

## Effects of distal robot-assisted therapy combining with task-oriented training on paretic upper extremity functions in clients with sub-acute stroke: A preliminary study

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### ABSTRACT

**Background:** Robot-assisted therapy (RT) is revolutionizing stroke rehabilitation, offering new hope for improving upper extremity function. When integrated with task-oriented training (TOT), RT has the potential to enhance recovery by promoting more meaningful, functional outcomes for stroke survivors. Despite its promise, evidence on the effectiveness of distal RT combined with TOT remains limited, leaving clinicians and researchers searching for clearer evidence on the best rehabilitation strategies.

**Objective:** This study aimed to investigate the feasibility of distal RT combined with TOT on the function of the paretic upper extremity in sub-acute stroke patients.

**Materials and methods:** This preliminary randomized controlled, assessor-blinded study recruited 15 sub-acute stroke patients. Participants were randomly assigned to either the experimental group (EG; enrolled, N=8; completed, N=7) or the control group (CG; enrolled, N=7; completed, N=7). Both groups received conventional occupational therapy. The EG additionally underwent one hour of distal robot-assisted task-oriented training twice a week for six weeks. Paretic upper extremity function was assessed at baseline and post-rehabilitation using the Fugl-Meyer Assessment for Upper Extremity (FMA-UE) and the Functional Test for Hemiplegic Upper Extremity Thai Version (FTHUE-Thai version).

**Results:** Fourteen patients completed the program. No significant differences in post-intervention mean scores were found between groups. However, change scores were significantly higher in the EG for distal FMA-UE ( $p=0.002$ ), total FMA-UE ( $p=0.004$ ), and FTHUE-Thai Version ( $p=0.026$ ). Additionally, effect size analysis also indicated high effects in the EG for proximal FMA-UE ( $d=0.94$ ), distal FMA-UE ( $d=2.28$ ), total FMA-UE ( $d=1.66$ ), and FTHUE-Thai version scores ( $d=1.89$ ), suggesting clinically meaningful improvements.

**Conclusion:** Combining distal RT with TOT has the potential to enhance upper extremity function in sub-acute stroke patients. Although further research is needed to confirm these findings, the results are promising for developing more effective rehabilitation strategies.

### Introduction

Stroke is the second leading cause of death and a major cause of disability worldwide.<sup>1</sup> In Thailand, approximately 200,000 new stroke cases are diagnosed annually, imposing significant burdens on families, society, and healthcare systems.<sup>2</sup> Around 70% of stroke survivors experience upper limb function impairment, leading to difficulties in performing activities of daily living (ADLs) and a reduced quality of life (QoL).<sup>3-6</sup> Previous research emphasizes the importance of intensive upper limb rehabilitation within

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the first six months post-stroke particularly during the sub-acute phase (3-6 months), when brain recovery remains robust, and patients are in a more stable medical condition for intensive training.<sup>7-10</sup> Therefore, developing effective rehabilitation approaches for sub-acute stroke survivors is crucial.<sup>11</sup> Occupational therapy incorporates a variety of evidence-based interventions to address motor dysfunction, focusing on enhancing movement quality, task performance, and overall participation in daily activities.<sup>12,13</sup> To achieve these goals, advancements in the field have introduced technology-driven tools, such as robotic devices, alongside task-specific training to improve motor deficits more efficiently and effectively.

Robot-assisted therapy (RT) is widely used in stroke rehabilitation, as it delivers highly repetitive, consistent movements with greater training intensity, enhancing patient engagement and functional recovery.<sup>14</sup> Emerging studies suggest that RT may support somatosensory and motor cortex reorganization, making it a valuable tool for comprehensive stroke rehabilitation.<sup>15-20</sup> A systematic review and meta-analysis by Bertani et al. highlighted the potential benefits of RT for upper extremity rehabilitation in chronic stroke patients.<sup>15</sup> However, its effectiveness for sub-acute stroke patients remains inconclusive.<sup>13</sup> To date, most studies have predominantly employed proximal robotic devices that target the shoulder and elbow joints, while distal robotic rehabilitation, which targets wrist and finger function, has been relatively underexplored despite its importance for functional hand use.<sup>13,19</sup> Distal robotic devices offer a promising solution by facilitating isolated and coordinated hand movements including grasp-and-release activities while integrating multisensory feedback (visual, auditory, and proprioceptive) to enhance engagement and cortical activation.<sup>16,21,22</sup> The hand contains numerous motor units and sensory receptors responsible for fine and precise movements. When, the nervous system controlling hand function is damaged, prolonged and repeated stimulation is to achieve functional recovery.<sup>23</sup> Therefore, the benefits of distal robot-assisted therapy, such as the Gloreha Sinfonia, need to be further validated for distal upper extremity recovery.

Task-oriented training (TOT) aims to improve performance and function through goal-directed practice and repetition.<sup>13,24,25</sup> It requires an intensity exceeding 70% of total training time and is grounded in motor control, motor learning, and motor behavior principles. Previous study indicates that incorporating daily life activities and using real-life objects during training can boost motivation and improve movement efficiency in stroke patients.<sup>26</sup> Moreover, TOT promotes motor learning by enabling patients to transfer learned movements to their daily routines.<sup>27,28</sup> It also reduces long-term reliance on compensatory strategies for performing everyday

tasks.<sup>28,29</sup> Therefore, combining distal RT with TOT could offer a more effective approach to improving function in stroke patients by engaging them in task-specific activities supported by robotics.

This study investigates the potential effects of integrating the distal RT with TOT to enhance upper limb function in sub-acute stroke patients. It hypothesizes that distal RT combining with TOT has the potential to enhance recovery of upper limb function. To the best of our knowledge, this is the first study to examine the integration of RT specifically designed for finger movements with TOT incorporating real-life objects and activities. This combined approach holds the potential to provide a more comprehensive solution for functional recovery after stroke.

## Materials and methods

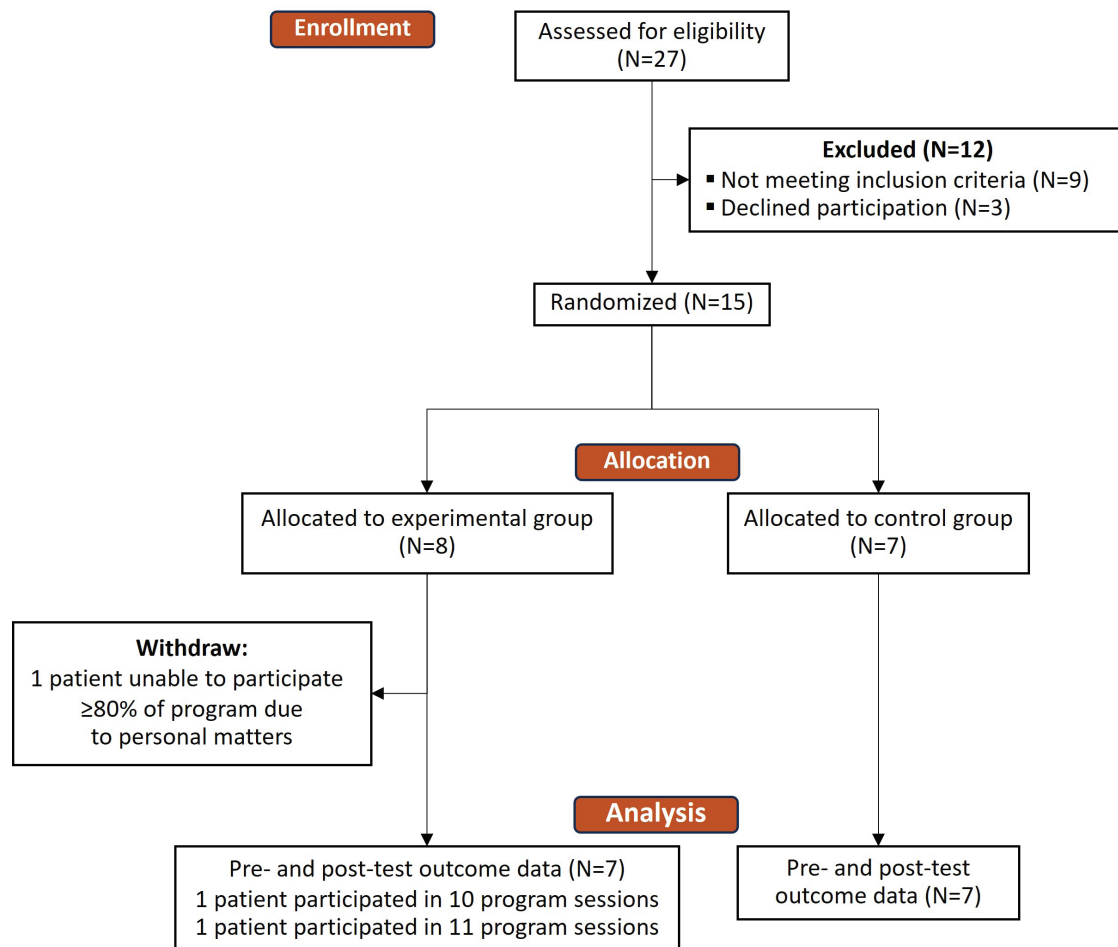
### Design

This preliminary randomized controlled, assessor-blind study was reviewed and approved by the Thai Clinical Trials Registry Committee on July 2022 (TCTR identification number: TCTR20220719006). Sub-acute stroke patients were recruited from two hospitals and one health center, Chiangmai, Thailand, between August 2022 and December 2024. The study was conducted with ethics committee approval, and all participants signed informed consent forms prior to participation.

### Participants

Between August 2022 and December 2024, 27 patients were assessed for eligibility. However, due to several recruitment challenges, including a limited number of eligible patients, participation inconvenience, travel constraints, and time limitations, 15 participants were initially enrolled in the study. Patients were eligible if they were over 18 years old, had experienced a first-time cerebrovascular disease resulting in hemiplegia for 3-6 months, were in Brunnstrom stages II-V of motor recovery for the arm and hand, and had a Modified Ashworth Scale score of less than 3. Exclusion criteria included cognitive impairment (MSET-10 Thai version score:  $\leq 17$  for primary education or  $\leq 22$  for higher education), peripheral nerve injury or musculoskeletal disorders (e.g., arthritis, muscle or bone injury), severe unilateral neglect, proprioceptive impairment, communication or vision difficulties, and prior treatments for spasticity such as botulinum toxin type A or acupuncture.

Participants were randomly assigned to either the experimental group (EG) or the control group (CG) using simple random sampling via the Research Randomizer tool. However, one participant from the EG withdrew due to an inability to complete at least 80% of the training sessions, resulting in a final sample of 14 participants. A flowchart outlining the recruitment and retention process was presented in Figure 1.



**Figure 1.** Flow chart of the study

### Instruments

The Gloreha Sinfonia was employed as the primary intervention tool in this study. This distal robotic device is specifically designed to target the distal upper extremity, providing five degrees of freedom. Its dynamic support system stabilizes the proximal upper extremity against gravity during training. The device features a glove that provides partial or complete support for finger flexion and extension across six movement patterns. Additionally, it includes four training modes: passive mobilization, bilateral training, active-assisted mobilization, and interactive games allowing therapists to customize rehabilitation programs to meet individual patient needs.<sup>21,30</sup>

This study utilized the Gloreha Sinfonia in its active-assisted mobilization mode, focusing on two key functions, including free grasping and tri-digital free pinch. The choice of function was based on the specific training activity and the participant's motor abilities. In this mode, the therapist could adjust glove sensitivity, finger flexion/extension support levels, and range of motion to match each participant's needs. The sensor glove detected individual finger movements and provided movement assistance based on the user's residual motor skills, ensuring a personalized and adaptive rehabilitation experience.

### Interventions

All participants received conventional occupational therapy, which included 1-hour/sessions, at least 1 session/week for six weeks. The conventional program included spasticity inhibition, bilateral hand activities, grasp-and-release tasks, and pinch activities, customized by the therapist for each patient.

In addition to conventional therapy, the experimental group (EG) received robot-assisted task-oriented training using the Gloreha Sinfonia device for 1-hour sessions, twice a week, over six weeks. Each session consisted of two phases:

1. *Preparatory phase* (15 minutes): This phase included weight-bearing or prolonged stretching exercises aimed to normalized muscle tone.

2. *Robot-assisted task-oriented training phase* (45 minutes): During the first session, patients selected three out of five training activities, including drinking water from a bottle, folding fabric, using a fork and spoon for eating, using scissors, and opening/closing a book). The details of each activity were outlined in Table 1. These activities were chosen from the top 100 ranked activities, organized from the most to the least beneficial for stroke patients.<sup>31</sup> Only activities related to daily living that were analyzed and deemed suitable for

use with the Gloreha device were selected. The selection process began with the top-ranked activity and continued sequentially until a total of five activities were chosen. Each training session lasted 45 minutes, with 15 minutes per activity using the Gloreha device in active-assisted mode. Task difficulty and robotic assistance were adjusted

based on individual progress. If participants mastered any task from the initial selection, they had the option to select new activities to maintain challenge and engagement. Training activities were performed in a randomized order to enhance motor learning and adaptability.

**Table 1.** Training activities.

| Activity                          | Description                                                                                                                                                                                                   | Chosen frequency (times) |
|-----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|
| Drinking water from a bottle      | Patients reach out with the affected hand to grasp the bottle, bring it to their mouth as if drinking, then return it to the table and release it.                                                            | 7                        |
| Folding fabric                    | Patients fold the fabric using both hands.                                                                                                                                                                    | 2                        |
| Using a fork and spoon for eating | Patients use both hands to hold a spoon and fork according to their preference, scoop beads from a plate, bring them to their mouth as if eating, then return them to the plate.                              | 7                        |
| Using scissors                    | Patients use their affected hand to hold the scissors and their unaffected hand to hold the paper, then cut along specified lines in various shapes, such as straight lines, triangles, squares, and circles. | 1                        |
| Opening/closing a book            | Patients use their affected hand to open the book.                                                                                                                                                            | 4                        |

*Note: Details and materials of each activity were adjusted according to the patient's abilities.*

### Outcome measures

Motor function was assessed at baseline and post-intervention using the following tools:

1. The Fugl-Meyer Assessment-Upper Extremity (FMA-UE) is a widely used tool for assessing upper extremity motor function. It includes 33 items divided into four categories: upper extremity (36 points), wrist (10 points), hand (14 points), and coordination (6 points). The total possible score is 66 points. The FMA-UE has demonstrated excellent inter-rater reliability (ICC=0.99), test-retest reliability (ICC=0.96), and strong construct validity ( $r=0.92$ ).<sup>32</sup>

2. The Functional Test for Hemiplegic Upper Extremity-Thai Version (FTHUE-Thai Version) is a performance-based test adapted from the Hong Kong version to align with Thai cultural contexts.<sup>33</sup> It measures functional limitations due to upper extremity impairments. The FTHUE-Thai version comprises 14 tasks across seven functional levels, arranged in order of increasing difficulty. The tasks are related to activities of daily living, such as holding a bag, using a spoon to eat, and drinking water from a glass. Tasks are scored on a pass/fail basis: a 'pass (+)' is awarded if the task is completed within three minutes, while a 'fail (-)' is given if the task is incomplete or exceeds the time limit. Functional level scores are awarded upon the completion of all tasks within each level. Scores range from 1 to 7, with higher scores indicating greater functional ability. From level 5 onward, the time taken to complete each task is also recorded. The FTHUE-Thai version has demonstrated good content validity and strong inter-rater reliability.<sup>34</sup>

### Statistical analysis

Descriptive statistics were used to summarize demographic and baseline characteristics. Continuous variables are presented as means  $\pm$  standard deviations, while categorical variables are presented as frequencies and percentages (N, %). Between-group differences in baseline characteristics were analyzed using Fisher's exact test for categorical variables and multivariate analysis of variance (MANOVA) for continuous variables. The normality of the data was tested using the Shapiro-Wilk test, and due to the lack of normality, non-parametric statistics were used. Within-group comparisons were performed using the Wilcoxon signed-rank test. Between-group comparisons were assessed using the Mann-Whitney U test. A significance level of  $p<0.05$  was used for all tests. Effect sizes were calculated using Cohen's  $d$  coefficient, where an effect size greater than 0.8 was considered large, between 0.2 and 0.8 moderate, and less than 0.2 small.<sup>35,36</sup>

## Results

### Baseline characteristics

The demographic and clinical characteristics of the participants at baseline were summarized in Table 2 and 3. There were no statistically significant differences between the EG and the CG across any measured baseline characteristics, confirming the comparability of the two groups at the start of the study.

**Table 2.** Baseline characteristics for categorical variables.

| Characteristic         | N (%)     |           | p     |
|------------------------|-----------|-----------|-------|
|                        | EG (N=7)  | CG (N=7)  |       |
| <b>Gender</b>          |           |           | 1.000 |
| Male                   | 5 (71.43) | 4 (57.14) |       |
| Female                 | 2 (28.57) | 3 (42.86) |       |
| <b>Education level</b> |           |           | 0.266 |
| High school            | 1 (14.29) | 4 (57.14) |       |
| Above high school      | 6 (85.71) | 3 (42.86) |       |
| <b>Affected side</b>   |           |           | 1.000 |
| Left                   | 4 (57.14) | 3 (42.86) |       |
| Right                  | 3 (42.86) | 4 (57.14) |       |
| <b>Etiology</b>        |           |           | 0.592 |
| Infraction             | 5 (71.43) | 3 (42.86) |       |
| Hemorrhage             | 2 (28.57) | 4 (57.14) |       |

Note: The *p* values were calculated according to the Fisher's Exact Test, EG: experimental group, CG: control group, \**p*<0.05.

**Table 3.** Baseline characteristics for continuous variables.

| Characteristic                               | Mean (SD)      |                | p     |
|----------------------------------------------|----------------|----------------|-------|
|                                              | EG (N=7)       | CG (N=7)       |       |
| Age (year)                                   | 53.29 (14.96)  | 64.29 (10.45)  | 0.137 |
| Post-stroke duration (days)                  | 127.14 (34.30) | 139.71 (28.92) | 0.473 |
| Brunnstrom stage of arm                      | 3.14 (0.69)    | 3.43 (0.79)    | 0.484 |
| Brunnstrom stage of hand                     | 3.57 (0.98)    | 3.71 (1.38)    | 0.827 |
| MAS score of arms                            | 1.21 (0.39)    | 1.07 (0.19)    | 0.403 |
| MAS score of hands                           | 0.71 (0.76)    | 1.00 (0.50)    | 0.421 |
| MSET-10 score                                | 26.43 (3.56)   | 25.57 (2.99)   | 0.634 |
| Total duration of conventional therapy (hrs) | 6.86 (2.27)    | 7.71 (2.93)    | 0.552 |

Note: The *p* values were calculated according to the multivariate analysis of variance (MANOVA), EG: experimental group, CG: control group, MAS: Modified Ashworth Scale, MSET-10: Mental State Examination T10.

#### **Effects of robot-assisted therapy combining with task-oriented training on paretic upper extremity functions**

Changes in upper extremity function from pre- to post-intervention were presented in Table 4. The results of the study found that there were significant improvements between pre- and post-intervention of proximal FMA-UE scores (*p*=0.018), distal FMA-UE scores (*p*=0.017), coordination FMA-UE scores (*p*=0.041), total FMA-UE scores (*p* = 0.018), and FTHUE-Thai Version scores (*p*=0.014) within the EG whereas there was only significant improvement between pre- and post-intervention of the proximal FMA-UE scores (*p*=0.026) and the total FMA-UE score (*p*=0.017) in the CG.

When compared between groups, no significant differences between group were found in mean scores of FMA-UE or FTHUE-Thai Versions after the intervention. However, significant change scores were observed in the distal FMA-UE (*p*=0.002), total FMA-UE (*p*=0.004), and FTHUE-Thai Version (*p*=0.026), indicating greater improvement in the EG (Table 5). These findings are further supported by Cohen's *d* effect sizes, which indicate a high effect for proximal FMA-UE scores (*d*=0.94), distal FMA-UE scores (*d*=2.28), total FMA-UE score (*d*=1.66), and FTHUE-Thai Version scores (*d*=1.89) (Table 5).

**Table 4.** Within-group comparison of proximal, distal, coordination, and total FMA-UE scores and FTHUE-Thai version scores between pre-test and post-test.

| Outcome measure/group     | Pre-test Mean (SD) | Post-test Mean (SD) | Within group <i>p</i> value |
|---------------------------|--------------------|---------------------|-----------------------------|
| <b>FMA-UE</b>             |                    |                     |                             |
| Proximal                  |                    |                     |                             |
| EG (N=7)                  | 17.00 (6.03)       | 24.71 (8.44)        | 0.018*                      |
| CG (N=7)                  | 18.00 (8.81)       | 21.00 (9.97)        | 0.026*                      |
| Distal                    |                    |                     |                             |
| EG (N=7)                  | 8.86 (7.58)        | 15.43 (5.97)        | 0.017*                      |
| CG(N=7)                   | 11.71 (8.75)       | 12.71 (8.18)        | 0.197                       |
| Coordination              |                    |                     |                             |
| EG (N=7)                  | 1.29 (1.89)        | 3.00 (2.16)         | 0.041*                      |
| CG (N=7)                  | 1.86 (1.86)        | 2.71 (1.98)         | 0.102                       |
| Total                     |                    |                     |                             |
| EG (N=7)                  | 27.14 (13.85)      | 43.14 (15.85)       | 0.018*                      |
| CG (N=7)                  | 31.57 (17.83)      | 36.43 (18.50)       | 0.017*                      |
| <b>FTHUE-Thai Version</b> |                    |                     |                             |
| EG (N=7)                  | 3.43 (0.53)        | 4.29 (0.49)         | 0.014*                      |
| CG (N=7)                  | 3.71 (0.76)        | 3.86 (1.07)         | 0.317                       |

Note: The *p* values were calculated using Wilcoxon signed-rank test, FMA-UE: Fugl-Meyer Assessment-Upper Extremity, FTHUE-Thai Version: Functional Test for Hemiplegic Upper Extremity-Thai Version, EG: experimental group, CG: control group, \**p*<0.05

**Table 5.** Between-group comparison of proximal, distal, coordination, and total FMA-UE scores and FTHUE-Thai version scores pre-test and post-test and the variance between CG and EG.

| Outcome measure/group        | Pre-test Mean (SD) | Post-test Mean (SD) | Change scores Mean (SD) | Cohen's <i>d</i> |
|------------------------------|--------------------|---------------------|-------------------------|------------------|
| <b>FMA-UE</b>                |                    |                     |                         |                  |
| Proximal                     |                    |                     |                         |                  |
| EG (N=7)                     | 17.00 (6.03)       | 24.71 (8.44)        | 7.71 (6.13)             | 0.94             |
| CG (N=7)                     | 18.00 (8.81)       | 21.00 (9.97)        | 3.00 (3.51)             |                  |
| Between group <i>p</i> value | 1.000              | 0.535               | 0.053                   |                  |
| Distal                       |                    |                     |                         |                  |
| EG (N=7)                     | 8.86 (7.58)        | 15.43 (5.97)        | 6.57 (2.82)             | 2.28             |
| CG(N=7)                      | 11.71 (8.75)       | 12.71 (8.18)        | 1.00 (2.00)             |                  |
| Between group <i>p</i> value | 0.805              | 0.710               | 0.002*                  |                  |
| Coordination                 |                    |                     |                         |                  |
| EG (N=7)                     | 1.29 (1.89)        | 3.00 (2.16)         | 1.71 (1.60)             | 0.55             |
| CG (N=7)                     | 1.86 (1.86)        | 2.71 (1.98)         | 0.86 (1.46)             |                  |
| Between group <i>p</i> value | 0.710              | 0.710               | 0.318                   |                  |
| Total                        |                    |                     |                         |                  |
| EG (N=7)                     | 27.14 (13.85)      | 43.14 (15.85)       | 15.86 (8.73)            | 1.66             |
| CG (N=7)                     | 31.57 (17.83)      | 36.43 (18.50)       | 4.86 (3.34)             |                  |
| Between group <i>p</i> value | 0.805              | 0.710               | 0.004*                  |                  |

**Table 5.** Between-group comparison of proximal, distal, coordination, and total FMA-UE scores and FTHUE-Thai version scores pre-test and post-test and the variance between CG and EG. (Continue)

| Outcome measure/group        | Pre-test Mean (SD) | Post-test Mean (SD) | Change scores Mean (SD) | Cohen's <i>d</i> |
|------------------------------|--------------------|---------------------|-------------------------|------------------|
| <b>FTHUE-Thai Version</b>    |                    |                     |                         |                  |
| EG (N=7)                     | 3.43 (0.53)        | 4.29 (0.49)         | 0.86 (0.38)             | 1.89             |
| CG (N=7)                     | 3.71 (0.76)        | 3.86 (1.07)         | 0.14 (0.38)             |                  |
| Between group <i>p</i> value | 0.535              | 0.209               | 0.026*                  |                  |

Note: The *p* values were calculated using Mann-Whitney U, FMA-UE: Fugl-Meyer Assessment-Upper Extremity, FTHUE-Thai Version: Functional Test for Hemiplegic Upper Extremity-Thai Version, EG: experimental group, CG: control group, Cohen's *d*=effect size between change scores, \**p*<0.05.

## Discussion

This study aimed to evaluate the effects of combining distal robot-assisted therapy (distal RT) with task-oriented training (TOT) on upper extremity function in sub-acute stroke patients. The findings demonstrated significant within-group improvements in the EG across proximal, distal, total FMA-UE scores, and FTHUE-Thai version scores after six weeks. In contrast, the CG showed significant improvement only in proximal and total FMA-UE scores. Although no statistically significant differences in the mean post-intervention score of both outcome measures were observed between groups, significant change scores were found for distal and total FMA-UE and FTHUE-Thai Version. These changes, confirmed by high effect sizes indicated clinically meaningful improvements in the EG, emphasizing the potential benefits of integrating TOT with distal RT.

Regarding the FMA-UE results, a significant improvement in total and distal FMA-UE change scores was observed in the EG compared to the CG. This may be attributed to the structured training program provided by the Gloreha Sinfonia device. The Gloreha Sinfonia is a robotic device designed to facilitate repetitive hand movements, such as grasp-and-release activities, while providing dynamic support to the proximal upper extremity against gravity. Its glove-based system offers adjustable support for finger flexion and extension, allowing therapists to customize rehabilitation programs for each patient. Interestingly, the effects of distal RT and TOT were supported not only by the moderate to high effect sizes observed through Cohen's *d* values but also by the significant differences in distal and total FMA-UE change scores. The EG exhibited an improvement of 7 points (8.29 vs 1.29) for distal FMA-UE and 11 points (15.86 vs 4.86) for total FMA-UE. These results exceed the minimal clinically important differences (MCID) for distal FMA-UE (1 to 3 points) and total FMA-UE (9 to 10 points). Although no significant difference was found in the proximal FMA-UE change score, the change in the EG was 7.71 points, which is within the MCID range for proximal FMA-UE (5 to 7 points), whereas the CG showed a change score below the MCID (3 points).<sup>37</sup> These findings suggest that the combined effects of distal RT and TOT may provide clinically meaningful improvements in upper extremity function for sub-acute stroke patients, as evidenced by the greater distal and total FMA-UE change scores in the EG.

Given that the observed difference exceeds the MCID threshold for FMA-UE, this approach may hold significant potential for enhancing upper extremity recovery in stroke rehabilitation.

The significant improvement in FTHUE-Thai version change scores (*p*=0.026) further supports the effectiveness of distal RT combined with TOT in enhancing functional movement and facilitating the transfer of motor improvements to activities of daily living (ADLs). TOT emphasizes goal-directed practice and repetition, which are essential for motor learning and functional recovery.<sup>24,38</sup> Additionally, the active-assisted mode of distal RT allows patients to perform hand movements independently enhancing motor learning, motivation, and a sense of accomplishment. These findings align with studies such as Wu *et al.*<sup>26</sup> which demonstrated that real-life task integration promotes motor recovery and functional independence. Similarly, a study by Lee and Howe<sup>39</sup> highlighted the effectiveness of using real-life activities to improve motor function and ADLs in stroke patients.

The greater improvements in upper extremity function seen in the EG (Table 5) may be attributed to the combination of highly repetitive, intensive movements provided by distal RT and the goal-directed, task-specific nature of the TOT. Repetition and intensity are crucial for promoting neuroplasticity and motor learning, which are key components of post-stroke recovery.<sup>7</sup> The Gloreha Sinfonia facilitates repetitive hand and finger movements and provides dynamic support that enables initiation of proximal upper extremity motion against gravity-enhancing the functional execution of training tasks. Additionally, engaging patients in real-life activities, such as drinking water from a bottle, folding fabric, using a fork and spoon for eating, using scissors, and opening/closing a book, likely enhanced patient engagement and facilitated the application of motor gains to everyday tasks.<sup>38</sup> These findings align with those of Shi *et al.*,<sup>40</sup> which demonstrate that distal RT provides practical assistance for stroke patients, enabling them to perform training tasks more independently and intensively. This leads to improvements in upper extremity function, with effects that may persist for at least three months post-training. Although the selected activities were not fully client-centered due to technical limitations of the robotic device, including finger-only assistance, limited hand prehension types,

and a fixed glove-to-unit connection length-allowing participants to choose three out of five training activities provided a sense of autonomy and motivation, fostering sustained engagement and motor learning. Furthermore, the use of real materials in most activities, along with continuous feedback, helped reinforce functional movements and replicate real-world demands.<sup>39,41</sup> This approach aligns motor learning principles by creating practical, behaviorally relevant experiences essential for skill acquisition, ultimately leading to improved functional recovery in this study.

The results of this preliminary study suggest that combining distal RT with TOT is a feasible and potentially effective adjunct to conventional occupational therapy for improving upper extremity function in sub-acute stroke patients. These findings emphasize the importance of incorporating real-life tasks and distal RT into rehabilitation programs to enhance motor recovery and functional independence. However, further research with larger sample sizes is needed to confirm these results.

### Limitation

The small sample size (N=14) was a limitation of this study, potentially contributing to the lack of statistically significant between-group differences. Larger studies are needed to confirm these findings. Moreover, the lack of long-term follow-up data may limit our understanding of the sustained effects of the intervention. Additionally, variations in stroke severity and patient-specific factors such as motivation and cognitive function may have influenced the outcomes.

Future research should focus on full-size randomized controlled trials to further investigate the effects of combining distal RT and TOT. Also, their long-term effects should be investigated. Additionally, exploring the impact of such interventions on different stroke populations (e.g., chronic stroke patients) could provide more comprehensive insights. Moreover, future studies should control for the total dosage of therapy across comparison groups to enable a more accurate assessment of intervention effects. Investigating the specific contribution of distal RT and TOT compared to conventional task-oriented training (TOT) alone would provide further insight into the added value of RT.

### Conclusion

Although no statistically significant differences in mean scores were observed between the EG and CG, the significant score changes and medium to high effect sizes highlight the potential of combining distal RT with TOT for improving upper extremity function in sub-acute stroke patients. Further research with larger sample sizes, longer follow-up periods, is needed to confirm these findings and establish the long-term benefits of robot-assisted task-oriented training in stroke rehabilitation. The evidence can help therapists develop more effective training programs to improve upper limb function in stroke patients.

### Ethical approval

This study received ethics approval from the Research Ethics Committee of Faculty of Associated Medical Sciences, Chiang Mai University (No. 267/2565), Maharaj Nakorn Chiang Mai Hospital (No. 355/2565) and Chiangmai Neurological Hospital (No. EC 021-67).

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### Conflict of interest

The authors declare no conflict of interests.

### CRediT authorship contribution statement

**Pakpoom Jitrunguangchai:** conceptualization, methodology, investigation, formal analysis, writing-original draft, and visualization. **Jananya P Dhippayom:** conceptualization, methodology, writing-review and editing, and supervision. **Sopida Apichai:** validation, writing-review and editing, and supervision. All authors have read and agreed to the published version of the manuscript.

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