Japanese Journal of Comprehensive Rehabilitation Science (2024)

Case Report

Effect of combining an upper limb rehabilitation support robot with task-oriented training on severe upper limb paralysis after spinal cord infarction: A case report

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ABSTRACT
Yokoi A, Miyasaka H, Ogawa H, Itoh S, Okazaki H, Sonoda S. Effect of combining an upper limb rehabilitation support robot with task-oriented training on severe upper limb paralysis after spinal cord infarction: A case report. Jpn J Compr Rehabil Sci 2024; 15: 42−48.

Objective: This study examined the effect of an upper limb rehabilitation support robot and task-oriented training on treating a patient with severe upper limb paralysis after spinal cord infarction who required total assistance with self-care.

Case: A 60-year-old man was diagnosed with watershed infarction in the C5−7 spinal cord region. He was admitted to our hospital 18 days after onset of the disease. The patient had severe paralysis of both upper limbs, and the total score for the Functional Independence Measure (FIM) motor items was 25 points. Regarding the Canadian Occupational Performance Measure (COPM), three goals were listed: "eating," "going to the toilet," and "raising one's hand in a meeting." The performance of "going to the toilet" was rated three points, and the performance and satisfaction of other items were one point. The intervention was practiced for 1 h/day, mainly items selected from COPM. The training using an upper limb rehabilitation support robot was added for 1 h/day. The upper limb rehabilitation support robot adjusted the range of motion and dosage according to the patient's motor function level and recovery status. About three months after admission, he improved until his upper limbs could be held in space on activities of daily living (ADL), and the total score for the FIM motor items improved to 81 points. The satisfaction and performance of all items listed as goals in COPM at the time of admission improved to ten points, and the patient was discharged 108 days after admission.

Conclusions: The upper limb rehabilitation support robot training that matched the level of motor function improved the motor function and active range of motion (ROM). ADL generalization through task-oriented training helped improve self-care. The use of COPM for the training to enable the patient to acquire the ability to perform meaningful activities led to improved COPM performance and satisfaction.

Key words: upper limb function, spinal cord infarction, upper limb rehabilitation support robot

Introduction

Spinal cord infarction is a relatively rare disease, accounting for about 1−2% of stroke patients [1]. The degree of clinical symptoms and dysfunction of spinal cord infarction differs depending on the disease occurrence site and ischemia range [2, 3]. Naik et al. performed a meta-analysis of 147 patients with spinal cord infarction and showed that rehabilitation did not affect outcomes for 53.7% of the patients [4]. Due to

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Accepted: August 16, 2024.
Conflict of Interests: The authors have no conflict of interest directly relevant to the content of this article.

the variety of induced disability, spinal cord infarction is difficult to predict, and effective rehabilitation methods have not been clarified.

Among patients with spinal cord infarction, those with "man in the barrel (MIB)" syndrome appear to have motor paralysis localized to the proximal muscles of both upper limbs [5, 6]. A previous study showed that among 55 patients with spinal cord infarction, three patients were identified as MIB [7]. MIB has a low occurrence frequency, and no report has described in detail the prognosis for motor function and the effects of rehabilitation.

Gait rehabilitation support robots have recently been reported as a means of gait reconstruction after spinal cord infarction [8, 9]. On the other hand, upper limb rehabilitation support robots have been used for patients with upper limb paralysis due to spinal cord injury [10]. However, no report has described upper limb rehabilitation support robots for patients with spinal cord infarction-related upper limb paralysis. This study examined the use of an upper limb rehabilitation support robot and occupational therapy centered on task-oriented training to treat a patient with spinal cord infarction-induced severe upper limb paralysis. Informed consent was obtained from the patient for the publication of this case report.

Case

The present case was a 60-year-old man who was right-handed and independent in activities of daily living (ADL) before he became diseased. He was employed in the civil service. The patient had an acute myocardial infarction and percutaneous transluminal coronary angioplasty. After surgery, the patient was unable to lift his arm, and T2-weighted magnetic resonance imaging (MRI) analysis of his cervical spinal cord revealed a watershed infarction in the C5−7 spinal cord region (Figure 1). The patient was admitted to Fujita Health University Nanakuri Memorial hospital for rehabilitation 18 days after onset of the disease.

Evaluation upon Admission

Physical examination revealed grade D on the American Spinal Injury Association (ASIA) Impairment scale, with motor function scores of 36 on the right and 43 on the left. The localized impairment decreased voluntary movement in the muscles innervated by the nerves in the C5−7 region, including bilateral deltoids and biceps brachii. Regarding sensory function, light touch was 50 points on the right and 53 points on the left, and pinprick was 51 points on the right and 54 points on the left, with mild hypesthesia observed from the right upper arm to the fingers (Table 1). The active ROM (right/left) was shoulder joint flexion of 0/15 degrees, shoulder joint abduction of 0/5 degrees, and elbow joint flexion of 0/30 degrees (Figure 2). Grip strength was 7 kg on the right and 20 kg on the left, and the patient was able to grasp handrails and objects. Furthermore, the Manual Muscle Test (MMT) score for the abdominal trunk muscles was four, the MMT score for the lower limbs was five, and the patient was able to walk with supervision from the time of admission. In terms of ADL, the Functional Independence Measure (FIM) motor item score was 25 points, the cognitive item score was 25 points, the score between bed and wheelchair transfer was five points, and the locomotion (using a wheelchair) was four points. Other self-care activities, such as grooming, eating, and dressing, required full assistance. Cognitive function as measured by the Mini-Mental State Examination score was 30 points. Based on the Canadian Occupational Performance Measure (COPM), three goals were listed: "eating," "going to the toilet," and "raising one's hand in a meeting." Only the performance of

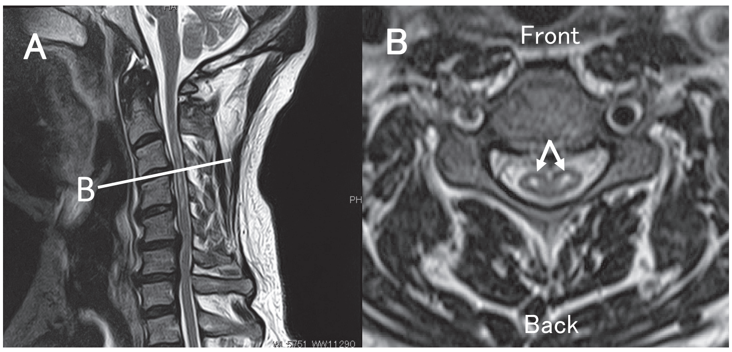

Figure 1. The T2-weighted cervical magnetic resonance imaging (MRI) (Admission).
A. Sagittal section showed a high-signal area within the spinal cord at C2–5.
B. Horizontal section at the C4 level. A high-signal area was observed in the watershed area (arrow).

"going to the toilet" was rated three points, and the performance and satisfaction of the other items were both one point. Furthermore, regarding his current situation, he said, "I can't lift my arms. It's all over," and he had a strong sense of loss.

Intervention and Progress

Figure 2 and Table 1 show the findings of progression from admission to discharge and the training content for this case. The short-term goals of the intervention were based on the tasks selected by COPM to materialize actions frequently used in ADLs using the remaining function of the left upper limb: "eating independently while maintaining the left upper limb in space" and "putting on and taking off underwear using both upper limbs when toileting, and independently cleaning up using the left upper limb." The long-term goal of the intervention was to materialize the action of "attending a local meeting and raising one's hand with the left upper limb." For this patient, raising his hand during meetings was often used to express an opinion, approval, or disapproval, and it was also an important goal for him to return to work.

Occupational therapy consisted of ADL training, task-oriented training, and ROM training within 1 h/day of the occupational therapy time. In the task-oriented training, two types of tasks were set: repeated tasks with difficulty adjusted to match changes in physical function (shaping) and simulated tasks to help the patient adapt to a real environment (task practice). During the first month after admission, the patient was affected by severe paralysis of both upper limbs. He had difficulty using his upper limbs in self-care, so the training focused on shaping tasks. Thirty-eight days after onset, the patient was able to use his left upper limb to eat, and the shaping task was transitioned to self-training, focusing on task-practice training. In addition, occupational therapy focused on task-oriented training of the distal upper limbs using remaining functions, which made it difficult to increase the amount of training through repetitive joint movements to improve the proximal upper limbs. We thought that by improving the proximal function of the upper limbs, we could reduce the need for assistance with self-care; therefore, we added an upper limb rehabilitation support robot, which is known to be effective in improving upper limb function. Ten days after admission, the patient had become independent in transfer movements. An upper limb rehabilitation support robot was used for 1 h/day on the left upper limb, where more voluntary muscle contraction remained. The upper limb rehabilitation support robots used were ReoGo®-J (Teijin Pharma Limited) and Shoulder Movement Assisting RoboT (SMART) (DHS Co., Ltd. Matsusaka, Mie, Japan) [11]; each

Table 1. ASIA results from admission to final evaluation.

Number of days since onset		18 days	48 days	78 days	108 days
Motor function					
Upper limb Key muscle (Right / Left)	C5	1/2	2/3	2/3	2/3
	C6	3/4	3/4	3/4	3/4
	C7	1/4	2/4	2/4	3/5
	C8	3/4	3/4	3/4	4/4
	T1	3/4	3/4	3/4	4/4
Lower limb key muscle of L2-S1: 5 points on both sides from admission (total 25 points)					
	Motor function total	36/43	38/44	38/44	41/45
Sensory function Light touch (Right / Left)*	C5	1/1	1/1	1/1	1/1
	C6	1/1	1/1	1/1	1/1
	C7	1/1	1/1	1/1	1/1
	C8	1/2	1/2	1/2	1/2
	T1	1/2	2/2	2/2	2/2
	S1	1/2	2/2	2/2	2/2
	Light touch total	50/53	52/53	52/53	52/53
Pin prick (Right / Left)*	C5	1/2	1/2	1/2	1/2
	C6	1/2	1/2	1/2	1/2
	C7	1/2	1/2	1/2	1/2
	S1	1/1	2/2	2/2	2/2
	S2	1/1	2/2	2/2	2/2
	Pin touch total	51/54	53/56	53/56	53/56

ASIA, American Spinal Injury Association.
*Show only deducted points

Case history (Number of days since onset)		admission (18 days)	10 days later (28 days)	1 month later (48 days)	2 month later (78 days)	3 month later (108 days)
Needs		Raise of hand during meeting →	Eat a meal by yourself →	Eating without assistive devices →	Increase the things one can do →	Move right hand
Goal setting		Self-care such as eating and toileting was modified Independence (6–8 weeks)				Acquiring a raise of hand (discharge)
ASIA motor function (points) (R/L)		36/43		38/44	38/44	41 /45
Active ROM (degree) (R/L)	Shoulder joint flexion	0/15		10/30	30/70	30/85
	Shoulder joint abduction	0/5		5/30	15/45	15/80
	Elbow joint flexion	0/30		5/90	45/145	80/145
MMT (R/L)*	Anterior deltoid	0/1		1+/2	1+/2	1/2
	Middle deltoid	0/1		1+/2	1+/2	1/2
FIM (points)	Motor items	25		56	69	81
	Cognitive items	25		35	35	35
COPM (Performance/ satisfaction)	Eating	1/1				10/10
	Toileting	3/1				10/10
	Raise of hand	1/1				10/10
ADL	Eating	Total assistance		Independent eating with forearm support (with self-help device)	Eating independently on elbow	
	Dressing upper body	Total assistance		Clothes can be put on and taken off on the table	Clothes can be put on and taken off without a table	
	Bathing	Total assistance		Able to wash part of the lower limbs	Able to wash body parts other than head and back	Able to wash head and back wash
	Transfer (Bed/Toilet)	Minimal assistance	Complete Independence			
	Social activity	—	—	—	—	Acquiring a raise of hand
Occupational therapy intervention	Occupational therapy	ADL training Task-oriented training Range of motion training → (through discharge)				
	Additional training	ReoGo J → From admission to approximately 2.5 months SMART → From admission to approximately 2 months Task-oriented training → (from approximately 2 months to discharge)				

Figure 2. Progress of each assessment, ADL, and training content from admission to discharge.
ASIA, American spinal injury association; ROM, Range of motion; MMT, Manual muscle test; FIM, Functional independence measure; ADL, Activities of daily living; COPM, Canadian occupational performance measure.
*Only muscle strength that could not be evaluated by ASIA's key muscle in Table 1 was shown.

was administered for 30 min. According to the characteristics of the upper limb rehabilitation support robots, ReoGo®-J was introduced to improve shoulder joint abduction and reach motion to the mouth, and SMART was introduced to improve forward reaching motion (shoulder joint flexion). The appearance and specifications of SMART are shown in Figures 3 and 4.

1. Twenty-eight days after onset (early stage of robot training)

The upper limb rehabilitation support robot training was performed on the left upper limb, which still had voluntary muscle contraction based on the evaluation of upper limb function in this case to achieve independence in eating (carrying a cup or spoon to the mouth), manipulating pants, and excretory movements. The target angles for active ROM were based on the shoulder and elbow flexion angles required for self-care movements reported in a previous study [12], with shoulder flexion at 70° and elbow flexion at 120°. The settings for ReoGo®-J were a low robot arm height and trajectory assist mode, and the main movements were shoulder joint abduction and elbow joint flexion-extension on a horizontal plane; added tasks included polygonal and circular trajectories and reaching to the mouth. The motion range at the start of SMART was set from zero to 60 degrees, the threshold at which the robotic assistance started (trigger threshold) was set equal to the upper limb body weight, and the exercise was performed 90 times daily.

2. Forty-eight days after onset (self-care independence in a weightless position)

The active ROM of the left shoulder joint improved to 30° of flexion and abduction and 90° of elbow joint flexion. The patient was able to independently eat, groom, and dress with the forearm resting on the table. The settings for ReoGo®-J were changed to the training menu of radial direction reach and abduction direction reach in the trajectory assist mode. In addition, an eight-way spatial holding task was introduced with the aim of acquiring upper limb placement during ADL. The motion range of SMART was changed from 20 to 80 degrees, and the trigger threshold was set lower than that of upper limb body weight to obtain more muscle contraction.

3. Seventy-eight days after onset (self-care independence in an antigravity position)

The active ROM of left shoulder joint flexion improved to 70 degrees, abduction to 45 degrees, and elbow joint flexion to 145 degrees. In addition, the MMT scores for left shoulder joint flexion, abduction, and elbow joint flexion all improved to three. In terms of ADL, the patient was able to eat by resting his elbows on the table, and he was able to change clothes independently without a table. The ReoGo®-J setting enabled abduction and radial direction reach without compensatory movements in trajectory assist mode. Therefore, the training menu was changed to the automatic exercise mode, and the simulated reach was added to further improve the function with the goal of achieving reach to the mouth. Regarding ReoGo®-J, the training was terminated when the patient was able to reach the mouth using active upper limb movements in daily life without compensatory movements, and the task-oriented training was conducted focusing on actual movements of ADL and IADL. Moreover, SMART was terminated when the initially set target angle was reached.

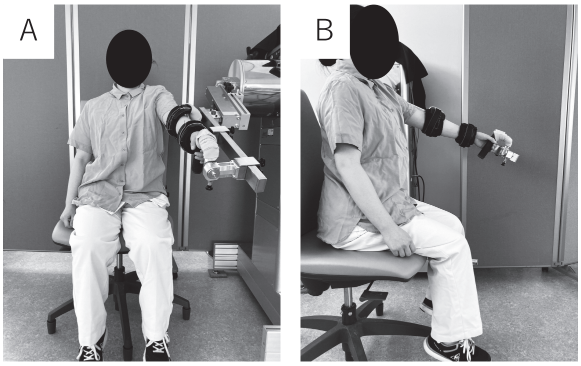

Figure 3. Shoulder Movement Assisting RoboT (SMART) (A: Front view, B: Side view).
Shoulder Movement Assisting RoboT (SMART) is a robot with repetitive vertical movement of the shoulder joint. This robot is designed to be triggered by the torque of shoulder joint flexion; the robot arm assists in shoulder joint flexion. Adjustments to the threshold at which assist is initiated (trigger threshold) and the angle setting of the target to be reached can be modified depending on the severity of the paralysis. The trigger threshold is based on the patient's upper limb body weight, and active movement can be performed if the trigger threshold is set lower than the upper limb body weight. On the other hand, if the trigger threshold is set higher than the upper limb body weight, passive movement is possible.

4. Final evaluation (acquisition of long-term goals)

ASIA motor function scores 108 days after onset were 45 on the right and 46 on the left; the active ROM of left shoulder joint flexion improved to 85 degrees, abduction to 80 degrees, and elbow joint flexion to 145 degrees. In terms of ADL, the patient was able to hold the upper limbs in space, and was independent in washing hair, hairdressing, and wiping the rear, although with compensatory movements. As a result, the FIM motor score improved to 81 points (supervised only on toileting and bathing, independent of other items), and the cognitive score improved to 35 points. In addition, the COPM score improved to ten points in both satisfaction and performance for all items of "eating," "going to the toilet," and "raising one's hand in a meeting."

Discussion

This patient required assistance with most self-care activities due to severe motor paralysis of both upper limbs, and he had low performance and satisfaction with the COPM items. As a result of the combined use

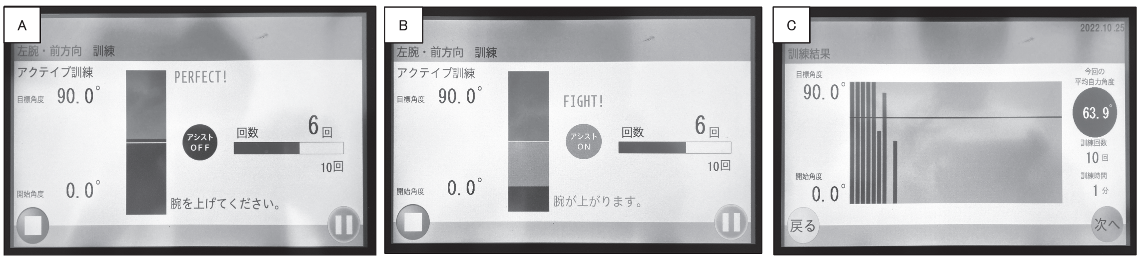

Figure 4. Display of Shoulder Movement Assisting RoboT.
The display shows the range of movement according to the subject's movement and assistance range.
A. "PERFECT!" will be displayed if you were able to move the device to the target range of motion by yourself.
B. If you were unable to move to the target range of motion by yourself, "FIGHT!" will be displayed. The arm moves passively from the stopped range of motion to the final range of motion; the passive range of motion changes to a different color on the display.
C. After all tasks were completed, the results of the range of motion and average angle for each exercise were displayed.

of repeated tasks of a difficulty level appropriate for physical function and upper limb rehabilitation support robot training, the patient was able to acquire the active ROM required for ADL, leading to improvements in FIM and COPM.

The prognosis of patients with spinal watershed infarction is limited to case reports because the rarity of the disease prevents large-scale studies. According to these reports, in cases where the strength of the deltoid and biceps was normal at the onset of the disease but weakness was present in the triceps and wrist and finger extensor muscles, all patients with the disease showed slight improvement in muscle strength over time [13, 14]. However, our patient had severe motor paralysis in the deltoid and biceps muscles of both upper limbs, and as there have been no reports on the recovery process for patients with similar symptoms, the prognosis for functional recovery was unclear. Additionally, the patient clinically required assistance in all self-care activities due to severe paralysis, and his upper limbs were used infrequently, making synergistic functional improvement difficult.

In Japan's medical insurance system, the daily rehabilitation fee for each disease in a comprehensive rehabilitation ward is capped at nine units (three hours), and treatment must be prioritized within the limited rehabilitation training time. Therefore, it was considered necessary to improve the function of the upper limb and expand its manipulability in self-care activities in this patient's occupational therapy. In this case, it was possible for the occupational therapist to manually repeat the movement with the aim of improving function. However, it would be difficult to repeat movements with an accurate dosage due to therapist fatigue. Furthermore, it was considered difficult to ensure the amount of training that focused on both functional improvement and manipulability expansion within the limited time of occupational therapy. Based on the complementarity of training content, an upper limb rehabilitation support robot has the advantage of increasing the number of movements and training intensity through accurate dosage [15]. For severe paralysis, such as this case, the number of movements can be increased by adjusting parameters (movement range, trigger threshold, dosage, and mode selection) according to the remaining function to maximize voluntary contraction. Frullo et al. reported that movement repetition by "assist as needed" may improve the quality of movement as a setting for an upper limb rehabilitation support robot for severe motor paralysis with poor voluntary contractions after spinal cord injury [10]. Furthermore, Lynskey et al. reported that rehabilitation-based active movement involving voluntary control promoted sensorimotor recovery after spinal nerve trauma [16]. They reported that repetitive training promotes plasticity in the motor cortex or descending pathways in cases of incomplete spinal cord injury, although this was unclear in cases of complete spinal cord nerve injury. Therefore, it was possible that neural plasticity was the mechanism behind the functional improvement in this patient. In addition, two types of upper limb rehabilitation support robots were used in this patient: SMART was used to strengthen shoulder joint flexion movement, and ReoGo®-J was used to expand the reach range involving flexion and extension of the shoulder and elbow joints. Thus, the appropriate choice of an upper limb rehabilitation support robot equipped with the ability to move in the direction of the movement to be strengthened was effective in improving the function.

In this patient, training using an upper limb rehabilitation support robot improved the active ROM necessary for self-care, resulting in improvements in ADLs, such as eating, dressing, and toileting. Gates et al. reported that the shoulder and elbow flexion angles required for eating (carrying a cup to the mouth) were 71 and 121 degrees, respectively, and the shoulder and elbow flexion angles required for cleaning up after voiding were 55−63 and 90−107 degrees, respectively [12]. In this patient, training using an upper limb rehabilitation support robot improved the shoulder joint flexion angle to 85 degrees and elbow joint flexion angle to 145 degrees in the antigravity position, enabling the use of the upper limb in eating and toileting activities. As a result, the patient began to use his upper limbs more frequently during ward life. Conroy et al. reported that by priming the motor system with a rehabilitation assistive robot and adding task-oriented training, it may be possible to change the improved function to active use [17]. In this case, the training using an upper limb rehabilitation support robot facilitated the improvement of motor function and active ROM, and practical ADL training was possible through task-oriented training, which contributed to ADL improvement.

Finally, the effectiveness of using COPM in patients with spinal cord injury has recently been reported [18]. The present patient received full assistance with all ADLs at the time of admission. He wanted to return to work, and it was necessary to solve the issues step by step. The merits of using COPM in this patient included the sharing of issues between the patient and the therapist and the clarification of the patient-specific treatment program. In addition, the patient was able to play an active role in training to acquire activities that were meaningful for him, which ultimately resolved the issue and led to improved performance and satisfaction with COPM.

Conclusions

In a patient with severe paralysis of the proximal muscles of both upper limbs and full ADL assistance due to a watershed infarction in the C5−7 spinal cord region, COPM was used to share goals, and an upper limb rehabilitation support robot and task-oriented training were used in combination to solve the problems. The upper limb rehabilitation support robot led to functional improvement by increasing the number of movements and adjusting the difficulty level according to the level of upper limb function. In addition, the combined use of task-oriented training to generalize the improved functions to ADLs may have contributed to the improvement in self-care.

However, the results of this case study cannot be generalized because it involved a single patient. Comprehensive intervention for patients with severe paralysis due to spinal cord infarction might be able to improve occupational performance.

Acknowledgments

We thank the patient and family, members of the Fujita Health University Nanakuri Memorial Hospital, who helped with patient assessment. This study was partially supported by JSPS KAKENHI Grant Number 19K11399.

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