated measures (2 x 3) ANOVA was used to analyse the change in the outcome measures and revealed that NDS plus CS group showed statistically significant main effects for group on pain level ($F(2, 5.34) = 0.89$, $p < 0.001$ and m NCV ($F(2, 5.21) = 0.40$, $p < 0.03$). Significant time and group x time interaction effects were also found. **Conclusions.** The findings of the study revealed that neurodynamic mobilisation plus core stability were found effective in improving pain level and motor nerve conduction velocity of the tibial nerve in athletes with lumbar radiculopathy.

Key words: lumbar pain, neural mobilisation, exercises, pain, nerve conduction velocity

Introduction

Lumbar radiculopathy (LR) is defined as spinal nerve-related symptoms such as back and leg pain, with variable presence of paraesthesias, reflex changes, and secondary interference of normal activities [1]. Lumbar radiculopathy (LR) is a common debilitating condition of lumbar origin which influences both the general population and athletes alike [2, 3, 4]. LR is a form of low back pain which has a major socioeconomic impact. According to a study conducted by Global Burden of Disease (GBD), LR is a second major cause of years lived with disability [5]. Its prevalence has been estimated to be 3-5% of the population, affecting both men and women [6]. The cumulative lifetime prevalence of low back pain in elite level athletes is around 61% [7]. Most cases have an atraumatic onset but risk factors include frequent movements (especially with twisting motions at extreme ranges) [8]. Since athletic activities involve combinations of motion at extreme ranges of motion, athletic population is more at risk of developing this problem. Diagnosis of LR is mainly based on clinical presentation and physical examination of the athlete. Several studies have been done to analyse this predisposition of athletes to herniated disc problem [9, 10]. LR caused by disc herniation has a favorable natural history in the vast majority of patients. As per research, around 70-80% of patients improve significantly in terms of pain and disability

within a span of 4-6 weeks with relative rest. However, according to one study, around 30% of patients still reported persistent pain and moderate disability at one year [11]. Considering that it is not completely self-limiting in significant percentage of patients, the importance of intervention in athletes becomes even more pertinent [1]. Pain and decrease in the motor nerve conduction velocity (m NCV) are commonly seen findings in those afflicted with LR. M NCV is a reliable and valid means of measuring the impact of radiculopathy on nerve conduction ability [12]. The clinical presentation of lumbar radiculopathy depends on the nerve root impinged. In this study, we included athletes with mechanical lower lumbar radiculopathy (L4-L5 and L5-S1). Increased joint play due to poor intervertebral joint stabilisation and neural hypomobility have been reported to be two main impairments commonly seen in patients with LR [13, 14]. Therefore, both neurodynamic mobilisation (NDM) and core stability (CS) exercises are rational approaches to manage this problem. Some previous studies conclude that both approaches have shown initial promising results for pain reduction and optimising m NCV values [15, 16]. However, the combined effect of both on athletic population is yet to be ascertained. NDM is a form of manual therapy which aims to assess and restore normal mobility, i.e. slide of the neural structures within the anatomical containers, which are supposed to be responsible for the musculoskeletal disorders [17, 18]. The compression of the sci-

atic nerve in the lumbar region leads to mechanical interference in its ability to slide as the motor movements of limbs and spine happen. This mechanical interference leads to the generation of pain along the nerve trunk. This prolonged nerve compression and immobility impairment leads to the ischemic damage to the structure. Therefore, neural mobilisation has a vital role in reducing the intraneural edema, restoring the blood flow and axonal flow in nerve fibres. This forms the basis of correcting mobility impairments seen in lumbar radiculopathy. CS exercises help to condition the stabilisation component of the spine and mobiliser muscles which work in unison to support the spinal column during movement. The stabiliser group of muscles are responsible for controlling the intersegmental movement and providing a stable background for appendicular skeleton motion [19]. There is scant evidence due to limited studies and conflicting evidence comparing the effects of NDM combined with CS exercises in athletes with LR; therefore, more scientific research needs to be done to determine the facts [20, 21]. We hypothesized that the NDM plus CS exercises would lead to significantly greater improvement in the outcome measures (pain and m NCV) assessed in the present study as compared to the core stability alone in athletes. The aim of the study was to evaluate the effect of neurodynamic mobilisation plus core stability and core stability alone on pain and motor nerve conduction velocity (Tibial nerve) in athletes with LR.

Material and Methods

This study was a parallel-group, randomised, controlled trial. The sample size for the study was calculated using Software G. Power 3.192 and was based on detecting 2.0 points between groups difference in pain (VAS level), assuming standard deviation of 1.8, alpha level of 0.05 and power (1-beta) of 90% [22]. The estimated sample size of 12 athletes per group (including 12% drop out) was found to be required for the study. A total of 24 male athletes clinically diagnosed with LR and fulfilling the inclusion criteria were randomly assigned to one of the two groups (NDM plus CS and CS alone). The athletes were recruited from the physiotherapy clinic of the university. The inclusion criteria for the study were as follows: a) university athletes in age range of 18-35 years; b) clinically diagnosed lower LR based on four positive tests/findings (pain in back and radiation complaints in the leg below the knee along with mild paraesthesia, positive straight leg raising test ≤ 60 degrees, increased pain on coughing, sneezing or straining); c) VAS level $\geq 4/10$; d) affected by LR for ≥ 1 year. The physical examination clinical diagnosis was performed using a battery of tests based on following established criteria in the literature [23]. Athletes with bilateral lumbar radiculopathy, any vertebral fractures and spinal surgery in the past two years, any cardiovascular or neurological disorders, metabolic and inflammatory diseases of the spine which could affect the study variables were excluded. A thorough assessment was done and if the athlete fulfilled the aforementioned inclusion criteria, the study was explained to him. The athlete's willingness to join the study was sought, following which a signed informed consent was obtained from the athletes. The study was ethically approved by the institutional ethics committee of the university (IEC No.156/8/120/JMI/IEC/16). After the recruitment, athletes were randomly divided into NDM plus CS group and CS group. Fifteen athletes had right sided pain, while 9 had pain on the left side. Athletes in NDM plus CS group were treated with neurodynamic mobilisation combined with core stability exercises, whereas athletes in CS group underwent core stability exercises alone. Patients in both groups were treated

during 14 sessions on alternate days. M NCV of the tibial nerve and pain assessment (VAS) was performed at baseline (pre-intervention), on 7th day and on 14th day. The baseline anthropometric measurements were performed (body mass, body height and body mass index (BMI)). All measurements were made by a single evaluator as per the guidelines of International Standards for Anthropometric Assessment (ISAK) protocol [24]. The pain level assessment for the intensity of pain in LR was performed with the help of the Visual Analogue Scale (VAS) [25]. In this linear scale, ranging from 0 to 10 cm, the left extreme point (0) corresponds to no pain at all and the right extreme point (10) corresponds to unbearably intense pain. The participants were asked to indicate their level of pain by adding a mark on the VAS scale. The m NCV was measured as per recommendations in previous studies by a qualified and experienced physiotherapist at the university clinic [26, 27]. The m NCV of the tibial nerve was measured with electrophysiologic apparatus (RMS Salus Aleron 4 series, serial no R25-456390876) at the baseline, mid-point and post-intervention. The recruited athletes were briefly told about the procedure. Then, the athletes were made to lie down on the table with the knee slightly flexed and ankle supported on table. Alcohol swabs were used for reduction of skin impedance as a standard procedure. Active black electrode was placed over the abductor hallucis (anterior-distal to the navicular tuberosity). Reference electrode was placed distally near the metatarsal head. The nerve testing was first done on the area just posterior to medial malleolus (athlete in supine position), while the second stimulus was done proximally in the region just lateral to midline in the popliteal fossa (athlete in side-lying). The distance between the two stimulation sites was measured using a measuring tape to calculate m NCV of the tibial nerve (Fig. 1). The normal m NCV value of the tibial nerve is in the range of 41-45m/s [27]. The athletes in NDS plus CS group were submitted to neurodynamic mobilisation of the tibial and core stability exercises. The knee was lifted to the point just short of pain or where the first barrier to movement was encountered. After achieving the symptomatic position of the limb, neural mobilisation along with core stability exercises were performed in this group. Neural mobilisation of the tibial nerve was performed as per guidelines and by a qualified physiotherapist [18]. The therapist lifted passively the leg by placing one hand around the Achilles tendon lowered a few degrees down. At this point, ankle dorsiflexion and/or eversion was performed to mobilize the sciatic nerve. This was performed for 5 sets of 30 repetitions with a break of 10 seconds between the sets [18]. A total of 14 sessions on alternate days were performed. The amplitude of technique was increased according to the subject's response. The core stability exercises comprised unilateral piriformis stretching, bilateral quadriceps stretching and lumbosacral stabilisation exercises for 14 sessions on alternate days. The lumbosacral stabilisation exercises comprised abdominal bracing (supine lying athlete was asked to

Figure 1. m NCV testing a) Distal stimulation behind medial malleolus; b) Proximal stimulation in popliteal fossa

brace the abdomen as if trying to hold his navel away from his belt without holding the breath), bridging (with the athlete initially in crook lying position, the athlete raised the buttocks to achieve hip flexion angle to zero degrees), pelvic tilts (with the athlete in quadruped position, lower back sagging and arching was performed rhythmically for 10 seconds), alternate arm/leg raise (with the activated abdominal muscles in quadruped position, athlete raised one arm and the opposite leg and held for 10 seconds and repeated the same with the opposite side). All the stabilisation exercises were performed for 2-3 sets of 10 repetitions each. The stretching exercises (piriformis and quadriceps) were performed for 5 repetitions and held for 20 seconds each time. Athletic exercise routine was progressed according to their symptomatology [20]. The athletes in the CS only group performed the same core stability exercise protocol as performed in NDS plus CS group. This protocol was adapted and given to both groups [20].

Data Analysis

The SPSS version 21.0 software program was used for data analysis (SPSS Inc. Chicago, IL, USA). The Shapiro-Wilk test was used to verify the normality of variables distribution. Descriptive statistics were calculated for all variables and the data was demonstrated as mean $\pm$ standard deviation (SD). Independent t-test was used to compare the continuous data and chi-square test was used for categorical data for measuring baseline criterion readings between the two groups to evaluate their homogeneity. Paired samples t-test (within-group) was used to compare the mean $\pm$ SD of the measurements of pain and m NCV of the tibial nerve between baseline, mid-point follow-up and post-intervention. The assumptions of homogeneity of variance for the two-way ANOVA were checked with Levene's test. Mauchly's test of sphericity was utilised to test the assumption of sphericity with $p < 0.05$ denoting violation of sphericity. Two-way repeated measure ANOVA (analysis of variance) (2×3) was conducted with time (baseline, mid-point follow up, i.e. 7th session, and post-intervention, i.e. 14th session) as within subject factors and group (NDS plus CS and CS only), as between subject factors to examine the effect of interaction on each outcome (pain intensity, m NCV of the tibial nerve). The hypothesis of interest was group, time and group $\times$ time interactions. Effect size was denoted through measures of partial eta squared and defined as small (0.01), moderate (0.06) and large (0.14) [10, 21]. The significance level was set at $p \leq 0.05$ for all tests. Post-hoc tests (pair-wise multiple comparisons) used to determine the significant pair(s) after ANOVA were found significant.

Results

Thirty consecutive athletes with symptoms of low back pain with radiation to the leg were screened as per reported symptoms. Twenty-four male athletes met the criteria, agreed to participate and were randomly allocated to NDS plus CS group ($n = 12$) or CS only group ($n = 12$). None of the subjects reported any adverse event after the interventions. The participants from both groups demonstrated similar demographic characteristics at baseline (Tab. 1). The outcome measures improved significantly during treatment in NDS plus CS group (baseline to 7th session, 7th to 14th session, and overall mean change for pain and m NCV was found to be 4.74 ± 0.37 and -6.43 ± 3.08 , respectively) (Tab. 2). Levene's test for homogeneity revealed $p > 0.05$; therefore, equal variances were assumed for the data. Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, $p = 0.07$ and equal variances were as-

sumed. Two-way repeated measures (2×3) ANOVA was used to analyse the change in the outcome measures and revealed statistically significant main effects for group on pain level ($F(2, 5.34) = 0.89$, $p < 0.001$ and m NCV ($F(2, 5.21) = 0.40$, $p < 0.03$ (Tab. 4). Statistically significant main effects for time on pain level ($F(2, 4.34) = 0.88$, $p < 0.001$ and m NCV ($F(2, 3.89) = 0.91$, $p < 0.001$ were reported. ANOVA also found a significant group $\times$ time interaction effect for pain level ($F(2, 5.11) = 0.78$, $p < 0.001$ and m NCV ($F(2, 4.98) = 0.40$, $p < 0.001$ (Tab. 3, Fig. 2a and 2b). The group effects for pain level were found to be 0.89 (high) and 0.40 (high) for m NCV of the tibial nerve (Tab. 3). Post-hoc test (Bonferroni) was used and it was found to be significant for all the pairwise comparisons (baseline to 7th session, 7th session to 14th session and baseline to 14th session (Tab. 3).

Discussion

The purpose of the present study was to examine the effect of NDM plus CS exercises on pain intensity and m NCV of the tibial nerve in clinically diagnosed university level athletes with LR. The study concluded that NDS plus CS group had a significant improvement in pain and m NCV of the tibial nerve in athletic population over CS only group. All the outcome parameters were measured at baseline, mid-point and after fourteen sessions of the intervention in both groups, and it was found that there was a significant difference in pain levels and m NCV

Table 1. Demographic data of study population

Variables	NDS plus CS Group	CS Group	t-test	p-value
Age (years)	22.25 $\pm$ 3.51	24.83 $\pm$ 4.06	1.665	0.110**
Body weight (kg)	65.94 $\pm$ 7.80	65.68 $\pm$ 5.88	0.883	0.387**
Body height (m)	170.83 $\pm$ 3.56	169.67 $\pm$ 2.87	0.094	0.926**
BMI (kg/m ²)	22.80 $\pm$ 2.16	22.83 $\pm$ 1.72	0.033	0.974**
D.O.S (months)	13.62 $\pm$ 2.2	14.01 $\pm$ 1.72	1.02	0.320**
Sports (A/F/H/V)	3:4:2:3	4:1:4:3	0.05	0.90**

Data is in the form of MEAN $\pm$ SD, SD – standard deviation, BMI – body mass index, D.O.S – duration of symptoms; ** – non-significant $p > 0.05$; A/F/H/V – athletics, football, hockey, volleyball.

Table 2. Comparison of means and mean difference in pain level and m NCV at three time-points

Group/ Variables	Time-points					
	B.L. (a)	7 th sess. (b)	14 th sess. (c)	M.D. (a-b)	M.D. (b-c)	M.D. (a-c)
NDS plus CS Pain (VAS)	6.75 $\pm$ 0.62	4.56 $\pm$ 0.66	2.01 $\pm$ 0.22	2.19 $\pm$ 0.41 ^S	2.55 $\pm$ 0.44 ^S	4.74 $\pm$ 0.37 ^S
m NCV (TN)	38.10 $\pm$ 7.21	41.34 $\pm$ 4.86	44.53 $\pm$ 4.23	-3.24 $\pm$ 1.12	-3.19 $\pm$ 0.92 ^S	-6.43 $\pm$ 3.08 ^S
CS Pain (VAS)	6.58 $\pm$ 0.79	6.02 $\pm$ 1.21	4.95 $\pm$ 0.20	0.56 $\pm$ 0.71 ^{NS}	1.07 $\pm$ 0.11 ^{NS}	1.63 $\pm$ 0.13 ^{NS}
m NCV (TN)	38.92 $\pm$ 6.37	39.21 $\pm$ 4.35	39.17 $\pm$ 5.45	-0.29 $\pm$ 1.76 ^{NS}	0.04 $\pm$ 1.45 ^{NS}	-0.25 $\pm$ 4.15 ^{NS}

Data is in the form of MEAN $\pm$ SD; SD – standard deviation, VAS – visual analogue scale; m NCV – motor nerve conduction velocity; TN – tibial nerve; S – significant $p \leq 0.05$.

Table 3. Summary of repeated measures ANOVA and post hoc

Variables	Main effect (T)			Main effect (G)			Interaction effect (G x T)			Post hoc (Bonferroni)		
	F	p	P.E.S.	F	p	P.E.S.	F	p	P.E.S.	B.L.-7 th sess.	7 th -14 th sess.	B.L.-14 th sess.
Pain (VAS)	4.34	<0.001*	0.88	5.34	<0.001*	0.89	5.11	<0.001*	0.78	0.02 ^s	0.02 ^s	0.01 ^s
m NCV(TN)	3.89	<0.001*	0.91	5.21	<0.030*	0.40	4.98	<0.001*	0.40	0.04 ^s	0.03 ^s	0.02 ^s

VAS – visual analogue scale, m NCV – motor nerve conduction velocity; TN – tibial nerve; * – significant $p \leq 0.05$; P.E.S. – partial eta squared; T – time; G – group.

Figure 2. Interaction plot of pain level (a) and m NCV (b)

in NDM plus CS group in comparison to CS only group. Repeated measures ANOVA also demonstrated significant group, time and group x time interaction effects for both pain and m NCV outcome measures. In concordance to our findings, previous literature pointed out that combined neural mobilisation and exercise of the median nerve helped to avoid the surgical intervention and the improved results (pain and m NCV) were maintained for over 6 months with conservative management [15, 28]. In continuation, a study performed on healthy adults also revealed an increase in m NCV of the tibial nerve after the neural mobilisation procedure [14]. In contrast, there are studies which have reported that the addition of NDM to motor control exercises does not significantly improve pain and disability in LR patients [29]. There are two plausible physiological rationales for the results which can be elucidated from the literature review. Firstly, pain reduction might have occurred due to the improved stabilisation of the lumbopelvic region owing to core exercises when combined with neural mobilisation. The improved stabilisation helped to decrease and optimise the neutral zone range which ultimately allowed extremity movement on a more stable axial background. This optimised neutral zone motion decreases the unnecessary overstimulation of the mechanoreceptors and/or pain sensitive capsuloligamentous structures, thereby decreasing pain intensity [19, 30]. Secondly, NDM has been reported to regulate and correct the hypersensitive and chemosensitive AIGS (abnormal impulse generating site) zone, when the therapist does a scientifically selected passive oscillatory movement in pain free zone. AIGS are present on the axonal surface of the nerve fibres. This movement also

decreases the reflex inhibition in movements by decreasing intraneural, perineural edema and alteration in sodium ion channels [31, 32]. Cadaveric studies have also been performed with NDM (repetitive SLR, 30 reps per min for five minutes). Initial longitudinal dye was injected by the researchers at L4 nerve root level and post-mobilisation dispersion of the fluid was seen. The study concluded that NDM promotes nerve function by limiting and altering intraneural fluid accumulation. The results of the above mentioned study are in congruence with our study results and also help to physiologically rationalise our results [33]. There are a number of strengths of this study. Firstly, it is amongst the few initial studies that have examined the effect of NDM plus CS on athletic population suffering from chronic LR. Secondly, the sample size was adequate. Thirdly, it gives the clinicians another conservative management option in chronic recalcitrant cases with no reported adverse effects. The limitation of the study is that we did not do long term follow-up of the athletes which could have revealed the long-term stability of our results and, secondly, we restricted our sample to L4-S1 level LR only. Future studies can target longer interventions of around 12 weeks and do follow-up and then examine the temporal stability of the results and take LR of L1-L3 level as well.

Conclusions

The findings of the study revealed that NDS plus CS exercises were effective in significantly improving pain intensity and m NCV of the tibial nerve in athletes with LR when compared with CS alone. The NDS plus CS exercise is a safe, effective and conservative method of managing return to sports in chronic athletic LR cases.

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References

1. Koes B.W., Van Tulder M.W., Peul W.C. (2007). Diagnosis and treatment of sciatica. *BMJ* 334(7607), 1313-1317.
2. Atlas S., Keller R., Wu Y., Deyo R., Singer D. (2005). Long-Term outcomes of surgical and nonsurgical management of sciatica secondary to a lumbar disc herniation: 10 year results from the maine lumbar spine study. *Spine* 30(8), 927-935. DOI: 10.1097/01.brs.0000158954.68522.2a.
3. Awad J.N., Moskovich R. (2006). Lumbar disc herniations: surgical versus nonsurgical treatment. *Clinical Orthopaedics and Related Research* 443, 183-197. DOI: 10.1097/01.blo.0000198724.54891.3a.
4. Hangai M., Kaneoka K., Hinotsu S., Shimizu K. et al. (2009). Lumbar intervertebral disk degeneration in athletes. *The American Journal of Sports Medicine* 37(1), 149-155.
5. Hay S.I., Jayaraman S.P., Truelsen T., Sorensen R.J., Milliar A. et al. (2017). GBD 2015 disease and injury incidence and

- prevalence collaborators. Global, regional, and national incidence, prevalence, and years lived with disability for 310 diseases and injuries, 1990-2015: A systematic analysis for the global burden of disease study. *Lancet* 389(10064), 388-389. DOI: 10.1016/S0140-6736(17)32154-2.
6. Berry J.A., Elia C., Saini H.S., Miulli D.E. (2019). A review of lumbar radiculopathy, diagnosis, and treatment. *Cureus* 11(10). DOI: 10.7759/cureus.5934.
 7. Fett D., Trompeter K., Platen P. (2017). Back pain in elite sports: a cross-sectional study on III4 athletes. *PloS One* 12(6), 35-48. DOI: 10.1371/journal.pone.0180130.
 8. Stochkendahl M.J., Kjaer P., Hartvigsen J., Kongsted A., Aaboe J. et al. (2018). National Clinical Guidelines for non-surgical treatment of patients with recent onset low back pain or lumbar radiculopathy. *European Spine Journal* 27(1), 60-75. DOI: 10.1007/s00586-017-5099-2.
 9. Gray B.L., Buchowski J.M., Bumpass D.B., Lehman Jr R.A., Mall N.A., Matava, M.J., (2013). Disc herniations in the national football league. *Spine* 38(22), 1934-1938. DOI: 10.1097/brs.0b013e3182a67678.
 10. Guten G. (1981). Herniated lumbar disk associated with running: a review of 10 cases. *The American Journal of Sports Medicine* 9(3), 155-159. DOI: 10.1177/036354658100900305.
 11. Weber H. (1994). The natural history of disc herniation and the influence of intervention. *Spine*, 19(19), 2234-2238.
 12. Galardi G., Amadio S., Maderna L., Meraviglia M.V., Brunati L. et al. (1994). Electrophysiologic studies in tarsal tunnel syndrome. Diagnostic reliability of motor distal latency, mixed nerve and sensory nerve conduction studies. *American Journal of Physical Medicine & Rehabilitation* 73(3), 193-198.
 13. Coulter I.D., Crawford C., Hurwitz E.L., Vernon H., Khorasan R. et al. (2018). Manipulation and mobilization for treating chronic low back pain: a systematic review and meta-analysis. *Spine Journal* 18(5), 866-879. DOI:10.1016/j.spinee.2018.01.013.
 14. Allegri M., Montella S., Salici F., Valente A., Marchesini M. et al. (2016). Mechanisms of low back pain: a guide for diagnosis and therapy. *F1000Research* 5, 1530. DOI:10.12688/f1000research.8105.1.
 15. Goyal M., Mehta S.K., Rana N., Singal R., Mittal A. et al. (2016). Motor nerve conduction velocity and function in carpal tunnel syndrome following neural mobilization: A randomized clinical trial. *International Journal of Health & Allied Sciences* 5(2), 104-10.
 16. Jung J.H., Moon D.C. (2020). The effect of neurodynamic technique of tibial nerve on range of motion, pain, and mechanosensitivity of the lower extremity in healthy individuals: A preliminary study. *Journal of Human Sport and Exercise*. DOI: 10.14198/jhse.2021.164.17.
 17. Butler D.S. (2005). *The neurodynamic techniques: a definitive guide from the Noigroup team*. Adelaide City West, S. Australia: Noigroup Publications.
 18. Coppieters M.W., Butler D.S. (2008). Do 'sliders' slide and 'tensioners' tension? An analysis of neurodynamic techniques and considerations regarding their application. *Manual Therapy* 13(3), 213-221. DOI: 10.1016/j.math.2006.12.008.
 19. McGill S. (1998). Low Back Exercises: Evidence for Improving Exercise Regimens. *Physical Therapy* 78(7), 754-765. DOI:10.1093/ptj/78.7.754.
 20. Cleland J., Hunt G.C., Palmer J. (2004). Effectiveness of neural mobilization in the treatment of a patient with lower extremity neurogenic pain: a single-case design. *Journal of Manual & Manipulative Therapy* 12(3), 143-152.
 21. Basson A., Olivier B., Ellis R., Coppieters M., Stewart A., Mudzi W. (2017). The effectiveness of neural mobilization for neuromusculoskeletal conditions: a systematic review and meta-analysis. *Journal of Orthopaedic & Sports Physical Therapy* 47(9), 593-615. DOI: 10.2519/jospt.2017.7117.
 22. Childs J.D., Piva S.R., Fritz J.M. (2005). Responsiveness of the numeric pain rating scale in patients with low back pain. *Spine* 30(11), 1331-1334.
 23. Luijsterburg P.A., Verhagen A.P., Ostelo R.W., van Os, T.A., Peul W.C., Koes B.W. (2007). Effectiveness of conservative treatments for the lumbosacral radicular syndrome: a systematic review. *European Spine Journal* 16(7), 881-899. DOI: 10.1007/s00586-007-0367-1.
 24. Marfell-Jones M.J., Stewart A.D., De Ridder J.H. (2012). *International standards for anthropometric assessment*. Wellington, New Zealand: International Society for the Advancement of Kinanthropometry.
 25. Langley G.B., Sheppeard H. (1985). The visual analogue scale: its use in pain measurement. *Rheumatology International* 5(4), 145-148.
 26. Mallik A., Weir A. (2005). Nerve conduction studies: essentials and pitfalls in practice. *Journal of Neurology, Neurosurgery and Psychiatry* 76(suppl 2), 23-31. DOI: 10.1136/jnnp.2005.069138.
 27. Kimura J. (1984). Principles and pitfalls of nerve conduction studies. *Annals of Neurology: Official Journal of the American Neurological Association and the Child Neurology Society* 16(4), 415-429.
 28. Hamzeh H., Madi M., Alghwiri A.A., Hawamdeh Z. (2020). The long-term effect of neurodynamics vs exercise therapy on pain and function in people with carpal tunnel syndrome: A randomized parallel-group clinical trial. *Journal of Hand Therapy* 1130(20), 30144-7. DOI: 10.1016/j.jht.2020.07.005.
 29. Plaza-Manzano G., Cancela-Cilleruelo I., Fernández-De-Las-Penás C., Cleland J.A., Arias-Burúa J.L. et al. (2020). Effects of adding a neurodynamic mobilization to motor control training in patients with lumbar radiculopathy due to disc herniation: a randomized clinical trial. *American Journal of Physical Medicine & Rehabilitation* 99(2), 124-132. DOI: 10.1097/PHM.0000000000001295.
 30. Panjabi M., White A. (2001). *Biomechanics in the musculoskeletal system*. New York: Churchill Livingstone.
 31. Kobayashi S., Yoshizawa H., Yamada S. (2004). Pathology of lumbar nerve root compression Part I: Intraradicular inflammatory changes induced by mechanical compression. *Journal of Orthopaedic Research* 22(1), 170-179. DOI:10.1016/s0736-0266(03)00131-1.
 32. Brown C.L., Gilbert K.K., Brismee J.M., Sizer P.S., Roger James C., Smith M.P. (2011). The effects of neurodynamic mobilization on fluid dispersion within the tibial nerve at the ankle: an unembalmed cadaveric study. *The Journal of Manual & Manipulative Therapy* 19(1), 26-34. DOI: 10.1179/2042618610Y.0000000003.
 33. Gilbert K.K., Smith M.P., Sobczak S., James C.R., Sizer P.S., Brismee J.M. (2015). Effects of lower limb neurodynamic mobilization on intraneural fluid dispersion of the fourth lumbar nerve root: an unembalmed cadaveric investigation. *The Journal of Manual & Manipulative Therapy* 23(5), 239-24.

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