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Original Article

Robot-aided training for upper limbs of sub-acute stroke patients

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ABSTRACT

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Purpose: To evaluate the effects of short-term robot-assisted training on upper extremity paralysis after a stroke.

Methods: The subjects consisted of 21 patients 6–12 weeks after their first stroke. Two weeks of robot-assisted training and 2 weeks of conventional training were performed using a crossover method. During the robot-assisted training period, robot-assisted training (1 hour/day, 5 days/week) was added to conventional training. At the initiation of training and after 2 and 4 weeks, motor function was evaluated in terms of the upper extremity items of the Stroke Impairment Assessment Set and Fugl-Meyer Assessment (FMA), active angles of shoulder flexion and abduction, and items of the Motor Activity Log (MAL). Values before and after each type of training and gains were compared between robot-assisted and conventional training using the Wilcoxon signed-rank test.

Results: Compared with the conventional training after 2 weeks, significant improvements could be seen for the scores of the FMA of shoulder and elbow, the Amount of Use of MAL, and Quality of Movement of MAL items of robot-assisted training.

Conclusion: After intensive robot-assisted training of the paralyzed extremity even for a short period, improvement was observed in the proximal function and frequency of use of the affected extremity in daily life.

Key words: stroke, rehabilitation, upper limb hemiparesis training, manipulandum

Introduction

In recent years, rehabilitation using robots has been performed and reported to be useful for improving function and ability [1]. Various types of robot have been developed for the upper extremity on the paralyzed side after a stroke, including those used for uni- or bilateral extremities or those utilizing visual or somatosensory feedback [2, 3]. The In Motion ARM^{TM} Robot (MIT-MANUS/In Motion 2, Interactive Motion Technologies: ARM Robot) [4, 5] is one such robot developed by Krebs et al. for robot-assisted training of the affected upper extremity after a stroke, and its effects have been described in many studies [6]. To use this device, patients apply their paralyzed hand and forearm to the arm of the device, and move the marker indicating the hand position on the monitor screen in front of them to reach the target. As motor tasks, an algorithm has been incorporated to repeat horizontal movement and instruct the device to move passively when patients cannot move the marker by themselves. Therefore, even patients with severe paralysis can use this device [7].

Regarding studies using the ARM Robot, Volpe et al. performed robot-assisted therapy 3 times a week for 6 weeks in patients in the chronic stage more than 6 months after a stroke, and reported that shoulder and elbow functions improved compared with those after upper extremity training by therapists, and this improvement was maintained for 3 months [8]. Fasoli et al. performed robot-assisted therapy 5 times a week for 5 weeks in patients in the acute stage starting at an average time since stroke onset of two weeks, and compared this training with training in which the paralyzed upper extremity was applied to the robot arm and moved with assistance from the unaffected

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upper extremity [9]. The robot-assisted training group showed improvement in shoulder and elbow functions and an increase in muscle strength compared with the control group, and these functions continued to improve during the hospitalization period. Finley et al. performed 3 weeks of robot-assisted therapy in patients with severe paralysis with a minimum time of 6 months since stroke onset, and reported significant functional improvement even after this short intervention period [10].

In previous studies, the subjects consisted of patients within 2 weeks or $\geq$ 6 months after a stroke; there have been no studies on convalescent patients (2 weeks to 6 months after a stroke). In addition, short-term training effects have not been adequately evaluated. Therefore, we provided 2-week ARM Robot-assisted training to patients 6−12 weeks after a stroke, and evaluated the short-term training effects during the convalescence period.

Subjects

Twenty-seven first stroke patients with unilateral supratentorial lesions who were admitted to our hospital between June 2013 and March 2014 participated in this study. The exclusion criteria were severe complications (Liu's comorbidity index [11] $\geq$ 4), difficulty in understanding instructions during training, and higher brain dysfunction such as global aphasia or hemispatial neglect. In addition, 4 weeks after admission, patients were excluded if they had mild paralysis showing a total score for the upper extremity motor items of the Fugl-Meyer Assessment (FMA) [12] $\geq$ 65 or a score $<$ 4 for transfers of the Functional Independence Measure (FIM) [13], or could not tolerate robot-assisted training for 1 hour/day due to difficulty in maintaining a sitting position or a poor condition. Before participation in this study, consent was obtained in accordance with the approval contents (No. 119) of the ethics committee of our hospital.

Methods

• Intervention methods

The design of this study is shown in Figure. 1. The effects of robot-assisted training were evaluated using a crossover method by dividing the patients randomly into two groups. While the first group received 2 weeks of robot-assisted training followed by 2 weeks of conventional training, the other group first received the 2 weeks of conventional training followed by the 2 weeks of robot-assisted training.

During the entire training period, patients received physical and occupational therapies as the conventional training for a total of 2−3 hours (physical therapy: mean, 1.2 hours/day; occupational therapy, mean, 1.2 hours/day) 7 days/week. The conventional training included electric stimulation therapy, repetitive facilitative exercise, gait training, and ADL training excluding robot-assisted training. During the robot-assisted training period, 1-hour robot-assisted training (5 days/week) was added to this conventional training (physical therapy: mean, 1.1 hours/day; occupational therapy: mean, 1.0 hour/day; robot-assisted training: 1.0 hour/day).

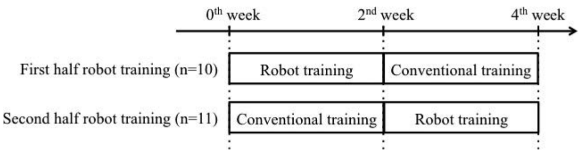

Figure 1. Crossover design.
The subjects were divided into two groups: robot training for the first 2 weeks, followed by conventional training for 2 weeks, or conventional training for the first 2 weeks, followed by robot training for 2 weeks. Evaluation was performed before (0^{th} week), and in the 2^{nd} and 4^{th} week after training.

• Robot-assisted training of the upper extremity

In this study, training concentrating on shoulder and elbow movements on a horizontal plane was performed using an ARM Robot [4, 5]. The subjects were fixed in the chair using a trunk strap, and performed reaching movements while compensatory trunk movements were limited. The subjects held the grip of the robot arm with their paralyzed hand, placed their forearm on the robot arm, and operated the robot arm by moving their shoulder and elbow. The grip position of the robot arm on the plane was indicated on the monitor screen placed about 1 m in front of the subjects (Figure. 2).

Concerning the training task, the monitor displays 8 peripheral targets equally spaced on the circumference of a circle with a 14-cm radius around a central target. The subject first places the marker indicating the grip position at the central target, and subsequently moves it to each peripheral target. After the completion of reaching or a certain time (3.5 seconds), the central point is indicated as the target again, and the subject moves the marker from each peripheral target to the central target. This was repeated clockwise, and a total of 8 back-and-forth reaching movements (16 movements) were completed.

Using the ARM Robot, the amount of robotic assistance changes with the amount of the subject's voluntary movement. Hogan et al. developed an algorithm enabling the marker finally to reach the target using a force field preventing lateral deviation of the track, called a 'virtual slot', and a force field providing assistance to subjects when they cannot reach the target [7].

In the robot-assisted training, on the basis of this algorithm, the subjects performed 3 sessions (320 movements × 3 sessions) using the assist mode and 4

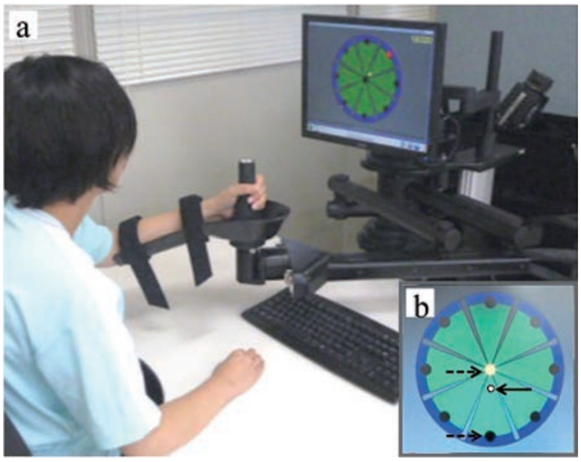

Figure 2. In Motion ARM^{TM} Robot training.
a. The subject held the grip of the robot arm with their paralyzed hand, concentrating on shoulder and elbow movements on a horizontal plane.
b. The marker (solid arrow) showed the position of the patient's hand. The patient moved the marker to eight targets (dotted arrow) on the circumference and center.

unassisted sessions (16 movements × 4 sessions) before as well as after the assisted sessions, completing more than 1,000 repetitive movements/day.

• Evaluation items

The evaluation items were the upper extremity movement items of FMA excluding the tendon reflexes and coordination (total score, 54) [12], upper extremity movement items of the Stroke Impairment Assessment Set (SIAS) (Knee-Mouth test: KM, Finger-Function Test: FF) [14], active angles of shoulder flexion and abduction, Amount of Use (AOU) and Quality of Movement (QOM) of the Motor Activity Log (MAL) [15], and items of FIM [13]. These items were evaluated in an unblinded manner before as well as 2 and 4 weeks after training (total, 3 times) by occupational therapists who were in charge of training on the day of evaluation.

• Statistical analysis

The values of the evaluation items before and after training were compared between the robot-assisted and conventional training periods. Subsequently, the degree of improvement (gain) was compared between the periods. For comparison, the Wilcoxon signed rank test was used, and $p < 0.05$ was regarded as significant. As statistical software, Macintosh JMP 9.0 was used.

Results

• Number of patients

Of the 27 subjects, 6 dropped out. One patient suffered a non-training-related fall outside the hospital during the conventional training period, and the final evaluation could not be performed. The other 5 patients received robot-assisted training a few times, but complained of marked fatigue, and refused further

Table 1. Patient characteristics at baseline.

Number of patients	21
Age [year]	58.8±13.6
Sex (male / female)	17 / 4
Paretic side (right / left)	7 / 14
Lesion type (hemorrhagic / ischemic)	6 / 15
Days after stroke onset [day]	59.3±11.7

The values are mean ± standard deviation.

Table 2. Results of robot training and conventional training.

		Robot training		Conventional training	
		before	after	before	after
SIAS	Knee-mouth	2.0±1.2 (2)	2.3±1.2 (2)	2.2±1.3 (2)	2.2±1.3 (2)
	Finger-function	1.3±1.6 (1)	1.7±1.7 (1)*	1.5±1.6 (1)	1.6±1.8 (1)
Active ROM [deg]	Shoulder flexion	53.1±53.5 (50)	59.8±57.2 (50)*	57.4±56.0 (55)	59.5±58.7 (50)
	Shoulder abduction	54.8±45.8 (50)	60.2±47.9 (60)*	55.2±46.2 (60)	59.3±49.6 (60)
FMA	Shoulder and elbow	9.4±8.1 (6)	11.3±8.7 (9)**	10.0±9.1 (7)	10.0±8.7 (6)
	Wrist	1.2±2.5 (0)	1.7±3.2 (0)	1.4±2.7 (0)	1.4±2.8 (0)
	Finger	2.9±4.4 (1)	3.6±4.3 (2)	2.9±4.3 (1)	3.4±4.7 (1)
	Total	13.5±14.1 (8)	16.6±15.1 (13)*	14.3±15.2 (9)	14.8±15.4 (9)
MAL	AOU	0.3±0.8 (0)	0.5±1.0 (0.1)**	0.4±1.0 (0)	0.5±1.0 (0.1)**
	QOM	0.3±0.8 (0)	0.5±0.9 (0.1)**	0.4±0.9 (0)	0.5±1.0 (0.1)*

SIAS, Stroke Impairment Assessment Set.
ROM, Range of Movement.
FMA, Fugl-Meyer Assessment.
MAL, Motor Activity Log.
AOU, Amount of Use.
QOM, Quality of Movement.

The values are mean ± standard deviation (median).
** $p < 0.01$, * $p < 0.05$

Table 3. Gain of each item and comparison with robot training and conventional training.

		Robot training	Conventional training
SIAS	Knee-mouth	0.2±0.4 (0)	0.0±0.2 (0)
	Finger-function	0.3±0.6 (0)	0.1±0.5 (0)
Active ROM [deg]	Shoulder flexion	6.7±13.3 (0)	−0.2±19.8 (0)
	Shoulder abduction	5.5±12.5 (0)	−1.0±12.9 (0)
FMA	Shoulder and elbow*	1.9±3.2 (0)	−1.3±2.9 (0)
	Wrist	0.5±1.2 (0)	−0.3±1.1 (0)
	Finger	0.7±2.3 (0)	−0.1±2.1 (0)
	Total	3.1±5.9 (1)	−1.8±4.8 (0)
MAL	AOU**	0.2±0.2 (0.1)	0.1±0.1 (0)
	QOM**	0.2±0.2 (0.1)	0.1±0.1 (0)

SIAS, Stroke Impairment Assessment Set.
ROM, Range of Movement.
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The values are mean ± standard deviation (median).
**: $p < 0.01$, *: $p < 0.05$

participation. Of these 5 patients who discontinued participation, 4 had complete paralysis including 3 with flaccid paralysis, and could not move the upper extremity by themselves. Thus, as the subjects of the final analysis, 21 patients were included, consisting of 10 who received robot-assisted training during the former half period and 21 who received this training during the latter half period. The characteristics of the subjects are shown in Table 1. No adverse events due to robot-assisted training occurred.

- **Comparison between before and after each type of training**

The median values and mean values ± SD for each evaluation item before and after robot-assisted or conventional training are shown in Table 2. After the robot-assisted training, since patients performed shoulder and elbow movements, significant improvement was observed in the active angles of shoulder flexion and abduction, FMA scores of the shoulder and elbow items, and the total score for the FMA upper extremity motor items. In addition, FF of SIAS and AOU and QOU of MAL also improved. After the conventional training, AOU and QOU of MAL significantly improved.

- **Comparison of gains between robot-assisted and conventional training**

The gains after the robot-assisted and conventional training are shown in Table 3. The gain in the FMA shoulder and elbow items was 1.9 ± 3.2 (median, 0) after the robot-assisted training and −1.3 ± 2.9 (median, 0) after the conventional training, showing significant improvement after the former ($p < 0.05$). The gains in AOU and QOM of MAL were both 0.2 ± 0.2 (median, 0.1) after the robot-assisted training and 0.1 ± 0.1 (median, 0) after the conventional training, showing significant improvement after the former ($p < 0.01$).

Discussion

This study, using a crossover design, showed that 2 weeks of robot-assisted training can improve the proximal function of the paralyzed upper limb and the frequency of its use in daily life in patients 6−12 weeks after a stroke. As previous studies [8−10] have also shown, more marked improvement was observed after robot-assisted training than after conventional training.

Finley et al. performed 3 weeks of robot-assisted therapy in stroke patients in the chronic stage, and reported improvement in the total score for the upper limb items of FMA by 1.2 [10]. In this study, the total score for the upper limb items of FMA improved by 3.1 points after 2 weeks of robot-assisted training. The difference in effects between the two studies may have been associated with the duration since the stroke. In convalescent patients, more marked effects may be obtained even after short-term training. Volpe et al. administered 6 weeks of robot-assisted training to stroke patients in the chronic stage, and observed an approximately 3-point increase in the score for FMA shoulder and elbow items [8]. In this study, the score for FMA shoulder and elbow improved by 1.9 points, which suggests that further functional improvement can be achieved by longer-term intervention.

In this study, since the subjects consisted of patients 6−12 weeks after a stroke, the influences of spontaneous recovery during the study period cannot be ignored. Hendricks et al. reported that spontaneous recovery contributes to motor function until 6 months after onset [16]. Therefore, in this study, to exclude the bias of spontaneous recovery, effects were evaluated using a crossover method. In terms of the results, functional improvement after 2 weeks of conventional training was slight while improvement after robot-assisted training was comparable to or more marked than the improvement reported in previous studies.

In this robot-assisted training, shoulder and elbow flexion and extension were used and repeated more than 1,000 times/day. Frequent movement repetitions and an increase in the amount of training may have been effective for improving the function. The ARM Robot uses an algorithm appropriate for the degree of paralysis. The algorithm adjusts the level of difficulty as a major element of motor learning, which may have been one of the factors associated with functional improvement. Visual and somatosensory feedback, such as reaching in the movement direction while confirming with the monitor, may also have contributed to the improvement.

In this study, in addition to the motor function, MAL as an index for evaluation of the frequency of use in daily life was employed as an evaluation scale, and MAL improved after robot-assisted training. This improvement suggests that spontaneous use of the paralyzed upper limb was induced in parallel to functional improvement after targeted repetitive training. Concerning the number of repetitive movements and spontaneous use of the upper extremity, Han et al. reported that upper extremity movement should be repeated 420 times or more per session for the appearance of spontaneous use, and that spontaneous use is subsequently maintained by more than 1,000 movements/day [17]. In this study, functional improvement was observed probably because the movement was repeated more than 1,000 times, increasing spontaneous use. In addition, since robot-assisted training was added to conventional training, there is also a possibility that the increase in the training time is associated with functional improvement on the affected side.

Van der Lee et al. reported that the minimum clinically important difference of MAL was 0.5 points [18]. The results of the present study were below this value. In the present subjects, the mean total upper extremity score on FMA at the initiation of the study was 13.1 (median, 8), and the mean scores for AOU and QOM of MAL were both 0.3 (median, 0). This may have been due to the entry of many patients with severe paralysis. Finley et al. also performed ARM Robot therapy in patients with severe paralysis, and showed significant improvement in FMA but slight clinical improvement [10]. Therefore, even if significant differences are observed, further studies are necessary to determine whether the paralyzed upper extremity can be clinically used. In addition, the number of patients in this study may have been insufficient. The validity of statistical interpretation should be carefully considered.

In the future, it is necessary to compare the robot-assisted training group and control group based on a design with the same training time, to use an adequate number of samples, and to determine whether the effects of robot-assisted training are maintained. In this study, the lower limb function was not evaluated because the robot-assisted training was aimed at improving the upper extremity function. Further evaluation is necessary to determine whether or not improvement of the upper extremity function is related to that of the lower extremity function.

References

1. Mehrholz J, Hädrich A, Platz T, Kugler J, Pohl M. Electromechanical and robot-assisted arm training for improving generic activities of daily living, arm function, and arm muscle strength after stroke. Cochrane Database Syst Rev 2012; 6.
2. Burgar CG, Lum PS, Shor PC, Machiel Van der Loos HF. Development of robots for rehabilitation therapy: the Palo Alto VA/Stanford experience. J Rehabil Res Dev 2000; 37: 663−73.
3. Hesse S, Schulte-Tigges G, Konrad M, Bardeleben A, Werner C. Robot-assisted arm trainer for the passive and active practice of bilateral forearm and wrist movements in hemiparetic subjects. Arch Phys Med Rehabil 2003; 84: 915−20.
4. Krebs HI, Hogan N, Volpe BT, Aisen ML, Edelstein L, Diels C. Overview of clinical trials with MIT-MANUS: a robot-aided neuro-rehabilitation facility. Technol Health Care 1999; 7: 419−23.
5. Krebs HI, Volpe BT, Aisen ML, Hogan N. Increasing productivity and quality of care: Robot-aided neuro-rehabilitation. J Rehabil Res Dev 2000; 37: 639−52.
6. Basteris A, Nijenhuis SM, Stienen AH, Buurke JH, Prange GB, Amirabdollahian F. Training modalities in robot-mediated upper limb rehabilitation in stroke: a framework for classification based on a systematic review. J Neuroeng Rehabil 2014; 11: 111.
7. Hogan N, Krebs HI, Rohrer B, Palazzolo JJ, Dipietro L, Fasoli SE, et al. Motions or muscles? Some behavioral factors underlying robotic assistance of motor recovery. J Rehabil Res Dev 2006; 43: 605−18.
8. Volpe BT, Lynch D, Rykman-Berland A, Ferraro M, Galgano M, Hogan N, et al. Intensive sensorimotor arm training mediated by therapist or robot improves hemiparesis in patients with chronic stroke. Neurorehabil Neural Repair 2008; 22: 305−10.
9. Fasoli SE, Krebs HI, Ferraro M, Hogan N, Volpe BT. Does shorter rehabilitation limit potential recovery poststroke? Neurorehabil Neural Repair 2004; 18: 88−94.
10. Finley MA, Fasoli SE, Dipietro L, Ohlhoff J, MacClellan L, Meister C, et al. Short-duration robotic therapy in stroke patients with severe upper-limb motor impairment. J Rehabil Res Dev 2005; 42: 683−92.
11. Liu M, Domen K, Chino N: Comorbidity measures for stroke outcome research: a preliminary study. Arch Phys Med Rehabil 1997; 78: 166−72.
12. Fugl-Meyer AR, Jaasko L, Leyman I, Olsson S, Steglind

S. The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. Scand J Rehabil Med 1975; 7: 13−31.

13. Granger CV. The emerging science of functional assessment: our tool for outcomes analysis. Arch Phys Med Rehabil 1998; 79: 235−40.
14. Chino N, Sonoda S, Domen K, Saitoh E, Kimura A. Stroke impairment assessment set (SIAS). In: Chino N, Melvin JL editors. Functional Evaluation of Stroke Patients. Tokyo: Springer-Verlag; 1996. pp. 19−31.
15. Uswatte G, Taub E, Morris D, Vignolo M, McCulloch K. Reliability and validity of the upper-extremity motor activity log-14 for measuring real-world arm use. Stroke 2005; 36: 2493−6.
16. Hendricks HT, van Limbeek J, Geurts AC, Zwarts MJ. Motor recovery after stroke: a systematic review of the literature. Arch Phys Med Rehabil 2002; 83: 1629−37.
17. Han CE, Arbib MA, Schweighofer N. Stroke rehabilitation reaches a threshold. PLoS Comput Biol 2008; 4: e1000133.
18. van der Lee JH, Wagenaar RC, Lankhorst GJ, Vogelaar TW, Deville WL, Bouter LM. Forced use of the upper extremity in chronic stroke patients: results from a single-blind randomized clinical trial. Stroke 1999; 30, 2369−75.