Effect of High Tone Power Therapy on Cervical Proprioception and Pain in Cervical Radiculopathy Patients: A Randomized Controlled Trial

Lama Saad El-Din Mahmoud[1], Mohamed Ahmed Abd-Elgwad[2], Osama Yacoub[3], Mohammad Sadik Badawy[4]

1. Assistant Professor, Department of Physical Therapy for Neurology and its Surgery, Faculty of Physical Therapy, October 6 University, Egypt. Orcid: https://orcid.org/0000-0003-4914-214 .
2. Demonstrator of Physical Therapy, Department of Physical Therapy for Neurology and its Surgery, Faculty of Physical Therapy, October 6 University, Egypt. https://orcid.org/0009-0005-5845-5475 .
3. Lecturer, of Neurology, Department of Neurology, Faculty of Medicine, Cairo University, Egypt. https://orcid.org/0000-0002-4227-0928
4. Professor of Physical Therapy, Department of Neuromuscular Disorders and its Surgery, Faculty of Physical Therapy, Cairo University, Egypt. Orcid: https://orcid.org/0000-0001-6245-6706

Corresponding author: Lama Saad El-Din Mahmoud
Email address: lamaelsedawyy@hotmail.com; lama.elsedawy.pt@o6u.edu.eg
ORCID: https://orcid.org/0000-0003-4914-2141.

Abstract
Introduction: Cervical radiculopathy (CR), is a major disorder that could affect individual function due to the irritation of the nerve roots causing pain, disability, and decreasing neck proprioceptive function, thus this study aims to investigate the impact of High Tone Power Therapy (HTT) on neck pain and proprioception in cervical radiculopathy. **Material and methods:** Forty two patients underwent pre- and post-treatment evaluations. The cervical joint position sense error (JPSE) test using the laser pointer, the neck disability index (NDI), the cervical range of motion (CROM) goniometer device measurements, and the visual analogue scale for pain (VAS-P) were among the outcome measures. The control group received the selected physical therapy program and sham High Tone Power Therapy without current flow, while the study group received High Tone Power Therapy and the selected physical therapy program. Both groups had three sessions per week for four weeks. **Results:** Following treatment, the results showed a considerable improvement, with the study group's cervical range of motion scores increasing more than the control group's and the neck cervical joint position sense error, neck disability index, and VAS-P significantly declining ($p < 0.05$). **Conclusions:** An efficient physical therapy intervention for enhancing neck proprioception and reducing the symptoms of cervical radiculopathy should include High Tone Power Therapy.
Keywords: High Tone Power Therapy, Neck Pain, Cervical Radiculopathy, Proprioception, Joint position error.

Introduction

The disorder known as cervical radiculopathy (CR) is characterized by dysfunction of the cervical nerve roots and is often accompanied by radiating pain from spondylosis, cervical disc herniation, or osteophyte formation. These abnormalities can cause irritation of the spinal nerve roots, which can affect proprioception, muscles, and ligaments or cause radicular symptoms [1].

Pain, numbness, weakness, and tingling are some of these symptoms, frequently found in the upper extremities and linked to involvement of the cervical nerve roots [2].

Since the neck's sensory-motor system plays a major role in postural control and neck proprioception is essential for optimal neck performance during activities, disruptions in the integration of proprioceptive and somatosensory inputs may lead to postural instability, frequently as a result of damaged neural pathways in the spinal cord. Postural control may be hampered by maladaptive alterations in sensorimotor coordination and decreased cervical proprioceptive input [3].

The posture's capability to perceive its position and motion is known as proprioception, and it includes both kinesthesia (the feeling of movement) and joint position sensing [4]. Mechanoreceptors found in muscles, tendons, joints, fascia, and skin are the main source of proprioceptive sensory input. Because of components like the muscle spindle, joints are regarded as an important source of sensor information [5].

A strong proprioceptive system is indicated by the elevated intensity of muscle spindles in the cervical musculature. In both static and dynamic situations, the cervical position sense is essential for preserving joint stability, also a higher vulnerability to neck pain is associated with decreased proprioception [4].

Cervical proprioception deficiencies and neck discomfort are related because the pain can interfere with afferent signals from the proprioceptors in the neck, leading to imprecise proprioceptive feedback [6].

The dynamic variation of amplitude and frequency in high-tone therapy (HTT) sets it apart from conventional electrotherapy techniques, as Tissue receives higher energy levels than other methods. Consequently, there has been a high significance in using HTT for several neuromusculoskeletal conditions [7].

Medium-frequency alternating current (4,000 Hz to 33,000 Hz) with simultaneous amplitude and frequency modulation is used in HTT, this method uses alternating electric fields to stimulate different tissues while applying significant energy through electrodes on the cutaneous surface. Crucially, HTT enhances its therapeutic efficacy by enabling simultaneous modification of current frequency and intensity [8].

The neurophysiologic and neurochemical processes that electrotherapy stimulates may underlie the efficacy of HTT muscle electrical stimulation. The effectiveness of the HTT is based on activating different tissues by delivering more energy into tissues via skin surface electrodes. The precise mechanisms are unknown, but it has been hypothesized that HTT leads to greater bioavailability of nitric oxide via improved vasodilatation, increases the discharge of endogenous analgesics, and uses alternating sinusoidal currents to improve endoneural blood flow and microcirculation. Advanced electrotherapy known as HTT has been demonstrated to enhance quality of life (QOL) and alleviate pain, anxiety, insomnia, and motor control issues [9]. This study was conducted to ascertain whether HTT is an effective intervention to recover neck proprioceptive functions, cervical pain, and function post-cervical radiculopathy, as no previous study examined the effects of HTT on cervical proprioceptive function and pain.

MATERIALS AND METHODS:

Design of the study and randomization:

It is considered a prospective study with a pre-and post-experimental randomized design, and anonymity and confidentiality were ensured. Using the opaque closed envelope method, patients were assigned in a random way to two equal groups for four weeks. The study group received HTT along with a physical therapy selected treatment, while the control group received the same physical therapy treatment along with sham HTT therapy with no current flow. No patients left the experiment after randomization and intervention **(Figure 1).**

-Subjects:

Patients of both sexes with mild to moderate disc prolapse based on magnetic resonance imaging (MRI) and cervical radiculopathy were referred by a neurologist. All patients were given verbal and written information about the study prior to its start, and they all signed a written consent form. All procedures were conducted by institutional rules and applicable regulations, guaranteeing confidentiality and anonymity. The requirements for inclusion were as follows: Their body mass index (BMI) was from 18.5 to 29.9 Kg/m2, they were between the ages of 35 and 50, and they had illness for at least six months. Any prior conditions affecting the cervical, dorsal, or lumbar spine, any spinal surgery, any other neurology or musculoskeletal issues surrounding the cervical area, deformities like hyperkyphosis and scoliosis, and vestibular issues (like vertigo) were excluded.

Ethical approval for the study:

The study was accepted by the Ethics Committee of the Faculty of Physical Therapy at Cairo University in Egypt (P.T.REC/ 012/005400) and clinical trials.gov ID NCT06695312.

Sample size:

Based on measurements and data produced by Kulis et al.[10]. To determine the sample size, GPOWER statistical software was utilized. The ideal sample size for this study was determined to be N=42 (version 3.1.9.2; Franz Faul, Universitat Kiel, Germany). F tests-MANOVA: The computation employed within-between interaction, repeated measures, effect size = 0.8 and α=0.05, β=0.2.

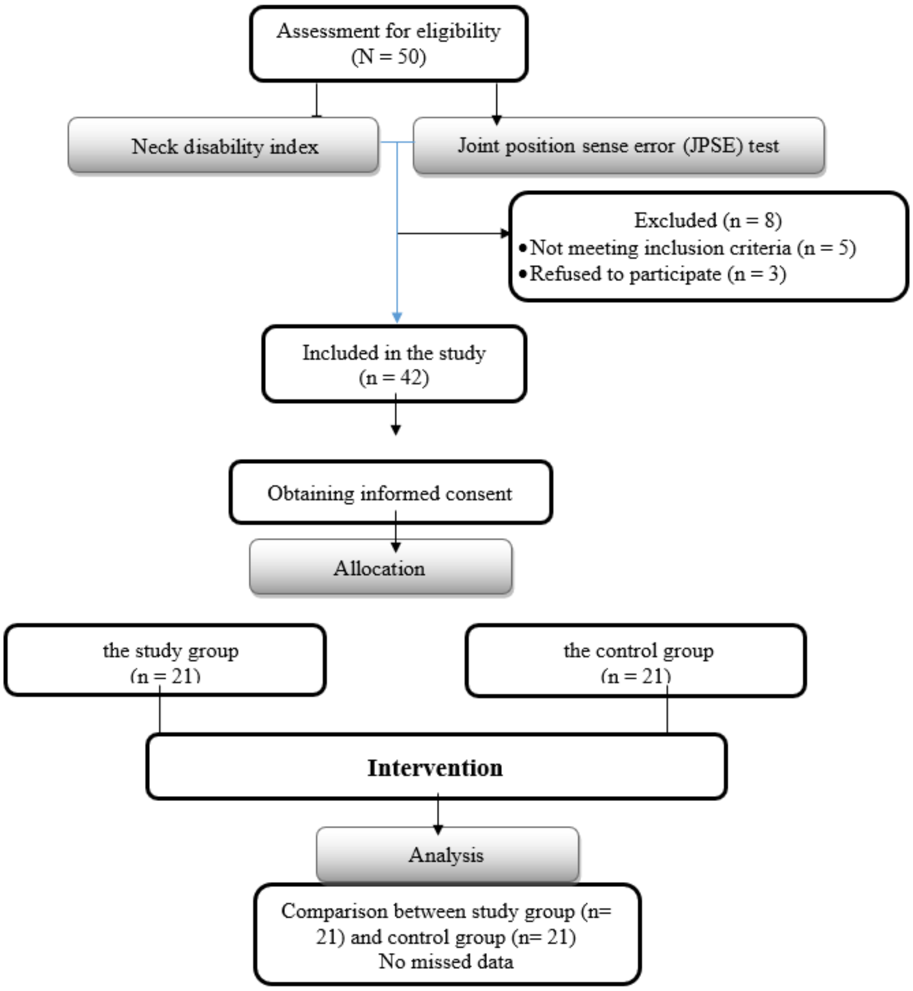

Figure (1). Flow chart showing the experimental design of the study.

The outcome of measures:

1- Cervical joint Position Sense Error (JPSE) test, for Cervical proprioception:

The most fundamental metric for clinically assessing proprioception of the cervical with the laser pointer approach is the cervical Joint Position Sense Error (JPSE). A target paper was placed on the wall at the patient's eye level, and approximately 90 cm away from the patient, at the top part of the patient's head, the laser pointer was fixed (Figure 2). Then, the patient was directed to move the neck in different directions: rotation to the right and left, flexion, and extension, and to return to the beginning position with their eyes open and then with them closed. The distance between the starting place and the patient's reach is evaluated by the therapist. Relocation scores that are abnormal are greater than 7 cm or greater than 4.5 degrees (horizontal) [11]. (Figure 2).

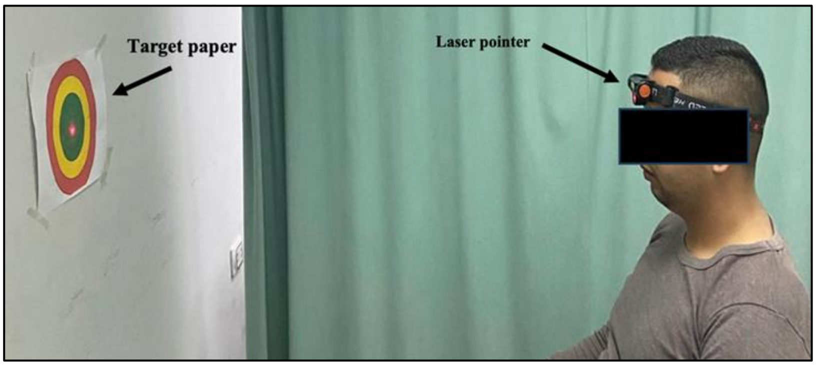

Figure (2). Cervical JPSE test, the arrows represent the laser pointer overhead and target paper position.

2- Cervical range of motion (CROM) Measurement:

Cervical range of motion (ROM) was measured in Rotation, flexion, and extension directions using the CROM device [12].

3- Neck disability index (NDI):

To ascertain the patient's impairment, function, and pain, as the NDI is a validated questionnaire, it consists of 10 elements, each with a score (0:5). The highest possible score is 50, as the following (widespread disability > 34, severe disability = 25:34, moderate disability = 15:24, mild disability = 5:14, no disability = 0:4,) [13].

4- Visual analogue scale for pain (VAS-P):

A 10-cm-long horizontal straight line was used to measure the patient's level of pain using the VAS-p. The patient was told to check the line according to the severity of their discomfort, with a higher score denoting more pain [14].

Interventions:

For four weeks, the study group got High-tone electrical muscle stimulation (HTEMS) therapy three times a week in addition to the selected physical therapy program. A portable 5000V power supply device (HiToP® 1toutch; Gbo Medizin Technik, Rimbach, Germany) that produces an initial frequency of 4,096 Hz was used to conduct an external muscle stimulation program [15]. Before the procedure, the patient was informed of all the treatment procedures of the device, and the patient's skin should be uncovered and metal-free. The electrodes were placed in the prone lying position, on the patient's paracervical and pain course (Figure 3), using the frequency of 4,096 Hz that was elevated over 3 seconds to 32,768 Hz held at maximum for 3 seconds, and pulse widths of ≤350 mA, ≤70 V, then decreased to the initial frequency [9], The intensity was set for 30 minutes at a level that didn't elicit any pain or paresthesia.

Without any current flow, the control group received sham HTEMS therapy. Additionally, the selected physical therapy program was given to the study and control groups as follows: 1- Using an ultrasound therapeutic device (Enraff, model 2760, 120-240V, 50/60Hz, built 2/2016, serial number T11238, Mexico) with 1MHz frequency, pulsed, 0.5mw/cm2, duty cycle of 12%, and a rate of 4 cm/s for 5 minutes, on paravertebral in the cervical area [16]. 2- For ten minutes, the cervical region, paravertebral region, and shoulders were heated using a suitable hot pack size while the patient was in a prone lying position [17]. 3-Static neck exercise: included isometric resistance in four directions (flexion, extension, and right and left side bending), 4-also flexibility stretching exercises for the pectoralis for 30 seconds hold, then release 30 seconds, and hold relax technique for both upper trapezius and levator scapulae muscles, with Hold for 10 seconds, then release for 10 seconds, with a pain-free limit, each direction repeated five times [18].

Figure (3). HTT application on the patient's paracervical and pain course from a prone lying position

Statistical Analysis:

To compare subject characteristics between groups, An unpaired t-test was used. The Shapiro-Wilk test was conducted to test the data Normal distribution, while to test the homogeneity between groups, Levene's test for homogeneity of variances was used, and to study the effect of treatment on JPE, VAS, NDI, and cervical ROM Mixed MANOVA was conducted. For subsequent multiple comparisons, the Post-hoc tests using the Bonferroni correction were carried out. For every statistical test, the significance level was set at $p < 0.05$. The statistical package for social studies (SPSS) version 25 for Windows (IBM SPSS, Chicago, IL, USA) was used for all statistical analyses.

RESULTS

- **Patient characteristics**

Group A (study) and B (control) subject characteristics are shown in Table (1). Age, weight, height, BMI, duration of illness, and sex distribution did not significantly differ between groups ($p > 0.05$).

- **Effect of treatment on JPE, VAS, NDI, and cervical ROM:**

Mixed MANOVA revealed a significant interaction effect of treatment and time ($F = 121.59$, $p = 0.001$, partial eta squared = 0.97). There was a significant main effect of treatment ($F = 42.47$, $p = 0.001$, partial eta squared = 0.93). There was a significant main effect time ($F = 1070.96$, $p = 0.001$, partial eta squared = 0.99).

- **Within-group comparison**

When comparing the JPSE of flexion, extension, right and left rotation, and VAS and NDI to the pre-treatment values, there was a significant decrease in both groups after treatment (p >

0.001) (Table 2,3). While there was a significant increase in flexion, extension, right and left rotation ROM post-treatment in both groups compared with pre-treatment (p > 0.001). (Table 4).

- **Between groups comparison**

There was a significant decrease in JPSE of cervical flexion, extension, right and left rotation, VAS, and NDI of group A compared with that of group B post-treatment (p < 0.01). (Table 2-3). While there was a significant increase in cervical flexion, extension, right and left rotation CROM of group A compared with that of group B post-treatment (p < 0.001). (Table 4)

Table 1. Patients' general characteristics : age, weight, height, BMI, duration of illness, and gender between groups comparison.

	Group A	Group B			
	Mean ±SD	**Mean ±SD**	**MD**	**t- value**	**p-value**
Age (years)	44.33 ± 3.35	42.00 ± 3.38	1.05	1.05	0.29
Weight (kg)	78.05 ± 3.37	75.90 ± 2.86	1.33	1.47	0.14
Height (cm)	171.67 ± 2.37	170.14 ± 2.59	1.05	1.39	0.17
BMI (kg/m²)	26.43 ± 1.19	26.19 ± 1.27	0.13	0.28	0.78
Duration of illness (months)	20.05 ± 4.68	17.90 ± 3.08	1.33	1.21	0.23
Gender distribution					
Females	8 (38%)	8 (38%)			
Males	13 (62%)	13 (62%)			

BMI: body mass index, SD: Standard deviation, t value: Unpaired t-value, p-value: Probability value, MD: Mean difference.

Table 2. Mean cervical JPSE pre and post treatment of group A and B:

JPE (cm)	Group A	Group B		
	Mean ±SD	**Mean ±SD**	**MD (95% CI)**	**p value**
Flexion JPE				
Pre treatment	**9.10 ± 1.89**	**8.81 ± 1.08**	**0.29 (-0.68: 1.25)**	**0.55**
Post treatment	**3.76 ± 1.00**	**5.14 ± 0.85**	**-1.38 (-1.96: -0.80)**	**0.001**
MD (95% CI)	**5.34 (4.72: 5.95)**	**3.67 (3.05: 4.28)**		
% of change	**58.68**	**41.66**		
	p = 0.001	***p = 0.001***		
Extension JPE				
Pre treatment	**8.43 ± 0.87**	**8.33 ± 0.58**	**0.1 (-0.37: 0.56)**	**0.67**
Post treatment	**3.90 ± 0.70**	**5.24 ± 0.62**	**-1.34 (-1.75: -0.92)**	**0.001**
MD (95% CI)	**4.53 (4.20: 4.84)**	**3.09 (2.78: 3.42)**		
% of change	**53.74**	**37.09**		
	p = 0.001	***p = 0.001***		
Right rotation JPE				
Pre treatment	**10.52 ± 1.12**	**10.10 ± 0.94**	**0.42 (-0.22: 1.08)**	**0.18**
Post treatment	**3.76 ± 0.89**	**5.33 ± 0.80**	**-1.57 (-2.10: -1.05)**	**0.001**
MD (95% CI)	**6.76 (6.40: 7.13)**	**4.77 (4.40: 5.13)**		
% of change	**64.26**	**47.23**		
	p = 0.001	***p = 0.001***		
Left rotation JPE				
Pre treatment	**10.05 ± 0.86**	**9.81 ± 0.98**	**0.24 (-0.34: 0.81)**	**0.41**
Post treatment	**4.90 ± 0.89**	**5.71 ± 0.78**	**-0.81 (-1.33: -0.29)**	**0.003**
MD (95% CI)	**5.15 (4.75: 5.54)**	**4.10 (3.70: 4.49)**		
% of change	**51.24**	**41.79**		

	p = 0.001	*p = 0.001*		

JPSE: joint position sense error, MD: Mean difference, SD: Standard deviation, %: percentage. p-value: Probability value.

Table 3. Mean VAS and NDI pre and post treatment of group A and B:

	Group A	Group B		
	Mean ±SD	**Mean ±SD**	**MD (95% CI)**	**p value**
VAS				
Pre treatment	**7.95 ± 0.80**	**7.71 ± 0.72**	**0.24 (-0.24: 0.71)**	**0.32**
Post treatment	**1.86 ± 0.73**	**5.05 ± 0.74**	**--3.19 (-3.65: -2.73)**	**0.001**
MD (95% CI)	**6.09 (5.78: 6.41)**	**2.66 (2.35: 2.98)**		
% of change	**76.60**	**34.50**		
	p = 0.001	***p = 0.001***		
NDI (%)				
Pre treatment	**19.24 ± 1.87**	**18.52 ± 1.57**	**0.72 (-0.36: 1.79)**	**0.19**
Post treatment	**3.67 ± 0.80**	**9.90 ± 1.09**	**-6.23 (-6.83: -5.64)**	**0.001**
MD (95% CI)	**15.57 (14.96: 16.18)**	**8.62 (8.01: 9.23)**		
% of change	**80.93**	**46.54**		
	p = 0.001	***p = 0.001***		

MD: Mean difference, SD: Standard deviation, VAS-P: visual analogue scale for pain, NDI: neck disability index, %:percentage, p-value: Probability value.

Table 4. Mean cervical ROM pre and post-treatment of groups A and B:

ROM (degrees)	Group A	Group B		
	Mean ±SD	**Mean ±SD**	**MD (95% CI)**	**p value**
Flexion				
Pre treatment	45.48 ± 3.04	45.29 ± 2.70	0.19 (-1.61: 1.99)	0.83
Post treatment	60.10 ± 2.86	50.71 ± 2.69	9.39 (7.65: 11.11)	0.001
MD (95% CI)	-14.62 (-15.43: -13.81)	-5.42 (-6.24: -4.62)		
% of change	32.15	11.97		
	p = 0.001	***p = 0.001***		
Extension				
Pre treatment	50.38 ± 3.31	51.33 ± 2.33	-0.95 (-2.74: 0.83)	0.29
Post treatment	64.90 ± 3.02	56.24 ± 4.98	8.66 (6.10: 11.23)	0.001
MD (95% CI)	-14.52 (-16.21: -12.84)	-4.91 (-6.59: -3.22)		
% of change	28.82	9.57		
	p = 0.001	***p = 0.001***		
Right rotation				
Pre treatment	48.95 ± 4.73	49.76 ± 3.87	-0.81 (-3.50: 1.89)	0.54
Post treatment	69.90 ± 4.30	57.90 ± 3.19	12 (9.64: 14.36)	0.001
MD (95% CI)	-20.95 (-22.25: -19.65)	-8.14 (-9.44: -6.84)		
% of change	42.80	16.36		
	p = 0.001	***p = 0.001***		
Left rotation				
Pre treatment	49.00 ± 3.59	49.29 ± 3.07	-0.29 (-2.37: 1.80)	0.78
Post treatment	70.14 ± 3.76	59.29 ± 2.69	10.85 (8.82: 12.90)	0.001
MD (95% CI)	-21.14 (-22.53: -19.76)	-10 (-11.39: -8.62)		
% of change	43.14	20.29		
	p = 0.001	***p = 0.001***		

MD: Mean difference, SD: Standard deviation, ROM: range of motion, %: percentage, p-value: Probability value.

DISCUSSION

Although cervical radiculopathy is a common neurological condition that disturbs neck function and proprioception and alleviates pain intensity, several studies have demonstrated that HTEMS therapy is an important intervention that can be used safely to treat cervical disorders. As a result, the current study looked at how it affected cervical radiculopathy and neck proprioception. The findings demonstrated the efficacy of the HTEMS therapy by showing that it significantly improved cervical proprioception and decreased pain and radiculopathy symptoms in the study group when compared to the control group.

As in disc degeneration, alternations in sensorimotor control of cervical and proprioceptive impulses brought on by neck pain are thought to be a defensive reaction to lessen further stimulation of pain. According to recent studies, one of the main concerns with cervical discomfort is the weakening of cervical proprioceptive function, which leads to abnormalities in cervical sensorimotor control [19].

The cervical proprioceptive impulses from the facet joints and cervical discs, which are in charge of the best possible recruitment of cervical muscles, are directly linked to the function of cervical motor control. In pathological conditions like cervical disc degeneration, improper inputs of proprioception distort the direct interface of neck proprioception, leading to disturbances in spatial representation and posture orientation, which is manifested as unbalanced perception and a sense of instability [19].

Additionally, it has been proposed that HTEMS may enhance the sense of joint motion and proprioceptive impulses by improving muscle action through neuromuscular electrical stimulation, which would increase spinal motor control in a manner to that of motor control exercises [9]**,** which is inconsistence with the current study that

impaired cervical proprioception can result in injuries or decreased joint stability, especially during daily activities, the HTEMS improves neck proprioception and joint sense, Therefore, when proprioceptive input from the cervical spine is compromised, it can disrupt the coordination of muscles and joints, potentially causing pain and dysfunction [4]**.**

The neurochemical and neurophysiological effects that the electrotherapy stimulates may be responsible for the efficiency of HTEMS. It increases the endoneural circulation and discharge of endogenous analgesics. It is also hypothesized that HTEMS decreases sympathetic afferent activity, which lowers the transmission of pain to the brain. HTEMS has shown greater efficacy in providing short-term pain relief because it increases the nitric oxide bioavailability [9]

Since HTT was a successful technique for greatly improving function and cervical control in patients with cervical pain, the results of the current study were consistent with those of a prior study that examined the therapeutic benefits of HTT for pain alleviation in the cervical spine as there was a noticeable decrease in spinal pain [10], additionally, the HTT analgesic efficacy promotes its continued application in the management of polyneuropathy, sciatica, low back pain syndrome, and other disorders, hence it appears to be a useful technique for raising the pain threshold and thereby lowering pain compared to transcutaneous electrical nerve stimulation (TENS) [9].

Neuropathic pain, as well as other chronic pain syndromes like back pain, phantom-limb pain, and severe angina, can be effectively relieved by HTT, it is thought that its positive benefits are partially due to its ability to alleviate circulatory abnormalities, furthermore, HTT causes circulatory effects and improves blood flow to the nerves hence improving motor nerve conduction velocity, a crucial electrophysiological parameter [20],[21], also there is evidence that HTT promotes myelin sheath regeneration [15].

HTEMS may be able to reduce the inflammatory pain brought on by cervical radiculopathy because it affects tissue metabolism by using frequency scanning to oscillate tissue structures, which helps eliminate waste and reduces inflammation-related pain. HTT has a different effect on tissue stimulation than conventional electrical stimulation because of its unique frequency

modulation. It also affects tissue metabolism by changing the potential of cell membranes and increasing cellular energy. By using a wide range of frequencies, it may be possible to normalize both cellular processes and tissue metabolism, which would improve neuro-musculoskeletal disorders [7].
According to a prior study that supported the current study's findings, long-term use of HTEMS leads to significant clinical improvements, including neuropathic pain, by activating the dorsal columns that reduce the C fibers. This means that HTEMS was nearly three times more effective than other electrotherapy approaches such as TENS at reducing pain and discomfort [22].

CONCLUSION

It would be advantageous to incorporate HTT into the physical therapy program to enhance neck proprioception in patients with cervical radiculopathy, as the results of this study suggest that it can improve neck function and position sense while reducing cervical pain and disability.

Acknowledgments
The authors would like to acknowledge all the patients in the study for their participation.
Conflict of interest: Authors state no conflict of interest.
Disclosure statement: No author has any financial interest or received any financial benefit from this research.
Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES:

[1] Borrella-Andrés S, Marqués-Garc\'\ia I, Lucha-López MO, Fanlo-Mazas P, Hernández-Secorún M, Pérez-Bellmunt A, et al. Manual therapy as a management of cervical radiculopathy: a systematic review. Biomed Res Int 2021;2021:9936981.
[2] Boyles R, Toy P, Mellon J, Hayes M, Hammer B. Effectiveness of manual physical therapy in the treatment of cervical radiculopathy: a systematic review. J Man Manip Ther 2011;19:135–42.
[3] Abdelkader NA, Mahmoud AY, Fayaz NA, Mahmoud LSE-D. Decreased neck proprioception and postural stability after induced cervical flexor muscles fatigue. J Musculoskelet Neuronal Interact 2020;20.
[4] Reddy RS, Tedla JS, Dixit S, Abohashrh M. Cervical proprioception and its relationship with neck pain intensity in subjects with cervical spondylosis. BMC Musculoskelet Disord 2019;20:1–7.
[5] St-Jean P, Clark OG, Jemtrud M. A review of the effects of architectural stimuli on human psychology and physiology. Build Environ 2022;219:109182.
[6] Geisinger D, Ferreira E, Suarez A, Suarez H. Head tilt response: a complementary test to the subjective visual vertical. J Vestib Res 2010;20:381–9.
[7] Namvar H, Olyaie G, Bagheri H, Naiemi E, Hoseinifar M, Sargolzehi M. Effect of high-tone external muscle stimulation (high-tone therapy) in neuro-musculoskeletal disorders: A narrative review. J Mod Rehabil 2022;16:208–13.
[8] Spanidis I, Hidmark A, Fleming T, Volk N, Eckstein V, Gröner JB, et al. External muscle stimulation differentiates circulating hematopoietic stem cells in diabetes patients. Diabetol Und Stoffwechsel 2016;11:FV29.
[9] Kempf K, Röhling M, Darwish E, Martin S, Jander S, Herdmann J, et al. High-Tone External Muscle Stimulation for the Treatment of Chronic Sciatica--A Randomized Controlled Crossover Trial. Open Pain J 2018;11.

[10] Kulis A, Meres R. High tone power therapy in the streatment of pain in the cervical spine. Tarnow Sci. Colloq., vol. 3, 2017, p. 69–77.
[11] Pettorossi VE, Schieppati M. Neck proprioception shapes body orientation and perception of motion. Front Hum Neurosci 2014;8:895.
[12] Reynolds J, Marsh D, Koller H, Zenenr J, Bannister G. Cervical range of movement in relation to neck dimension. Eur Spine J 2009;18:863–8.
[13] MacDermid JC, Walton DM, Avery S, Blanchard A, Etruw E, Mcalpine C, et al. Measurement properties of the neck disability index: a systematic review. J Orthop Sport Phys Ther 2009;39:400–17.
[14] 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. Arthritis Care \& Res 2011;63:S240--S252.
[15] Strempska B, Bilinska M, Weyde W, Koszewicz M, Madziarska K, Golebiowski T, et al. The effect of high-tone external muscle stimulation on symptoms and electrophysiological parameters of uremic peripheral neuropathy. Clin Nephrol 2013;79:S24--7.
[16] Dundar U, Solak O, Samli F, Kavuncu V. Effectiveness of ultrasound therapy in cervical myofascial pain syndrome: a double blind, placebo-controlled study. Turkish J Rheumatol 2010;25.
[17] Kuligowski T, Skrzek A, Cieślik B. Manual therapy in cervical and lumbar radiculopathy: a systematic review of the literature. Int J Environ Res Public Health 2021;18:6176.
[18] Liang L, Feng M, Cui X, Zhou S, Yin X, Wang X, et al. The effect of exercise on cervical radiculopathy: a systematic review and meta-analysis. Medicine (Baltimore) 2019;98.
[19] Peng B, Yang L, Li Y, Liu T, Liu Y. Cervical proprioception Impairment in neck pain-pathophysiology, clinical evaluation, and management: a narrative review. Pain Ther 2021;10:143–64.
[20] Di Iorio B, Marzocco S, Di Micco L, Adesso S, De Blasio A, Sirico ML, et al. High-tone external muscle stimulation in patients with acute kidney injury (AKI): beneficial effects on NO metabolism, asymmetric dimethylarginine, and endothelin-1. Clin Nephrol 2014;82:304–12.
[21] Moez RABA, Hady AAAA, Attia FAK, El Nahas NG. High Tone External Muscle Stimulation versus Aerobic Exercise on Endothelial Dysfunction and Walking Parameters in Peripheral Arterial Disease 2022.
[22] Reichstein L, Labrenz S, Ziegler D, Martin S. Effective treatment of symptomatic diabetic polyneuropathy by high-frequency external muscle stimulation. Diabetologia 2005;48:824–8.