Verification of Immediate Effect on the Motor Function of a Plegic Upper Limb after Stroke by using UR-System 2.2

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Abstract. In this study, we developed a new rehabilitation support system, UR-System 2.2, for restoring the motor function of a plegic upper limb after a stroke. Its design is based on knowledge gained during clinical testing of the previous UR-System. The UR-System 2.2 is equipped with a facilitating function of elbow extension based on a proprioceptive neuromuscular facilitation technique and the measurement function for evaluating isolated movements. In the study, we verified the immediate effect and the facilitation effect of training with the UR-System 2.2 on two hemiplegic subjects. The results confirmed improvement in abnormal muscle contraction of the forearm during the training. Furthermore, a hemiplegic individual could easily extend his/her elbow when resistance was provided to the movement of the forearm, and the abnormal muscle contraction decreased. The results suggest that training with the UR-System 2.2 effectively restores the motor function of the upper limb.

1. Introduction

In Japan, there were 1.179 million stroke patients in 2014 [1]. Following a stroke, most patients experience motor paralysis. This has led to the development of a variety of robots that are designed to aid in the recovery of the motor function for hemiplegic patients following a stroke. The synergistic movement patterns that are often observed in hemiplegic patients following a stroke are a factor that inhibit the improvement of their motor function. According to the Brunnstrom recovery stages of hemiplegia, elbow flexion, pronation/supination of the forearm, wrist flexion, and finger flexion abnormally and simultaneously occur in hemiplegic patients during the early stages of recovery. These movements are referred to as the synergistic movement patterns. In the recovery stage, synergistic movement patterns of patients gradually disappear, and they are able to individually extend the elbow and supinate the forearm, wrist, and fingers [2].

The fifth author (H.T.) is a therapist who developed a manual therapy for the recovery of the motor function of the upper limb [3]. In the therapy, the therapist conducts training for isolated movements that are intended to aid in recovery from synergistic movement patterns. Subsequently, the therapist uses a repetitive technique that facilitates muscle contractions through manipulation by the therapist’s hands by using techniques derived from Proprioceptive Neuromuscular Facilitation (PNF). Specifically, PNF is an effective therapy in facilitating recovery from spastic paralysis [4, 5].

In the present study, we developed a training system for the recovery of normal movement isolated from the synergistic movement patterns by facilitating muscle contraction in elbow
extension and forearm supination. The study focused on the manual repetitive therapy that is typically performed by a therapist.

In a previous study, we developed a training system (UR-System 2.1: Useful and Ultimate Rehabilitation System 2.1) for the recovery of the motor function of the plegic upper limb after a stroke. The UR-System 2.1 is shown in Fig. 1. The UR-System 2.1 consists of the UR-System and Brace 2015 (Fig. 2). This system used PNF to promote muscle contraction. The UR-System 2.1 was used for active exercise training. It was not equipped with motors, and thus, it was extremely safe, reliable, and economical. Clinical evaluation of the therapeutic effect of training with the UR-System 2.1 was performed in a chronic patient. Active ranges of motion (A-ROM) of elbow extension and forearm supination improved after training with the UR-System 2.1. Additionally, the modified Ashworth scale (MAS) scores [6] of elbow extension and forearm supination increased. This indicated that spastic paralysis was reduced. These results show the immediate effect of training with the UR-System 2.1 for the recovery of the motor function of the upper limb [7,8].

The weight support structure was developed to support the load of Brace 2015 [9]. However, the results indicated that the weight support structure restricted the movement of a hemiplegic patient.

In the present study, we developed a new training system (UR-System 2.2) to solve the problem above and investigated the immediate effect of the training with the UR-System 2.2 from the viewpoints of the recovery of isolated movements by using sensors equipped on the UR-System 2.2. First, we evaluated the immediate effect of the training with the UR-System 2.2 and compared the pronation torque of a healthy individual and that of hemiplegic subjects. Subsequently, we investigated the facilitation effect by the measurement function of the UR-System 2.2 and myoelectricity measuring instrument when the resistance to the movement of the forearm was provided during the training.

2. UR-System 2.2

In order to solve the problems of the UR-System 2.1, we developed the UR-System 2.2. The UR-System 2.1 had a weight support structure. Nevertheless, it restricted the elbow extension/flexion movement of hemiplegic individuals. Additionally, a few subjects indicated that the brace was heavy when they extended their elbows while training with the UR-System 2.1. The measurement system also had a disadvantage. In a previous experiment, the measuring range exceeded the limit, and the measuring time was limited due to the A/D converter.

The UR-System 2.2 is shown in Fig. 3. The system consists of a controller and a mechanical system. In the controller, four different resistance patterns were installed. The details of the resistance patterns are shown in Ref. [10]. The mechanical system consists of a training arm, a powder brake (SINFONIA TECHNOLOGY CO.LTD., PRB-2.5H), and Brace 2016 (Fig. 4). Brace
2016 is used to secure the patients’ forearm to the training system and has three degrees of freedom that permit rolling, yawing, and pitching motions of the fixing plate.

The UR-System 2.2 is equipped with a measurement function as well as UR-System 2.1. Brace 2016 is equipped with a potentiometer (ALPS ELECTRIC CO. LTD., RDC803001A) and a six-axis force sensor (Leptrino Co. Ltd., FFS055F251M8R0AS). The potentiometer measures the roll angle of the brace. The six-axis force sensor measures the force and torque exerted on the Brace 2016 by the forearm. It is possible to switch the rolling motion between free motion and fixed motion with a dial, and they are referred to as rolling free mode and rolling constraint mode, respectively. In the rolling free mode, the UR-System 2.2 is used to evaluate isolated movements. In the rolling constraint mode, we conduct training with the UR-System 2.2 while evaluating the muscle activity of supination/pronation of the forearm.

A comparison of Brace 2015 and Brace 2016 is shown in Table 1. In order to avoid using the weight support structure, we changed the fixing position of the training arm and the brace and saved the weight of the brace. In order to reduce the weight, we employed a six-axis force sensor that is lighter than that of Brace 2015. Additionally, its rated capacity is higher. The fixing position was changed to the center of the forearm. The training arm supports the weight of Brace 2016. The weight and moment of Brace 2016 are lower than those of Brace 2015. Thus, the weight support structure was not useful. The roll angle is locked at a voluntary position from 0º to 90º by the dial (0º indicates supination position). Therefore, it is possible for the individuals who cannot maintain the supination position to perform training with the UR-System 2.2.

We also changed the measurement system from the UR-System 2.1. In the UR-System 2.1, we measured the force, torque, roll angle, yaw angle, pitch angle, and training arm angle. However, the results indicated that the yaw angle and pitch angle were not useful in measuring the synergistic movement. Therefore, we removed 2 potentiometers, and this led to weight reduction. In order to measure the values for a long time, we changed the A/D converter and successfully measured the values for a sustained period.

Furthermore, the UR-System 2.2 was equipped with the facilitating function of elbow extension. In PNF training, the therapist facilitates elbow extension by using facilitation elements such as resistance to the movement of the forearm, compression of the elbow joint, and the motion restraint of the forearm. In the UR-System 2.2, the resistance to the movement of the forearm was simulated by the brake and the motion restraint of the forearm was simulated by Brace 2016. However, the compression of the elbow joint was not simulated because it is difficult to adjust the setting. The brake generates resistance to facilitate muscle contraction when the patient moves the forearm forward.

Pronation/supination of the forearm is not permitted during elbow extension/flexion movement.
because the forearm is fixed on the fixing plate of Brace 2016, and this prevents the occurrence of synergistic movement patterns. The movement constraint is expected to facilitate isolated movements.

3. Immediate effect by training with UR-System 2.2

We verified the immediate effect of the training with the UR-System 2.2. For this purpose, we measured the X-axis torque that represents the torque in pronation direction during training on two hemiplegic subjects following a stroke. Additionally, in order to evaluate abnormal muscle contraction, we measured the EMG signals of the biceps and triceps of paralysis side during training with the UR-System 2.2. The information on the subjects is listed in Table 2.

In the training, paralysis forearm was fixed on Brace 2016, and the training corresponded to the elbow extension/flexion movement with the UR-System 2.2. The number of training sets was 3, and a set consisted of 50 repetitive elbow extensions and flexions.

The facilitation element of the resistance to the movement of the forearm was used for the second set of Sub. 1. The magnitude of the resistance to the movement of the forearm is 36 [N], and this was determined by the therapist.

We used a three-dimensional motion analysis system VICON (Vicon Motion Systems Ltd.) to measure the movement of the subjects’ upper limb during the training. In order to verify the immediate effects, we investigated the X-axis torque of Brace 2016 and the patients’ elbow movement. The markers of VICON were attached to the elbow, wrist, hip joint of the paralysis side, and shoulders.

Each subject provided written informed consent prior to the experiment. This study was approved by the ethics committees of Nagoya Institute of Technology (No. 28-015) and Shonan University of Medical Sciences (No. 15-002).

4. Results and discussion

First, we confirmed that there was no indication that the brace was heavy while extending the elbow in the training with the UR-System 2.2. In the study, we focus on the pronation torque during the training.

A healthy individual can move his/her forearm forward while maintaining the supination position of the forearm during the training, and thus the value of the pronation torque that is exerted on the fixing plate by the forearm is almost 0. Conversely, hemiplegic subjects are unable to maintain the supination position during the training, and thus pronation torque occurs. Figures 5 and 6 show the mean values of maximum pronation torques during each elbow extension of Subs. 1 and 2, respectively. As shown in the figures, the value of the pronation torque decreased through training.

Table 1 Brace 2015 and Brace 2016 (Moment: Torque by gravity acting on the fixing plate)

<table>
<thead>
<tr>
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<th>Brace 2015</th>
<th>Brace 2016</th>
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<tbody>
<tr>
<td>Moment [Nm]</td>
<td>1.14</td>
<td>0.172</td>
</tr>
<tr>
<td>Weight [kg]</td>
<td>1.76</td>
<td>1.46</td>
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</tbody>
</table>
| Rotation range [deg] | Roll -180 +180 0 - +90  
|                      | Pitch -90 +90 -60 +60  
|                      | Yaw -180 +180 -180 +180  

Table 2 Information on the subjects

<table>
<thead>
<tr>
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<th>Sex</th>
<th>Age</th>
<th>Paralysis side</th>
<th>Brunnstrom stage</th>
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<tbody>
<tr>
<td>Sub. 1</td>
<td>Male</td>
<td>40’s</td>
<td>Left</td>
<td>V</td>
</tr>
<tr>
<td>Sub. 2</td>
<td>Male</td>
<td>40’s</td>
<td>Right</td>
<td>III</td>
</tr>
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</table>
The decreasing rate from the first set to the third set corresponded to 23.7 % and 10.9 % as shown in Figs 5 and 6, respectively. However, it was difficult to compare this result with that in the previous study [8] because the subjects as well as the conditions of the subjects were different.

Table 3 shows the MAS scores and A-ROM before and after the training. As shown in Table 3, A-ROM of supination and MAS scores of elbow extension of Sub. 1 became worse. It is considered that the reason for the deterioration was that there were several degrees of freedom in the forearm movement. The observations of subjects’ movement during the training revealed that hemiplegic subjects’ upper arms twitched during the elbow extension. Therefore, the abnormal muscle contraction of the upper arm increased. Additionally, the comments of the therapist and Subject 2 confirmed that the fixing plate could move freely in the yaw direction, and thus the patient’s shoulder abduction occurred, and the elbow was not extended.

The results indicate that the training with the UR-System 2.2 is effective in decreasing the pronation torque, and therefore it was effective in decreasing the abnormal muscle contraction of the forearm. However, it is not effective in decreasing the abnormal muscle contraction of upper arm.

Furthermore, Figs. 7 and 8 depict the mean values of the max EMG signals of the biceps and the triceps during elbow extension, respectively. Generally, when a healthy individual extends the elbow, the values of EMG signals of biceps and triceps are low and high, respectively. As shown in Fig. 7, when the resistance to the movement of the forearm was provided, the value of the EMG signal of the biceps became lower. However, as shown in Fig. 8, a major change did not occur in that of the

<table>
<thead>
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<th>Table 3 A-ROM and MAS scores</th>
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<tr>
<td><strong>A-ROM [°]</strong></td>
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<tr>
<td><strong>Before</strong></td>
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<tr>
<td>Sub. 1</td>
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<tr>
<td>Sub. 2</td>
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</table>
triceps. Moreover, the range of the elbow angle became wider when resistance to the movement of the forearm was provided.

The results indicate that providing resistance to the movement of the forearm was effective in decreasing abnormal muscle contraction of the upper arm and especially the extensor and in ensuring the ease of extension of the elbow.

5. Conclusion

In this study, we verified the immediate effect of training with the UR-System 2.2 on two hemiplegic subjects. Additionally, we verified the facilitation effect of providing resistance to the movement of the forearm during training with the UR-System 2.2.

A future study will involve developing a system to compress the elbow joint to facilitate elbow extension, installing the same on the UR-System 2.2, and verifying the facilitation effect of the compression system.

Acknowledgements

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References


