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Efficacy of robotic hand glove on upper limb motor recovery and gait speed in patients with chronic stroke – an experimental study

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Abstract

Background: More than 50% stroke patients shown more impairment in upper limb motor functions. With upper limb impairment, gait speed is also affected due to inter limb coupling which is controlled by central pattern generators (CPGs) and corpus callosum during walking. Various interventions are used to improve upper limb motor function but training with robotic hand glove training is not used widely for rehabilitation.

Objective: To assess the effectiveness of robotic hand training on upper limb motor functions and gait speed in patients with chronic stroke**.**

Methodology: Total of 26 participants were included in the group as per criteria. Patients were randomly divided into two groups, Experimental group (Group-A) who received robotic hand training and conventional therapy and Control group (Group-B) who received only conventional therapy for 5 days per week for total 4 weeks. Pre and post intervention assessment carried out by using Wolf motor function test (WMFT), Fugl-Meyer assessment for upper extremity (FMA-UE), 10meter walk test (10MWT).

Result: After 4 weeks of training both groups showed significant improvement ($p<0.05$), but Robotic hand glove training group showed significant improvement than control group in patients with chronic stroke. ($p<0.05$)

Conclusion: This study concluded that soft robotic hand glove training in addition to conventional therapy is useful to improve upper limb motor functions and gait speed in patients with chronic stroke.

Keywords: Arm swing, chronic stroke, Gait speed, Soft robotic glove training, and upper limb motor function

Introduction

Stroke is also a major public health problem in India, where the incidence of stroke ranges from 105/100,000 to 152/100,000 per year, with an incidence that continues to increase year by year. Age is a major factor influencing the incidence of stroke in India, where increasing longevity and declining fertility rates have led to an increasingly aging society, with the population over 60 years of age expected to account for 19.1% of the total population by 2050. [1] According to the Global Burden of Disease Study, the prevalence of stroke has decreased, the age of those affected, their sex and their geographic location mean that the socio-economic burden of stroke has increased over time. [2]

In stroke common risk factors are there out of that some are the modifiable risk factors including smoking, hypertension, hyperlipidaemia, diabetes, obesity, alcohol consumption, and non-modifiable risk factors including age, gender, race, genetics, TIA (Transient ischemic stroke).[2, 3, 4] Common affections are seen which includes hemiplegia or hemiparesis on the opposite side of the body from the lesion are the hallmarks of motor dysfunction other neurological impairments according to brain area affection. These impairments can lead to difficulties in activities of daily living. Strokes remain a major source of functional disabilities in the elderly because of their frequency and consequences. [5]

Such impairments affect an individual's ability to complete everyday activities (disability) and affect participation in everyday life situations. Residual muscles fatigue, abnormal movement strategies, and spasticity cause an altered gait style. [6] The majority of individuals reach a level of independent gait after stroke, many suffer sustained gait impairment that affects their daily activity performance and functional independence. The hemiparetic abnormalities with asymmetry and increased stride variability, along with muscle weakness, put individuals with stroke at a high risk of falls during walking it led to impaired equilibrium, a higher chance of falling and elevated energy consumption while walking which ultimately leads to decrease gait speed.[6] Furthermore, an estimated two-thirds of patients have lower-limb functional disability and an estimated 30% have long-term impairments in independent walking. [7]

Patients with stroke walk independently with use of orthosis or device but the upper limb recovery occur less often due to abnormal synergy pattern, weakness, disuse atrophy spasticity and also deficits in somatic sensations (body senses such as touch, temperature, pain, and proprioception) after stroke are common with prevalence rates variously reported to be 11–85%. Disability from upper limb impairment depends primarily on the loss of hand function. [8] Motor impairment affects 80% of stroke survivors. Upper limb (i.e. arm, hand and/or finger) motor impairments are often persistent and disabling. Up to 70% of individuals experience difficulties using their upper limb (UL, arm and hand) to perform meaningful activities after stroke.

Various treatment techniques or therapies have been used to improve impaired motor functions of the upper extremity. [9, 10, 11, 12] Focused on the treatment efficacy of repetitive exercise of the paralyzed upper limb to alter motor performance in patients with chronic stroke. Robots are particularly useful to train highly repetitive tasks and provide an accurate, automated movement control for the rehabilitation, which do not require the continuous presence of a therapist. Therefore, it decreasing the time demands on each therapist. [13, 14] Robot assisted rehabilitation training to the hand would be more effective than to the proximal joints, e.g. wrist, elbow, etc. in improving the overall function of the whole upper limb. This has directly prompted the development of hand functions. [15] Patients with chronic stroke with impaired hand function gave positive feedback for a soft robotic glove system in functional tasks. It is effective in assisting hand function in subacute and chronic patients with partial or complete hand weakness. [16] Rehabilitation with robotic glove (Gloreha) can positively promote functional recovery of arm function in a patient with stroke [17]

Gait is the most basic behavior of humans. Normal gait is required interaction between more than two joints of the body in harmonious movement. The natural movement of upper limb occurs during gait, and then the arm swing and lower limb swing appear to move reciprocally. Reciprocal arm swing is a typical feature of humanwalking, it minimizing energy consumption, optimizing stability, and optimizing neural performance. [18]

Lower limb coupling relates to specific neural signals from the upper limbs. The normal phase of arm swing during human locomotion plays an active role in body postural control. When amplitude of the arm and leg is increased, gait speed will be increased. The cyclical motion of the upper limbs is considered a supportive component of human gait aiming for energy cost conservation. [19] stroke tends to be much slower, and generally more limited in their choice of gait speed. [20]

Enhancing upper limb functionality could potentially contribute to improved ambulation capacity. Speed is an important factor, which develop inter-limb coordination and augments gait performance. With the decrease of upper limb functionality efficacy of gait was affected in a post-stroke hemiplegic patient. Hence, during the rehabilitation of post-stroke hemiplegic patients, it is recommended to engage the patient early in upper limb exercises to improve functionality, which will in turn help to improve walking.

Past studies support the motor recovery of upper limb but literature may not applicable fully to the Indian stroke population. Moreover, scarcity of evidences suggesting upper limb motor recovery in small setups. The role of the upper limb during walking demonstrated by the alteration of gait speed after upper limb constraining both in a healthy and in a pathologic population. Especially in pathologic individuals, upper extremity movements may provide crucial information about the walking strategy. Along with the motor recovery of upper limb very rare studies have been done in India to see the effect on gait speed. So, the present study is to find the effectiveness of robotic hand glove on upper limb motor recovery and gait speed and in patients with chronic stroke.

Materials and methods

The ethical clearance was taken from Institutional Ethical Committee (IEC). After getting the ethical approval researcher contacted different head of physiotherapy OPDs located in Surat city for seeking permission. Researcher contacted patients individually for permission. The patients were screened on the basis of inclusion and exclusion criteria. Patients with Stroke patients with unilateral hemiplegia, chronic stroke (≥ 6months), Age between 30 and 65 years, mini mental scale score ≥ 24, Modified Ashworth score ≤ 2 were included in the study. Also, patients should be able to sit on the chair, able to walk 10 metre distance without assistive devices and orthosis and with any no clinical evidence of limited passive range of motion in UL were included. Patients were excluded if they had any neurological conditions apart from stroke, musculoskeletal problems e.g. severe pain in any joints of the paretic upper extremity, other skin condition or scar over affected upper limb, any vestibular dysfunction, uncorrected visual and hearing impairment and sensory impairments. Sample size was calculated by using G-Power version 3.1.9.7 software with effect size 1.37 and $\alpha = 0.05$. Calculated sample size was 26. By using purposive sampling technique patients were divided in two groups. A signed consent form in a language of their choice was taken before the commencement of the study.

Total 41 patients were assessed for eligibility. Out of 41, 14 patients did not meet the criteria. So total 27 patients were enrolled in the study and the patients were allocated into two groups randomly using lottery method in which first patient was allocated to Group-A and second to Group-B. This same sequence was maintained throughout the study. There were 14 patients in Group-A (Experimental Group) received robotic hand glove training along with conventional therapy and 13 patients in Group-B (Control Group) received only conventional therapy. Experimental group received task specific robotic hand glove training along with conventional therapy. For that, patient was seated on the chair and wears the PG02E-1 Power-assisted glove and pulls the Velcro straps over the wrist and sticks it on. So, there is no gap between the wrist and the glove when making a fist. Glove was connected with the host and then long press the power button for turned on the system. Then press the passive training button and set start and stretch level. With the use of soft robotic hand glove patients performed total of 20 sessions of drinking task i.e. 5 days/week for 4 weeks. [15] Task of drinking water using a glass was performed. The drinking task can be broken down into 4 events: 1) reach from rest to grasp glass, 2) lift glass to mouth, 3) return and release glass, and 4) return arm to rest position. [21]

During the session, the patients were instructed to continuously practice drinking task within one hour. Prior to the training, 10 min were required to put the soft robotic glove on patient’s hand. 10-min session was given to the patient then 5-min rest was given to prevent muscle fatigue, again 10-min session was given and 5-min rest. After the last 10-min of session 10-min taken to remove the glove, within one-hour training session. To further maximize patient’s voluntary efforts, patients were allowed and suggested to apply more force to perform task.

Conventional therapy was given for 45-min per session for both the groups 5 days per week for 4 weeks. It includes: (10 repetition of each) [22] Active/Passive range of motion exercise of upper limb and lower limb, weight bearing exercise for affected upper limb (10sec hold), reaching activities, grasping, holding and release, home advice for Upper extremity ADL, gait training with or without parallel bar, static and dynamic balance activities, and stretching of upper and lower limb tight muscles (3 repetition & 30-60sec hold).

Outcome measures were assessed at the initiation of the study, and after 4 weeks duration. For both the groups upper limb motor recovery on affected side was measured using Wolf Motor Function Test [23] and Fugl Meyer Assessment [24] for Upper Extremity and the gait speed was measured using 10-meter walk test [25].

Results

All the tests and calculations were performed using Jamovi 2.3.28 version. Socio-demographic data was tested by descriptive data analysis. Shapiro-wilk test was used to check the normality of the data. On base of normality distribution Wilcoxon sign rank test (non-parametric test) was used for within Group analysis of WMFT (15 functional task), Weight to box (strength task) and 10MWT and Paired t-test (Parametric test) was used for within Group analysis of FME-UE and Grip strength (strength task). Mann whitney test (non-parametric test) was used for between Group Analysis of WMFT, Weight to box & 10MWT and independent t-test (Parametric test) was used for between Group Analysis of FME-UE and Grip strength. Confidence interval was kept at 95% and level of significance for all statistical data was set at $p<0.05$. Total 26 patients participated in the study and all 26 were analyzed for the results.

Table 1: Socio-demographic characteristics of patients

Variables	Group-a	Group-b
	Mean±sd	**Mean±sd**
Age(years)	53.23±9.17	53.61±5.59
Gender	1.61±0.51	1.5±0.5
Hemiparetic side	1.69±0.48	1.61±0.51
Pre WMFT	40.08±4.25	36.23±17.21
Pre-weight to box	0.77±0.33	0.69±0.25
Pre-grip strength	2.61±0.79	2.03±0.77
Pre FMA-UE	91±4.85	88.77±7.30
Pre 10MWT	0.24±0.11	0.46±0.21

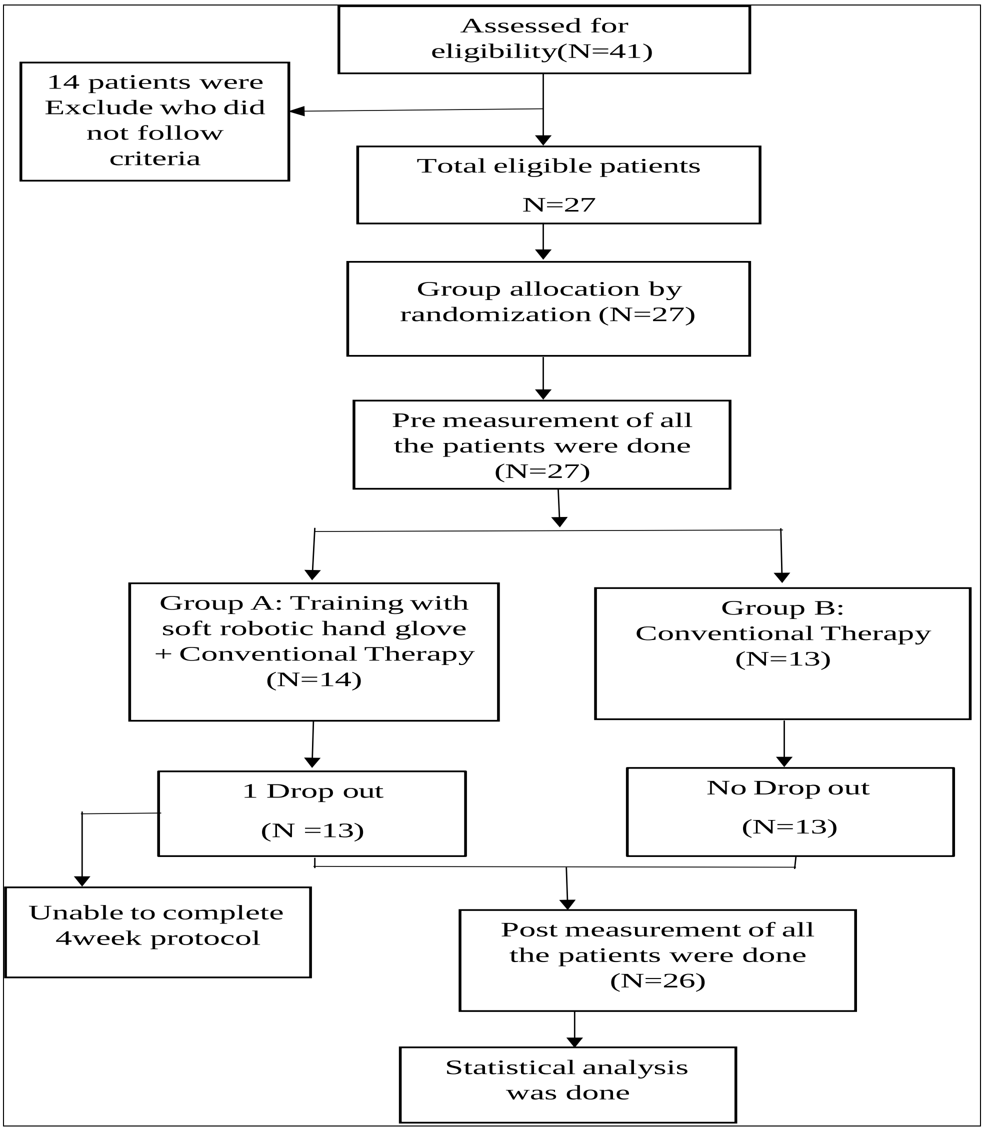

Fig 1: Consort flow diagram

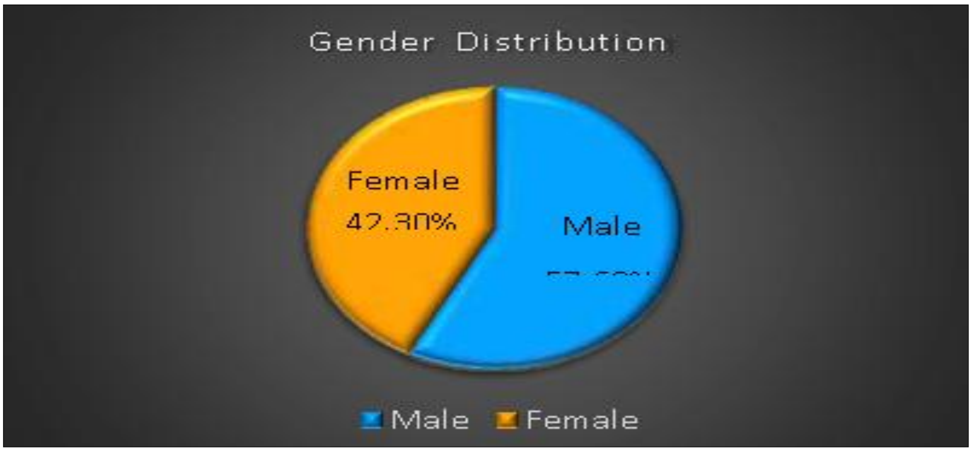

Fig 2: Gender wise distribution of patients

Table 2: Normality distribution of all the outcome measures

Outcome measures	Pre-value Group-a Mean±sd	Pre-value Group-b Mean±sd	P- value
WMFT	40.08±4.25	36.23±17.21	0.001
Weight to box	0.76±0.33	0.69±0.25	<0.001
Grip strength	2.61±0.79	2.03±0.77	0.262
FMA-UE	91±4.84	88.77±7.30	0.307
10MWT	0.24±0.11	0.4±0.21	<0.001

Wilcoxon sign rank test used to compare the value of WMFT, Weight to box & 10MWT and Paired t-test used to compare the value of FMA-UE and Grip strength in pre-intervention and post intervention both groups. (Table 3) Both the groups show significant improvement in all outcome measures at 4 weeks.

Mann-whitney test used to compare the value of WMFT, Weight to box & 10MWT and independent t-test used to compare the value of FMA-UE and Grip strength in both groups. (Table 4)

Table 3: Within group comparison of groups

Groups	Outcome Measures	Pre-value Mean±sd	Post-value Mean±sd	P -value
Group A	WMFT	40.08±4.25	48.54±4.48	0.002
	Weight to box	0.76±0.33	1.53±0.51	0.001
	Grip strength	2.61±0.79	3.88±0.74	<0.001
	FMA-UE	91±4.84	111.38±5.16	<0.001
	10MWT	0.24±0.11	0.29±.012	<0.001
Group B	WMFT	36.23±17.21	40.15±16.61	0.002
	Weight to box	0.69±0.25	1.27±0.43	0.001
	Grip strength	2.03±0.77	2.42±0.93	0.002
	FMA-UE	88.77±7.30	100.15±6.99	<0.001
	10MWT	0.4±0.21	0.46±0.21	<0.001

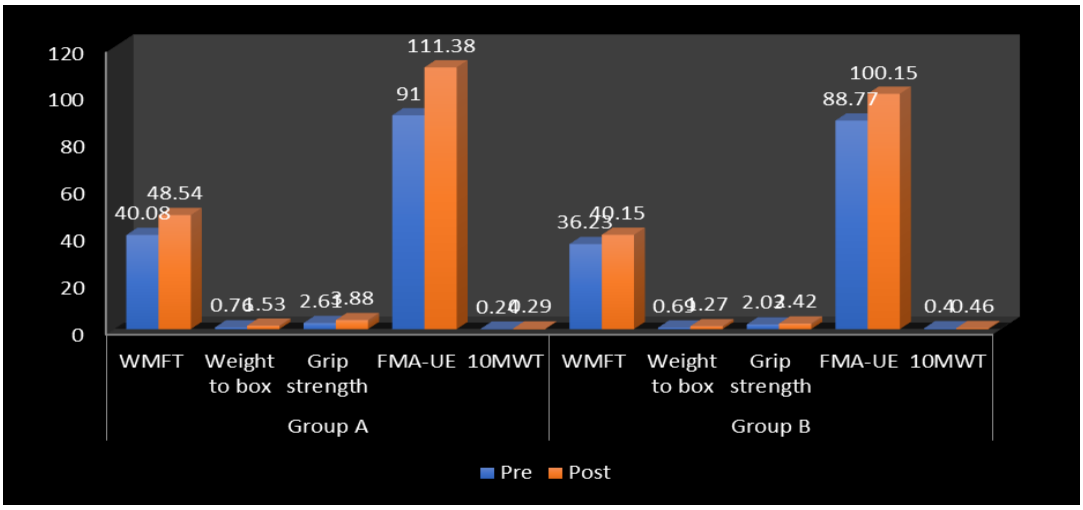

Fig 3: Within group comparison of groups

Table 4: Between group comparison

Outcome Measure	Group-a Mean±sd	Group-b Mean±sd	P-value
WMFT	8.46±1.45	3.92±1.65	<0.001
Weight to box	0.85±0.24	0.42±0.40	0.039
Grip strength	1.26±0.63	0.38±0.36	<0.001
FMA-UE	20.38±4.99	11.3±6.13	<0.001
10MWT	0.05±0.02	0.006±0.003	<0.001

Results show that all of the outcome measures showed statistically significant improvement in ($p<0.05$) in experimental group than control group in all of the outcome measures. It means robotic hand glove training along with conventional therapy is effective to improve grip strength, upper limb function and gait speed

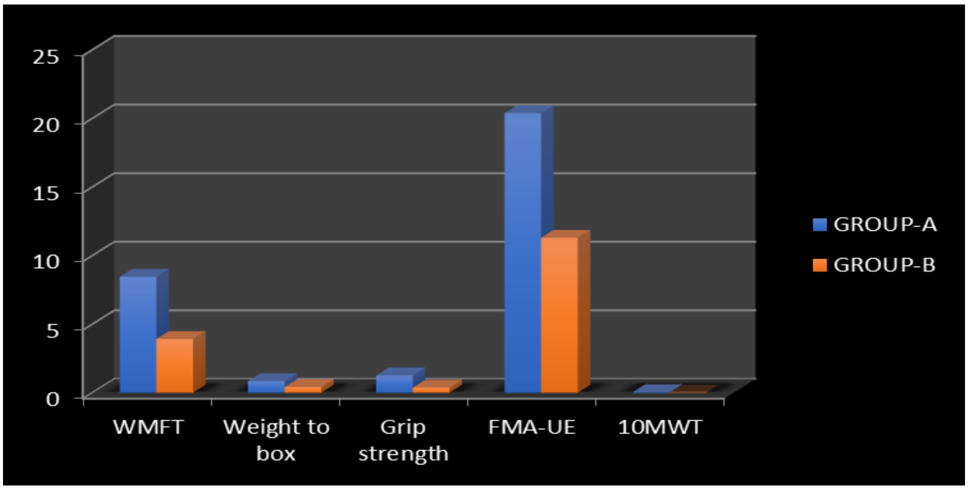

Fig 4: Between group comparison

Discussion

The study was aimed to check the effectiveness of robotic hand training on upper limb motor function and gait speed in patients with chronic stroke. Study was conducted in various physiotherapy OPDs by seeking their permission for same. Samples were collected using purposive sampling. Sample who met criteria included in the study. All the patients were divided into two groups and were assessed by WMFT, FMA-UE, 10MWT outcome measures on 1st day of 1st week an after 4 consecutive weeks.

Descriptive analysis for both groups in terms of genders, age groups, hemiparetic side and outcome measures used in the study was done. Mean and SD for age of participants in both the Group A and Group B were 53.23±9.17 years and 53.61±5.59 years respectively. Statistically significant difference was found for within and between group comparison of WMFT (weight to box and grip strength), FMA-UE, 10MWT score at $p<0.05$ levels in both groups. Above results suggested that both groups were statistically significant but experimental group shows more improvement.

In our study soft robotic glove provides repetitive functional task-oriented upper limb training. Soft robotic glove was safe and effective which helping the patients with chronic stroke to achieve positive outcomes when performing the drinking task. The control unit of soft robotic glove was characterized by low weighted, portable and easy to use. As per motor learning principle, component wise training in correct direction and the repetitive practice of one task should improve the motor functions. We have added drinking task which was targeted to the one activity which include reach to glass, grasp it, lift it to the mouth, return and release it. As these components has been an essential skill for every human being in daily life and in performing daily activities. Intrinsic and extrinsic feedback improves the task skill in relation to the amount of practice and repetitive practice which enhance cortical plastic reorganization. So, the patient re-learned the impaired motor functions of upper limb. As given training is not only limited to the hand but included whole arm during the task training so it showed improvement in FMA-UE score. Results from our assessment also reported improvement in the grip strength ($p < 0.001$).

Previous study Min-Gu Kang, *et al* (2020) [26] and Paolo Milia, *et al* (2019) [16] showed that during task-oriented training intrinsic feedback includes sensory information from muscles, joints, and tendons and extrinsic feedback through external sources such as correct directions of task from therapists. This feedback with correct pattern of task is very helpful for patients to re-learn impaired motor function through the activation of internal action-related representation and this effect promote to improvement of motor performance in patients with chronic stroke. [16, 26]

Xiang Qian Shi, *et al* (2021) [13] studies highlighted that grip strength was positively correlated with motor function and ADL performance. They also mention that the strength of compromised fingers should be an indicator of motor recovery in chronic stroke patients. [13]

Stefano Mazzoleni, *et al* (2018) [14] they found that the improvement in the FME- UE score in all patients who received the wrist training only. Significant improvements were observed both in distal and proximal components after distal upper limb robot-assisted training. [14] Jean-Claude Metzger, *et al* (2014) [27] suggested that impairment was found to be reduced especially at the level of the hand and wrist, where the interaction with the robot takes place, but also at the level of the proximal part of the arm. So, it suggested that wrist training only seems to reduce proximal segment motor impairment in the same way as proximal segment training does. [27]

Improvement in upper limb motor functions will further help the patients to improve arm swing during walking. The concept of central pattern generators (CPGs) which is the functional network of neurons, corpus callosum and basal ganglia. They control the interaction between the movements of the right and left limbs. CPGs, are primarily consider to be responsible for the rhythmic movements of limb during walking without any conscious effort and feedback. The CPGs may reduce the work of other supraspinal structures in modulating the lower limb rhythm during walking with variable speed. CPGs are also considered to be crucial for simultaneous coupled movement of upper and lower limbs. The rhythmic training of upper limbs may enhance the walking ability due to the activation of CPGs. Neuroanatomically, the corpus callosum connects both the brain hemisphere and coordinates the bimanual upper limb movements and basal ganglia is control the arm swing during walking. So, study shown the improvement in gait speed also with upper limb motor functions.

Sunee Bovonsunthonchai, *et al* (2012) [18] reported that during normal gait humans swing their upper limbs alternately with contralateral lower limb and this synchronization between upper limb and lower limb is referred to as interlimb coupling. Interlimb coupling is controlled by central pattern generators (CPGs) and corpus callosum during walking. It is mediated by spinal inter neuronal circuits which are under the supraspinal control. This neuronal control regulates the upper and lower limb circuits manifested in the arm swing during walking. Thus, in post stroke patients the motor paresis of contralateral side of body to lesioned brain exhibit asymmetry between right and left limbs thus altered interlimb coupling mechanism. [18]

D. S. Pushpika, *et al*. (2023) [20] studied to showed that with the reduce upper limb functionality, efficacy of gait was affected in a post-stroke hemiplegic patient. So, during the rehabilitation of post-stroke hemiplegic patients, it is necessary to engage the patient early in upper limb exercises to improve functionality, which will help to improve walking. [20] A pilot randomized control study by Arya, *et al* 2019 developed a protocol based on interlimb coupling of upper and lower limb and examined its effect on gait and motor recovery. The findings of this study showed recovery of upper and lower limb along with reduction in gait deviations in response to interlimb activities. [28] Study by Ma, *et al* 2014 findings showed significant change in 10meter walk test and 6 min walk test in post stroke patients in experimental group who performed reinforced arm swing exercises. It stated that arm swing exercises showed significant changes in activation of latissimus dorsi and gluteus maximus and arm swing improved distance walked by increasing gait speed and energy consumption. [29]

By showing these all the findings it was suggested that improvement in robotic hand glove training along with conventional therapy and conventional therapy alone, but more improvement showed in robotic hand glove training group. Result also suggested that there was improvement in gait speed. Limitations of present study including, it is time consuming to complete intervention protocol because after 40 minutes of continuous training, the equipment enters the rest mode and the training can be resumed after 40minute of rest and post intervention follow up was not taken into consideration. Hence, long term benefits of intervention are unknown. Some future recommendations including, sub-acute and acute stroke subjects could be considered in future trials to evaluate the effects of early interventions. In future this study can be conducted including larger sample size. The hands subsection and coordination/speed subsection should be investigated separately in further studies as distal arm training at the level of the wrist may result in proximal arm function recovery. To show the effects of intralimb coordination one can include bilateral hemiplegia or quadriplegic patients with stroke in future studies.

Conclusion

The study concluded that robotic hand glove training along with conventional therapy and conventional therapy alone shows improvement in upper limb motor functions and gait speed. However, robotic hand glove training along with conventional therapy shows more improvement than conventional therapy alone in upper limb motor functions and gait speed.

References

1. Mehta SL, Vemuganti R. Mechanisms of stroke induced neuronal death: multiple therapeutic opportunities. Advances in Animal Veterinary Sciences,2014:2(8):438-6.
2. Kuriakose D, Xiao Z. Pathophysiology treatment of stroke: present status future perspectives. International journal of molecular sciences,2020:21(20):7609.
3. Kuriakose D, Xiao Z. Pathophysiology treatment of stroke: present status future perspectives. International journal of molecular sciences,2020:21(20):7609.
4. Murphy SJ, Werring DJ. Stroke: causes clinical features. Medicine,2020:48(9):561-6.
5. Mercier L, Audet T, Hébert R, Rochette A, Dubois MF. Impact of motor, cognitive, perceptual disorders on ability to perform activities of daily living after stroke. Stroke,2001:32(11):2602-8.
6. Langhorne P, Coupar F, Pollock A. Motor recovery after stroke: a systematic review. The Lancet Neurology,2009:8(8):741-54.
7. Broderick P, Horgan F, Blake C, Ehrensberger M, Simpson D, Monaghan K *et al*. Mirror therapy treadmill training for patients with chronic stroke: a pilot randomized controlled trial. Topics in Stroke Rehabilitation,2019:26(3):163-72.
8. Volpe BT, Lynch D, Rykman-Berland A, Ferraro M, Galgano M, Hogan N, *et al*. Intensive sensorimotor arm training mediated by therapist or robot improves hemiparesis in patients with chronic stroke. Neurorehabilitation neural repair,2008:22(3):305-10.
9. Pollock A, Farmer SE, Brady MC, Langhorne P, Mead GE, Mehrholz J, *et al*. Interventions for improving upper limb function after stroke. Cochrane Database of Systematic Reviews, 2014(11).
10. Oujamaa L, Relave I, Froger J, Mottet D, Pelissier JY. Rehabilitation of arm function after stroke. Literature review. Annals of physical rehabilitation medicine,2009:52(3):269-93.
11. Doumen S, Sorba L, Feys P, Tedesco Triccas L. Efficacy Dose of Rehabilitation Approaches for Severe Upper Limb Impairments Disability During Early Acute Subacute Stroke: A Systematic Review. Physical Therapy,2023:103(4):pzad002.

12. Westerveld AJ, Schouten AC, Veltink PH, van der Kooij H. Passive reach grasp with functional electrical stimulation robotic arm support. In2014 36th Annual International Conference of the IEEE Engineering in Medicine Biology Society 2014, 3085-3089. IEEE.
13. Shi XQ, Heung HL, Tang ZQ, Li Z, Tong KY. Effects of a soft robotic hand for hand rehabilitation in chronic stroke survivors. Journal of Stroke Cerebrovascular Diseases,2021:30(7):105812.
14. Mazzoleni S, Tran VD, Dario P, Posteraro F. Wrist robot-assisted rehabilitation treatment in subacute chronic stroke patients: From distal-to-proximal motor recovery. IEEE Transactions on Neural Systems Rehabilitation Engineering,2018:26(9):1889-96.
15. Thimabut W, Terachinda P, Kitisomprayoonkul W. Effectiveness of a soft robotic glove to assist hand function in stroke patients: a cross-sectional pilot study. Rehabilitation Research Practice, 2022.
16. Milia P, Peccini MC, De Salvo F, Sfaldaroli A, Grelli C, Lucchesi G, *et al*. Rehabilitation with robotic glove (Gloreha) in poststroke patients. Digital Medicine,2019:5(2):62.
17. Koo HM, Lee SY. Gait analysis on the condition of arm swing in healthy young adults. Physical Therapy Rehabilitation Science,2016:5(3):149-54.
18. Bovonsunthonchai S, Hiengkaew V, Vachalathiti R, Vongsirinavarat M, Tretriluxana J. Effect of speed on the upper contralateral lower limb coordination during gait in individuals with stroke. The Kaohsiung Journal of Medical Sciences,2012:28(12):667-72.
19. Jonsdottir J, Recalcati M, Rabuffetti M, Casiraghi A, Boccardi S, Ferrarin M, *et al*. Functional resources to increase gait speed in people with stroke: strategies adopted compared to healthy controls. Gait & posture,2009:29(3):355-9.
20. Pushpika GD, Samaranayake TN. The Impact of Upper Limb Functioning on Gait Patterns in Individuals with Post-Stroke Hemiplegia. Asian Journal of Medicine Health,2023:21(11):220-7.
21. Christopher SM, Johnson MJ. Task-oriented robot-assisted stroke therapy of paretic limb improves control in a unilateral bilateral functional drink task: A case study. In2014 36th Annual International Conference of the IEEE Engineering in Medicine Biology Society, 2014, 1194-1197. IEEE.
22. Alon G, Levitt AF, McCarthy PA. Functional electrical stimulation enhancement of upper extremity functional recovery during stroke rehabilitation: a pilot study. Neurorehabilitation neural repair,2007:21(3):207-15.
23. Morris DM, Uswatte G, Crago JE, Cook III EW, Taub E. The reliability of the wolf motor function test for assessing upper extremity function after stroke. Archives of physical medicine rehabilitation,2001:82(6):750-5.
24. Hernandez ED, Galeano CP, Barbosa NE, Forero SM, Nordin Å, Sunnerhagen KS, *et al*. Intra- inter-rater reliability of Fugl-Meyer assessment of upper extremity in stroke. Journal of rehabilitation medicine,2019:51(9):652-9.
25. Cheng DK, Nelson M, Brooks D, Salbach NM. Validation of stroke-specific protocols for the 10-meter walk test 6-minute walk test conducted using 15- meter 30-meter walkways. Topics in stroke rehabilitation,2020:27(4):251-61.
26. Kang MG, Yun SJ, Lee SY, Oh BM, Lee HH, Lee SU, Seo HG. Effects of upper-extremity rehabilitation using smart glove in patients with subacute stroke: results of a prematurely terminated multicenter randomized controlled trial. Frontiers in Neurology,2020:11:580393.
27. Metzger JC, Lambercy O, Califfi A, Dinacci D, Petrillo C, Rossi P, *et al*. Assessment-driven selection adaptation of exercise difficulty in robot-assisted therapy: a pilot study with a hand rehabilitation robot. Journal of neuroengineering rehabilitation,2014:11:1-4.
28. Arya KN, Pandian S, Sharma A, Kumar V, Kashyap VK. Interlimb coupling in poststroke rehabilitation: A pilot randomized controlled trial. Topics in Stroke Rehabilitation,2020:27(4):272-89.
29. Ma JS, Kim HJ. The effect of arm swing exercise on gait balance in stroke patients. American Journal of Clinical Experimental Medicine,2014:2(6):151.