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The Impact of MRC Exoskeleton Rehabilitation in Improving Upper Limb Fugl-Meyer Assessment in Stroke Patients

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ABSTRACT: Impairment of upper-limb motor function is a prevalent issue that can restrict a patient's capacity to engage in functional activities following a stroke. Robotic devices have been created to enable repetitive and structured motor training, thanks to advancements in rehabilitation technology. The Mechatronics and Robotics Control (MRC) Exoskeleton Rehabilitation device was created to assist in the rehabilitation of upper-limb motor function in post-stroke patients. The objective of this study was to evaluate the efficacy of conventional therapy and MRC exoskeleton rehabilitation therapy in the rehabilitation of the upper limb in stroke patients. Thirty-two post-stroke patients were randomly assigned to either the MRC Exoskeleton Rehabilitation group (n=16) or the conventional therapy group (n=16) in this pilot randomized controlled trial. From January to June 2026, the study was implemented. For a period of six weeks, both groups participated in training sessions twice a week. The outcome were Fugl-Meyer Assessment–Upper Extremity (FMA-UE) and the Box and Block Test (BBT). Assessments were administered both prior to and subsequent to the six-week intervention. The MRC Exoskeleton Rehabilitation group demonstrated a significantly greater improvement in motor function than the conventional therapy group, as assessed by the FMA-UE. On the other hand, the BBT did not reveal any substantial disparity between the two groups in terms of the enhancement of manual dexterity

1. INTRODUCTION

Stroke constitutes a major health problem, standing as one of the primary causes of mortality and disability among people globally, with its frequency increasing twofold every ten years after the age of 55.^[1] In 2019, the global occurrence of stroke impacted 101.47 million persons, reflecting an 85% rise from 1990.^[2] Roughly 85% of individuals who have suffered a stroke exhibit a deterioration in upper extremity functionality. Despite completing conventional rehabilitation for 3 to 6 months, approximately 50 to 80% of patients do not completely restore upper-limb functionality, which hinders their ability to conduct activities of daily living (ADL). Conversely, 75–83% of patients attain recovery of lower-limb functionality, including the capacity to ambulate.^[1]

Rehabilitation therapy is essential in the rehabilitation process following a stroke.^[1] Nevertheless, traditional rehabilitation therapy frequently encounters numerous obstacles in attaining sufficient restoration of motor and functional capabilities due to its dependence on manual exercises and therapist-directed functional tasks.^[3] Robotic innovations, like robotic exoskeleton gloves, present a viable approach to improving rehabilitation efficacy through the provision of organized, repeated, and precise workouts.^[4] Robotic therapy, a neuroplasticity-based approach, has been extensively implemented in the context of neurological

rehabilitation to mitigate motor impairments. Robotic therapy provides the benefit of delivering focused and intensive sensorimotor stimulation, which contributes to improved cortical reorganization, a critical neuroplasticity mechanism in post-stroke recovery. Previous research has demonstrated that the combination of robotic therapy and mirror therapy is more effective than conventional therapy in enhancing the motor function of the upper extremities in stroke patients.^[5]

An innovation that has been developed to aid in the upper-limb rehabilitation of stroke patients is the Mechatronics and Robotics Control (MRC) Exoskeleton Rehabilitation system. This system aims to enhance motor function through repetitive exercises, this prototype is intended to facilitate controlled, purposeful hand and finger movements. The objective of the investigation is to compare the efficacy of the MRC Exoskeleton Rehabilitation system with conventional rehabilitation therapies in the restoration of upper-limb motor function in stroke patients. The results are anticipated to facilitate the advancement of technology-based rehabilitation therapies in Indonesia that are more cost-effective, efficient, and effective.

2. MATERIALS AND METHODS

2.1 Study Design

This research is an experimental investigation employing a pilot randomized controlled trial framework. This functions as an initial investigation as the MRC Exoskeleton is a recently created robotic apparatus; hence, foundational evidence concerning its viability for upper-limb rehabilitation in post-stroke individuals is necessary. The research will be place from January to June 2026 at Hasanuddin University Hospital. Participants will be randomly allocated to one of two groups: an intervention group undergoing MRC exoskeleton rehabilitation therapy and a control group getting standard therapy. Upper-limb motor strength will be evaluated by the Fugl-Meyer Assessment for Upper Extremities (FMA-UE), while hand dexterity will be measured using the Box and Block Test (BBT); subsequently, the outcomes from both cohorts will be contrasted.

2.2 Participants

The research subjects were post-stroke patients with upper-extremity motor function impairment undergoing rehabilitation services at Hasanuddin University Hospital who met the study criteria. The inclusion criteria for this study were as follows:

- 1) Patients aged 20 years or older experiencing their first stroke.
- 2) Non-hemorrhagic (infarction) or hemorrhagic stroke.
- 3) Patients with upper-extremity hemiparesis resulting from a right-sided stroke.
- 4) Modified Ashworth Scale (MAS) score for fingers and hand <3.
- 5) Patients who had not previously undergone robotic therapy.
- 6) Hand anthropometric measurements compatible with the exoskeleton (palm length between 92 mm and 108 mm; thumb length between 45 mm and 51 mm).
- 7) Patients capable of understanding the informed consent for study participation.

The exclusion criteria for this study were as follows:

- 1) Patients with severe spasticity or contractures in the upper extremity.
- 2) Patients with severe cognitive impairment that would interfere with study objectives (MMSE score < 24).
- 3) Patients who had undergone Digital Subtraction Angiography (DSA) within the last month.
- 4) Patients with a history of seizures or epilepsy.
- 5) Patients with visual field deficits or severe visual impairment.
- 6) Patients unable to sit upright without assistance.
- 7) Uncontrolled medical conditions (musculoskeletal, neuromuscular, cardiorespiratory) likely to interfere with the ability to perform exercises.

The drop-out criteria for this study were as follows:

- 1) Participant death.
- 2) Participant attended fewer than 3 exercise sessions over two consecutive weeks.
- 3) Participant refused to continue exercise sessions.
- 4) Participant experienced hemodynamic instability during the exercise program.
- 5) Participant experienced neurological complications during the exercise program.

2.3 Randomization

Research subjects were randomly assigned, using a computer-generated randomization, to either the MRC Exoskeleton Rehabilitation group or the conventional therapy group. Interventions were administered by therapists, while FMA-UE and BBT assessments were conducted by the researchers. None of the subjects were aware of the differences in therapy between the groups.

2.4 Intervention

Both groups underwent the intervention twice weekly for six weeks, comprising a total of 12 sessions with 30 minutes of active exercise per session. The intervention group received therapy assisted by the MRC Exoskeleton Rehabilitation device, while the control group performed conventional active exercises under therapist supervision. In the MRC Exoskeleton Rehabilitation group, the affected hand was positioned in the device after a protective glove was fitted. The device facilitated finger and wrist flexion-extension movements using servo motors and a push-pull mechanism. Patients were instructed to actively follow the movements facilitated by the device, in accordance with their motor capabilities. In the control group, patients performed active upper-extremity exercises, including finger flexion-extension, thumb opposition, finger adduction-abduction (accompanied by object-grasping tasks), and wrist flexion-extension. These exercises were conducted under therapist supervision and tailored to each patient's capabilities and tolerance levels.

Throughout the study period, all subjects in both groups continued to receive routine physiotherapy based on their respective clinical needs. If fatigue or pain occurred during exercise, the session was temporarily halted, and the patient was given a five-minute rest period; this rest time was not included in the active exercise duration. **Table 1** showed the differences in interventions between the two groups.

Table 1. The Differences in Interventions Between the Two Groups

Component	Intervention Group	Control Group
Total of Subjects	16 subjects	16 subjects
Frequency	twice/week	twice/week
Duration of intervention	6 weeks	6 weeks
Total of session	12 session	12 session
Active training duration	30 minutes/session	30 minutes/session
The side being trained	Upper extremity on the affected side (right)	Upper extremity on the affected side (right)
Finger flexion-extension	Facilitated by an MRC exoskeleton	Active exercise
Thumb movement/opposition	Facilitated in accordance with the device's movement pattern.	Active thumb opposition exercise

Component	Intervention Group	Control Group
Grasp/finger activity	The grasping movement is facilitated in accordance with the device's programming.	Active exercise accompanied by object-grasping and -retrieving activities.
Wrist flexion-extension	Facilitated by an MRC exoskeleton	Active exercise
Movement support source	Servo motor and push-pull mechanism	Voluntary patient movement under therapist supervision
Patient's role	Actively following device-facilitated movements according to one's ability.	Engage in active exercise according to your ability.
Rest periods when tired or in pain	5 minutes; not counted as active exercise duration	5 minutes; not counted as active exercise duration
Routine physiotherapy	Continued to be administered based on clinical need.	Continued to be administered based on clinical need.
Outcome	FMA-UE and BBT, pre-test and post-test	FMA-UE and BBT, pre-test and post-test

2.5 Evaluation

FMA-UE and BBT assessments were conducted pre- and post intervention in both groups. The BBT assessment was performed on the affected and unaffected sides.

FMA-UE

FMA-UE scores range from 0 to 66, with higher scores indicating better upper-extremity motor function. The FMA-UE motor assessment comprises several sections: upper extremity (maximum score of 36), wrist (maximum score of 10), hand (maximum score of 14), and coordination and speed (maximum score of 6). Each item is rated using a three-point ordinal scale: a score of 0 if the movement cannot be performed, a score of 1 if the movement can be performed partially, and a score of 2 if the movement can be performed fully. The assessment is conducted using equipment consistent with standard FMA-UE procedures and the FMA-UE scoring sheet.

BBT

The BBT is used to assess unilateral gross manual dexterity. The BBT apparatus consists of a box divided into two compartments by a partition and contains 150 blocks. The box is placed lengthwise in front of the subject, with the compartment containing the blocks positioned on the side of the hand being tested. Prior to the assessment, the subject receives instructions on the procedure and an opportunity for a 15-second practice trial. The assessment involves asking the subject to transfer the blocks one by one from one compartment to the other using a single hand over a period of 60 seconds.

2.6 Data Analysis

Data analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 29.0. Subject characteristics, including gender, age, Mini Mental State Examination (MMSE) score, stroke type, stroke onset, stroke history, hemiparesis, and spasticity, were analyzed for both groups. A Chi-square test was used to assess differences in gender and stroke onset between the groups. An independent t-test was used to compare age and MMSE scores. Fisher's exact test was employed to compare spasticity levels, as the data did not meet the requirements for the Chi-square test. Differences regarding stroke type, stroke history, and hemiparesis could not be statistically analyzed due to the nature of the data (absolute results). Normality testing for

the numerical variables FMA-UE and BBT was conducted using the Shapiro-Wilk test; the results indicated a normal distribution. An independent t-test was used to determine the effect of MRC exoskeleton rehabilitation on improvements in upper-extremity FMA-UE and BBT scores among post-stroke patients. A paired t-test was used to assess pre- and post-intervention differences in FMA-UE and BBT scores within the groups. The study utilized a 95% confidence level.

3. RESULTS AND DISCUSSION

3.1 Characteristics of Research Subject

This research had 32 participants, consisting of 16 individuals in the experimental group and 16 individuals in the control group. The characteristics of the subjects are displayed in **Table 2**. There were no differences in characteristics between the intervention and control groups regarding gender ($p=1.000$), age ($p=0.113$), MMSE ($p=0.513$), stroke onset ($p=0.710$), and spasticity based on the Modified Ashworth Scale (MAS) ($p=1.000$). Spasticity was observed in 4 subjects (25.0%) in the intervention group and 5 subjects (31.3%) in the control group. All subjects in both groups had non-hemorrhagic stroke, a history of first-time stroke, and right-sided hemiparesis.

Table 2. Baseline Characteristics of Study Subjects

Characteristics	Intervention Group (n=16)	Control Group (n=16)	p-value
Gender			1.000 ^a
Men	10 (62.5%)	10 (62.5%)	
Women	6 (37.5%)	6 (37.5%)	
Age	54.12 $\pm$ 9.09	59.56 $\pm$ 9.75	0.113 ^b
MMSE	28.00 $\pm$ 2.52	27.37 $\pm$ 2.80	0.513 ^b
Type of Stroke			n/a
Non-hemorrhage	16 (100%)	16 (100%)	
Onset			0.710 ^a
Subacute	11 (68.8%)	10 (62.5%)	
Chronic	5 (31.3%)	6 (37.5%)	
History of Stroke			n/a
First Onset	16 (100%)	16 (100%)	
Hemiparesis			n/a
Right-sided	16 (100%)	16 (100%)	
Spasticity (MAS)			1.000 ^c
Yes	4 (25.0%)	5 (31.3%)	
No	12 (75.0%)	11 (68.8%)	

^aChi-square ^bIndependent T-Test, ^cFisher's Exact Test

Abbreviation: MMSE: Mini Mental State Examination, MAS: Modified Ashworth Scale, n/a: not available

3.2 The Effect of MRC Exoskeleton Rehabilitation on FMA-UE Improvement in Post-Stroke Patients

There was no difference in FMA-UE scores between the two groups prior to the intervention (intervention: 40.43 $\pm$ 15.05 vs. control: 42.18 $\pm$ 12.24; $p = 0.721$). Analysis also showed no difference in FMA-UE scores between the groups following the intervention (intervention: 51.43 $\pm$ 12.65 vs. control: 45.93 $\pm$ 13.37; $p = 0.242$). However, the analysis revealed a statistically significant difference between pre- and post-intervention FMA-UE scores in the intervention group, indicating a trend of improvement ($p < 0.001$). The difference between pre- and post-intervention FMA-UE scores in the control group was also statistically significant ($p = 0.009$). A comparison of the FMA delta between the two groups showed a significant difference, with a delta of 11.00 $\pm$ 9.33 in the intervention group and 3.75 $\pm$ 4.98 in the control group ($p = 0.010$) (**Table 3 and Figure 1**).

Table 3. Effect of MRC Exoskeleton Rehabilitation on Upper Extremity FMA Improvement in Stroke Patients

FMA	Intervention Group (n=16)	Control Group (n=16)	p-value
Pre	40.43±15.05	42.18±12.24	0.721 ^a
Post	51.43±12.65	45.93±13.37	0.242 ^a
Delta	11.00±9.33	3.75±4.98	0.010 ^a
	<0.001 ^b	0.009 ^b	

^aComparison of mean FMA intervention scores between the two groups using an independent t-test, ^bChanges in mean FMA scores between pre- and post-intervention in each group were analyzed using the paired t-test.

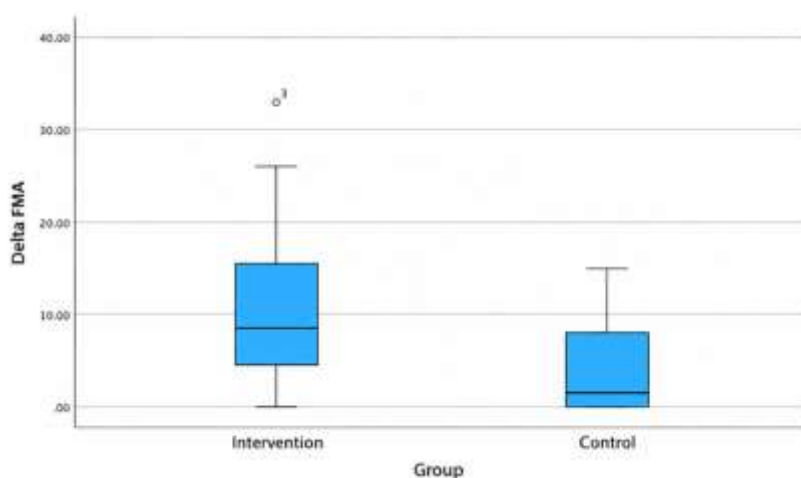


Figure 1. Comparison of Delta FMA between the two groups.

3.3 The Effect of MRC Exoskeleton Rehabilitation on BBT Improvement in Post-Stroke Patients

The statistical analysis showed that prior to the intervention, there was no significant difference in mean BBT scores between the intervention and control groups on either the affected side ($p=0.896$) or the unaffected side ($p=0.200$). Following the intervention, there was likewise no significant difference in mean BBT scores between the two groups on either the affected side ($p=0.491$) or the unaffected side ($p=0.352$) (**Table 4** and **Table 5**).

Table 4. The Effect of MRC Exoskeleton Rehabilitation on BBT Improvement in Stroke Patients (Affected Side)

BBT	Intervention Group (n=16)	Control Group	p-value
		(n=16)	
Pre	23.68±9.83	24.18±11.50	0.896 ^a
Post	32.00±12.46	28.81±13.38	0.491 ^a
Delta	8.31±8.63	4.62±4.47	0.140 ^a
	<0.001 ^b	<0.001 ^b	

^aComparison of mean FMA intervention scores between the two groups using an independent t-test, ^bChanges in mean FMA scores between pre- and post-intervention in each group were analyzed using the paired t-test.

Table 5. The Effect of MRC Exoskeleton Rehabilitation on BBT Improvement in Stroke Patients (Unaffected Side)

BBT	Intervention Group (n=16)	Control Group (n=16)	p-value
Pre	44.75±8.59	40.56±9.47	0.200 ^a
Post	51.43±10.94	47.87±10.37	0.352 ^a
Delta	6.68±7.82	7.31±6.69	0.810 ^a
	0.002 ^b	<0.001 ^b	

^aComparison of mean FMA intervention scores between the two groups using an independent t-test, ^bChanges in mean FMA scores between pre- and post-intervention in each group were analyzed using the paired t-test.

A comparison of pre- and post-intervention BBT scores revealed a significant improvement in the intervention group on both the affected side ($p<0.001$) and the unaffected side ($p=0.002$). Significant improvement was also observed in the control group on both the affected side ($p<0.001$) and the unaffected side ($p<0.001$) (**Table 4 and Table 5**).

A comparison of the change (Δ) in BBT scores between the two groups showed no significant difference on the affected side, with mean Δ BBT values of 8.31 ± 8.63 for the intervention group and 4.62 ± 4.47 for the control group ($p=0.140$). Similarly, on the unaffected side, there was no significant difference between the intervention and control groups, with mean Δ BBT values of 6.68 ± 7.82 and 7.31 ± 6.69 , respectively ($p=0.810$) (**Figure 2 and Figure 3**).

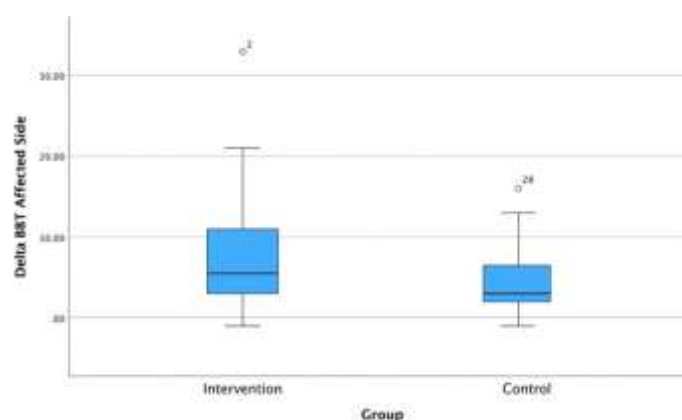


Figure 2. Comparison of Delta BBT (Affected Side) Between the Two Groups

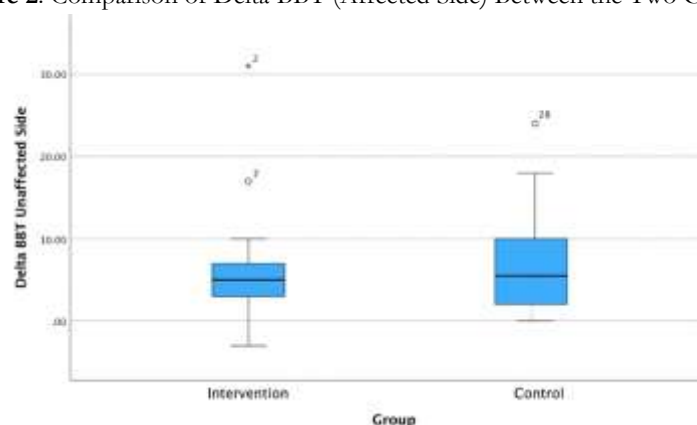


Figure 3. Comparison of Delta BBT (Unaffected Side) Between the Two Groups

3.4 Discussion

This research reveals a notable disparity in FMA-UE delta between the two groups, with a more evident trend identified in the MRC exoskeleton group. This corresponds with a comprehensive evaluation conducted by Yang et al. (2024), which indicated that rehabilitation utilising exoskeletons can enhance motor function, as evaluated by the FMA, relative to traditional rehabilitation.^[6] In addition, Morone et al. (2026) demonstrated that the exoskeleton intervention group exhibited a substantially greater improvement in FMA scores than the control group, with a median between-group difference of 22 points ($P < 0.001$).^[7] Chen et al. (2021) conducted a study that demonstrated that an exoskeleton-assisted anthropomorphic movement training intervention can substantially enhance FMA scores in post-stroke patients.^[8]

Following the exoskeleton intervention, there were improvements in FMA scores, as the device is capable of producing thousands of movement repetitions with consistent quality during each training session. Furthermore, the intervention facilitated active engagement, high-intensity task repetition, and enhanced proprioceptive feedback through robotic assistance.^[9] While maintaining a stable position, rehabilitation robots allow patients to perform high-intensity repetitive exercises. Repetitive exercise also enhances the transmission efficacy of neural circuits, expands the cortical representation area corresponding to the trained site, and improves bodily motor function.^[10] High-intensity training with an exoskeleton is a critical factor in the reorganisation of the central nervous system through neuroplasticity mechanisms, which in turn leads to enhanced FMA scores. Exoskeleton interventions can improve motor cortex neuroplasticity by increasing neurotrophic factors, such as BDNF, and promote hippocampal neuroplasticity and structural remodelling, indicating brain recovery.^[11, 12]

The corticospinal network is perpetually activated by repetitive motor training with an exoskeleton, which subsequently fortifies intact synaptic connections and establishes new neural pathways. This phenomenon is consistent with the principle of Hebbian plasticity, which posits that the efficiency of synaptic transmission is improved by the recurrent activation of presynaptic and postsynaptic neurones through the mechanism of long-term potentiation or LTP. As a result, motor control is enhanced, resulting in improved voluntary movement capabilities, as evidenced by higher FMA scores.^[12, 13]

Singh et al. (2021) also describe that enhancements in sensorimotor capabilities and function—as indicated by elevated FMA scores—are linked to a variety of device characteristics. Throughout the therapy session, patients are motivated and engaged by visual and proprioceptive feedback regarding their performance during each trial. In general, the increase in FMA scores is attributed to the enhancements in active range of motion and spasticity that are typically achieved during the intervention period.^[14] The significance of the intensity and timing of rehabilitation interventions is emphasised by the intricate relationship between neuroplasticity and the recovery of motor function following a stroke. The brain's capacity to adapt and reorganise itself is substantially impacted by these factors.^[15]

Through motor repetition, which can enhance neuroplasticity, the exoskeleton also improved upper-limb motor function after six weeks of rehabilitation as measured by the BBT in affected side, although this difference was not statistically significant. The BBT is a performance-based test that evaluates gross manual dexterity and requires the integration of several components, such as the ability to sustain performance for 60 seconds, speed, visuomotor coordination, object transport, and release. Consequently, improvements in basic motor skills do not necessarily translate into improvements in manual activity of the same intensity and speed. These results align with Rodgers et al. (2019), which found no advantage of robot-assisted training over enhanced upper-limb therapy or standard care regarding the primary outcome of upper-limb function. However, secondary outcome analyses revealed improvements in upper-limb impairment as assessed by the Fugl-Meyer Assessment. This reinforces the notion that increased functional activity does not always equate to reduced motor impairment.^[16]

The increase in BBT on the unaffected side observed in this study is another finding that supports the complexity of post-stroke motor recovery. The motor system is bilaterally organised, and the two hemispheres interact during the planning and execution of movements. Additionally, prior to the stroke, all study participants exhibited right-sided hemiparesis and were right-handed users. Patients' reliance on the left hand for daily activities was likely exacerbated by their limitations in using the right hand. This increased utilisation offered additional exposure to motor activity, which could potentially aid in motor learning on the unaffected side. The neurophysiological foundation for bilateral adaptation is also provided by the phenomenon of cross-education (or interlimb transfer). In chronic stroke patients, Sun et al. (2018) have shown that five weeks of unilateral wrist extension training resulted in strength gains in both the trained and contralateral limbs, as well as changes in spinal and

cortical plasticity parameters. The study suggests that the adaptations that arise from unilateral training are not exclusively limited to the trained limb and may also entail modifications to the central nervous system.^[17]

However, the BBT improvement on the unaffected side in this study cannot be directly attributed to cross-education. The direction of transfer was different from that of the current study's protocol, as Sun et al. (2018) trained the less affected limb and assessed the transfer to the more affected side. Additionally, both groups experienced improvements on the unaffected side with a similar magnitude of Δ BBT. Consequently, this enhancement is more effectively comprehended as a multifactorial transformation, which may encompass the following: motor learning, bilateral motor system adaptation, post-stroke recovery processes, potential familiarisation with the BBT assessment, and increased compensatory use of the left hand.^[17]

MRC exoskeleton rehabilitation has the potential to aid in the recovery of upper-limb motor function following a stroke by offering repetitive motor exercises that can physiologically stimulate neuroplasticity and motor learning. Nevertheless, the functional changes observed in the control group suggest that conventional therapy and the biological post-stroke recovery process also contribute. Consequently, the MRC exoskeleton's specific effects must be assessed not solely on pre-to-post improvements, but also on the extent of the difference in changes between groups. The potential of the MRC exoskeleton as an adjunct modality in post-stroke upper-limb rehabilitation is supported by these findings; however, they are insufficient to establish that it is superior to conventional therapy in all aspects of upper-limb function.

The absence of a follow-up assessment of FMA-UE and BBT scores following the conclusion of the intervention period is a limitation of this study. As a result, the results only indicate changes in gross manual dexterity and motor function immediately following the six-week intervention, rendering the sustainability of the effects after the intervention's conclusion uncertain. The capacity to ascertain whether the enhancements in FMA-UE and BBT were sustained over time or merely reflected changes that occurred during the intervention period is restricted by the absence of follow-up evaluations, such as those conducted one month post-intervention. This is of particular importance since the majority of the subjects were in the subacute phase, a time during which the effects of rehabilitation training may occur concomitant with spontaneous biological recovery processes. The retention and sustainability of the effects of MRC exoskeleton rehabilitation after the intervention program have concluded should be assessed through follow-up assessments of FMA-UE and BBT in future research.

4. CONCLUSION

The MRC rehabilitation exoskeleton has the potential to aid in the recovery of upper-limb motor function following a stroke by delivering repetitive motor exercises that can physiologically stimulate neuroplasticity and motor learning.

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None

AUTHOR CONTRIBUTIONS

SA, HM, and SEA developed the research concept. SA collected and analyzed the data and drafted the manuscript. HM, SEA, AAZ, YW, and AA provided supervision. All changes to this article have been approved by all authors.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICS STATEMENT

This study received ethical approval from the Ethics Committee of the Faculty of Medicine, Hasanuddin University, and authorization from Hasanuddin University Hospital. All subjects were informed about the research procedures and consented to participate by signing an informed consent form. All subjects agreed to the publication of the findings, with their identities anonymized.

DATA AVAILABILITY STATEMENT

The research data is not generally available.

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