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# Feasibility and preliminary efficacy of a soft robotic glove for hand rehabilitation in early subacute stroke: a pilot investigation

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## Abstract

**Objectives** This pilot study aimed to investigate the feasibility, safety, and preliminary efficacy of a rehabilitation program utilizing *Syrebo*™ *SY-HR03E* soft robotic glove with pneumatic actuators for hand function recovery in patients with early subacute stroke.

**Methods** A single-blind pilot randomized controlled trial was conducted in an inpatient clinical setting. The intervention was administered 5 days per week for 4 weeks (20 session's total). During this period, the robotic therapy (RT) group ($n=10$) received 30-min daily sessions with the soft robotic glove, while the conventional therapy (CT) group ($n=10$) received 30-min daily sessions of conventional hand therapy. Both groups additionally participated in an identical 1-h daily conventional rehabilitation program excluding hand training. The outcome measures included the Fugl–Meyer Assessment for the hand (FM-Hand) and upper limb (FM-UL), the modified Barthel index (MBI), and the Brunnstrom stages (BS). Intervention effects were analyzed using two-way repeated-measures ANOVA.

**Results** All participants completed the intervention without dropouts or adverse events, confirming the feasibility and safety of the protocol. Baseline motor impairment was comparable between groups (FM-Hand: 2.20±1.93 vs. 2.50±2.64; FM-UL: 19.60±14.76 vs. 16.70±14.50). A significant *Group* × *Time* interaction was found for the FM-Hand [$F(1,18)=4.743$, $p<0.05$] and the MBI [$F(1,18)=7.728$, $p<0.05$]. Simple effects analysis revealed that both groups improved significantly in FM-Hand, while only the RT group showed a significant improvement in MBI after interventions. For the FM-UL, a significant main effect of *Time* [$F(1,18)=24.931$, $p<0.001$] in both groups was observed without an interaction. In the BS, a significant main effect of *Time* was found for both hand and upper limb, with only the RT group showing significant within-group improvement for the hand.

**Conclusions** *Syrebo*™*SY-HR03E* soft robotic glove is a feasible and safe tool for hand rehabilitation in early subacute stroke. The results provide preliminary signals for improving hand function and translating gains into activities of daily living compared to conventional therapy alone. However, because both groups were in the early subacute stage, the observed gains likely reflect a combination of intervention effects and spontaneous recovery. These findings justify further investigation through larger-scale, definitive trials.

*Trial Registration*: ChiCTR2000034614||http://www.chictr.org.cn/ with the Clinical Trial Registry (2020/07/12).

**Keywords** Stroke · Hand rehabilitation · Soft pneumatic actuators · Soft robotics

## Introduction

Stroke is a leading cause of adult disability worldwide and affects approximately one in four people over their lifetime [1]. Common motor impairments in stroke survivors include reduced precision of voluntary hand movements, abnormal muscle activation, impaired coordination, and spasticity [2]. Among these, flexor hypertonia in the hand is a significant contributor to post-stroke functional limitations [3], severely impairing individuals' ability to perform tasks of daily living (ADL) and reducing their overall quality of life (QoL) [4]. Although there have been considerable advancements in acute ischemic stroke treatment, rehabilitation techniques have not seen the same level of progress [5].

Restoring hand function remains a major challenge in stroke rehabilitation, despite the extensive research and focus on understanding post-stroke hand function impairments [3, 6, 7]. High-intensity, repetitive, and patient-initiated rehabilitation training is considered especially important for promoting motor recovery [8–10] functional use [11], and sensorimotor retraining [12]. Conventional hand rehabilitation largely depends on one-to-one therapist-delivered treatment, such as stretching, facilitation, and task-oriented practice. Although clinically valuable, this approach is labor-intensive and difficult to scale when high-dose practice is required, creating a strong rational for assistive technologies that can support repetitive hand training [13].

Robotic technology has emerged as a promising solution in this context, offering repetitive and assistive rehabilitation exercises. Robots can deliver repetitive movements without fatigue and provide precise control and quantifiable assistance [14]. In addition, robotic systems can be combined with virtual reality or exergame-based interfaces, which may increase motivation and engagement while also enabling movement monitoring during therapy [15, 16].

Hand-specific robotic devices include both rigid exoskeletons and soft robotic gloves. Compared with rigid exoskeletons, soft robotic gloves may offer practical advantages for stroke rehabilitation, because their compliant structures comfort and safety in patients with hypertonia or limited passive range of motion [17, 18]. There is, therefore, increasing interest in soft robotic systems that incorporate active-assistive modes based on user intention. Prior studies have shown that soft robotic gloves [19] and hand exoskeletons [20] can improve motor outcomes and functional task performance in chronic or mixed-phase stroke populations. However, evidence for their use in the early subacute phase remains limited, despite the fact that this stage represents a time-sensitive period of spontaneous recovery and heightened neuroplastic potential. Experimental and clinical studies suggest that appropriately dosed, task-specific rehabilitation during this period may exert a disproportionate influence on longer-term motor outcomes [21, 22].

*Syrebo*$^{TM}$*SY-HR03E* is a commercially available soft robotic glove that uses pneumatically actuated bellows sleeves and a pressure transducer to detect the user's intention to open or close the hand, thereby enabling active-assistive grasp-release training. In the present pilot trial, a simple repetitive hand opening–closing protocol was deliberately selected rather than an exergame-based task. Gross grasp-release movements are a prerequisite for many higher-level hand functions and can be delivered in a standardized way with a low-complexity protocol. This approach was chosen to minimize cognitive and technical burden while first establishing feasibility and safety in a clinically vulnerable early subacute population.

Accordingly, the primary aim of this study was to evaluate the feasibility and safety of incorporating *Syrebo*$^{TM}$*SY-HR03E* training into the rehabilitation program of individuals with early subacute stroke. Feasibility outcomes included recruitment, adherence, and adverse events. Exploratory clinical outcomes included changes in FM-Hand, FM-UL, BS-Hand, BS-UL, and MBI scores. It was hypothesized that *Syrebo*$^{TM}$*SY-HR03E* training

would be feasible and safe and would yield preliminary signals of greater improvement in hand motor function and possibly ADL performance than conventional hand therapy alone.

## Results

### Feasibility and safety

All twenty enrolled participants completed the 4-week intervention protocol, yielding a completion rate of 100%. Participants in the RT group completed the full 10-h robotic training program, and no adverse events were recorded in either group.

As summarized in Table 1, the two groups were well-matched at baseline, with no statistically significant differences in demographic or clinical characteristics.

### Clinical outcomes

For the FM-Hand, the two-way ANOVA revealed a significant *Group* × Time interaction ($F(1, 18) = 4.743$, $p < 0.05$) and a significant main effect of Time [$F(1, 18) = 36.907$, $p < 0.001$]. Simple effects analysis indicated that both the RT and CT groups improved significantly from baseline to post-intervention ($p < 0.05$ for both).

For the FM-UL, a significant main effect of *Time* was observed [$F(1, 18) = 24.931$, $p < 0.001$], without a significant *Group* × *Time* interaction, indicating improvement in both groups. A detailed breakdown is provided in Table 2.

For the MBI, a significant *Group* × *Time* interaction was identified [$F(1, 18) = 7.728$, $p < 0.05$], alongside a significant main effect of *Time*. Post hoc simple effects analysis showed a statistically significant increase in MBI scores in the RT group ($p < 0.001$) but not in the CT group.

In terms of the BS, a significant main effect of *Time* was found for both the hand [$F(1, 18) = 13.460$, $p < 0.05$] and upper limb [$F(1, 18) = 32.667$, $p < 0.001$] subscales, with no significant *Group* × *Time* interaction. Subsequent analysis indicated that for the BS-Hand, only the RT group showed a significant within-group improvement post-intervention. In contrast, for the BS-UL, both groups exhibited significant recovery after the intervention.

**Table 1** Demographic and clinical data

| | RT group | CR group | Test statistics | *P* |
|---|---|---|---|---|
| Sex (M/F) | 7/3 | 8/2 | *U*=45.00 | 0.615 |
| Age (years) | 62.6±6.363 | 61.4±11.635 | *F*=7.677 | 0.778 |
| Stroke of type (H/I) | 4/6 | 2/8 | *U*=40.00 | 0.342 |
| Duration (days) | 34.50±14.207 | 42.70±14.967 | *F*=0.049 | 0.225 |
| Hemiplegic side (R/L) | 4/6 | 3/7 | *U*=45.00 | 0.648 |
| Pre-FM-Hand | 2.20±1.932 | 2.50±2.635 | *F*=0.712 | 0.775 |
| Pre-FM-upper limb | 19.60±14.759 | 16.70±14.499 | *F*=0.012 | 0.663 |
| Pre-BS-Hand | 2.10±1.101 | 2.50±0.972 | *F*=0.286 | 0.400 |
| Pre-BS-upper limb | 2.50±1.269 | 2.70±1.494 | *F*=0.248 | 0.751 |
| Pre-MBI | 42.00±14.855 | 51.00±12.428 | *F*=0.814 | 0.159 |

*BS* Brunnstrom stage, *FM* Fugl–Meyer, *MBI* Modified Bathel Index

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**Table 2** Assessment results before and after rehabilitation

| | Pre | Post | Repeated measurement *F* test | | |
|---|---|---|---|---|---|
| | M±SD | M±SD | *F* | *P* | Partial $\eta^2$ |
| FM-Hand | | | | | |
| RT | 2.20±1.932 | 5.80±3.938 | 34.055 | <0.001** | 0.654 |
| CT | 2.50±2.635 | 4.20±3.327 | 7.594 | <0.05* | 0.297 |
| *F* | 0.084 | 0.963 | | | |
| *P* | 0.775 | 0.339 | | | |
| Partial $\eta^2$ | 0.005 | 0.051 | | | |
| $F_{Group/Time/Group*Time}$ | 0.253/36.907/4.743 | | | | |
| $P_{Group/Time/Group*Time}$ | 0.621/<0.001**/<0.05* | | | | |
| Partial $\eta^2_{Group/Time/Group*Time}$ | 0.014/0.672/0.209 | | | | |
| FM-UL | | | | | |
| RT | 19.60±14.759 | 28.70±18.809 | 17.186 | <0.05* | 0.488 |
| CT | 16.70±14.499 | 23.10±17.641 | 8.501 | <0.05* | 0.321 |
| *F* | 0.196 | 0.472 | | | |
| *P* | 0.663 | 0.501 | | | |
| Partial $\eta^2$ | 0.011 | 0.026 | | | |
| $F_{Group/Time/Group*Time}$ | 0.346/24.931/0.756 | | | | |
| $P_{Group/Time/Group*Time}$ | 0.564/<0.001**/0.396 | | | | |
| Partial $\eta^2_{Group/Time/Group*Time}$ | 0.019/0.581/0.040 | | | | |
| MBI | | | | | |
| RT | 42.00±14.855 | 61.30±14.392 | 32.546 | 0.000* | 0.644 |
| CT | 51.00±12.428 | 57.00±16.533 | 3.145 | 0.093 | 0.149 |
| *F* | 2.159 | 0.385 | | | |
| *P* | 0.159 | 0.543 | | | |
| Partial $\eta^2$ | 0.107 | 0.021 | | | |
| $F_{Group/Time/Group*Time}$ | 0.149/27.964/7.728 | | | | |
| $P_{Group/Time/Group*Time}$ | 0.704/<0.001**/<0.05* | | | | |
| Partial $\eta^2_{Group/Time/Group*Time}$ | 0.008/0.608/0.300 | | | | |
| BS-Hand | | | | | |
| RT | 2.10±1.101 | 3.00±1.563 | 12.903 | <0.05* | 0.418 |
| CT | 2.50±0.972 | 2.90±0.994 | 2.549 | 0.128 | 0.124 |
| *F* | 0.742 | 0.029 | | | |
| *P* | 0.400 | 0.866 | | | |
| Partial $\eta^2$ | 0.040 | 0.002 | | | |
| $F_{Group/Time/Group*Time}$ | 0.091/13.460/1.911 | | | | |
| $P_{Group/Time/Group*Time}$ | 0.767/<0.05*/0.175 | | | | |
| Partial $\eta^2_{Group/Time/Group*Time}$ | 0.005/0.428/0.100 | | | | |
| BS-UL | | | | | |
| RT | 2.50±1.269 | 3.40±1.174 | 27.000 | <0.05* | 0.600 |
| CT | 2.70±1.494 | 3.20±1.135 | 8.333 | 0.010* | 0.316 |
| *F* | 0.104 | 0.150 | | | |
| *P* | 0.751 | 0.703 | | | |
| Partial $\eta^2$ | 0.006 | 0.008 | | | |
| $F_{Group/Time/Group*Time}$ | 0.000/32.667/2.667 | | | | |
| $P_{Group/Time/Group*Time}$ | 1.000/0.001**/0.120 | | | | |
| Partial $\eta^2_{Group/Time/Group*Time}$ | 0.000/0.645/0.129 | | | | |

*FM-hand* The Fugl–Meyer motor assessment of hand, *FM-UL* The Fugl–Meyer motor assessment of upper limb, *BS-Hand* Brunnstrom of hand, *BS-UL* Brunnstrom of upper limb, *MBI* Modified Bathel Index, *RT* Robotic Therapy, *CT* Conventional Therapy

## Discussion

This pilot study primarily evaluated the feasibility and safety of integrating a pneumatically driven soft robotic glove (*Syrebo*$^{TM}$*SY-HR03E*) into rehabilitation for individuals with early subacute stroke. The absence of dropouts and adverse events, together with full completion of the planned sessions, supports the feasibility of this intervention in a supervised clinical setting.

Beyond establishing feasibility, this study offers preliminary insights into the potential functional implications of the RT intervention. The observed *Group* × *Time* interaction on the FM-Hand provides a preliminary signal that glove-assisted repetitive hand training may enhance distal motor recovery. These findings align with previous studies [23, 24] that have demonstrated the benefits of robotic systems in stroke rehabilitation, where active-assistive motions enhance motor recovery by facilitating neuroplasticity and muscle retraining. Similarly, the significant within-group improvement in BS-Hand in the RT group only, suggests that the intervention may positively influence the quality of motor patterns. However, mechanistic interpretations should be made cautiously, because the present study did not include neurophysiological or neuroimaging measures and, therefore, cannot directly demonstrate neuroplastic changes. These signals, though generated from a small sample, are crucial for identifying the most relevant outcome measures for a future definitive trial.

The results for the MBI further contribute to this emerging picture. The significant improvement in MBI scores exclusively within the RT group, while preliminary, hints at a potentially meaningful translation of trained motor skills into daily activities. While some prior studies [25–27] did not directly employ the MBI to assess ADL, they utilized functional scales (e.g., ARAT, Jebsen–Taylor) that are closely correlated with daily living function. Their findings of improvement on these scales provide indirect evidence supporting the beneficial effect of the pneumatic glove on ADL performance. However, this finding should not be overstated.

Although no significant between-group differences were found for FM-UL and BS-UL, both groups improved over time. This finding is consistent with previous literature [28, 29], which indicates that hand-focused rehabilitation, particularly when delivered through task-oriented and high-intensity training paradigms, can lead to generalized functional improvements across the entire upper limb in stroke patients. These gains likely reflect a combination of the study interventions, background conventional rehabilitation, and spontaneous recovery during the early subacute period. Future studies should incorporate a control group specifically designed to determine whether the hand-focused robotic intervention elicits additional benefits in upper limb function beyond those achieved through standard care alone.

## Limitations and future directions

The interpretation of these findings must be considered in light of several limitations. The small sample size, single-center design, and lack of a long-term follow-up period are inherent constraints that limit the generalizability and definitive conclusions regarding efficacy.

A major limitation is that outcome assessments were anchored to the beginning and end of the intervention rather than to fixed timepoints after stroke onset. Because spontaneous recovery varies across the early subacute phase, the design does not allow complete separation of treatment-related effects from natural recovery.

Another limitation is that repetitive hand opening and closing over 30-min sessions may have induced fatigue in some participants, particularly in the early subacute stage, which could have influenced performance during training and assessments. Although sessions were supervised and could be adjusted as needed, future studies should more systematically monitor and report fatigue and consider incorporating adaptive rest periods or individualized progression to optimize tolerability and training dose.

In addition, high adherence may partly reflect the supervised inpatient setting; therefore, feasibility in home-based or less supervised contexts remains unknown. Future trials should incorporate a CONSORT-aligned

feasibility framework, report recruitment and adherence metrics in greater detail, anchor assessments to stroke onset, and include larger multicenter samples with longer follow-up.

## Conclusion

This pilot study successfully demonstrates that a rehabilitation program utilizing the *Syrebo*$^{TM}$*SY-HR03E* soft robotic glove is safe, feasible, and acceptable for individuals in the early subacute phase of stroke. The observed gains in hand function and ADL are encouraging but should be interpreted as preliminary because of the pilot design and the likely contribution of spontaneous recovery. These results support the conduct of a larger, fully powered trial.

## Methods

### Study design

This study was a single-blind, randomized controlled trial conducted in an inpatient clinical setting. After enrollment, participants were randomly allocated to either the Robotic Therapy (RT) group ($n = 10$) or the conventional therapy (CT) group ($n = 10$). The outcome assessor was blinded to group allocation throughout the study, whereas participants and treating therapists were not blinded because of the nature of the interventions.

### The design of Syrebo$^{TM}$SY-HR03E

*Syrebo*$^{TM}$*SY-HR03E* is a commercially available hand rehabilitation device composed of a glove unit and a tabletop control unit, with a total system weight of $3.5 \pm 0.5$ kg. The glove is connected to the control unit, which functions as the main operating system and requires an external power source (Fig. 1A). A pressure transducer is integrated

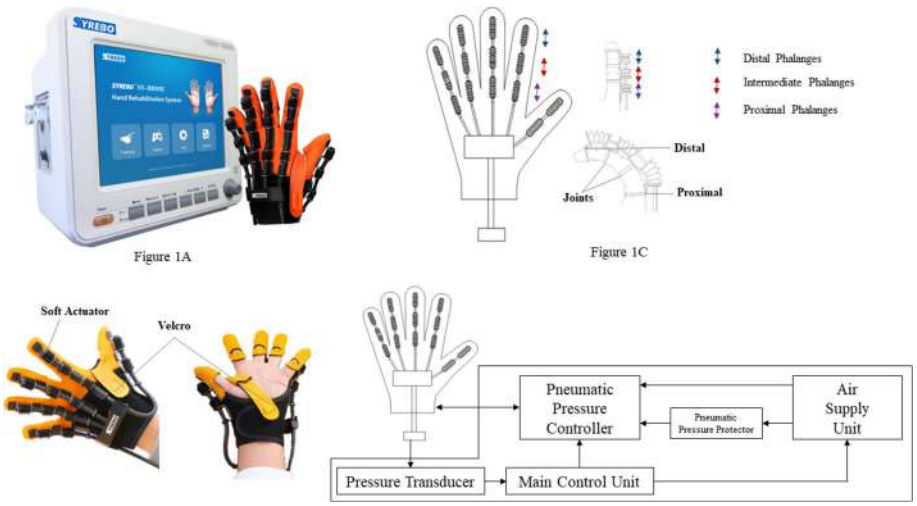


**Fig. 1** *Syrebo*$^{TM}$*SY-HR03E*. **A** *Syrebo*$^{TM}$*SY-HR03E*, a commercially available hand rehabilitation device composed of a glove unit and a tabletop control unit. **B** Glove design, constructed with elastic, deformable bellows sleeve. **C** Actuator and finger joint design layover, the alignment of the dorsal soft pneumatic actuators with the anatomical finger joints to support coordinated flexion–extension movements. **D** Control scheme for the soft robotic glove, user-initiated pressure changes are detected and translated by the controller into pneumatic inflation or deflation of the actuators to assist hand opening and closing

into the system to detect the user's intention to activate or deactivate the glove. The device employs pneumatically controlled soft elastomeric actuators mounted on the dorsal side of the hand to assist finger movements,

The glove is designed to balance functionality, comfort, and ease of use. It is constructed with elastic, deformable bellows sleeve that allow controlled axial contraction and extension. To facilitate donning and doffing, the glove incorporates an open-palm and Velcro fastenings (Fig. 1B). The glove itself weighs only 110 g, which is well below the 400–500 g range previously reported as an acceptable weight for wearable hand [30]. The soft actuators are aligned with the natural length and configuration of the fingers to support assisted hand opening and closing.

The Syrebo$^{TM}$SY-HR03E assists hand movement through a reversible bellows–sleeve mechanism, hand closing is achieved by deflating the bellows, whereas hand opening is achieved by inflating them. The pneumatic system consists of one central airway connected to five branched airways, each corresponding to an individual bellows sleeve (Fig. 1C). A pressure transducer located in the central airway continuously monitors pressure changes caused by the user's attempted finger movements, thereby allowing the system to detect movement intention and trigger assisted mass flexion or extension of the hand.

At the start of operation, the bellows sleeves remain in a neutral state, neither inflated nor deflated. When the user attempts a gross hand movement, such as closing or opening the hand, the bellows contract or expand accordingly, leading to a corresponding decrease or increase in pneumatic pressure. Once the pressure change exceeds 0.7 Kpa (the preset activation threshold), the pressure transducer registers the movement intention. The control unit then inflates or deflates the bellows sleeves to assist the user in completing the intended movement, thereby enabling active-assistive hand training (Fig. 1D).

A fundamental training task delivered by *Syrebo$^{TM}$SY-HR03E* is repetitive hand opening and closing. This movement pattern is essential for grasping and releasing objects and therefor has direct relevance to ADL and distal upper limb function. In the present study, each training cycle began with an auditory cue instructing the participant to actively extend the fingers, followed by the robot-assisted hand opening. The opening phase included a 3-s pause, during which participants were encouraged to exert maximum effort in finger extension. A computer-generated cue then prompted the participant to close the hand, with robotic assistance provided for finger flexing. After a further 3-s pause, the next cycle began.

Because active movement capacity varied across participants, the exact number of repetitions performed during a 30-min session could not be fully standardized. Nonetheless, this simple and clinically relevant grasp-release paradigm provided the basis for the active-assistive hand training program used in this study and may serve as a foundation for more complex task-oriented rehabilitation in future applications.

## Subjects

This study enrolled stroke survivors with lesions located in the basal ganglia region from the Department of Rehabilitation Medicine at Jingan Branch of Huashan Hospital, Fudan University. Twenty individuals with early subacute post-stroke hemiparesis were recruited (Table 3). Eligibility was restricted to basal ganglia stroke to reduce lesion-related heterogeneity and improve interpretability of feasibility and preliminary efficacy signals in this small pilot sample.

The inclusion criteria specified individuals aged 18 years or older, who had experienced an early subacute stroke (7 days to 3 months), with a Fugl–Meyer score (FM) [31] for hand function scores between 2 and 10 points and Brunnstrom stage (BS) [32] for the hand II and IV. Participants also needed to have difficulties performing ADL with the more affected upper extremity and hand.

Exclusion criteria included a history of multiple strokes or other neurological disorders, severe finger spasticity (Modified Ashworth Scale (MAS) [33] score greater than 1+, MAS was applied to categorize resistance during passive movement, ranging from 0 to 4, where +1 indicates a slight increase in muscle tone [34]), unstable coronary artery disease, uncontrolled hypertension, cognitive impairment defined by a Folstein Mini-mental Status Exam (MMSE) [35] score below 24, or hand function affected by another diagnosis.

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**Table 3** Demographic characteristics ($N=20$)

| Subject | Age (years) | Gender (M/F) | Time post-stroke (days) | Stroke type | Lesion brain side |
|---|---|---|---|---|---|
| RT1 | 66 | M | 30 | H | R |
| RT2 | 66 | F | 28 | I | R |
| RT3 | 61 | M | 27 | I | R |
| RT4 | 58 | M | 46 | H | L |
| RT5 | 63 | M | 16 | I | L |
| RT6 | 58 | M | 30 | H | L |
| RT7 | 59 | M | 37 | I | R |
| RT8 | 61 | F | 19 | I | R |
| RT9 | 56 | M | 52 | H | L |
| RT10 | 78 | F | 60 | I | R |
| CR1 | 78 | M | 33 | I | R |
| CR2 | 54 | M | 45 | I | L |
| CR3 | 66 | F | 64 | H | R |
| CR4 | 78 | M | 53 | I | R |
| CR5 | 74 | M | 50 | I | R |
| CR6 | 52 | M | 57 | I | L |
| CR7 | 47 | F | 16 | H | R |
| CR8 | 53 | M | 48 | I | L |
| CR9 | 54 | M | 36 | I | R |
| CR10 | 58 | M | 25 | I | R |

All subjects were right-handed; *H* hemorrhagic, *I* ischemic

Ethical approval for this study was obtained from the Ethics Committee of the Jingan Branch of Huashan Hospital prior to subject recruitment. Written informed consent was obtained from all participants, and the study was conducted in accordance with the principles of the Declaration of Helsinki.

## Interventions

All participants underwent 20 intervention sessions delivered 5 days per week over 4 weeks. In addition to the assigned hand interventions, all participants received a standardized, 1-h daily conventional rehabilitation program in accordance with the Chinese stroke rehabilitation guidelines. This usual-care program was delivered in the clinical setting and excluded additional therapeutic activities specifically targeting the impaired hand.

Participants in the RT group received 30-min daily sessions using the *Syrebo*$^{TM}$*SY-HR03E* under the supervision of a specially trained occupational therapist. Prior to the first formal session, a preliminary familiarization trial was conducted. Each session began with a 5-min stretching routine. During each 30-min session, participants performed repetitive hand opening and closing exercises in an active-assistive mode while seated with the forearm supported on a table (Fig. 2). The wrist was kept in a neutral position, with the shoulder abducted at 45°, the elbow flexed at 90°, and the arm supported by the table to ensure comfort. No additional support was provided to the proximal arm, allowing free movement of the upper arm. The therapist monitored wrist posture and compensatory trunk motion during training. Due to individual variations in active movement capabilities, the exact number of repetitions performed during a 30-min session is difficult to standardize across participants.

Participants in the CT group received 0.5-h daily sessions of conventional physical or occupational therapy specifically targeting the impaired hand.

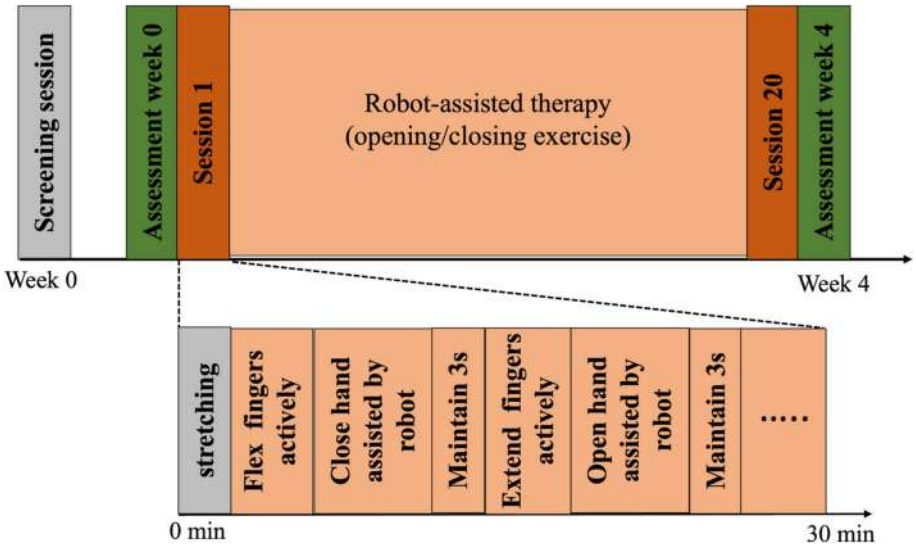


**Fig. 2** Proposed therapy protocol. Each 30-min session consisted of repetitive hand opening–closing cycles in an active-assistive mode, initiated by an auditory cue, with a 3-s hold at maximal attempted finger extension followed by robot-assisted hand closing

## Outcomes and assessments

Subjects were assessed at week 0 and week 4 by an occupational therapist who was not involved in treatment. The outcome measures included the Fugl–Meyer assessment (FM) of hand function (FM-Hand) and upper extremity function (FM-upper extremity), and BS for hand and upper extremity function and Modified Barthel Index (MBI) [36]. The FM-Hand scale ranges from 0 to 14, with each task scored on a 3-point ordinal scale (0 = cannot perform, 2 = can perform fully) [37]. The FM-upper extremity scale ranges from 0 to 66. BS scoring for the hand and upper extremity was also performed, with scores ranging from 1 to 6, assessing the degree of voluntary movement recovery.

## Statistical analysis

All rehabilitation assessment data were independently double-entered into Excel and subsequently analyzed using SPSS version 26.0. Baseline comparisons between the two groups were conducted using independent samples *t* tests. The normality of the data distribution and the homogeneity of variances were verified using the Shapiro–Wilk test and Levene's test, respectively, confirming that the underlying assumptions for the parametric tests were met. To examine the intervention effects, a two-way repeated-measures analysis of variance (ANOVA) was employed, with "*Group*" (RT vs. CT) as the between-subjects factor and "*Time*" (pre- vs. post-intervention) as the within-subjects factor. In the event of a significant *Group* × *Time* interaction ($\alpha = 0.05$), simple effects analyses were performed using the Least Significant Difference (LSD) post hoc test for adjusted pairwise comparisons. If the interaction was not significant, the main effects were interpreted. The significance level for all tests was set at $p < 0.05$.

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**Author contributions** All authors contributed to the study's conception and design. Jie Jia and Yanyan Huang were responsible for the design of the pilot study. Data collection and analysis were carried out by Yingnan Lin and Chuankai Wang. Yingnan Lin wrote the first draft of the manuscript. Rehabilitation therapy was administered by Chuankai Wang and Yansheng Lin. The *Syrebo* 3 and related technology were provided by Gavin Yin. Illustrations were created by Jie Gu, Sujing Xu and Xueli Shan. All authors reviewed and approved the final manuscript.

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**Data availability** Data could be made available from the corresponding author on reasonable request.

## Declarations

**Ethics approval and consent to participate** Participants involved in the study were reviewed and approved by the ethical committee of Jingan Branch of Huashan Hospital, Fudan University. All participants gave written informed consent.

**Consent for publication** Not applicable.

**Competing interests** The authors declare no competing interests.



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