Combination of Exoskeletal Upper Limb Robot and Occupational Therapy Improve Activities of Daily Living Function in Acute Stroke Patients

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Purpose: Previous studies have suggested that upper limb rehabilitation using therapeutic robots improves motor function of stroke patients. However, the effect of upper limb robotic rehabilitation on improving functioning in activities of daily living (ADL) remains unclear. The present study aimed to determine whether upper limb rehabilitation using single joint Hybrid Assistive Limb (HAL-SJ) affects ADL function and the use of a hemiparetic arm in ADLs of acute stroke patients. *Materials and Methods:* Twelve acute stroke patients participated in the study and were randomly divided into group A or group B. The patients in group A followed an A-B-A-B design and those in group B followed a B-A-B-A design. The patients received combination HAL-SJ and occupational therapy during A and conventional occupational therapy during B. *Results:* Upper limb motor function and ADLs, in particular, dressing the upper body, were improved during combination HAL-SJ and occupational therapy. Interestingly, the use of a hemiparetic arm in daily life evaluated using the motor activity log was also significantly improved during A in group A. *Conclusions:* Combination HAL-SJ and occupational therapy affects ADL function and real use of a hemiparetic arm in the daily life of acute stroke patients.

Key Words: Acute stroke—rehabilitation—single joint hybrid assistive Limb—upper limb function—activities of daily living—motor activity log

Introduction

Rehabilitation programmes have been gaining attention for their use of robotic devices to achieve better motor function recovery after stroke.[1-3] Bertani et al conducted a systematic review and meta-analysis of the effects of robot-assisted upper limb rehabilitation in stroke patients and confirmed the potential of robotic-assisted devices to elicit improvements in upper limb function.[4] Conversely, other systematic reviews and meta-analyses were unable to show evidence for an added value of robot-assisted therapy for the paretic upper limb regarding upper limb capacity.[5] In general, upper limb motor function deficit tends to be more severe than that of the lower limb.[6] Therefore, many robotic devices for upper limb rehabilitation have been developed.[7-9] Hybrid Assistive Limb (HAL) is a new rehabilitation robot. Movement of the attached exoskeleton is triggered by the patient's voluntary muscle activity as recorded by electromyography (EMG),[2] and it is able to support the patient's voluntary movements. Although original HAL is attached to the whole lower

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limb to support the patient's gait training, newly developed single joint HAL (HAL-SJ) was able to attach to the elbow joint or knee joint, supporting the movement of the attached joint. Fukuda et al reported the effect of using multiple types (original and SJ type) of HAL for acute stroke patients in a rehabilitation programme.[10]

Although many studies and articles have reported on robotic rehabilitation for gait function in stroke patients,[11-13] little consensus exists regarding the effects of robotic rehabilitation on upper limb motor function deficit, in particular, how it influences activities of daily living (ADL) function. Improvements of upper limb motor function and ADL function are really important in respect to patient's ability to live their daily life independently.[14] Volpe et al found that robotic rehabilitation of chronic stroke patients showed better treatment outcomes for shoulder and elbow joint function than did conventional rehabilitation of upper limb function with a therapist.[15] Miyasaka et al also reported that upper limb robotic rehabilitation affected recovery of upper limb motor function in convalescent phase stroke patients.[16] However, in their study, the patients underwent robotic rehabilitation as additional treatment (there was no control group due to their research design), and it is possible that prolonged rehabilitation time alone affected the outcome. In fact, a systematic review performed by Kwakkel et al confirmed that robotic upper limb rehabilitation of stroke patients has a positive effect on proximal upper limb function but not on ADLs.[17] Systematic reviews performed by Bertani et al or Veerbeek et al also showed no significant improvement of ADLs.[4,5]

Here, we evaluated whether combination HAL-SJ and occupational therapy improves ADL function in acute stroke patients using randomized A-B-A-B or B-A-B-A designs.

Materials and Methods

Subjects and Study Protocol

In total, 30 acute stroke patients (18 men and 12 women) participated in the study. Inclusion criteria were (1) first-time stroke, (2) Brunnstrom recovery stage (Br-stage) II to IV, and (3) study participant within 2 weeks after stroke onset. Patients were excluded if (1) the surface electrode could not be attached to the skin due to cutaneous disease or (2) they were not able to follow instructions. The study was approved by the Araki Neurosurgical Hospital ethical committee, and all patients provided written informed consent.

Participants were randomly divided into group A or B. The patients in group A followed an A-B-A-B design, and those in group B followed a B-A-B-A design. A consisted of 5 days of combination therapy (robotic rehabilitation using HAL-SJ and occupational therapy), and B involved 5 days of occupational therapy without using HAL-SJ. The patients in both groups A and B participated in the study at 2 weeks after stroke onset. The total time of combination therapy during A and occupational therapy during B was equivalent. In the current Japanese medical

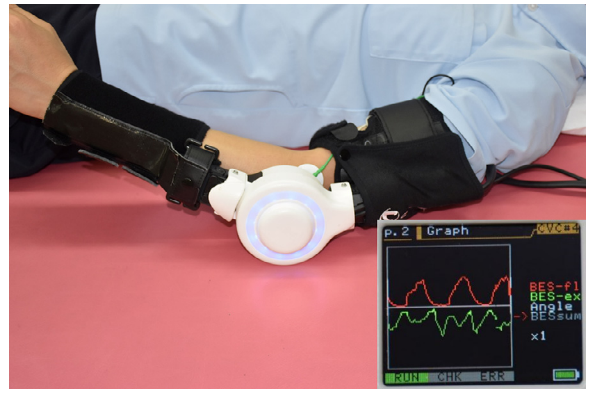

Figure 1. ***HAL-SJ used in this study.*** *HAL-SJ attached to the elbow joint, and EMGs of the biceps brachii and triceps brachii muscles were recorded.*

system, the medical doctor prescribes a rehabilitation programme, and rehabilitation therapists (occupational therapist, physiotherapist, and speech therapist) design individually tailored exercise programmes for acute stroke patients for up to 3 hours per day.[18] In our study, the total time of whole rehabilitation was also equivalent.

Robotic Rehabilitation Using HAL-SJ and Occupational Therapy

In the present study, HAL-SJ was attached to the elbow joint, and the patients were supported flexion and extension movement of the elbow joint (Fig 1). A surface electrode was attached to the patient on the muscle belly of the biceps brachii and triceps brachii muscles to record the EMG. Configuration parameters of HAL-SJ included assist gain (intensity of assist) and assist balance (balance between flexor muscle assist and extensor muscle assist), and the parameters were individually designed by the

Table 1. *Baseline characteristics of study patients*

	Group A (n = 6)	Group B (n = 6)	Significance
Age, years	62.33 ± 10.23	59.67 ± 24.56	*P* = .699
Sex, n (%)			
Male	5 (83.3%)	3 (50%)	*P* = .272
Female	1 (16.7%)	3 (50%)	
Stroke type, n (%)			
Cerebral infarction	3 (50%)	4 (66.7%)	
Cerebral hemorrhage	3 (50%)	2 (33.3%)	*P* = .5
SAH	0 (0%)	0 (3.4%)	
Affected side, n (%)			
Right	4 (66.7%)	3 (50%)	*P* = .5
Left	2 (33.3%)	3 (50%)	

Abbreviation: SAH, subarachnoid hemorrhage.
Data are presented as mean ± SD or n (%).

Table 2. *Comparisons of clinical outcomes on day 14 from stroke onset*

	Group A (n = 6)	Group B (n = 6)	Significance	95% CI	Test statistic
12-grade hemiplegia recovery grade (upper limb)	2.67 ± 0.82	4.17 ± 2.4	P = .276	−4.02∼1.02	U = 11.5
Br-stage, n					
Upper limb (Ⅱ/Ⅲ/Ⅳ)	4/2/0	2/2/2	P = .264	–	$\chi 2$ = 2.667
Finger (Ⅰ/Ⅱ/Ⅲ/Ⅳ/Ⅴ/Ⅵ)	2/2/2/0/0/0	2/1/2/1/0/0	P = .721	–	$\chi 2$ = 1.333
Lower limb (Ⅰ/Ⅱ/Ⅲ/Ⅳ/Ⅴ/Ⅵ)	0/1/3/1/0/1	0/2/2/1/1/0	P = .639	–	$\chi 2$ = 2.533
MI	42.83 ± 10.32	49.5 ± 15.11	P = .288	−23.62∼10.28	U = 11.5
Grip strength	1.12 ± 2.74	3.89 ± 6.56	P = .4	−9.7∼4.16	U = 14
MAS, n (0/1/1+/2)	3/2/0/1	5/1/0/0	P = .4	–	$\chi 2$ = 1.833
Sensory function, n					
(normal/mild/intermediate/severe)	2/2/1/1/	2/1/3/0/	P = .506	–	$\chi 2$ = 2.333
FIM					
Motor subscore			P = .873	−16.71∼17.04	U = 17
Cognitive subscore Total	38.83 ± 14.02	38.67 ± 12.06	P = .936	−7.97∼13.31	U = 17.5
	26.67 ± 5.32	24 ± 9.88	P = .873	−23.05∼28.72	U = 17
	65.5 ± 18.23	62.67 ± 21.7			
BI	46.67 ± 21.6	42.5 ± 19.69	P = .806	−22.45∼30.78	U = 16.5
MMSE (*1)	27.83 ± 5.01	26.8 ± 4.6	P = .562	−5.73∼7.8	U = 12.5

Abbreviations: BI, Barthel Index; Br-stage, Brunnstrom recovery stage; FIM, Functional Independence Measure; MAS, Modified Ashworth Scale; MI, Motricity Index; MMSE, Mini Mental State Examination.

Data are presented as mean ± SD or n.

*1: Group B; n = 5.

occupational therapists depending on the patient's symptoms. During A, the patients underwent robotic rehabilitation using HAL-SJ for 40 minutes per day and performed at least 200 movements (flexion and extension) of the elbow joint.

Occupational therapy included passive or active mobilization, task-specific training, and ADL training such as eating, grooming, dressing (upper and lower body), toileting, and bathing. Occupational therapy focusing on the patient's ADL function and the distribution of each programme was individually designed depending on the patient's symptoms.

Assessment of Clinical Outcomes

Clinical outcomes were measured on days 14, 19, 24, 29, and 34 after stroke onset. The following were measured as functional parameters: recovery grade (1-12) hemiplegia (upper limb item),[19] Br-stage (upper limb, finger, and lower limb), motricity index (MI), grip strength of the affected hand, Modified Ashworth scale (MAS) of the biceps brachii, and sensory function.

In addition, the Functional Independence Measure (FIM) instrument and the Barthel index (BI) were used to measure ADL parameters. FIM consists of 13 items related to motor function and five items related to cognition. We calculated the total FIM score (FIM-total), total score of the motor items (FIM-motor subscore), and total score of the cognitive items (FIM-cognitive subscore). The total score on the BI (BI-total) was used for analysis. Both FIM and BI, those subscores predicted to be related to the patient's upper limb function (FIM: subscores of eating, grooming, dressing of the upper or lower body, toileting, and bathing; BI: subscores of eating, dressing, grooming, and toileting), were also used as individual parameters in the analysis. Moreover, motor activity log (MAL)[20] was used to evaluate the spontaneous use of a hemiparetic arm in daily life. Overall, 14 ADL items were evaluated in the MAL, and quality of movement (QOM) and amount of use (AOU) were measured. Mini-mental state examination

Table 3. *Score changes of clinical outcomes in group A*

	A	B	Significance	95% CI	Test statistic
12-grade hemiplegia recovery grade (upper limb)					
	1.5 ± 1.24	0.25 ± 0.62	*P* = .007**	0.64~1.86	*Z* = −2.714
Br-stage					
Upper limb	0.75 ± 0.45	0 ± 0	*P* = .003**	0.46~1.04	*Z* = −3
Finger	0.75 ± 0.45	0 ± 0	*P* = .003**	0.46~1.04	*Z* = −3
Lower limb	0.17 ± 0.58	0.17 ± 0.39	*P* = 1.0	−0.47~0.47	*Z* = 0
MI	5.25 ± 5.12	2.75 ± 7.19	*P* = .23	−2.21~7.21	*Z* = −1.2
Grip strength	2.49 ± 3.51	1.23 ± 2.89	*P* = .594	−2.06~4.6	*Z* = −0.533
FIM					
Dressing of upper body	0.58 ± 0.79	0.0 8 ± 0.29	*P* = .034*	0.72~0.93	*Z* = −2.121
Dressing of lower body	0.42 ± 0.79	0.08 ± 0.29	*P* = .102	−0.08~0.75	*Z* = −1.633
Eating	0.08 ± 0.29	0.25 ± 0.45	*P* = 0.317	−0.53~0.2	*Z* = −1
Grooming	0.33 ± 0.65	0 ± 0	*P* = .102	−0.08~0.75	*Z* = −1.633
Bathing	0.25 ± 0.45	0.25 ± 0.45	*P* = 1.0	−0.27~0.27	*Z* = 0
Toileting	0.67 ± 0.89	0.42 ± 0.9	*P* = .524	−0.65~1.15	*Z* = −0.638
Motor subscore	6.75 ± 4.99	2.42 ± 3.12	*P* = .006**	1.73~6.94	*Z* = −2.764
Cognitive subscore	0.75 ± 3.28	1 ± 2.3	*P* = .932	−3.51~3.01	*Z* = −0.085
Total	7.5 ± 6.13	3.42 ± 4.98	*P* = .061	−0.84~9.01	*Z* = −1.87
BI					
Dressing	1.67 ± 2.46	0 ± 0	*P* = .046*	0.10~3.23	*Z* = −2
Eating	1.25 ± 2.26	0.42 ± 1.44	*P* = .317	−1~2.67	*Z* = −1
Grooming	1.25 ± 2.26	0.42 ± 1.44	*P* = .317	−1~2.67	*Z* = −1
Toileting	0.42 ± 1.44	0.42 ± 1.44	*P* = 1.0	−1.35~1.35	*Z* = 0
Total	9.17 ± 5.97	1.67 ± 3.26	*P* = .007**	3.79~11.21	*Z* = −2.694
MAL					
AOU (put arm through sleeve)	0.67 ± 0.98	0 ± 0	*P* = .039*	0.04~1.29	*Z* = −2.06
QOM (put arm through sleeve)	0.67 ± 0.78	0 ± 0	*P* = .023*	0.17~1.16	*Z* = −2.271
AOU (total)	0.14 ± 0.15	0.06 ± 0.12	*P* = .15	−0.03~0.18	*Z* = −1.439
QOM (total)	0.16 ± 0.17	0.04 ± 0.096	*P* = .043*	0.14~0.22	*Z* = −2.028

Abbreviations: AOU, Amount of Use; BI, Barthel Index; Br-stage, Brunnstrom recovery stage; CI, confidence interval; FIM, Functional Independence Measure; MAL, Motor Activity Log; MAS, Modified Ashworth Scale; MI, Motricity Index; QOM, Quality of Movement.

Data are presented as mean ± SD.

$^*P < .05$, $^{**}P < .001$.

(MMSE) was evaluated on day 14. All clinical outcomes were measured by an occupational therapist.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics software version 22 (IBM Corp, Armonk, NY). Categorical variables were compared using chi-square test. Either the Mann-Whitney U-test or Wilcoxon signed-rank test was used for comparisons of continuous variables as appropriate. A P value <.05 was considered statistically significant.

Results

Baseline characteristics such as age, sex, stroke type, and affected side were similar between the groups (Table 1). No significant differences were seen in motor function severity as defined by recovery grade (1-12) of hemiplegia (upper limb), Br-stage (upper limb, finger, and lower limb), motricity index, grip strength, Modified Ashworth scale, or sensory function between groups on day 14 after stroke onset (Table 2). In addition, ADL limitations as defined by the FIM-total, FIM-motor subscore, FIM-cognitive subscore, and BI-total on day 14 after stroke onset were not significantly different between the groups. mini-mental state examination score was not significantly different between the groups.

The score changes of each parameter are shown in Tables 3 and 4. The score changes of recovery grade (1-12) of hemiplegia (upper limb), FIM-upper body dressing, FIM-motor subscore, BI-dressing, and BI-total during A were significantly higher than during B in both group A and group B (Fig 2A-D and Tables 3 and 4). The score changes of Br-stage (upper limb and finger), MAL-amount of use (put arm through sleeve), MAL-QOM (put arm through sleeve), and MAL-QOM (total score) during A were significantly higher than during B in group A only. In addition, FIM-total in group A tended to be high during A (P = .067) and was significantly higher during A than during B in group B. Moreover, there were no significant differences in other functional or ADL parameters between groups.

Table 4. *Score changes of clinical outcomes in group B*

	A	B	Significance	95% CI	Test statistic
12-grade hemiplegia recovery grade (upper limb)	1.33 ± 1.5	0.25 ± 0.45	P = .014*	0.13~2.04	Z = −2.456
Br-stage					
Upper limb	0.42 ± 0.51	0.17 ± 0.39	P = .257	−0.23~0.73	Z = −1.134
Finger	0.42 ± 0.51	0.17 ± 0.39	P = .257	−0.23~0.73	Z = −1.134
Lower limb	0.17 ± 0.39	0.08 ± 0.29	P = .564	−0.24~0.41	Z = −0.577
MI	5 ± 5.61	1.67 ± 4.66	P = .141	−1.69~8.36	Z = −1.474
Grip strength	0.93 ± 1.88	1.4 ± 1.94	P = .596	−2.14~1.21	Z = −0.53
FIM					
Dressing of upper body	1.17 ± 1.4	0.17 ± 0.58	P = .04*	0.1~1.9	Z = −2.058
Dressing of lower body	0.83 ± 1.2	0.33 ± 0.89	P = .221	−0.38~1.38	Z = −1.225
Eating	0.17 ± 0.39	0.08 ± 0.29	P = .317	−0.1~0.27	Z = −1
Grooming	0.42 ± 0.67	0.17 ± 0.39	P = .257	−0.23~0.73	Z = −1.134
Bathing	0.5 ± 1	0.17 ± 0.39	P = .257	−0.29~0.96	Z = −1.134
Toileting	0.5 ± 0.8	0 ± 0	P = .063	−0.007~1	Z = −1.857
Motor subscore	7.83 ± 5.57	1.83 ± 3.21	P = .009**	1.84~10.16	Z = −2.625
Cognitive subscore	1.08 ± 1.44	1.08 ± 1.83	P = 1.0	−1.46~1.46	Z = 0
Total	8.67 ± 6.20	2.92 ± 4.01	P = .016*	0.83~10.67	Z = −2.403
BI					
Dressing	1.67 ± 2.46	0 ± 0	P = .046*	0.1~3.23	Z = −2
Eating	0.83 ± 1.95	0.83 ± 1.95	P = 1.0	−1.92~1.92	Z = 0
Grooming	0.83 ± 1.95	0.42 ± 1.44	P = .564	−1.22~2.05	Z = −0.577
Toileting	0.83 ± 1.95	0.42 ± 1.44	P = .564	−1.22~2.05	Z = −0.577
Total	8.75 ± 7.72	2.5 ± 4.52	P = .036*	0.48~12.02	Z = −2.095
MAL					
AOU (put arm through sleeve)	0.42 ± 0.67	0.33 ± 0.65	P = .792	−0.61~0.77	Z = −0.264
QOM (put arm through sleeve)	0.58 ± 1	0.25 ± 0.62	P = .395	−0.49~1.16	Z = −0.85
AOU (total)	0.28 ± 0.39	0.14 ± 0.22	P = .225	−0.1~0.38	Z = −1.214
QOM (total)	0.24 ± 0.37	0.15 ± 0.24	P = .866	−0.19~0.36	Z = −0.169

Abbreviations: AOU, Amount of Use; BI, Barthel Index; Br-stage, Brunnstrom recovery stage; CI, confidence interval; FIM, Functional Independence Measure; MAL, Motor Activity Log; MAS, Modified Ashworth Scale; MI, Motricity Index; QOM, Quality of Movement.

Data are presented as mean ± SD.

*P < .05, **P < .001.

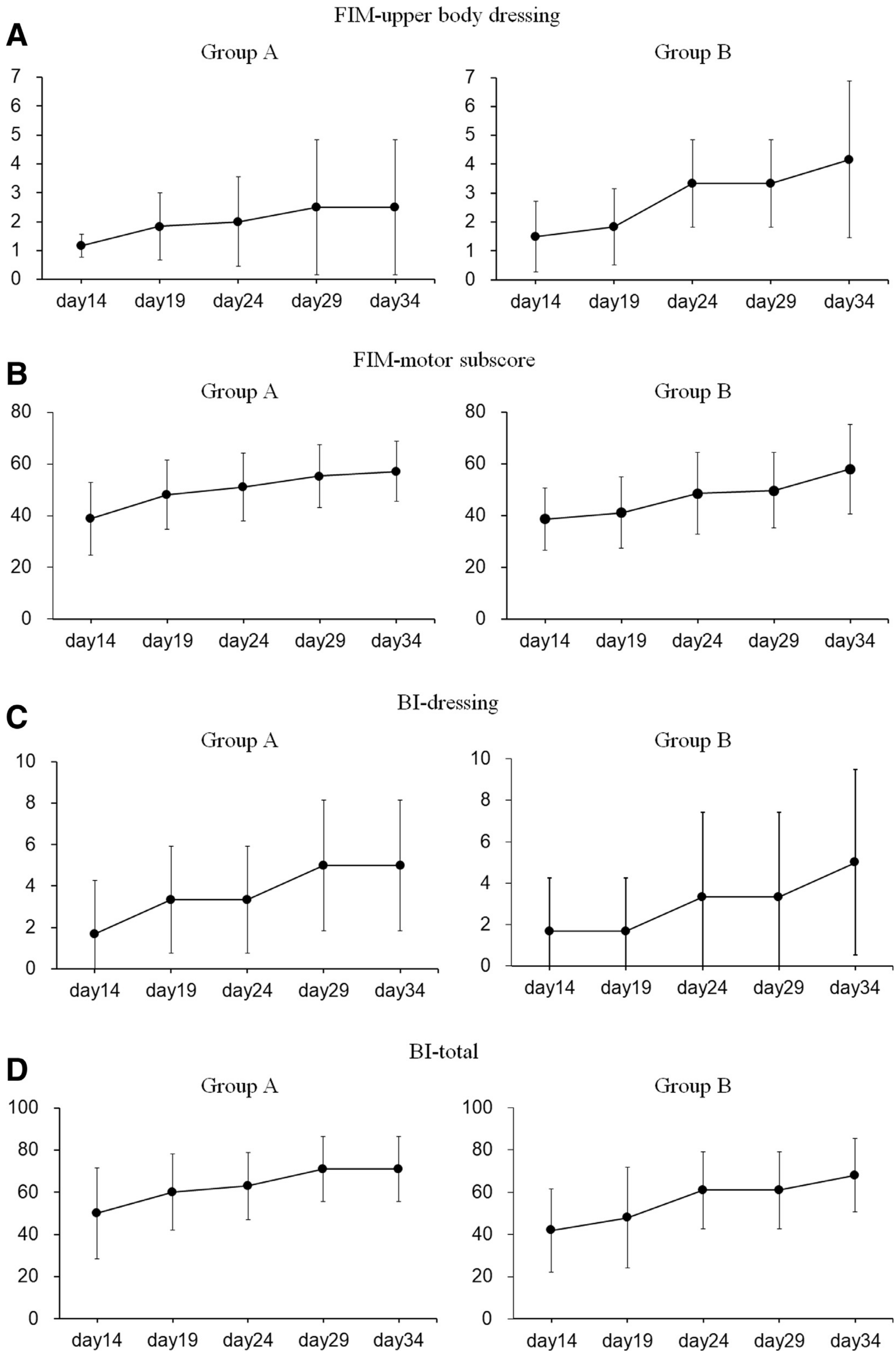

Figure 2. ***Score changes in group A and group B***. *The line graph shows mean ± SD of FIM-upper body dressing (A), FIM-motor subscore (B), BI-dressing (C), and BI-total (D).*

Discussion

The present study evaluated the effect of combination HAL-SJ and occupational therapy for improving clinical outcomes of acute stroke patients with intermediate-to-severe upper limb paralysis. To accomplish this goal, we applied randomized A-B-A-B or B-A-B-A designs, referring to the Werner protocol.[11]

In our study, the score change for the recovery grade (1-12) of hemiplegia was significantly higher during A than during B in both group A and group B, suggesting that combination HAL-SJ and occupational therapy has the positive effect of recovering upper limb function in stroke patients. Although Fukuda et al used HAL-SJ as part of an individually designed treatment programme using multiple types of HAL, they demonstrated the possible effect of HAL-SJ on acute stroke patients.[10] The results of the present study support those of previous studies reporting the effects of robotic rehabilitation of upper limb motor function of stroke patients.[8,9]

Both groups significantly improved during A in not only upper limb motor function but also ADL parameters such as FIM-motor, FIM-total, and BI-total. Subscore independent analysis revealed that the score changes of FIM-upper body dressing and BI-dressing were significantly higher during A than during B in both groups. The patients performed elbow flexion/extension exercises using HAL-SJ and ADL exercises to apply recovered upper limb function to ADL function. This combination rehabilitation strategy might improve ADL function in stroke patients. The characteristic of dressing action demonstrating the remarkable score change is strongly related to elbow function such as extension and flexion. In a review article, Seidler et al showed the process of motor skill learning and suggested that task similarity can lead to positive transfer in the learning process.[21]

Robotic devices for upper limb rehabilitation have been classified broadly into end-effector or exoskeleton. End-effector robots hold the patient's hand or forearm at one point and generate forces at the interface.[4] The joints of end-effector robots do not match with that of the human limb.[22] Meanwhile, exoskeleton robots have a structure that resembles that of the human upper limb, as robot joint axes match the upper limb joint axes of humans.[4] Bertani et al[4] conducted a systematic review, which showed that training with end-effector robot did not significantly improve arm function, but that with exoskeleton robot did significantly improved arm function. HAL-SJ is an exoskeleton robot for upper limb rehabilitation and was triggered by the patient's voluntary muscle activity, as recorded by EMG.[2] Hogan et al suggested that passive robotic motion is insufficient and the patient's active participation is required to achieve motor functional recovery.[23] We assume that the feature of HAL-SJ (muscle activity-triggered exoskeleton robot) might largely influence the improvement of the upper limb motor function and ADL function. Br-stage (upper limb and finger) and the use of a hemiparetic arm in daily life evaluated using MAL were improved during A in group A only. MAL is a semistructured interview for hemiparetic stroke patients to assess the use of their paretic arm and hand QOM during ADLs.[24] The results of using a hemiparetic arm in daily life differed from those of ADL parameters such as FIM and BI, possibly because MAL did not focus on "executing" compensatory movement of the nonhemiparetic arm but on "using" the hemiparetic arm in daily life. The score changes of MAL improved in group A only, and early initiation of combination HAL-SJ and occupational therapy from stroke onset might affect this result. Little clinical research has focused on the effect of robotic rehabilitation in acute stroke patients' ADL and use of an impaired arm in their ADL.

In the present study, acute stroke patients received combination therapy for only 5 days, and we have not yet evaluated whether this treatment duration was appropriate. Further, large-scale studies evaluating the optimal treatment duration of combination therapy are required. In addition, unblinded evaluation is a limitation of the present study due to its difficulty in daily clinical practice.

Conclusions

We provided novel evidence suggesting that combination HAL-SJ and occupational therapy affects ADL function and real use of a hemiparetic arm in the daily life of acute stroke patients.

Declaration of Interest

No potential conflict of interest was reported by the authors.

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