Analysing the Effects of Neuro-dynamics in Carpal Tunnel Syndrome in Pain and Disability: A Randomized Control Trial

Kuliyal Aditi[1], Jha K Manish[2], Agarwal Vaibhav[3], Nikku Yadav[4*]

[1]PG Scholar, Neurology, Department of Physiotherapy, Himalayan Institute of Medical Sciences, Swami Rama Himalayan University, Dehradun
[2]Assistant Lecturer, Department of Physiotherapy, Himalayan Institute of Medical Sciences, Swami Rama Himalayan University, Dehradun
[3]Lecturer, MPT (Neurology), Department of Physiotherapy, Himalayan Institute of Medical Sciences, Swami Rama Himalayan University, Dehradun
[4]Assistant Professor, Clinical Research, Department of Community Medicine Himalayan Institute of Medical Sciences, Swami Rama Himalayan University, Dehradun

***Corresponding Author**: Nikku Yadav

KEYWORDS

Carpal Tunnel Syndrome, Neurodynamics, Pain and disability, Exercises

ABSTRACT

INTRODUCTION: A peripheral neuropathy, Carpal tunnel syndrome (CTS) is chronic progressive disorder that leads to pain and disability in individuals hindering their day-to-day activities. The main symptoms include pain, numbness, tingling over median nerve distribution area. It effects majority of the population with the females being more prone to the condition than men are. Risk factors include ecological, extrinsic, intrinsic and neuropathic factors. There have been various treatment approaches for the carpal tunnel syndrome, which have been discovered in the past few years, but still a proper or peculiar approach needs to be designed. **METHODOLOGY:** 30 subjects screened for the inclusion and exclusion criteria. Randomization of subjects in control and experimental group, implemented. No subject left the study in between. Outcome measures including NPRS, BCTSQ and EROM (Extension) were assessed pre intervention. Control group received general (home) exercises while experimental group received static opener, one ended, two ended sliders and four levels tensioners (Neurodynamics) with home (general) exercises for 5 days. Afterwards, NPRS and EROM (Extension) assessed and at 2 weeks follow up NPRS and BCTSQ were taken. **RESULTS:** The data acquired from 30 individuals, irrespective of side involved and data analysis carried out. The outcome measure indicated significant improvement in both the groups after intervention and at 2 weeks follow up. Overall, when both the groups were compared the implication of neurodynamics with home (general) exercises were found to be more beneficial over control group which received home (general exercises) in NPRS (p-value – 0.36**, <0.01) , SSS (p-value- 0.001*, right side), FSS (0.079**) while control group remained significant in SSS (p-value – 0.319**) at two weeks follow up. In post group intervention comparison, Elbow extension ROM implicated superiority to neurodynamics group in right side (p –value – 0.65**) over left side (p-value – 0.907**). **CONCLUSION:** Neurodynamics with (home) general exercises found to be more beneficial over (home) general exercises in improving pain and disability in subjects with mild to moderate CTS patient. To add, this approach reduces the chances to undergo surgery for the CTS.

INTRODUCTION

Carpal tunnel syndrome (CTS) is a prevalent peripheral neuropathy that affects the median nerve, leading to symptoms such as numbness and tingling, primarily in the thumb, index, middle, and the radial side of the ring finger. Additionally, it can cause motor weakness beyond the wrist, resulting in reduced grip strength and impaired hand function..[1,2,3]

Approximately 2.7% of the general population and up to 7.8% of individuals engaged in repetitive hand movements experience median nerve entrapment within the carpal tunnel. This condition is most commonly observed in individuals aged 40 to 60 years, with a higher prevalence in females (9.2%) compared to males (6%). Patients often report symptoms such as aching, a sensation of itchiness, and numbness in the hands, which are indicative of carpal tunnel syndrome (CTS).[4,5]

Risk factors include diabetes, pregnancy, lipoma; obesity arthritis etc., among these most affected populations is of diabetes patients (30%).[6]

Carpal tunnel syndrome (CTS) is categorized into mild, moderate, and severe stages, diagnosed through characteristic symptoms, physical examination, and electrodiagnostic studies.[7] Due to its rising prevalence, CTS places a significant financial strain on healthcare systems, requiring both conservative treatments and surgical interventions for management.[8,9]

Various treatment strategies are there for CTS but the newest to the addition is Neurodynamics.[10] It is an integrated approach, which focuses on mechanical interface and neural structures to improve nerve mobility and elasticity.[11]There, is lack of evidence regarding the effectiveness of neurodynamics on CTS. Hence, there is need to set a peculiar protocol for the same for pain and disability with high quality evidences and most of the evidences are of low level.[12, 13]

ANATOMY[14]

The carpal tunnel is formed by the flexor retinaculum over the carpal bone on ventral surface of the wrist joint.

Flexor Retinaculum is a strong fibrous band bridging the anterior concave part of the wrist joint over the carpal bones forming a carpal tunnel, to form flexor retinaculum deep fascia modifies and form into it.

This retinaculum attaches medially to the pisiform bone, hook of hamate, tubercle of the scaphoid, crest of the trapezium and on the other side it divides into two slips - the medial (deep) and lateral (superficial) slip. The deep slip is laterally placed and attaches to the medial lip of the groove on the trapezium whereas the superficial slip or volar carpal ligament attaches on the pisiform bone.

The Median Nerve (C6-T1) is a peripheral nerve that arises from the medial and lateral cord of the brachial plexus. The median nerve supplies the skin over the lateral two thirds of the palm and the area over the thenar eminence through its palmar cutaneous branch (C6-C8), and through its palmar digital branches (C6-C8) it supplies lateral and medial side of the thumb and the lateral side of the index finger. The other digital branches of median nerve supplies the lateral 3 and a half digits, the nail beds of palmar skin. The same also supply the skin on the dorsal aspect of these digits and the distal phalanges.

PATHOPHYSIOLOGY[15]

Carpal tunnel syndrome (CTS) is the median nerve compression neuropathy, which is caused by various factors. The pathophysiology of CTS includes Idiopathic causes, Mechanical factors, biochemical changes in synovial tissue, and morphological changes in synovial tissue. Metabolic factors such as Diabetes, Pregnancy, Hyperthyroidism, Amyloid Deposition also causes Secondary CTS. Trigger digit can also give its contribution to cause CTS. The pathophysiology of CTS also includes Double crush Hypothesis.

Incompatibility between the contents of the carpal tunnel and the median nerve leading to the increased pressure within the carpal tunnel causing hindrance in the blood flow to the median nerve is one of the reason for the CTS to occur.

Flexor tendons and CTS, wear and tear of the flexor tendons causes strain and micro damages to the surrounding structures of the median nerve resulting the development of subsequent CTS.

Morphological and Biochemical changes, increase in fibroblast density, vascular proliferation and mechanical stresses in the synovial tissue inside the carpal tunnel causes major alterations to the tissue. As the result of the same, CTS begins to occur.

It has been seen that there the people with diabetes and pregnant women are more prone to have CTS as of metabolic changes and needs significant attention. There is a high prevalence of CTS in patients with diabetes, which has been estimated to be at 30% of the CTS cases. Pregnant women and those in labor have high chances of developing CTS. It has been observed the women may be diagnosed with CTS up to 3 years after the delivery.

Ganglions, wrist fractures and/or dislocations,lunatomalacia or synovial cysts results in increased pressure in the carpal tunnel leading to CTS.

Approximately 20% of patients has trigger digit as the cause of CTS mainly due to the tendon mechanism alternation.

One of the most important cause can be understood under the heading of Double Crush Hypothesis, which implies that proximal neuropathy can also cause CTS. Proximal limb ischemia cause nerve infarction leading to CTS.[17]

RISK FACTORS [5,6]

Risk factors of CTS depends upon various factors,

(1) Extrinsic Factors (either the contour of the tunnel changes or there is increase in the volume of the tunnel internally on the both sides of the nerve)
(2) Intrinsic factor (the volume of the tunnel increases from inside) and,
(3) Neuropathic factor, which involves metabolic misbalances.
(4) Ecological risk factors (frequent use of flexor muscles, excessive flexion and flexion)

Above mentioned factors affects the median nerve and the most common risk factors are as follows- Fluid Equilibrium inside the body, pregnancy, hyperthyroidism, menopause, obesity, congestive heart failure (CHF), Fractures of the distal radius , lumps or tumours with the tunnel, kidney failure, diabetes, alcoholism, vitamin deficiency or toxicity , exposure to toxins , rheumatoid arthritis, use of oral contraceptive pills.

STAGES OF THE CARPAL TUNNEL SYNDROME [15]

The first stage of carpal tunnel syndrome presents with no actual swelling visible, night awakenings with feeling of swollen or numb hand, patient may experience pain in the wrist radiating up to the shoulder with tingling in hand and fingers (brachialgia paresthethica nocturna). This is accompanied with the morning stiffness of hand.

In the second stage, symptoms may be felt during the day. The repeated hand movements or static positioning of the hand triggers the symptoms with decreased grip.

The final stage or the third stage of the disease presents with the hypertrophy or atrophy of the thenar muscles along with the no sensory symptoms to be felt**.**

DIAGNOSIS[16]

The basis of diagnosis of CTS is patient's physical or clinical findings which involves taking detailed description of patient's present history and the presentation of the signs and symptoms which are likely to be tingling and numbness. Generally, one should consider the bilateral CTS first than that of the Unilateral CTS. Different stages of CTS present with different signs and symptoms and one should look precisely for the same. Tingling sensation and numbness in median nerve distribution area is also considered to be a positive sign for CTS. Number of tests, according to the known sensitivity and specificity of them are performed to confirm CTS. Tests, which are performed to confirm CTS, are Phalen's test, Tinel's sign, Carpal compression test, Hand elevation test and Upper limb tension test for median nerve[10]. These tests must be performed with the utmost perfection and the results should be assessed carefully.

Other than this, Questionnaire such as Boston carpal tunnel Questionnaire (BCTSQ) which is consist of two scales – Functional Status Scale (FSS) and Symptom Severity Scale (SSS), used to identify the functional status and symptom severity associated with the CTS.[2]

TREATMENT APPROACHES

In a systemic review conducted by Ballestero-Pérez et al, published in 2017, the authors included 13 researches and compared neurodynamics exercises with other treatments available. Soft tissue mobilization, Paraffin wax, Ultrasound therapy, Wrist splint, Tendon and Nerve

gliding exercises , Carpal bone Mobilization , Steroid injections etc,. are the other treatment approaches which were seen to be compared against Neurodynamics.[18]

B.M. Huisstede et al,., In 2017 conducted a review of Randomized controlled trials done over the period of time in CTS. In this study more treatment approaches came in the limelight producing a significant improvement with the condition such as Short Wave Diathermy (SWD), Transcutaneous Electrical Stimulation(TENS), Magnetic field therapy, Heat wrap Therapy, etc,.[19]

Surgical approaches, Open carpal tunnel release and Endoscopic carpal tunnel release has also been described in various researches citing that if the conservative management fails, it works.[16]

METHODOLOGY

Study design: Randomized control trial

Participants:

30 patients screened and diagnosed with CTS were recruited from physiotherapy OPD, Himalayan hospital, Swami Rama Himalayan University, Jolly grant based on Inclusion and Exclusion criteria.

The inclusion criteria include obtaining patient consent, age over 18 years, presence of pain and paresthesia in the median nerve distribution, a positive Phalen's maneuver, a positive carpal compression test, the presence of Flick's sign, a positive Upper Limb Tension Test (ULTT) for the median nerve, a nerve conduction velocity of less than 50 m/s, and increased motor latency exceeding 4 m/s.

The exclusion criteria include the absence of patient consent or cooperation, a history of upper limb surgery or trauma, significant thenar muscle atrophy, metabolic conditions such as diabetes, pregnancy, severe thyroid disorders, and prior steroid injections in the carpal tunnel.

Outcome variables

The outcome variables taken in the study were Boston Carpal Tunnel Syndrome Questionnaire (BCTSQ), Numerical Pain Rating Scale (NPRS), and Elbow extension Range of motion (EROM) .These variables taken at different intervals during the study.

Procedure

The subjects were provided with the detailed explanation of the purpose of the study and the procedure to be performed before being screened for the study.

A detailed history of present illness, different diagnostic tests were performed and NCS were obtained from the patient to confirm the diagnosis in order to proceed further with the research. Based on the inclusion and exclusion criteria the subjects were included in the study and divided into two groups:

The first group is Experimental group (Neurodynamics + General {Home} exercises) and the other one is Control group (General {Home} exercises).

Patient's demographic and contact details were obtained. BCTSQ, NPRS and Elbow ROM in ULTT (Median Nerve) position taken in both groups for pretest evaluation. Total 30 minutes of intervention given to both the groups in every setting.

Experimental Group

The intervention was administered to patients in an upright sitting position. It involved a total of 10 repetitions per set, with three sets performed daily for five days, allowing a 10-second rest between sets. The session began with the static opener and concluded with the tensioner, either conducted by the therapist or performed under their supervision. Additionally, patients were provided with a general home exercise protocol, identical to the control group, to be followed independently. On the first day, they completed one supervised session of these general exercises.

General (home) exercises were as followed: [20]

Active range of motion exercises of wrist joint (Flexion/ Extension, Abduction/Adduction, Radial/Ulnar Deviation)

Wrist Stretches (Flexion and Extension stretches)

Tendon gliding exercises (Hook, Tabletop, Half fist, and Full fist)
Active resisted exercises of wrist joint
Median Nerve gliding exercises
Transverse friction massage (soft tissue manipulation) with lymphatic drainage.
Both the groups were advised for the hot fomentation (15 minutes) prior to the starting of these exercises, ergonomics and splinting advised

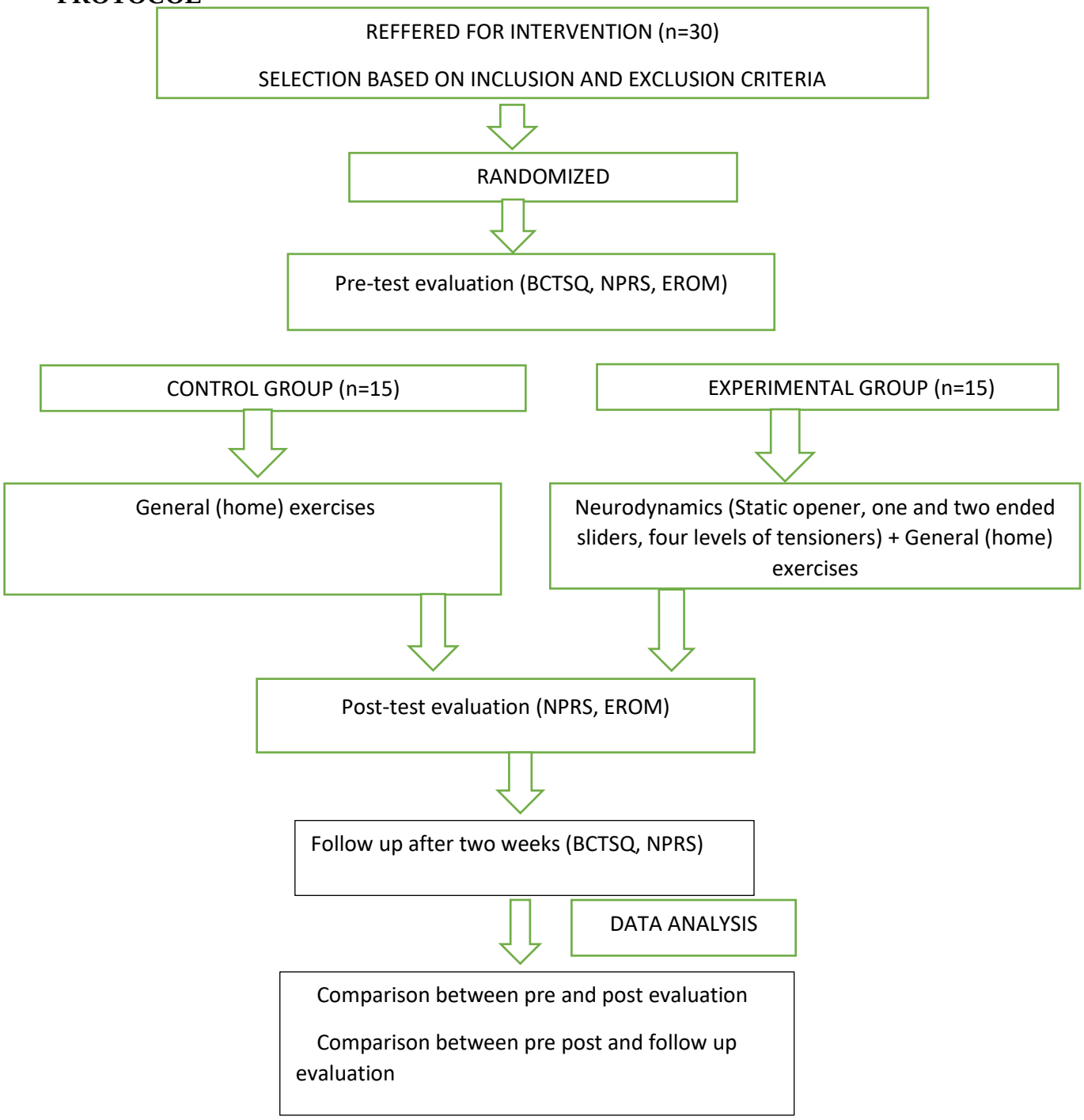
Control Group

Patients performed general exercises under the therapist's supervision in a single session, including active range of motion exercises, tendon and nerve gliding exercises, wrist flexion and extension stretches, soft tissue manipulation, and lymphatic drainage. These exercises were prescribed at a dosage of 10 repetitions per set, three times daily for two weeks. Following the session, patients received ergonomic guidance. A post-test evaluation was conducted for both groups, assessing NPRS scores and elbow extension range of motion in the ULTT position.
After two weeks, follow up was taken over telephone or in person (Telecommunication). The outcome variables (NPRS and BCTSQ) were assessed in both the groups.

Fig 1.One- ended slider

Fig 2. Soft tissue manipulation

PROTOCOL


REFFERED FOR INTERVENTION (n=30)
SELECTION BASED ON INCLUSION AND EXCLUSION CRITERIA
RANDOMIZED
Pre-test evaluation (BCTSQ, NPRS, EROM)
CONTROL GROUP (n=15)
EXPERIMENTAL GROUP (n=15)
General (home) exercises
Neurodynamics (Static opener, one and two ended sliders, four levels of tensioners) + General (home) exercises
Post-test evaluation (NPRS, EROM)
Follow up after two weeks (BCTSQ, NPRS)
DATA ANALYSIS
Comparison between pre and post evaluation
Comparison between pre post and follow up evaluation

Data Analysis

Data analysis performed on IBM SPSS software version 20. If $p > 0.05$, than the hypothesis is said to be significant and if $p < 0.05$, than hypothesis is said to be statistically insignificant.

Results

For both right and left side, comparison between pre- post interventions was performed and values for NPRS and Elbow extension range of motion obtained. At 2 weeks follow up, a comparison between post – follow up results of NPRS and BCTSQ components were done and the values were obtained.

The below mentioned tables 1 and 2 support the comparison results in both control and experimental groups.

Table 1. Within group descriptive statistics and comparison for control and experimental group (Right side)

Outcome measure	Group	Pre intervention	Post intervention	Follow up at 2weeks	Difference after the intervention	Difference at 2 weeks	p-value (pre-post)	p-value (post-follow-up)
NPRS	CONTROL median (SD)	6 (1.41)	5.73 (1.44)	4(1.18)	0.27	1.86	.046*	<0.01
	EXPERIMENTAL mean SD	5.50 (1.74)	2.57 (1.08)	1.36 (0.49)	2.93	1.21	<0.001	<0.01
SSS	CONTROL mean (SD)	23.4 (8.18)	------	19.47 (7.86)	-----	3.39	-----	<0.01
	EXPERIMENTAL mean (SD)	18.21(5.82)	------	12(1.6)	------	6.21	-----	<0.01
FSS	CONTROL Median (SD)	13 (4.54)	-------	11(3.58)	------	2.47	-----	<0.01
	EXPERIMENTAL mean(SD)	11.21 (3.06)	------	8.50 (2.09)	------	2.71	-----	.002
E.ROM	CONTROL mean (SD)	110.87 (15.48)	112.67 (14.09)	-------	-1.8	-----	.022	-----
	EXPERIMENTAL mean (SD)	112.29 (9.49)	125.57 (4.7)	------	-13.28	-----	.007	------

*Wilcoxon Signed Ranks Test

Table 2. Within group descriptive statistics and comparison for control and experimental group (Left side)

Outcome measure	Group	Pre intervention	Post intervention	Follow up at 2weeks	Difference after the intervention	Difference at 2 weeks	p-value (Pre-post)	p-value (post-follow-up)
NPRS	CONTROL mean (SD)	4.63 (2.26)	4.50 (2.20)	3.00 (1.77)	0.13	1.5	.351	.001
	EXPERIMENTAL mean (SD)	5.60 (1.34)	1.80(0.83)	1.20 (0.44)	3.8	0.6	.001	.305
SSS	CONTROL mean (SD)	20.13 (11.83)	------	17.63 (10.25)	-----	2.5	-----	0.11
	EXPERIMENTAL mean (SD)	18.80 (6.22)	------	11.60 (0.89)	------	7.2	------	0.40
FSS	CONTROL mean (SD)	12.00 (4.03)	-------	10.38 (2.50)	------	1.62	-------	0.24
	EXPERIMENTAL mean(SD)	12.80 (5.02)	------	8.20 (0.45)	---------	4.6	-------	0.98
E.ROM	CONTROL Median (SD)	125(15.12)	125 (15.12)	---------	0.00	-------	1.000*	------
	EXPERIMENTAL Mean (SD)	109.40 (12.89)	122.25 (6.89)	----------	-12.85	---------	0.19	------

*Wilcoxon Signed Ranks Test

The below mentioned table 3 supports the results of comparison of outcome variables in both the groups,

Table 3. Between group comparison for control and experimental group

Outcome measure		Control group (Mean ± S.D)	Experimental group (Mean ± S.D)	p-value (post – post)	p-value (post-follow up)
NPRS (Left)	Post	4.50 ± 2.20	1.80 ± 0.83	0.025	0.36**
	Follow up	3.00±1.77	1.20±0.44		
E.ROM (Left)		125±15.12	122.25±6.89	0.907**	--------
NPRS (Right)	Post	5.73±1.44	2.57±1.08	<0.01	<0.01
	Follow up	4 ± 1.18	1.36 ± 0.49		
E.ROM (right)		112.67±14.09	125.57±4.7	.065**	--------

**Mann Whitney Test

DISCUSSION

Carpal tunnel syndrome (CTS), a median nerve neuropathy characterised by tingling sensation, numbness over the median nerve distribution area. It happens to be more in females than in males. Although, it is idiopathic but risk factors include various factors such as metabolic, extrinsic, intrinsic and ecological factors leading to the compression of the nerve. There are

three stages of CTS and presenting sign and symptoms duly depends on these stages. Symptoms provocation while performing the diagnosis test is indicative of the median nerve compression at carpal tunnel but one should not rely on that and further investigations are must. The study conducted analysed the effects of neurodynamics in carpal tunnel syndrome in pain and disability and it revealed that neurodynamics with general exercises provide good results in carpal tunnel patients in terms of outcome variables.

The present study suggested that both neurodynamics with general exercises and general exercise alone were beneficial in reducing NPRS overall, irrespective of side involved after post intervention and at 2 weeks follow up. Although, the pain reduced significantly in both groups but neurodynamics wins the matter as a whole.

Elbow extension range of motion in subjects with CTS found to be deliberately reduced pre-intervention as patient's complaints of excessive pain or stretch beyond a certain limit of extension. The post intervention results completely supported neurodynamics over control group, which only depicted marginal improvement in extension.

NPRS, a unidimensional 11 point scale which measures of pain intensity in adults, it is somehow similar to Visual Analogue Scale (VAS).This scale interprets pain in the form of numbers , 0= no pain , 10 = worst pain imaginable. It is highly reliable, valid and acceptable with both literate and illiterate patients.[21]

BCTSQ, an outcome measure that is valid, reliable and widely accepted which is evidence based [2, 22, 23] scale was used in this study which quantifies about the symptom severity and functional status in the patient. The components of BCTSQ, SSS and FSS showed significant improvement at 2 weeks follow up for both hands. The overall results attained in FSS and SSS might differ for both the hands, slightly yet the results are more in favour of neurodynamics over control group intervention.

CONCLUSION

Neurodynamics is an interdisciplinary approach that, when combined with a structured home-based general exercise program, has been shown to be highly effective in reducing pain and disability in individuals with mild to moderate carpal tunnel syndrome (CTS). This approach enhances nerve mobility and function, addressing the underlying mechanical and physiological restrictions affecting the median nerve. Patients undergoing this intervention perform exercises such as active range of motion movements, tendon and nerve gliding exercises, wrist flexion and extension stretches, soft tissue manipulation, and lymphatic drainage. These are performed under supervision initially and then continued independently at home. The prescribed regimen includes 10 repetitions per set, three times daily for two weeks, along with ergonomic guidance. Research suggests that incorporating neurodynamic techniques alongside home exercises yields superior results compared to general exercises alone. Additionally, this conservative treatment strategy may help reduce the necessity for surgical intervention in CTS patients, promoting long-term functional recovery.

REFRENCES

1. Oskouei AE, Talebi GA, Shakouri SK, Ghabili K. Effects of neuromobilization maneuver on clinical and electrophysiological measures of patients with carpal tunnel syndrome. Journal of physical therapy science. 2014;26(7):1017-22.
2. Hamzeh H, Madi M, Alghwiri AA, Hawamdeh Z. 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. 2021 Oct 1;34(4):521-30.
3. Izadi S, Kardeh B, Hooshiar S, Neydavoodi M, Borhani-Haghighi A. Correlation of clinical grading, physical tests and nerve conduction study in carpal tunnel syndrome. *Scandinavian Journal of Pain*. 2018;18(3): 345-350.
4. Ibrahim I, Khan WS, Goddard N, Smitham P. Suppl 1: carpal tunnel syndrome: a review of the recent literature. The open orthopaedics journal. 2012;6:69.
5. Genova A, Dix O, Saefan A, Thakur M, Hassan A. Carpal tunnel syndrome: a review of literature. Cureus. 2020 Mar 19;12(3).

6. Wipperman J, Goerl K. Carpal tunnel syndrome: diagnosis and management. American family physician. 2016 Dec 15;94(12):993-9.
7. Burton C, Chesterton LS, Davenport G. Diagnosing and managing carpal tunnel syndrome in primary care. British Journal of General Practice. 2014 May 1;64(622):262-3.
8. Bebbington E, Furniss D. Linear regression analysis of hospital episode statistics predicts a large increase in demand for elective hand surgery in England. J Plast Reconstr Aesthet Surg 2015;68:243–51
9. Wolny T. The Use of Neurodynamic Techniques in the Conservative Treatment of Carpal Tunnel Syndrome-a Critical Appraisal of the Literature. Ortopedia, Traumatologia, Rehabilitacja. 2017 Oct 1;19(5):427-40.
10. Ostergaard PJ, Meyer MA, Earp BE. Non-operative Treatment of Carpal Tunnel Syndrome. Curr Rev Musculoskelet Med. 2020 Apr;13(2):141-147.
11. Shacklock M. Clinical neurodynamics: a new system of neuromusculoskeletal treatment. Elsevier Health Sciences; 2005 May 6.
12. Erickson M, Lawrence M, Jansen CW, Coker D, Amadio P, Cleary C, Altman R, Beattie P, Boeglin E, Dewitt J, Detullio L. Hand pain and sensory deficits: Carpal tunnel syndrome: Clinical practice guidelines linked to the international classification of functioning, disability and health from the academy of hand and upper extremity physical therapy and the academy of orthopaedic physical therapy of the American physical therapy association. Journal of Orthopaedic & Sports Physical Therapy. 2019 May;49(5):CPG1-85.
13. Page MJ, O'Connor D, Pitt V, Massy-Westropp N. Exercise and mobilisation interventions for carpal tunnel syndrome. Cochrane Database of Systematic Reviews 2012, Issue 6.
14. Chaurasia, B. D. "Upper limb and thorax." *BD Chaurasia's Human Anatomy: Regional and Applied Dissection and Clinical* 1.
15. Ghasemi-rad M, Nosair E, Vegh A, Mohammadi A, Akkad A, Lesha E, Mohammadi MH, Sayed D, Davarian A, Maleki-Miyandoab T, Hasan A. A handy review of carpal tunnel syndrome: From anatomy to diagnosis and treatment. *World J Radiol* 2014; 6(6): 284-300 [PMID: 24976931 DOI: 10.4329/wjr.v6.i6.284]
16. Uchiyama, S., Itsubo, T., Nakamura, K., Kato, H., Yasutomi, T., & Momose, T. (2010). Current concepts of carpal tunnel syndrome: pathophysiology, treatment, and evaluation. *Journal of Orthopaedic Science*, *15*(1), 1-13.
17. Werner, Robert A., and Michael Andary. "Carpal tunnel syndrome: pathophysiology and clinical neurophysiology." *Clinical Neurophysiology* 113.9 (2002): 1373-1381.
18. Ballestero-Pérez, R., Plaza-Manzano, G., Urraca-Gesto, A., Romo-Romo, F., de los Ángeles Atín-Arratibel, M., Pecos-Martín, D & Romero-Franco, N. (2017). Effectiveness of nerve gliding exercises on carpal tunnel syndrome: a systematic review. *Journal of manipulative and physiological therapeutics*, *40*(1), 50-59.
19. Huisstede, B. M., Hoogvliet, P., Franke, T. P., Randsdorp, M. S., & Koes, B. W. (2018). Carpal tunnel syndrome: effectiveness of physical therapy and electrophysical modalities. An updated systematic review of randomized controlled trials. *Archives of physical medicine and rehabilitation*, *99*(8), 1623-1634.
20. Heebner, Michelle L., and Toni S. Roddey. "The effects of neural mobilization in addition to standard care in persons with carpal tunnel syndrome from a community hospital." *Journal of Hand Therapy* 21.3 (2008): 229-241.
21. Hawker GA, Mian S, Kendzerska T, French M. Measures of adult pain: Visual Analog Scale for Pain (VAS Pain), Numeric Rating Scale for Pain (NRS Pain), McGill Pain Questionnaire (MPQ), Short-Form McGill Pain Questionnaire (SF-MPQ), Chronic Pain Grade Scale (CPGS), Short Form-36 Bodily Pain Scale (SF-36 BPS), and Measure of Intermittent and Constant Osteoarthritis Pain (ICOAP). Arthritis Care Res (Hoboken). 2011 Nov;63 Suppl 11:S240-52. doi: 10.1002/acr.20543. PMID: 22588748.
22. Mendoza-Pulido C, Ortiz-Corredor F. Measurement properties of the Boston Carpal Tunnel Questionnaire in subjects with neurophysiological confirmation of carpal tunnel syndrome: a Rasch analysis perspective. Qual Life Res. 2021 Sep;30(9):2697-2710.
23. Leite JC, Jerosch-Herold C, Song F. A systematic review of the psychometric properties of the Boston Carpal Tunnel Questionnaire. BMC musculoskeletal disorders. 2006 Dec;7(1):1-9.