

Original Article

Effect of Kinetic Control Retraining on Neck Proprioception and Function in Cervical Radiculopathy: A Randomized Controlled Trial

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Abstract

Objectives: Cervical radiculopathy is a prevalent neuromusculoskeletal disorder which negatively impacts quality of life. Kinetic control concept indicates that the main goals of rehabilitation are to improve motor control and stabilize the cervical spine. The aim of this study was to assess the impact of kinetic control retraining on neck proprioception and function in individuals with cervical radiculopathy. **Methods:** A total of forty-four participants, aged 40 to 55, diagnosed with chronic unilateral cervical spondylotic radiculopathy, were randomly divided into two equal groups. The study group received kinetic control retraining along with the conventional physical therapy protocol. The control group underwent a conventional physical therapy protocol, comprising three sessions weekly for eight successive weeks. Cervical joint position error was assessed through cervical range of motion, pain levels were measured by the Visual Analogue Scale, neck-related disability was evaluated using Arabic Neck Disability Index scores, and deep neck flexor performance was tested with a pressure-biofeedback device. **Results:** After eight weeks of intervention, statistically significant differences between groups were observed across all outcome measures, favoring the study group ($P < 0.05$). **Conclusion:** Kinetic Control retraining has a useful effect on managing chronic cervical radiculopathy by reducing pain and enhancing proprioception and functional abilities. ClinicalTrials.gov ID: NCT06803134.

Keywords: Cervical Pain, Cervical Radiculopathy, Kinetic Control, Motor Control, Proprioception

Introduction

Neck pain (NP) with radiculopathy commonly presents in medical settings¹. Cervical spondylotic radiculopathy (CSR) is one of the most common cervical disorders. CSR

manifests in around 70% of instances². The prevalence of degenerative changes in the cervical spine increases with age, reaching its zenith in adults in their fifties and sixties³. The signs and symptoms of CSR arise from a complex process in which spinal and disc anatomy alone inadequately accounts for pain; changes in anatomical, inflammatory, functional, and structural alignment converge to generate clinical complaints⁴. Although CSR can result from various sources, inflammation caused by mechanical and shearing stresses on nerve roots is a significant contributor to pain, restricted neck motion, and neurological problems⁵. Proprioception refers to the knowledge of bodily movement and positioning, which includes both position sense (joint position sense) and movement sense (kinesthesia). The ascending proprioceptive information conveys to the central nervous system via the afferent pathway, enabling

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movement and postural muscle regulation⁶. Neck muscles possess a high density of muscle spindles, indicating a robust proprioceptive system that enhances sensorimotor performance and is crucial for maintaining either static and dynamic postures along with adequate motor control⁷. In CSR, there may be compromised mechanoreceptor feedback, potentially resulting in neck muscle atrophy as well joint degeneration, which can cause unpredictable instability. Disruption of proprioception affects both neuronal and muscular regulation of normal cervical joint function, potentially leading to the premature development of unbalanced muscle force and increasing the joint's vulnerability to injury⁸. The results show that treating people with neck disorders should include both restoring neuromuscular function and relieving pain. Moreover, objective outcome measures should be utilized to examine neuromuscular characteristics during clinical evaluations, since these tools enable precise evaluation of rehabilitation efficacy⁹. Over the past twenty-five years, motor control exercises founded on the kinetic control (KC) concept have been developed, integrating various kinesiotherapy techniques within a scientifically justified framework¹⁰. The KC methodology employs the Motor Control Rating Scale (MCRS), integrating motor assessments to identify the anatomical location and directional characteristics of uncontrolled movements while administering activities aimed at motor control re-education¹¹. Improving motor control and stability in the cervical spine has been seen as a primary goal in the rehabilitation of individuals with neck pain¹². Previous literature indicates insufficient study on the impact of kinetic control retraining on neck pain, disability, and cervical proprioception. This research was conducted to investigate the effects of kinetic control retraining (KCR) on neck proprioception and function in people with cervical radiculopathy.

Materials and Methods

Setting

The trial was conducted between February and June 2025 at the outpatient clinic of the Faculty of Physical Therapy, Horus University, Egypt. Before the initial assessment, participants were fully informed about the study procedures and provided written informed consent using the approved forms. The research protocol adhered to CONSORT reporting standards.

Design

Assessor-blinded randomized controlled trial.

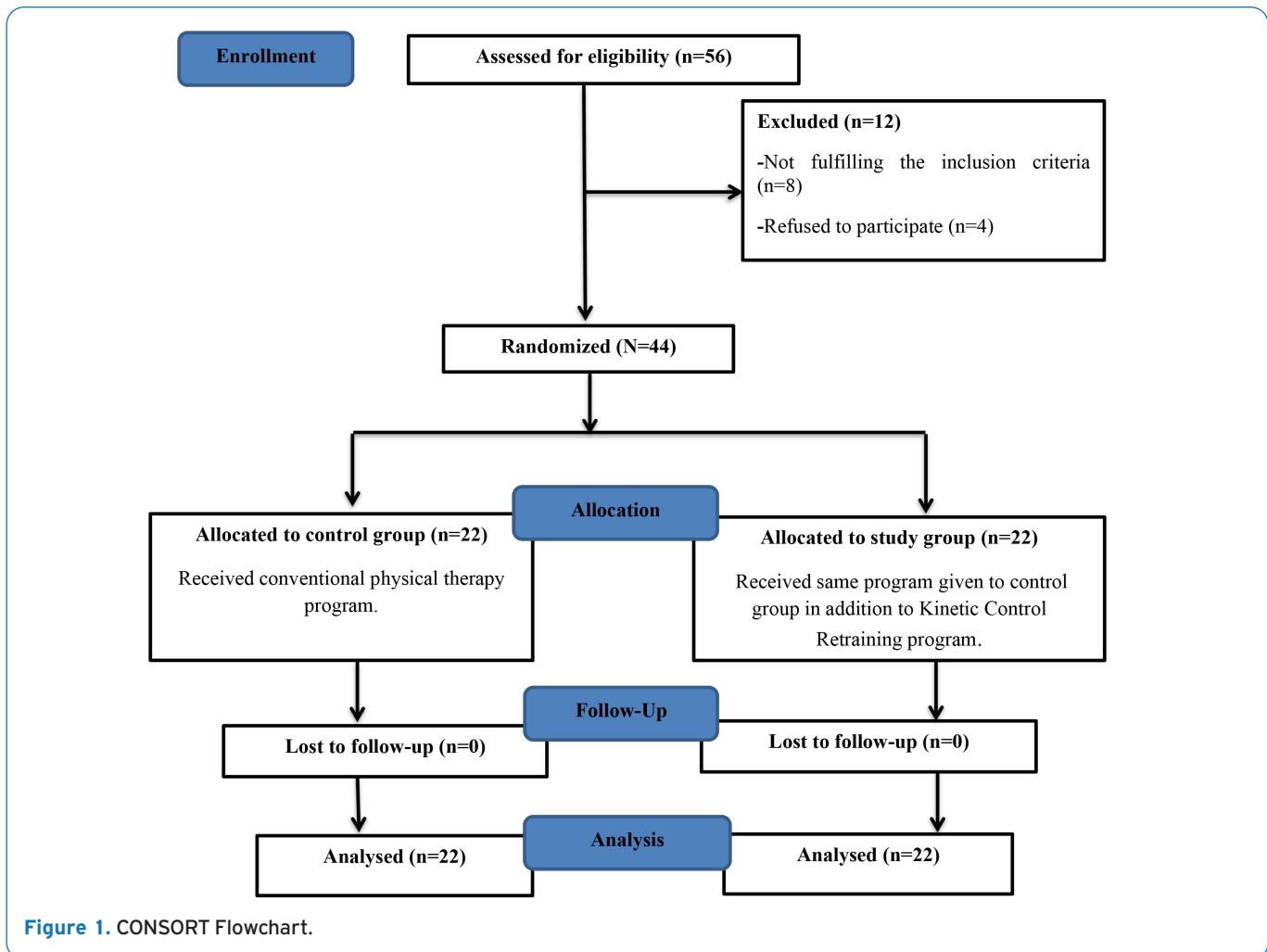
Study population

Sample size was estimated using G*POWER software (version 3.1.9.4), the calculation used t-tests for Wilcoxon-Mann-Whitney test (two groups) was applied, with $\alpha=0.05$, power=80%, effect size=0.88, allocation ratio=1. This

effect size was calculated from a study by Khosrokiani et al.¹³ on 30 participants (15 in each group). However, the actual sample size used was 44, consisting of 22 participants in study group and 22 participants in control group. A neurologist conducted careful clinical assessments to diagnose patients with cervical radiculopathy, subsequently confirming these diagnoses through radiological examinations such computed axial tomography or magnetic resonance imaging concerning cervical region. The research team established specific inclusion criteria for study participation: (i) participants were between 40 and 55 years of age, (ii) experience symptoms lasting 3-12 months, (iii) present with chronic unilateral cervical spine radiculopathy, and (iv) maintain a body mass index below 30 kg/m². The exclusion parameters eliminated subjects with: (i) cervical myelopathy with evidence of pyramidal, posterior column, and or spinothalamic tract lesions; (ii) Decreased range of motion of cervical spine secondary to congenital anomalies, musculature contracture, or bony block; (iii) Previous cervical or shoulder surgery or trauma; (iv) Cervical instability from structural abnormalities like ligament ruptures or spondylolisthesis, psychological conditions hindering comprehension of instructions or lacking directional preference; (v) Vertebral-basilar artery insufficiency, diabetic neuropathy; (vi) Concurrent medical conditions limiting physical function like strokes or severe cardiac disease; and (vii) Double crush syndrome and thoracic outlet syndrome.

Randomization

A randomization technique for the 44 participants was established utilizing randomly permuted blocks, with block sizes of 2 and 4, alongside an allocation ratio of 1:1 to minimize predictability. The allocations were placed into consecutively numbered, sealed, opaque envelopes by a research assistant who had no further involvement in the study. Each envelope included the assignment for a single participant, folded to conceal the allocation, and placed within tamper-proof, carbon-paper-lined envelopes. All envelopes were secured in a locked storage cabinet within the research facility, accessible solely by the study coordinator responsible for allocation. Envelopes were opened sequentially, subsequent to verifying participant eligibility and doing baseline measures, and always in the person's presence. To guarantee confidentiality, each envelope was affixed with tamper-evident tape and signed over the seal, which was examined before opening. The randomization strategy and envelope assembly procedure remained unchanged throughout the trial. All outcome measurements were conducted through the second author (NAS), who actually was blinded to the participants' group allocations and did not participate in giving the intervention, to reduce observer bias. The first author (EWS), who was not involved in outcome evaluation, administered the treatment according to the group allocation. Participants were randomly allocated to two equal groups, (Figure 1).



Outcome Variables and Measurements

The evaluation process was conducted twice: initially at baseline, one day before starting the treatment, and then again after the eight-week course. Patients' availability determined the schedule for their evaluations and treatment sessions. To ensure objectivity, an independent evaluator lacking knowledge of participants' group assignments performed all measurements.

Pain severity, i.e. the primary outcome, was assessed using the Visual Analogue Scale (VAS), comprising a ten-centimeter horizontal line with endpoints marked as 0 (pain-free) and 10 (maximum possible pain). Research widely recognises this instrument as among the most reliable quantitative measurement tools¹⁴.

Neck disability was assessed using Arabic neck disability index (ANDI), a ten-item self-reported questionnaire. Each question allowed responses ranging from none (zero) to significant (five) disability. Total scoring involved summing

individual item responses. The total score is based on a maximum of 50 points. The results can be represented into a percentage by multiplying the score by two. Increased NDI scores corresponded to greater patient-reported neck pain-related functional impairment¹⁵.

Cervical joint position error (JPE) was evaluated using the CROM instrument, a specialist goniometer designed for assessing neck range of motion (ROM). It comprises a plastic frame which fits perfectly to the subject's nasal bridge and ears, secured to their head by a Velcro strap. Three independent inclinometers mounted to the frame and also positioned orthogonally toward each other measure the subject's ROM¹⁶. Prior to the actual test, participants typically engage in one or more practice trials with their eyes open to acclimate to the movement and the target position. This ensures that the individual is aware of the necessary actions to take. A minute-long rest period was provided following each movement direction¹⁷. JPE was assessed according to the methodologies outlined by

Reddy et al.⁸. The examiner held the subject's head then gradually adjusted it toward the target head position, set at 50% of the previously recorded maximum cervical ROM, and then maintained this position for 3 seconds. The subjects subsequently memorized that target position, after which the examiner gently returned the subject's head to the neutral position. The subjects were instructed to actively attain the target position by moving their heads, and upon reaching the target, the reposition accuracy error was measured in degrees. The examiner assessed JPE using the target head position test in the sagittal (flexion, extension) and transverse (right and left rotation) planes. A straightforward chit method was employed to randomize the testing sequence. Every direction of JPE testing was conducted thrice, and the average error was utilized in the analysis. Joint position sense analyzed by calculating the angular displacement error of active angle repositioning of cervical movement (the absolute value of the difference between the target angle and subject's repositions angle).

Deep neck flexor (DNF) performance was assessed using a Pressure-biofeedback unit (PBU) via craniocervical flexion test (CCFT). The patient was lying supine in a crook-lying posture keeping the neck in neutral alignment. A pressure biofeedback sensor, filled with air, was positioned posterior to the neck and inflated to 20 mmHg to occupy the space under the neck without inducing lordosis. The pressure sensor tracked the minor reduction in cervical lordosis that transpired upon the activation of DNFs. The participant executed a subtle head-nodding motion of CCT across 5 progressive phases (22, 24, 26, 28, and 30mmHg) of augmented range (2 mm Hg per stage). The optimal DNF control must be capable of elevating pressure to 30 mmHg. The clinician assessed the quality of movement, advising against compensatory movements (e.g., retraction) or muscular techniques (e.g., excessive reliance on the superficial cervical flexor muscles¹⁸). The activation score can be defined just as the highest-pressure level (mmHg) attained as well maintained steadily for 10 seconds above the baseline pressure without employing any compensatory methods. The performance index was determined by multiplying the activation score by the quantity of successful repeats (mmHg × repetitions)¹⁹.

Intervention

Both groups (study and control) were provided with conventional physical therapy to improve pain intensity, neck-related functional performance, neck proprioception, and DNF performance.

The conventional treatment protocol incorporated Transcutaneous Electrical Nerve Stimulation (TENS) delivered at 80 Hz frequency with 10-30 mA intensity for twenty-minute sessions, with a 2-pole, which is easier to apply over the cervical pain region²⁰. TENS delivery employed the Intellect Advanced system (PHYSIOGO 100A ASTAR apparatus). Postural instruction emphasised optimal spinal alignment during sitting and standing activities²¹,

while deep cervical flexor strengthening involved supine positioning with neutral cervical spine alignment. Nodding technique Instruction accomplished: cervical curve flattening sustained for ten-second intervals throughout ten repetitions, with sternocleidomastoid monitoring to ensure minimal muscle activation during deep cervical flexor engagement as delineated by Petersen²². The study group also underwent kinetic control retraining exercises. All participants executed their designated interventions in regulated settings for three weekly sessions over eight weeks, culminating in twenty-four sixty-minute treatments.

The Kinetic Control Retraining program (KCR)

The establishing of a neutral region is an essential prerequisite for the training process. Retraining in site control and UCM direction is required as outlined below: 1- the UCM site as situated inside its neutral position, and the patient was instructed on how to activate the pertinent muscles to facilitate movement at this site, while concurrently moving a nearby joint (either superior or inferior) in the same direction, independent of the UCM. Control can be maintained at the UCM location and joint or myofascial limitations were allowed. 2- The retraining emphasis is on the joint and direction of movement that is isometrically controlled, rather than the location of active execution of the action. 3- A variety of feedback techniques (tactile, visual, adhesive tape, skin tension, or vocal cues) may be employed to instruct and improve the requisite retraining movement. 4- Incremental, low-effort repetitions are essential for establishing motor control patterns of movement. 5-The focus is on the quality of control. 6- The effectiveness of control at the UCM is initially more important than the range of motion at the adjoining joint. 7- Every movement is rehearsed till it becomes natural and instinctive. 8- The aim of this retraining is to enhance the active and ultimately automatic activation of the local and global stability muscular systems for movement regulation, while reinstating the proper utilization of stiff muscles. The KCR program was conducted thrice weekly for a duration of eight weeks. Each set consisted of ten repetitions, each maintained for ten seconds. The workout commenced with duration of two to three minutes for two sets daily, subsequently advancing based on tolerance. Concentrating on Cervical extension UCM through 1: Backward head lift test, the patient voluntarily extends the lower cervical spine from a flexed posture by elevating the head while sitting upright with unsupported feet, ensuring that the pelvis, scapula, temporomandibular joint (TMJ), and upper cervical spine are maintained in a neutral position. 2: Horizontal retraction test, the patient stands with arms extended forward at 90° flexion, with scapula, TMJ; the low and upper cervical spine are in the neutral. The patient then aggressively retracts both arms, ensuring the elbows flex, the forearms remain horizontal, and the scapulae retract to achieve 15–20° of horizontal shoulder extension. The facial plane must remain vertical, avoiding any protrusion

Table 1. The direction- movement control retraining exercises.

Exercise	Progression
1. Backward head lift	1: Hands against the wall, head unsupported, maintaining upper cervical control as in the initial posture. 2: Hands against the wall, head unsupported 3: leaning forward with table support. 4: adjustment by leaning backward with chair support.
2. Horizontal retraction	1: Initiate unilateral horizontal retraction and advance to bilateral arm movement as control enhances; 2: execute the exercise with a long lever full range against light resistance.
3. Head back hinge	Progression: from supported head and shoulder girdle postures to unsupported head and shoulder girdle postures.
4. Chin lift hinge	Progression from supported head and shoulder girdle postures to unsupported head and shoulder girdle postures.
5. Head turn	1: Correction in the supine position with head support. 2: Correction using wall support and unloaded shoulder girdle. 3: Correction when seated unsupported with active shoulder control. 4: Correction not supported by neural loading. 5: Correction not supported by neuronal unloading.

of the chin or forward movement of the head. 3: Head back hinge test, the patient voluntarily elevates the head to an upright posture by retracting from the cervical base, demonstrating mid-cervical control while seated upright with unsupported feet, and with the pelvis, scapula, and TMJ in neutral alignment. The lower cervical spine is flexed by permitting the head to hang forward completely. The upper and mid-cervical spine is subsequently aligned in a neutral posture. The therapist assesses the mid-cervical neutral posture by palpating the spinous process at the hinge point with a fingertip C3 or C4. 4: Chin lift hinge test, the patient voluntarily elevates the chin vertically through upper cervical extension, envisioning the flattening of the lordosis against an imaginary wall positioned at the back of the head while sitting upright with supporting feet, ensuring the pelvis, scapula, and TMJ are in a neutral position. The therapist assesses the mid-cervical neutral position by palpating the spinous process at the hinge point, specifically C3 or C4, using a single fingertip. 5: Head turn test, the patient deliberately performs a complete axial rotation of the head by turning to gaze over each shoulder while seated upright, with feet unsupported and the pelvis, scapula, TMJ, and both the lower and upper cervical regions maintained in a neutral position¹¹. The direction-movement control retraining exercises utilized in this research are presented in Table 1.

Statistical Analysis

Statistical analysis and comparison of measured variables utilised SPSS version 23 for Windows (SPSS, Inc., Chicago, IL) with alpha significance set at 0.05. Researchers screened data for normality assumptions, variance homogeneity, and extreme value presence. The

Shapiro–Wilk normality test confirmed normal distribution of measured variables (P value >0.05). Mean and standard deviation expressed all outcomes except sex and side of radiculopathy (counts). Additionally, assumptions specific to multivariate analysis were confirmed: multicollinearity between dependent variables was evaluated using Pearson's correlation coefficients, and homogeneity of covariance matrices was examined using Box's M test. Assumptions were judged to be sufficiently satisfied. Visual examination of residual plots for each dependent variable was done to evaluate distribution symmetry, possible outliers, and homoscedasticity even though global model fit indices are not relevant in MANOVA. There were no significant infractions found, and residuals seemed to be roughly normal and equally distributed. A two-way mixed design MANOVA compared groups regarding combined outcome effects. Statistically significant MANOVA results triggered follow-up univariate ANOVAs with Bonferroni correction for each outcome measure to prevent Type I error. Pearson correlation coefficients determined the correlation between pain, cervical JPE, ANDI and DNF.

Results

Tables 2 and 3 present data indicating no statistically significant difference between the groups regarding baseline patient characteristics (P value >0.5). Mixed design multivariate analysis was performed to evaluate between-group differences in outcome measure score changes. Statistically, significant multivariate effects emerged for main group effects (difference between groups): Wilk $\lambda = 0.31$, $F_{(10, 33)} = 7.54$, P value < 0.001, Partial Eta Squared (η^2) = 0.7. Time effects (pre-post treatment for all outcomes in all groups) also showed

Table 2. Baseline general characteristics of participants (N=44)*.

Characteristics	Study Group (n=22)	Control Group (n=22)	t- value	P value
Age (years)	48.19±3.11	48.45±2.65	-0.31	0.76
Weight (kg)	77.04±5.54	75.81±7.23	0.63	0.53
Height (cm)	174.5±5.5	173.23±6.5	0.7	0.49
BMI (kg/m ²)	25.37±2.35	25.33±2.72	0.05	0.96
Duration of pain (months)	6.8±1.78	7.2±1.67	-0.78	0.44
Sex, n (%)				
Female	15 (68.18%)	14 (63.64%)	$\chi^2=0.1$	0.75
Male	7 (31.81%)	8 (36.36%)		
Side of radiculopathy, n (%)				
Right	14 (63.64%)	12 (54.55%)	$\chi^2=0.38$	0.53
Left	8 (36.36%)	10 (45.45%)		

BMI, body mass index; χ^2 , Chi Square; Data are mean ± SD for all demographics except sex and affected side (%), P value < 0.05 indicates statistical significance.

Table 3. Baseline and after 8 weeks Clinical Characteristics of participants (N=44).

Outcomes	Time	Study Group (n=22)	Control Group (n=22)	MD (95% CI)	P value
VAS (cm)	Baseline	6.27±1.42	6.45±1.4	-0.18 (-1.04, 0.69)	0.67
	After 8 weeks	1.23±0.92	2.77±0.97	-1.52 (-2.12, -0.97)	0.0001
ANDI (score)	Baseline	31.5±3.62	30.75±3.47	0.75 (-2.32, 3.83)	0.63
	After 8 weeks	12.33±2.93	22.55±5.06	-10.21 (-12.73, -7.7)	0.0001
DNFP (mmHg)	Baseline	23.23±1.31	23±1.45	0.23 (-0.61, 1.07)	0.59
	After 8 weeks	27.41±1.18	24.95±1.65	2.46 (1.58, 3.33)	0.0001
Cervical flexion JPE (degree)	Baseline	4.29±0.98	4.06±0.85	0.24 (-0.39, 0.85)	0.46
	After 8 weeks	0.99±0.21	2.15±0.72	-1.15 (-1.6, -0.71)	0.0001
Cervical extension JPE (degree)	Baseline	7.35±1.44	7.63±1.6	-0.29 (-1.21, 0.64)	0.53
	After 8 weeks	2.1±0.81	5.31±1.6	-3.21 (-3.98, -2.44)	0.0001
Cervical right rotation JPE (degree)	Baseline	7.72±1.21	7.57±1.5	0.15 (-0.71, 1.01)	0.72
	After 8 weeks	1.95±0.96	5.48±1.63	-3.53 (-4.34, -2.72)	0.0001
Cervical left rotation JPE (degree)	Baseline	6.53±1.69	6.94±1.53	-0.41 (-1.4, 0.57)	0.4
	After 8 weeks	1.86±0.83	4.37±1.26	-2.51 (-3.16, -1.86)	0.0001

Data are mean± SD, MD; mean difference, CI; confidence interval, P value < 0.05 indicates statistical significance, VAS: visual analogue scale, ANDI: Arabic neck disability index, mmHg: millimetres of mercury, DNFP: deep neck flexor performance, JPE: joint position error.

statistical significance: Wilk $\lambda = 0.01$, $F_{(10, 33)} = 284.71$, P value < 0.001, $\eta^2 = 0.99$, plus group-time interaction (group*time) demonstrated statistical significance: Wilk $\lambda = 0.09$, $F_{(10, 33)} = 35.24$, P value < 0.001, $\eta^2 = 0.91$.

Between-groups comparison

Following eight weeks of intervention, Statistical analysis revealed significant differences between groups across all

measured outcomes, favouring the study group (P value < 0.05), as in Table 2-3.

Within-group comparison: In both groups, there were statistically significant differences between pre-post interventions in all measured variables in favour of the study group (P value < 0.05), as shown in Table 4.

Correlation between VAS, cervical JPE, ANDI and DNF: VAS is the primary outcome, cervical JPE, ANDI, and DNF

Table 4. Within-groups Comparisons for all outcome measures.

Outcomes	Study Group (n=22)		Control Group (n=22)	
	Change from baseline to 8 weeks		Change from baseline to 8 weeks	
	MD (95% CI)	P value	MD (95% CI)	P value
VAS (cm)	5.04 (4.38, 5.71)	0.0001	3.68 (3.02, 4.35)	0.0001
ANDI (score)	19.17 (16.67, 21.68)	0.0001	8.21 (5.7, 10.71)	0.0001
DNFP(mmHg)	4.18 (3.71, 4.65)	0.0001	1.96 (1.48, 2.43)	0.0001
Cervical flexion JPE (degree)	3.29 (2.88, 3.7)	0.0001	1.91 (1.5, 2.32)	0.0001
Cervical extension JPE (degree)	5.24 (4.78, 5.71)	0.0001	2.32 (1.85, 2.78)	0.0001
Cervical right rotation JPE (degree)	5.77 (5.19, 6.36)	0.0001	2.09 (1.51, 2.67)	0.0001
Cervical left rotation JPE (degree)	4.67 (4.08, 5.25)	0.0001	2.57 (1.99, 3.16)	0.0001

Data are mean ± SD, MD; mean difference, CI; confidence interval, P value < 0.05 indicates statistical significance, VAS: visual analogue scale, ANDI: Arabic neck disability index, mmHg: millimeters of mercury, DNFP: deep neck flexor performance, JPE: joint position error.

Table 5. Correlation between pain and joint position error (N=44).

	Secondary Outcomes	r value	P value	Sig
VAS (cm) (primary outcome)	Cervical flexion JPE	0.35	0.11	NS
	Cervical extension JPE	0.29	0.2	NS
	Cervical right rotation JPE	0.44	0.04	S
	Cervical left rotation JPE	0.54	0.01	S
	ANDI	0.39	0.08	NS
	DNFP	-0.09	0.69	NS

r value: Pearson correlation coefficient, P value: Probability value, S: significance, JPE: joint position error, VAS: visual analogue scale, ANDI: Arabic neck disability index, DNFP: deep neck flexor performance.

considered secondary outcomes. The correlation between VAS and cervical flexion JPE was weak non-significant ($r = 0.35$, P value = 0.11). Also, there was weak non-significant correlation between VAS and cervical extension JPE ($r = 0.29$, P value = 0.2). At the same time, there was a moderate positive, significant correlation between VAS and right rotation JPE ($r = 0.44$, P value = 0.04). Furthermore, a moderate positive and significant correlation existed between VAS and left rotation JPE ($r = 0.54$, P value = 0.01). In addition, weak positive non-significant correlation between VAS and ANDI ($r = 0.36$, P value = 0.08). Finally, there was weak negative non-significant correlation between VAS and DNF ($r = 0.09$, P value = 0.69) as in Table 5.

Discussion

The treatment of CSR ranges from conservative management to surgical interventions²³. Despite exercise

being the fundamental therapeutic intervention for neck pain conditions, substantial ambiguity surrounds the ideal exercise parameters and administration approaches necessary for optimising pain relief and functional improvement²⁴. Therefore, the present research sought to evaluate the impact of KC exercises on cervical proprioceptive abilities and function. However, the study's findings indicated that all evaluated indicators showed improvement in both groups, and the KC group benefited more than the control group.

The research group exhibited more favorable reflections on pain intensity, disability level, cervical proprioception, and deep neck flexor performance compared to the control group after completing the KCR program, indicating that the KCR has the potential to improve neck proprioception and function in cervical radiculopathy patients. These findings align with prior research^{25,26} revealing the clinical effectiveness of motor control interventions incorporating Kinetic Control-based motor control training into

rehabilitation significantly improved pain intensity and impairment levels compared to standard training alone. Their investigation emphasised how these exercise protocols restore physiological muscle activation patterns, as documented through electromyographic assessment, while facilitating movement pattern re-education. Additionally, current findings demonstrate consistency with O'Sullivan et al.²⁷ observations, indicating that correction or rehabilitation of motor control dysfunction produces significant reductions in pain recurrence frequency. Moreover, various therapeutic exercise approaches are practical across diverse patient populations. Rehabilitation strategies designed to address uncontrolled movement patterns, validated through clinical evidence, are experiencing increased recognition and professional acceptance since patients may exhibit similar diagnostic pathology yet demonstrate different kinematic mechanism presentations¹¹. Significantly, active movement interventions have demonstrated efficacy in alleviating short-term and intermediate-term pain symptoms and functional limitations among individuals experiencing chronic cervical pain²⁸.

Besides alleviating pain and disability level, we reported an enhancement in proprioception following 8 weeks of the KCR program. This aligns with previous studies^{29,30} findings, which indicated that motor control therapy exercises can enhance JPE, indicated that those exercises help regulate muscle tone, alleviate pain, and rectify sensorimotor incongruence. As discussed, cervical spondylosis (CS) may result in altered proprioceptive afferent signals coming from the skin, joints, and muscle spindle receptors caused by degenerative changes in capsuloligamentous structures, muscular dysfunction, as well mechanoreceptors³¹. Patients with CS exhibit heightened fatigue and diminished strength in both deep flexor and dorsal neck extensor muscles during higher force levels, as indicated by electromyography. Reduced muscular power and heightened muscle exhaustion may alter the activation of sensory receptors (Golgi tendon organs or muscle spindles), thereby altering afferent inputs and leading to diminished proprioception⁸. The observed enhancements may be elucidated by KCR integration of balanced movement pattern presentation with the optimal incorporation of critical sensorimotor neuromuscular control components, facilitated by afferent sensory feedback, particularly proprioceptive signals, central nervous system processing, coordinated motor responses, and suitable physiological loading to foster functional dynamic stability and regulated movement capacity¹¹. This reinforces the principle that motor control refers to the central nervous system's ability to generate coordinated and integrated movements that are functional in relation to the body and its surroundings. Alterations in motor control which could induce dysfunction or pain necessitate clinicians focusing upon the components of motor learning to execute an effective intervention that fosters adequate motor learning and retention. This intervention necessitates repetitive training. Consequently, Hidalgo

et al. (2015) stated that motor control exercises (MCEs) reduce JPE, and are pertinent for NP³². Also, Izquierdo et al. (2016) found that enhanced activation of deep neck flexors improves afferent feedback from muscle spindles, hence permitting more precise spatial awareness of head and neck position. So, MCEs assist in recalibrating the integration of visual, vestibular, and proprioceptive signals, thereby improving sensorimotor integration through repetitive, precise motions that promote cortical reconfiguration and enhance central processing of proprioceptive input³³. Additionally, in KC methodology, a low-load (facilitatory) proprioceptive stimulus that presents a proprioceptive challenge can serve as an effective facilitation and advancement strategy¹¹. Also, a moderate positive significant correlation has been identified in our research between VAS and cervical rotation JPE, matching the findings of Reddy et al. (2019) who reported a substantial positive correlation between the severity of neck pain and errors in position sense among those experiencing neck pain⁸. The literature is controversial on the relevance of JPE to CNP. Some studies reported varying JPEs^{34,35}. Others were unable to identify any distinctions between CNP patients and asymptomatic participants^{36,37}.

From an outcome's standpoint, there appear to be enhancements in deep neck flexor performance. Falla et al.'s (2012) results provide some explanation for this finding. They observed an elevation in electromyography amplitude for the deep cervical flexors during craniocervical flexion³⁸. Intrafusal fibers can be recalibrated through exercise, thereby interrupting the cycle of muscular tension, compromised circulation due to metabolite accumulation, and the pain linked to myofascial discomfort³⁹. Another theory posits that active therapies may enhance intermuscular function, leading to a cumulative effect on pain. Motor control training is thought to enhance the synchronization between the deep cervical flexors and the superficial neck flexors⁴⁰. Shah et al. also revealed notable disparities in DNF strength between groups, indicating that incorporating stability exercises into conventional physiotherapy produced superior outcomes in chronic neck pain patients⁴¹. The research presented showed greater pain and functional limitation reduction in the KCR cohort, potentially attributable to targeted restoration of normal movement coordination and muscle synergy, as proposed by Comerford and Mottram¹¹.

The research findings of the present study demonstrated a weak positive non-significant correlation between VAS and ANDI. Contrary to our study, Resnick et al. (2005) revealed a moderate correlation between pain intensity and the NDI score, despite his conclusion that acquiring a gold standard subjective outcome measure regarding neck pain would be challenging due to the diverse biopsychosocial influences affecting each patient individually⁴². As a result of this study, there was a weak negative non-significant correlation between VAS and DNF performance. In agreement with our study, this correlational study by Amiri Arimi et al. (2018)

found no significant correlation between VAS (pain) and several DNF size/endurance variables⁴³. A recent paper by Hong et al. (2020) revealed no significant correlation between DNF endurance/thickness and pain intensity⁴⁴. Contrary to our study, Desai and Ansari (2022) reported significant correlation was found between intensity of pain, functional disability and deep neck flexor endurance in individual with chronic non-specific neck pain⁴⁵.

The lack of correlation among most parameters might be ascribed to the limitation in sample size analyzed in our present research. Considering, the PBU is incapable of directly measuring muscle activation; it can only detect changes in pressure. This complicates the assessment of the activity level of DNFs⁴⁶. Subsequent research should evaluate the long-term effects of KCR and examine the influence of variables such as pain severity, patient age, and adherence to treatment programs on treatment outcomes. To enhance comprehension of the effects of these interventions on function, incorporating quality of life and engagement in daily activities. To elucidate the significance of KCR in the management of cervical radiculopathy, future research should focus on larger trials with extended follow-up durations.

Limitations

Lack of participant blinding, short follow-up, potential performance bias given active control content, and absence of adherence/fidelity data. Additionally, the investigation lacked control over confounding variables such as medication use, lifestyle factors, and home exercise adherence.

Conclusion

Kinetic Control retraining effectively complements physical therapy in managing cervical radiculopathy by addressing subtle deficits in spinal control; this method not only alleviates pain and enhances range of motion but also positively affects kinesthetic awareness and overall functional capacity.

Ethics Approval

The study was approved by the Ethics Committee of the Faculty of Physical Therapy, Cairo University (No. P.T.REC/O12/OO4919).

Consent To Participate

Written informed consent was obtained from all participants.

Authors' Contributions

EWS: conceived the concept, delivered the intervention, compiled and structured the data, and authored the article. NAS: was responsible for conducting and examining the literature and supervising it. NIR: critically reviewed and revised the manuscript. All authors have reviewed and approved the final manuscript and are accountable for its content and similarity index.

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