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Original Article

A study of the training method of sub-acute stroke patients of the upper extremity: decision tree analysis

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ABSTRACT
Miyasaka H, Ohnishi H, Hieda C, Kawakami K, Tanino G, Okuyama Y, Tomita Y, Sonoda S. A study of the training method of sub-acute stroke patients of the upper extremity: decision tree analysis. Jpn J Compr Rehabil Sci 2014; 5: 117−124.
Objective: We examined how differences in training method affected the improvement of paralysis.
Methods: One hundred and thirty-one patients with stroke were admitted to Nanakuri Sanatorium, Fujita Health University. We divided the patients randomly into five groups, mirror therapy (MT), integrated volitional control electrical stimulation (IVES), therapeutic electrical stimulation (TES), repetitive facilitative exercises (RFEs), and conventional training (control group). Each group performed an assigned exercise for 20 minutes. Decision tree analysis was performed to identify the effectiveness of rehabilitation training for improving motor function. The predicted variables were the FMA upper extremity items at 4 weeks. The explanatory variables were age, days after stroke onset, treatment technique, and evaluation test results.
Results: When patients had scores of FMA-finger < 3 and FMA-shoulder < 3, MT, TES, and RFEs were chosen as favorable determinants. If FMA-finger ≥ 8 and FMA-wrist < 8, MT, IVES, TES, and RFEs were chosen as favorable determinants.
Conclusion: Decision tree analysis appears to be a valid mean for deciding the best rehabilitation method for sub-acute stroke patients.

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Key words: stroke, upper limb hemiparesis training, decision tree analysis

Introduction

The purposes of post-stroke rehabilitation include early ambulation and discharge as well as independence in the activities of daily living (ADL) by effectively using the residual function and the environment. Improvement of these factors has been reported as the effects of rehabilitation [1, 2].

In the system for assessing the cost units of treatment in recovery rehabilitation wards covered by Japanese national health insurance, the upper limit per patient is 9 units per day (3 hours: 20 minutes per unit), and so an efficient training method within this limited time must be selected. Han et al. [3] reported that motor function was significantly improved by increasing the training time, but did not describe the details of the training for paralysis. An effective and efficient training method needs to be clarified.

Langhorne et al. [4] reported a systematic review of motor paralysis treatment, in which training methods for 19 regions were divided into the arm and hand functions, and the presence or absence of effects was investigated. They observed that constraint-induced movement therapy (CIMT) and robot-assisted therapy were effective for the arm function, for which many RCT-level studies have been reported, whereas no training method was effective for the hand function.

On the other hand, in the Cochrane database of systematic reviews, repetition of specific training, CI movement therapy, robot-assisted training, and mirror training were reported as effective training methods for the upper limb on the side with stroke-induced paralysis [5−8]. However, there are no criteria for selecting one from many training methods, and in many cases the method to be used is determined based on the experience of the individual providing the treatment and the facility's equipment. Moreover, intervened and control groups were compared in most previous studies, and no comparison of various training methods has been reported [9−11].

We randomly allocated stroke patients admitted to a recovery rehabilitation ward to five training methods, and used decision tree analysis to investigate whether differences among the training methods were related to the improvement of paralysis.

Methods

1. Subjects

The subjects were patients with initial stroke who were admitted to the recovery rehabilitation ward of our hospital between September 1, 2009 and July 31, 2011, and who gave consent to participate in this study. Patients with the following conditions were excluded: serious comorbidity interfering with training (Liu's comorbidity index [12] of 4 or higher, i.e., sufficient consideration and caution are necessary to perform rehabilitation), inability to understand the guidance for training, and higher brain dysfunction interfering with motor tasks of this study due to total aphasia and unilateral spatial neglect. This study was approved by the Ethical Committee of our hospital (approval number 46).

2. Selection of training method and study design

For the study design, a randomized controlled study by random allocation was adopted. A random number table for five groups was prepared using a computer, and the patients were allocated in the order of entry. For the training methods of the five groups, mirror therapy (MT) [9], integrated volitional control electrical stimulation (IVES) [10], therapeutic electrical stimulation (TES) [13], repetitive facilitative exercises (RFEs) [14], and conventional training were selected. In the conventional training, passive movement of joints and ADL training were performed without electrical stimulation and MT.

Greater importance was attached to balance with ADL training, and the training methods could be performed within 20 minutes per day. These methods have been reported to be effective in studies on motor paralysis in hemiplegic patients and in a randomized controlled trial (RCT). The training time was one hour each for PT, OT, and ST, and the assigned training method was performed within the training time of OT. When ST was not prescribed, PT or OT was performed.

2-1. Mirror therapy

A custom-made mirror box was used in MT. The training was performed with the patient in the position of sitting on a chair at a desk. The mirror was placed between the upper limbs of the patient so that he could observe the reflection of his unaffected upper limb in the mirror. Eight motions were performed with a metronome (40/min): 1) flexion-extension of the shoulder joint, 2) abduction-adduction of the shoulder joint, 3) flexion-extension of the elbow joint, 4) forward reaching, 5) dorsiflexion of the wrist joint, 6) flexion-extension of the fingers, 7) opposition of the fingers, and 8) radial abduction of the thumb. Each of these was performed for 2 minutes and 30 seconds. In MT, patients were instructed to watch the movement of their unaffected upper limb in the mirror and to imagine this movement as the movement of their affected upper limb while also simultaneously moving it.

2-2. IVES

IVES was performed with the patient in the position of sitting on a chair using the power assist mode of the Power Assist Stimulator system (OG Giken, Okayama, Japan). Training using IVES was applied to the proximal and distal regions. In the motor task for the proximal region, electrodes were attached to the anterior and middle fibers of the deltoid muscle, and wiping motion and abduction of the shoulder joint were performed for 5 minutes each (10 minutes in total) at a desk. For the distal region, electrodes were attached to the extensor digitorum muscle and extensor carpi radialis muscle, and dorsiflexion of the wrist joint and extension of the fingers were performed for 5 minutes each (10 minutes in total).

2-3. TES

For TES, the normal mode of the Power Assist Stimulator system was used (at the maximum allowable intensity for 5 seconds at a frequency of 50 Hz). The TES training was applied to the proximal and distal regions with the patient in the position of sitting on a chair. Electrodes were attached to the anterior and middle fibers of the deltoid muscle in the proximal region, extensor digitorum muscle and extensor carpi radialis muscle in the distal region, and electrical stimulation was applied for 10 minutes each (20 minutes in total). Patients did not perform active movement by themselves during the application of stimulation.

2-4. Repetitive facilitative exercises (RFEs)

In this training method, the descending motor pathways are repeatedly facilitated by stimulations with stretch reflex and skin-muscle reflexes, and the patient is meant to move simultaneously with the stimulations. This method was developed by Kawahira of Kagoshima University, and was reported to be effective for improving paralysis of stroke patients [14]. The tasks for the proximal region (flexion of the shoulder joint and flexion-extension of the elbow joint) and distal region (dorsiflexion of the wrist joint, extension and opposition of the thumb, and extension of each finger) were performed for 10 minutes each and repeated 100 times or more in either region.

2-5. Conventional training

Training other than those described above was performed. The training consisted of passive joint movement, repetitive tasks using objects, and ADL.

3. Flow of the training methods and program

The objective of this study was explained to the patients by a physician who was blind to the exclusion criteria on the first day of admission, and obtained an informed consent. The initial evaluation was performed on the second day after admission and the patient was allocated to a training method on the same day. Randomly assigned training was initiated on day 3. All patients performed the training at Nanakuri Sanatorium, Fujita Health University.

The total training time of PT, OT, and ST per day was about 3 hours, and the assigned 20 minutes of training was performed within the 3 hours. The training started on the third day after admission and continued until day 26 for 4 weeks.

Since our hospital provides rehabilitation 365 days a year, training and evaluation were performed by a person in charge on each day. Therefore, the staff who provided the treatment and performed the evaluation knew the assigned training.

A patient was excluded from the study if he/she did not wish to continue with the study or if his/her medical condition deteriorated.

4. Evaluation

The upper extremity motor items of the Fugl-Meyer Assessment (FMA) (shoulder/elbow, wrist joint, and fingers), grasp and pinch strengths on the paralyzed side, Modified Ashworth Scale (MAS) for the biceps brachii muscle and wrist flexors, and Functional Independence Measure (FIM) were evaluated on day 2 (admission) and day 28 (4 weeks) after admission. When muscle tonus of the biceps brachii muscle and wrist flexors was hypotonic, they were evaluated separately.

5. Statistical analysis

Biases of each subject were adjusted to ensure that the conditions were uniform before statistical analysis. Patients under the following conditions were excluded: 1) dropouts (36 patients), 2) time after onset was within 14 days or 61 days or more (16 patients), and 3) being treated with speech and language therapy for 40 minutes or longer per day (15 patients). Some patients overlapped with the subjects of a preceding study reported by Miyasaka et al. [15], but sampling biases, such as the time to initiation of rehabilitation after the onset and training time, were minimized by standardizing the conditions, in contrast to the preceding study.

Statistical analysis was performed using JMP9.0 for Macintosh. Each evaluation item at the time of initiation was compared between the conventional training and other groups using Dunnett's test, and gender, affected side, classifications of cerebral hemorrhage and brain infraction, and MAS of the biceps brachii muscle and wrist flexors were analyzed using the chi-square test. In addition, the gain calculated by subtracting the value at initiation from that at 4 weeks was compared between the conventional training and other groups using Dunnett's test. Furthermore, decision tree analysis (Partition) was performed to judge whether or not the training methods influenced functional improvement, in which the total score of the FMA upper extremity motor items at 4 weeks was regarded as a response variable, and the age, time after onset, training method, FMA scores of the shoulder/elbow, wrist joint, and fingers at initiation, MAS of the biceps brachii muscle and wrist flexors, grasp and pinch strengths on the paralyzed side, and motor and cognitive items of FIM were regarded as independent variables. The conditions of decision tree analysis were as follows: maximum depth of tree, 4; minimum value of parent node, 20; and minimum value of child node, 5.

Results

1. Number of patients

One hundred and ninety-eight patients were enrolled during the study period, and 131 were included in the final analysis after exclusion as described above. A flowchart of the study is shown in Fig. 1.

The final numbers of patients were 19, 26, 23, 27, and 36 in the MT, IVES, TES, RFE, and conventional training groups, respectively, and there were no significant differences in the conditions at initiation among these groups. Basic information of each group is shown in Table 1.

2. Gain of each item and comparison with conventional training

The gains of the evaluation items in each group are shown in Table 2. No significant difference was noted between the conventional training and other groups.

3. Results of decision tree analysis

The results of analysis regarding the total score of FMA upper extremity motor items as a response variable are shown in Fig. 2.

In severe paralysis patients with FMA finger and shoulder/elbow scores below 3, the outcomes of MT, TES, and RFEs were high. When the FMA finger score was 8 or higher with an FMA wrist joint score below 8, the outcomes of the training methods other than the conventional training were high.

Discussion

The five training methods for the upper limb on the paralyzed side were randomly assigned to stroke patients in the recovery phase, and whether or not

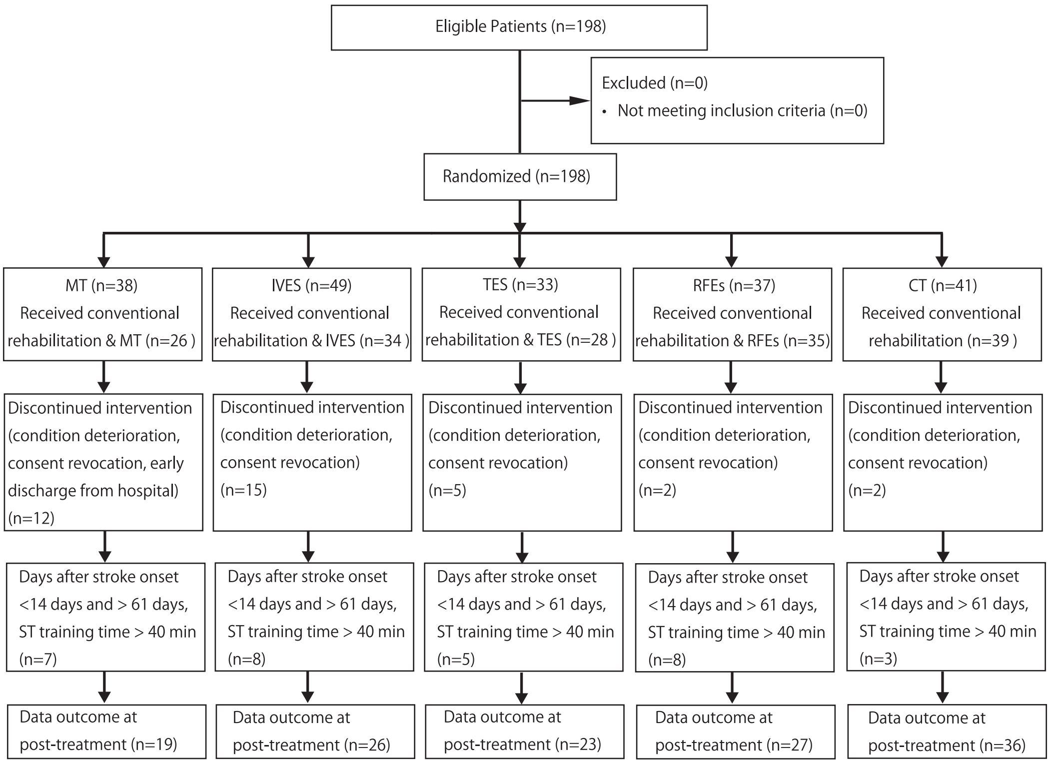

Figure 1. Flow diagram for randomizing the subject assignment of this study.

Table 1. Patient characteristics at baseline.

		MT	IVES	TES	RFEs	CT	*p*-Value
n		19	26	23	27	36	
Age (year)		63.5 ± 9.6	64.8 ± 13.6	70.6 ± 12.5	66.7 ± 14.7	67.4 ± 14.4	ns
Sex (Male/Female)		12/7	12/14	12/11	18/9	25/11	ns
Side of lesion (Right/Left)		8/11	11/15	9/14	16/11	16/20	ns
Days after stroke onset (day)		34.2 ± 8.8	35.7 ± 11.3	30.8 ± 10.4	37.8 ± 12.2	36.8 ± 12.5	ns
Lesion type (ischemic/hemorrhagic)		11/8	13/13	9/14	11/16	17/19	ns
Training time (hour)	total	2.5 ± 0.2	2.5 ± 0.2	2.5 ± 0.2	2.6 ± 0.2	2.5 ± 0.2	ns
	PT	1.1 ± 0.1	1.2 ± 0.1	1.1 ± 0.1	1.2 ± 0.1	1.2 ± 0.04	ns
	OT	1.2 ± 0.1	1.0 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.04	ns
FMA	shoulder/elbow	10.7 ± 11.2	13.3 ± 11.9	7.6 ± 10.5	10.9 ± 10.7	9.9 ± 11.8	ns
	wrist	2.5 ± 3.7	3.5 ± 4.1	2.1 ± 3.6	2.5 ± 3.4	2.5 ± 3.8	ns
	finger	4.6 ± 5.7	5.9 ± 5.5	3.4 ± 5.1	5.2 ± 5.5	4.7 ± 5.8	ns
	total	17.9 ± 19.4	22.7 ± 20.9	13.1 ± 18.4	18.6 ± 18.8	17.1 ± 20.8	ns
Grip (kgf)		3.0 ± 6.6	5.3 ± 9.0	2.7 ± 5.1	3.4 ± 6.5	3.9 ± 7.5	ns
Pinch (kgf)		1.3 ± 2.0	1.7 ± 2.1	1.1 ± 1.9	1.6 ± 2.6	1.6 ± 2.5	ns
MAS (0/1/1+/2/low)	biceps	5/6/3/0/5	7/11/3/0/5	8/6/2/1/6	9/6/7/0/5	14/11/6/0/5	ns
	wrist flexor	5/9/3/2/0	12/6/4/3/1	6/9/6/0/2	8/7/9/2/1	12/12/10/2/0	ns
FIM	motor	48.4 ± 17.3	45.4 ± 19.4	40.0 ± 17.4	46.9 ± 13.3	40.2 ± 15.0	ns
	cognitive	26.4 ± 7.7	25.7 ± 7.6	21.3 ± 9.0	24.9 ± 7.3	23.1 ± 8.4	ns

The values are mean ± standard deviation.
MT, Mirror Therapy; IVES, Integrated Volitional control Electrical Stimulation; TES, Therapeutic Electrical Stimulation; RFEs, Repetitive Facilitative Exercises; CT, Conventional Therapy; PT, Physical Therapy; OT, Occupational Therapy; FMA, Fugl-Meyer Assessment; MAS, Modified Ashworth Scale; FIM, Functional Independence Measure.
Dunnett's test was applied for the analysis of variables: Age, Days after stroke onset, Training time, FMA, Grip, Pinch, and FIM.
The Chi-square test was applied for the analysis of variables: Sex, Side of lesion, Lesion type, and MAS.
(ns: not significant)

Table 2. Gain of each item and comparison with conventional training.

	MT	IVES	TES	RFEs	CT	*p*-Value
FMA shoulder/elbow	4.9 ± 7.6	2.3 ± 3.8	3.4 ± 5.2	3.1 ± 5.7	1.6 ± 3.9	ns
FMA wrist	1.3 ± 2.4	0.8 ± 1.3	0.7 ± 1.9	0.9 ± 2.1	0.6 ± 1.9	ns
FMA finger	1.3 ± 2.3	1.7 ± 2.3	1.4 ± 2.2	1.0 ± 1.8	1.2 ± 2.1	ns
FMA total	7.5 ± 11.0	4.8 ± 5.7	5.6 ± 7.5	5.0 ± 8.4	3.4 ± 6.5	ns
Grip (kgf)	1.4 ± 2.4	0.2 ± 2.3	1.2 ± 2.1	1.7 ± 2.7	1.8 ± 2.6	ns
Pinch (kgf)	0.6 ± 0.8	0.5 ± 1.2	0.4 ± 0.8	0.4 ± 0.9	0.7 ± 1.1	ns
FIM motor	18.6 ± 10.3	13.7 ± 6.3	14.6 ± 9.6	15.6 ± 11.6	16.7 ± 9.2	ns
FIM cognitive	2.5 ± 3.0	1.8 ± 3.0	2.5 ± 4.5	1.8 ± 2.8	2.4 ± 3.5	ns

Values are mean ± standard deviation.
MT, Mirror Therapy; IVES, Integrated Volitional control Electrical Stimulation; TES, Therapeutic Electrical Stimulation; RFEs, Repetitive Facilitative Exercises; CT, Conventional Therapy; FMA, Fugl-Meyer Assessment; FIM, Functional Independence Measure.
Dunnett's test was applied for the analysis of variables: FMA, Grip, Pinch, and FIM.
(ns: not significant)

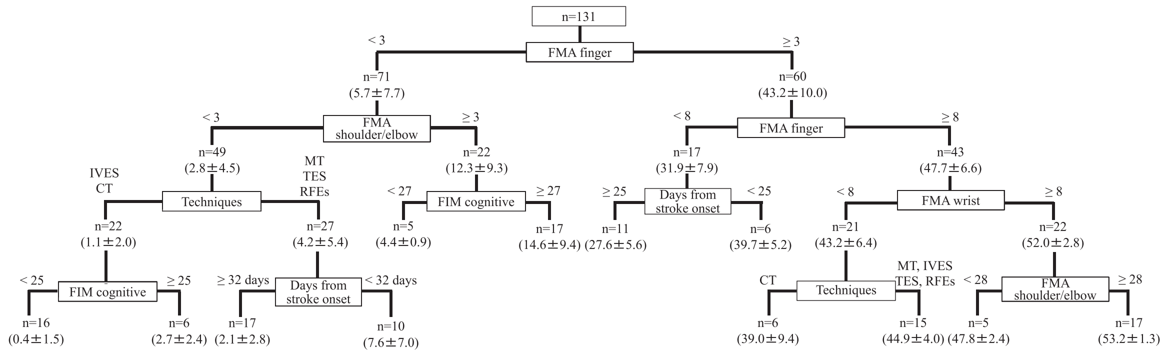

Figure 2. Result of decision tree analysis.
（　）: Show the mean and standard deviation of the FMA upper extremity total score of four weeks.
MT, Mirror Therapy; IVES, Integrated Volitional control Electrical Stimulation;
TES, Therapeutic Electrical Stimulation; RFEs, Repetitive Facilitative Exercises; CT, Conventional Therapy;
FMA, Fugl-Meyer Assessment; FIM, Functional Independence Measure.

differences among the training methods were related to the improvement of paralysis was investigated using decision tree analysis. Decision tree analysis is a method to identify a variable from data of interest. It is applicable to ordinal and nominal scales, and is used for classification and prediction. It has been used as an analytical method that is intuitively understandable and easily applicable for clinical cases because of the similarity of predictors between logistic regression and decision tree analyses [16] and the hierarchical tree structure [17, 18].

Decision tree analysis was performed using the total score of the FMA upper extremity motor items. Michaelsen et al [19]. classified the severity of FMA upper extremity motor dysfunction as follows: 0–19, severe; 20–64, moderate; and 65 or higher, mild. The scores were 2.8 and 43.2 for the training methods at the 3rd and 4th nodes, respectively, dividing patients into those with severe and moderate or severer paralysis levels. The outcomes of MT, TES, and RFEs were high in patients with severe paralysis, and the outcomes of the training methods other than the conventional training were high in patients with moderate or severer paralysis.

Coupar stated in a review of upper limb recovery on the paralyzed side that the initial motor function was the strongest predictor [20]. Although the difference in the recovery of the upper limb on the paralyzed side may have been due to the classification of lesions, it was assumed that the contribution by differences in the training method was greater.

In the result of prediction of the whole hemiplegic upper limb function, the effective training method differed between patients with severe and moderate or severer paralysis. In patients with moderate or severer paralysis, the levels of outcomes of the methods other than conventional training were high. The condition specified by decision tree analysis for patients classified into this group was an FMA finger score of 8 or higher with an FMA wrist joint score below 8. This condition included patients with moderate or severer paralysis, and they may have been those with joint movement accompanied by voluntary contraction. Since the FMA finger score was 8 or higher, they may have frequently used the upper limb using the fingers in ADL, which may have led to improvement of paralysis through conventional training. Since we provide about 3 hours of training per day, 7 days a week, the frequency and intensity of training were sufficient [21]. Han et al. reported that motor function was improved by increasing the training time [3], suggesting that the frequency and intensity of training affect the improvement of paralysis of patients. However, the other methods were beneficial for patients with moderate or severer paralysis compared with conventional training performed more frequently, suggesting that the combination of a paralyzed muscle-facilitating method, such as MT, IVES, TES, and RFEs, with highly frequent training further improves function. In the patients with severe paralysis, the levels of outcomes of MT, TES, and RFEs were high. These methods may be applicable for patients with difficulty in obtaining voluntary contraction, such as those with severe paralysis. MT has been reported to be effective for severe paralysis [22]. The observed effect may have been due to repeated visual feedback and motor imagery in MT. In TES, no active movement was performed during application of electrical stimulation. De Kroon et al. [23] stated in a review of electrical stimulation methods for stroke patients that electrical stimulation triggered by voluntary movement is more effective than that using no trigger. However, TES may be indicated for some patients because the muscle potential was not detected in some patients. IVES was not selected for severe paralysis patients, which may have been due to the difficulty of applying facilitation because the IVES device could not detect the muscle potential. Regarding RFEs, the effect for severe paralysis has not been verified [11, 24], but it is possible that repeated movement utilizing the stretch and skin reflexes is effective for severe paralysis patients regardless of the presence or absence of voluntary contraction. These findings suggest that the paralysis-improving effect of frequent conventional training is insufficient for severe paralysis patients, and the function may be improved only when the motor cortex is activated by methods capable of facilitating paralyzed muscle, such as MT, TES, and RFEs, followed by increasing the training frequency and intensity. Regarding problems to be solved, the mean total score of the FMA upper extremity motor items was 4.2 in severe paralysis patients after the training (TES, MT, and RFEs) who achieved high-level outcomes on decision tree analysis. Stewart et al. reported that a total score of FMA upper extremity motor items of 17 or higher is necessary for stroke patients to use the upper limb on the paralyzed side for daily living activities [25], but the scores after training with the methods with high-level outcomes were lower than this. Thus, although improvement of voluntary contraction was noted, it may not have reached the level required to use the upper limb on the paralyzed side in ADL. To identify whether or not the ameliorated upper limb on the paralyzed side is used in ADL, investigation of motor tasks and training time is necessary. At branching at which no training method was selected on the decision tree analysis, the time after onset and FIM cognitive items were involved. These are factors influencing improvement of motor paralysis [26, 27], and were selected when the degree of paralysis was severe. Therefore, the indication and effect should be judged by combining these factors when selecting a training method for patients with severe paralysis. Another important point is the appearance of nodes of the training method at the 3rd and 4th nodes, showing that it is necessary to pay attention to the fact that the influence of differences among the training methods on the outcome is smaller than that of the paralysis level on admission. The difference at the node of the training method between groups with high and low outcomes was 3 in the severe paralysis patients and 6 in the moderate or severe paralysis patients. Since no method for presenting the statistical significance of branching in decision tree analysis has been established, it is necessary to compare the results with those of other reports to judge whether or not the differences can be regarded as clinical differences. Kakuda et al. reported that treatment of the upper limb on the stroke-induced paralysis side with the combination of low-frequency repetitive transcranial magnetic stimulation and intensive occupational therapy significantly improved the total score of FMA upper extremity motor items by about 3 points [28]. The level of differences in our study was similar to or greater than this.

Factors of natural recovery cannot be ruled out because the patients were in the recovery phase, but differences in the paralysis-improving effect could be detected through the combination of frequent conventional and facilitative training, and this may be clinically applicable. Short-term interventions applicable within the limited time (20 minutes) were selected for the training methods to be covered by the Japanese medical service payment system, and no training method requiring several hours per day was selected. Accordingly, the improvement was limited, but, considering the balance between the ADL training time and achievement, the results may be reasonable at present. We are planning to investigate the selection of functional training corresponding to the severity of paralysis and the ratio of the training time for paralysis and to construct a system to achieve functional and ADL improvements synergistically.

Limitations of the Study

There were several limitations of this study. Firstly, the number of patients was small. To perform statistical analysis of typical patients in the absence of between-group differences as much as possible, we set exclusion criteria based on the amount of training and time after onset, which decreased the number of patients (smallest number among the groups: 19). Thus, the validity of the statistical interpretation should be considered carefully. Moreover, differences among the locations of lesions may have a marked influence, but the disease type and hematoma volume classifications are diverse depending on the locations of lesions, and so an investigation for each classification could not be performed. To investigate these by stratification, a very large number of patients would be necessary. We will attempt to perform a study involving more patients by limiting lesions. In addition, a final evaluation could not be performed in those patients who discontinued the study for some reason, and intention-to-treat analysis was difficult to perform. If these patients had been included in the analysis, different results may have been obtained.

Secondly, the amount of training of the upper limb may not have been homogeneous. Although OT and PT training performed within the specified time was identified in all patients, patients who voluntarily performed additional training were also included, suggesting that homogenization of the amount of training was insufficient. Since voluntary training and activities in ADL cannot be limited due to ethical constraints, a new study, such as investigation of the activities per day, may be necessary.

Thirdly, no follow-up data after 4 weeks of intervention, that is, data indicating the retention effect, were collected because the patients were discharged after rehabilitation and the number of patients would have decreased if follow-up data collection had been set as a requirement in the study system. Since the study was performed in the recovery rehabilitation period, differentiation from the effect of later training is also a problem and remains to be solved.

Conclusion

It was clarified that MT, TES, and RFEs effectively improve the upper limb function in severe paralysis patients, and some facilitative training of the paralyzed limb may be more effective than the conventional training for patients with moderate or severer paralysis. These results may facilitate the selection of a rehabilitation method for stroke patients in the recovery stage. Personalized paralysis recovery training may be established by analyzing the paralysis level and other profiles in the future.

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