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Original article

Effects of progressive neuromuscular control training on the functional mobility in stroke with bilateral osteoarthritic knee

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Abstract

Background: In low- and middle-income nations such as India, cases of stroke are increasingly being reported to contribute to premature mortality and disability. In fact, 29.0–32.0% of individuals impacted by stroke experience musculoskeletal problems. Musculoskeletal disabilities such as osteoarthritis (OA) limit functional mobility and interfere with rehabilitation. In addition to reduced muscle strength, patients with degenerative pathology of the knee have impaired proprioceptive acuity, damaged sensory receptors, and a deficiency in muscle activation.

Objective: To determine the effects of progressive neuromuscular control training on functional mobility in stroke patients with bilateral knee OA (KOA)

Methods: A total of 100 participants aged 45–75 years were randomly assigned to two equal groups for this case-control study: the experimental group received an 8-week neuromuscular control training program, while the control group received the standard therapy. The participants were all stroke survivors in the third stage of the Brunnstrom stages of recovery and had either Grade 1 or 2 OA of both knees.

Results: Both the Visual analog scale (VAS) at rest and the VAS during activity in the intervention group were significantly lower than in the control group ($P < 0.0001$). The range of knee flexion of the hemiparetic side was not significant between the two groups ($P = 0.8532$), but that of the nonhemiparetic limb in the intervention group was significantly lower than that in the control group ($P = 0.0029$). The hemiparetic limb's foot progression angle showed no significance, whereas the nonhemiparetic limb's foot progression angle was significantly lower in the intervention group than in the control group ($P < 0.0001$). The walking velocity, voluntary control grading, and the elderly mobility scale in the postintervention group were significantly greater than those in the control group ($P < 0.0001$).

Conclusion: Progressive neuromuscular control training was observed to improve pain, spatial and temporal gait parameters, voluntary control, and functional mobility. There was a lack of effect on the range of knee flexion and the degree of toe out of the hemiparetic limb and only a little effect on the range of knee flexion and the degree of toe out of the nonhemiparetic side.

Keywords: Elderly mobility scale (EMS), gait, neuromuscular control training, osteoarthritis, stroke

In low- and middle-income nations like India, stroke is increasingly contributing to premature mortality and disability. This trend is primarily attributable to changes in the population and is further exacerbated by the rising prevalence of major modifiable risk factors. [1]

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Stroke can be classified into hemorrhagic and ischemic types. Most cases of strokes are of the ischemic type, with hemorrhagic type accounting for only 20.0% of all cases. [2] A stroke with an ischemic etiology can occur due to embolism, thrombosis, or hypoperfusion. In 1970, the World Health Organization defined stroke as "rapidly developed clinical signs of focal (or global) disturbance of cerebral function, lasting more than 24 hours or leading to death, with no apparent cause other than that of vascular origin". [3] Significant variables leading up to a stroke include hypertension, diabetes, smoking, menopause, obesity, hyperlipidemia, atherosclerotic plaques, drug abuse, lack of physical activity, coronary artery diseases, and cardiomyopathy. The male population is much more likely to suffer a stroke. Premenopausal women are three times less likely to suffer from cardiovascular diseases than men of comparable age. (4) This aspect is attributed to the vascular protective effects of estrogen. (4) However, most stroke deaths now occur in females due to their greater life expectancy. (5) A cerebrovascular accident (CVA) involves the loss of consciousness along with alterations in tone, reflexes, and sensory, motor, perceptual, cognitive, and language functions.

More than one-third of all patients who have experienced an acute stroke suffer from aphasia, which is typically accompanied by hemiparesis or hemiplegia. (6) Stroke frequently stands as the primary factor contributing to aberrant limb motion mechanics and compromised gait performance, leading to pain, diminished muscle strength, impaired motor control, and the presence of spasticity. (7) Osteoarthritis (OA) is a progressive and degenerative condition with unlikely regression and restoration of damaged structures. (8) Musculoskeletal disabilities limit functional mobility and interfere with rehabilitation, possibly resulting from a preexisting condition or as a result of a direct complication of stroke. Especially notable is the occurrence of OA, a degenerative pathology of the joints that often accompanies stroke due to its heightened prevalence with advancing age. (9) As a chronic condition affecting the entire joint, including the articular cartilage, meniscus, ligaments, and peri-articular muscle, knee OA (KOA) is not just a localized disease of the cartilage. Moreover, it can be caused by a variety of pathophysiological processes. (10) On the contrary, the OA population exhibited a 36.0% higher overall incidence of stroke as opposed to the non-OA cohort. (11) Patients with degenerative pathology of the knee chiefly complain of pain that induces functional limitations in activities of daily living, sports, and recreation, culminating in withdrawal from physical activity in comparison to that in the general population. (12)

The initial approach to treating knee OA involves a combination of patient education, weight loss, and exercises. Positive effects were noted not only on pain but also on motor performance with aerobic training, local exercise, and strength training considering that muscle weakness of the lower limb is a common trait in individuals with KOA. (13) Apart from muscle weakness, patients with degenerative pathology of the knee have reduced proprioceptive acuity, damaged sensory receptors, and muscle activation deficiency. (14) Neuromuscular training (NMT) is conceptualized as a type of sensorimotor training hypothesized to improve unintentional motor behavior by stimulating afferent impulses and central processes responsible for dynamic joint control, thereby effectively incorporating neuromuscular and biomechanical principles. (15) NMT considers the complete spectrum of motor activation and control, encompassing: A) cognitive awareness involving higher cortical centers; B) brainstem control mediated by the vestibular and mechanoreceptor systems; C) spinal cord control mediated by reflexes. (16) NMT involves close kinematic chain exercises and muscular coactivation that reduces forces on the articular surfaces, involving all joints of the injured limb in an active movement of synergies. (12)

KOA occurring in subjects with poststroke hemiplegia or hemiparesis interferes with rehabilitation. Past studies have demonstrated that neuromuscular exercises incur a favorable effect on degenerative knee diseases, although no studies have so far shown any effects in patients who have survived a stroke and have OA in both knees. Our research aimed to determine the impact of progressive neuromuscular control training on functional mobility in stroke patients with bilateral KOA.

Materials and methods

A total of 100 participants of both genders and ages 45 to 75 years were enrolled in this case-control study. All participants were stroke survivors in the 3rd stage of Brunnstrom's stages of recovery and had bilateral KOA with grade 1 or 2 of the Kellgran and Lawrence classification. This study excluded subjects suffering from psychological, behavioral, and cognitive impairments as well as visual and auditory disturbances.

This research concerning human use adhered to all pertinent national regulations and institutional policies and aligns with the principles outlined in the Helsinki Declaration. Approval for the research was granted by the Institutional Ethical Committee of Krishna Vishwa Vidyapeeth, KIMSDU. (Protocol no. 056/2023-2024). Informed consent was procured from each participant of this study.

Procedure

The objective of this research was explained to all participants and their informed consent was obtained before beginning the research. Each participant's pain and range of motion (ROM) of both knees were assessed and recorded. The spatial parameters of gait, such as step length, base of support, stride length, and degree of toe out along with temporal parameters of gait, such as cadence and velocity, were assessed and recorded. Voluntary control was graded on the voluntary control grading (VCG) scale, and functional mobility was graded on the elderly mobility scale (EMS). The participants were assigned to two groups of 50 patients each on a random basis: groups 1 and 2. During the 8 weeks of this study, Group 1 (the study group) received an NMT program that progressed every 2 weeks, while group 2 (the control group) was provided traditional therapy. At the end of this duration, each participant's pain and ROM of both knees, along with the spatial and temporal parameters of gait, were assessed and recorded. Voluntary control and functional mobility were graded on the VCG scale and the EMS, respectively.

Outcome measures

Visual analog scale (VAS): The VAS is often used to quantify an individual's pain intensity by asking them to report their pain level on a 10-point scale, with 0 indicating no pain and ten indicating the worst pain imaginable. It is a reliable scale for determining how much pain people with OA of the knee experience. Test-retest reliability was performed to determine the intraclass correlation coefficient (ICC) = 0.97 [17]

Knee flexion ROM: Knee ROM is commonly used as an outcome measure in clinical trials of patients with knee OA. Goniometry is a reliable and valid method of measuring knee ROM as well as a convenient and accessible outcome measure utilized in clinical trials and physiotherapy practice. [18]

Stride length (cm): The distance covered by the complete gait cycle is calculated by measuring the distance between the point of the heel strike of one foot and the same point of the same foot during the next step. ICC = 0.96. [19]

Velocity (m/s): It is the distance walked by a subject per second. ICC = 0.92. [19]

Cadence (steps/min): The number of steps completed by a subject in a minute. ICC = 0.92. [19]

Degree of toe out: It is the angle formed by the foot with the plane of walking. It is calculated by measuring the angle formed between the line of walking and the line formed by. The normal degree of toe out is approximately 7º. [20]

Step length (cm): The distance covered when the subject takes one step. It is calculated by measuring the distance between the point of the heel strike of one foot and the same point of the contralateral foot. ICC = 0.91–0.98. [21]

Step width (cm): It is the mediolateral distance between both feet. It was calculated by measuring the distance between the central line of each foot parallel to the plane of walking. ICC = 0.91–0.98. [21]

Voluntary control grading (VCG): It is an evaluation scale ranging from 0 to 6 that is used to assess motor control in stroke patients who are in the Brunnstorm stages of recovery.

Elderly mobility scale (EMS): It is a tool used to assess functional mobility in elderly subjects, with a minimum score of zero and a maximum score of 20. It focuses on seven tasks employed in the daily routine, such as moving from lying to sitting position, moving from sitting to lying position, moving from sitting to standing position, standing, walking, the time taken to walk for 6 m, and functional reach. A total score of <10 indicated complete dependence on others for basic daily tasks, including transfers, dressing, and toileting. A score of 10–13 indicated borderline dependence in everyday activities, where the subjects required only a little help. A score of >13 indicated that the subject could independently perform the basic activities of daily living. EMS was found to have a highly substantial relationship with the Barthel index and functional independence measure. [22]

Exercise intervention

Study group

The study group included 50 subjects selected randomly to overcome bias. The exercise program was 8 weeks long, divided into four levels of 2 weeks each. Level 1 comprised a baseline treatment that included the application of a hot moist pack for 10–15 min and transcutaneous electrical nerve stimulation (TENS), followed by stretches, active assisted exercises, vastus medialis oblique (VMO) strengthening, basic bed mobility exercises, movement transitions, and functional mobility exercises such as strengthening. Levels 2–4 included neuromuscular control exercises along with baseline treatment that progressed with each level. Exercises in level 2 were performed with support, which then progressed to level 3 with either minimal or no support and only slightly increased in difficulty, for example in performing exercises on an uneven surface or with eyes closed. In level 4, which occurred during the 7th and 8th week, exercises were performed with increasing difficulty level and against resistance.

Control group

Group 2 included 50 subjects who were selected randomly. They were subjected to a conventional exercise program lasting for 8 weeks. It involved the application of a hot moist pack for 10–15 mins on both knees along with transcutaneous electrical nerve stimulation (TENS), followed by stretches of the biceps, hamstrings, and tendon Achilles, active assisted exercises, VMO strengthening, basic bed mobility exercises such as heel slides, pelvic bridges, cat and camel poses in quadruped, movement transitions from supine to side lying and from side lying to sitting, and functional mobility exercises that included reaching out exercises in supine, sitting, quadruped, and standing positions.

Statistical analysis

Excel sheets were used to record the obtained data, and SPSS 26.0 for Windows (SPSS Inc.,) was used to perform the statistical analysis. Pre- and post-training differences within the groups were found using unpaired *t*-tests in the statistical analysis that was conducted using descriptive statistics. The level of significance was set at $P < 0.05$.

Results

In this study, the subjects mainly comprised women, largely within the middle-aged demographics. Most patients presented with right-sided hemiparesis, albeit a smaller subset exhibited left-sided hemiparesis **(Table 1).** The paired test was performed to evaluate the pre- and postvalues in both groups. In the control group, VAS (at rest) displayed no significance (P = 0.0747). The average VAS on activity was found to be significant (P = 0.0001). The average of the range of knee flexion of the hemiparetic limb was, however, not significant (P = 0.1614). The degree of knee flexion of the nonhemiparetic limb also showed no significance (P = 0.8066). The step length proved to be significant (P = 0.0072). However, there was no significant difference in the step width and stride length between the pre- and post-treatment subgroups in the control group. The foot progression angle measured on the hemiparetic limb was significant (P = 0.0143).

In the control group, pre- and post-test comparisons revealed no statistically significant differences in the foot progression angle of the nonhemiparetic limb or the outcome velocity. The average cadence in the post-treatment group was significantly higher than that in the pre-treatment group. The average of the VCG and EMS were significantly higher in the post-test than in the pre-test **(Table 2).** The factors of step length, stride length, velocity, cadence, VCG, and EMS were significantly higher in the intervention group compared to the control group ($P < 0.0001$). The outcome measures were recorded at two intervals during this study, pre- and post-treatment **(Table 3)**. VAS at rest and VAS on activity were found to be significantly lower in the intervention group than in the control group ($P < 0.0001$). No significant difference was noted in the knee flexion ROM on the hemiparetic side between the intervention and control groups (P = 0.8532), whereas the range of knee flexion of the nonhemiparetic limb was significantly higher in the intervention group compared to that in the control group (P = 0.0026). The step length and stride length were significantly higher in the intervention group ($P < 0.0001$). The hemiparetic limb's foot progression angle revealed no significance, whereas the nonhemiparetic limb's foot progression angle was significantly lower in the intervention group than in the control group ($P < 0.0001$). The walking velocity, VCG, and EMS in the post-intervention group were significantly greater than in the control group ($P < 0.0001$).

A comparative analysis between the two groups revealed that the intervention group had statistically significant improvements across several functional outcomes when compared with those in the control group, including pain, gait parameters, and walking speed. Both groups exhibited significant changes in some gait metrics and muscle functions, although the intervention group consistently outperformed the control group across multiple measures **(Table 4)**.

Table 1. Demographic variables of participants who suffered a stroke and have bilateral knee osteoarthritis.

Age	Male	Female	Total
45 - 54 years	14	22	36
55 - 64 years	16	19	35
65 - 75 years	14	15	29
Total	**44**	**56**	**100**

Table 2. Pre- post, and *P*-values among the participants in the control group. VCG, voluntary control grading; EMS, elderly mobility scale.

Outcome measure	Pre	Post	*P*-value
VAS (at rest)	4.1 ± 1.2	4.0 ± 1.2	0.0747
VAS (on activity)	6.9 ± 0.8	6.5 ± 0.9	0.0001***
Knee ROM (hemiparetic side) (°)	41.0 ± 13.7	41.5 ± 12.9	0.1614
Knee ROM (non- hemiparetic side) (°)	109.8 ± 10.2	109.3 ± 17.6	0.8066
Step length (cm)	16.5 ± 4.4	16.3 ± 4.2	0.0072**
Step width (cm)	15.1 ± 1.6	15.0 ± 1.5	0.1322
Stride length (cm)	33.2 ± 8.6	33.3 ± 8.3	0.4553*
Foot progression angle (hemiparetic side) (°)	19.9 ± 3.6	19.6 ± 3.2	0.0143*
Foot progression angle (non-hemiparetic side) (°)	13.0 ± 2.5	13.0 ± 2.0	0.5518
Velocity (m/sec)	0.3 ± 0.2	0.3 ± 0.2	0.7119
Cadence (steps/min)	50.2 ± 10.3	50.5 ± 10.0	0.0055**
VCG	2.9 ± 0.4	3.0 ± 0.3	0.0068**
EMS	3.9 ± 2.5	4.0 ± 2.4	0.0334*

***, extremely significant; **, very significant; *, significant. EMS, electric muscle stimulation; VAS, Visual Analog Scale; VCG, voluntary control grading scale.

Table 3. Pre-post and *P*-values among the subjects in the intervention group.

Outcome measure	Pre	Post	*P*-value
VAS (at rest)	4.0 ± 1.1	1.7 ± 1.1	< 0.0001*
VAS (on activity)	7.0 ± 0.8	4.6 ± 1.2	< 0.0001*
Knee flexion range of motion (hemiparetic side) (°)	40.3 ± 14.1	41.0 ± 13.0	0.1761*
Knee flexion range of motion (non- hemiparetic side) (°)	98.6 ± 10.7	100.8 ± 8.4	0.0004*
Step length (cm)	24.0 ± 3.9	34.9 ± 3.8	< 0.0001*
Step width (cm)	17.9 ± 3.2	10.0 ± 2.2	< 0.0001*
Stride length (cm)	48.7 ± 7.3	70.9 ± 7.2	< 0.0001*
Degree of toe-out (hemiparetic side) (°)	19.3 ± 4.6	19.1 ± 4.4	0.0193*
Degree of toe-out (non-hemiparetic side) (°)	11.6 ± 1.5	11.5 ± 1.4	0.0580
Velocity (m/sec)	0.4 ± 0.2	0.5 ± 0.2	< 0.0001*
Cadence (steps/min)	41.7 ± 10.7	43.5 ± 10.6	< 0.0001*
VCG	2.9 ± 0.3	3.4 ± 0.7	< 0.0001*
EMS	4.4 ± 3.0	10.4 ± 1.9	< 0.0001*

***, extremely significant; **, very significant; *, significant. EMS, electric muscle stimulation; VAS, Visual Analog Scale; VCG, voluntary control grading scale.

Table 4. Analytical results of the post-test from groups 1 and 2.

Outcome measures	Post-test Intervention group 1	Post-test Control group 2	*P*- values for post-test
VAS (at rest)	1.7 ± 1.1	4.0 ± 1.2	< 0.0001
VAS (on activity)	4.6 ± 1.2	6.5 ± 0.9	< 0.0001
Knee flexion range of motion (hemiparetic side)	41.0 ± 13.0	41.5 ± 12.9	0.8531
Knee flexion range of motion (non- hemiparetic side)	100.8 ± 8.4	109.2 ± 17.6	0.0026
Step length (cm)	34.9 ± 3.8	16.3 ± 4.2	< 0.0001
Step width (cm)	10.0 ± 2.2	15.0 ± 1.5	< 0.0001
Stride length (cm)	70.9 ± 7.2	33.3 ± 8.3	< 0.0001
Foot progression angle (hemiparetic side)	19.1 ± 4.4	19.6 ± 3.2	0.5163
Foot progression angle (non-hemiparetic side)	11.5 ± 1.4	13.0 ± 2.0	< 0.0001
Velocity	0.5 ± 0.2	0.3 ± 0.2	< 0.0001
Cadence	43.5 ± 10.6	50.5 ± 9.9	0.0009
VCG	3.4 ± 0.7	3.0 ± 0.3	< 0.0001
EMS	10.4 ± 1.9	4.0 ± 2.4	< 0.0001

EMS, electric muscle stimulation; VAS, Visual Analog Scale; VCG, voluntary control grading scale.

Discussion

This study aimed to determine the effects of progressive neuromuscular control training on functional mobility in stroke survivors with bilateral KOA. This study involved 100 participants aged 45–75 years who were in the 3rd stage of Brunnstorm's stages of recovery and suffered from grade 1 or 2 OA in both knees. An individual's age and gender are prominent yet unmodifiable factors leading to a stroke and KOA. Men of ages 45–74 years demonstrated higher deaths and occurrence of stroke as opposed to women of age >74 years. [23] This disparity may be attributed to the fact that men are more likely than women to experience stroke because of neurovascular risk factors, including smoking, which is more prevalent and severe in men compared to women. Women have a relatively greater chance of developing KOA, as men have a greater volume of knee cartilage. There appears to be a stronger correlation between OA and stroke cases in the female population, and the greatest incidence of these diseases occurs in women around menopause. [24, 25] This report was supported by the present results, which indicated that women accounted for 56.0% and males accounted for 44.0% of all participants. The participants' ages ranged from 45 to 54 years (36.0%), 55–64 years (35.0%), and 65–75 years (29.0%). Injury to one side of the brain caused hemiparesis on the contralateral side of the body. In the year 2014, a study was conducted to determine the relationship between the side of hemiparesis and functional independence. Out of 130 survivors of stroke with OA of both knees that participated in this study, 46.9% had right-sided hemiparesis and the remaining 53.1% had left-sided hemiparesis. [26] In our study, most of the participants suffered from right-sided hemiparesis, with 42.0% suffering from left-sided hemiparesis.

The goal of rehabilitation in people who have suffered stroke is to provide them functional independence and restore the self-sufficiency they need to conduct everyday tasks and enable them to reintegrate into society. [27] KOA not only adds to the burden caused by the disabilities occurring in stroke survivors but also interferes with rehabilitation and slows down the recovery process. A study conducted in the year 2022 by Miryutova *et al*. studied the functional and restrictions of activities in patients after a stroke, which revealed that most patients after a stroke faced restrictions in the functioning of paretic limbs and activities that involved maintenance of the attitude of the body, walking, movement, transfer, manipulation of items, and hygiene leading to reliance on others in daily life. [28] In this study, functional mobility was graded by using the EMS, which is a 20-point scale used to grade the degree of dependence in disabled subjects in their day-to-day activities. The neuromuscular control training results showed extreme significance in terms of functional mobility in the study group. After undergoing an 8-week exercise intervention, the study group's average score on the EMS increased from 4.4 to 10.4, while the VCG scores improved from 2.9 to 3.4. Conventional therapy, which included the application of a hot moist pack, TENS, VMO strengthening, active assisted exercises, and general mobility exercises, was effective in group 2. However, the control group's average EMS score was 3.9 before and 4 following the standard therapy, exhibiting very little variation. Similarly, the average VCG score in group 2 only improved from 2.9 to 3.0.

Hemiplegic or hemiparetic gait patterns also reduced functional mobility and increased the extent of dependability. Spatial and temporal variables of gait markedly differed from those of an ideal individual in poststroke and OA patients. Stroke survivors displayed shorter step or stride length, a greater degree of toe out, a wider step width, and decreased velocity and cadence in contrast to non-disabled people of comparable age. [29] In this study, group 1 showed extremely profound improvements in the variables of gait as opposed to the control group. The average step length and length of stride increased from 24.0 and 48.7, respectively, to 34.9 and 70.9. The mean step length and stride length of the control group were, however, 16.5 and 33.2, respectively, before and 16.3 and 33.3, after the conventional therapy, indicating little to no improvement. The mean step width decreased from 17.9 to 10.0 in group 1, whereas the step width in group 2 only reduced from 15.1 to 15.0, indicating no improvement. The average cadence and velocity of the study group displayed promising improvements from 41.7 and 2.9, respectively, to 43.5 and 3.4, respectively. Group 2 showed little growth in the average cadence and velocity from 50.2 and 2.9, respectively, to 50.5 and 3. The degree of toe out of the hemiparetic limb showed a slight improvement in both groups, whereas, in the nonhemiparetic limb, there was no improvement in the degree of toe out in either group.

In 2021, a randomized controlled trial studied the outcomes of progressive NMT on pain, function, and balance in subjects with KOA and detected positive changes in pain, function, and balance. Pain intensity improved in the 1st group from 4.0 to 1.7 at rest and from 6.9 to 4.6 on activity. Whereas, pain at rest did not improve in the control group, reducing from 4.1 to 4.0 only. However, pain during activity improved slightly in the control group, reducing from 6.9 to 6.5. The average range of knee flexion of the hemiparetic limb did not improve in either group. The average range of knee flexion of the nonhemiparetic limb exhibited improvement only in the study group. The present research has certain restrictions in terms of being time- and geographically limited. In addition, the sample size of this study was small.

Conclusion

Progressive neuromuscular control training could alleviate pain, spatial and temporal parameters of gait, voluntary control, and functional mobility. However, no benefit was achieved in the range of knee flexion and the degree of toe out of the hemiparetic limb and only a little effect in the range of knee flexion and the degree of toe out of the nonhemiparetic side.

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Conflicts of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported.

Data sharing statement

All data generated or analyzed during the present study are included in this published article. Further details are available for noncommercial purposes from the corresponding author upon reasonable request.

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