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## Case Report

## The effect of Electromyography (EMG)-driven Robotic Treatment on the recovery of the hand Nine years after stroke

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## ABSTRACT

**Objective:** To investigate the effect of electromyography (EMG)-driven robotic therapy on the recovery of the hand in a stroke case lasting 9 years.

**Case:** An 18-year-old patient with hemiparesis due to the ischemic lesion was admitted to our clinic with hand impairment. Fifteen sessions (5 weeks x 3 times) of robotic rehabilitation were applied with the Hand of Hope. Average EMG (mV) of flexor digitorum superficialis (FDS) muscle, average force (N) and the rate of force development (RFD)(N/s) were also assessed before and after the treatment following the 5th and 10th sessions and at the end of treatment. Also, Fugl-Meyer Assessment of Upper Extremity Scale (FMU-UE), Motor Activity Log (MAL), Canadian Occupational Performance Score (COPM) and Visual Analog Scale (VAS) were used for assessment before and after the treatment.

**Results:** The average EMG measured from FDS increased from 0.093–0.133 mV. The average force and average RFD increased from 45.6–97.7 and from 135.6–172.6 respectively. While affected and/or unaffected side force ratio increased dramatically from 54%–82%, the FMA-UE score increased from 56–59. The MAL quality of use score increased from 3.93–4.13. Performance and satisfaction scores of COPM changed from 5.25–7.25 and 4.5–8.25 respectively. VAS score for fatigue changed from 6 to 4.

**Discussion:** The improvement achieved 9 years later with 15 sessions of rehabilitation suggests that improvement may be possible for chronic stroke patients.

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## Introduction

It has been reported that upper limb disability is common after stroke and many people cannot fully recover.<sup>1</sup> As a result, stroke

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affects the quality of life of individuals in various aspects including their roles at work, home, and in society.<sup>2</sup> After stroke rehabilitation, there is some improvement in the proximal motor functions of the shoulder and elbow joints, but the functional recovery of the wrist and hand is much more limited.<sup>3</sup> Patients who have flask patterns in their upper extremities after 2 weeks following stroke suffer from lack of recovery in hand motor skills after 6 months' and only a few of them regain their hand functions.<sup>4</sup> The recovery of hand functions after stroke reaches a plateau nearly after a year.<sup>5,6</sup> In addition, improvement was observed in the studies carried out with patients whose stroke duration ranged from 1–5 years, which indicates that post-stroke recovery is not limited to 1 year. However, there is no available data on the effect of rehabilitation in longer cases.<sup>7–9</sup>

Intensity and frequency of stroke rehabilitation are very important as they contribute to the improvement of functional impairment<sup>8</sup>. Since the treatment should be conducted under the supervision of a therapist, it limits the total amount of time available for treatment and reduces the efficiency of rehabilitation in the treatment process.<sup>10</sup> Therefore, robot-assisted therapy plays an important role in the rehabilitation program by giving an opportunity for more intensive and reproducible practice.<sup>11</sup> Electromyography (EMG) is frequently used in the control of robotic systems. The EMG signal of the respective muscle is generated in the direction of movement desired from the patient. The amplitude of EMG signal is correlated to the muscle activity level. The use of this mechanism in patients with serious loss of motor function, such as stroke, is very important in terms of patient participation and effectiveness of treatment in rehabilitation.<sup>12</sup>

The purpose of this paper is to report the effects of EMG-driven robotic therapy on the recovery of the hand in a stroke case lasting 9 years and make a contribution to the previous studies reporting the improvements in long lasting stroke cases.

## Materials and methods

This case report was designed to follow the case report guidelines of CARE.<sup>13</sup> The study was approved by ..... University (Approval number:.....), and the written consent of the patient was received. The study was conducted in the department of neurology at .....Hospital.

### Patient description

The patient was an 18-year-old left-handed female. Taking anamnesis and examining the MR images of the patient, we identified that she had a stroke 9 years ago because of ischemia affecting the basal ganglia on the right side (ICD I-63). The chief complaint of the patient, who had taken therapy at different intervals for 6 years, was her dissatisfaction with her limited ability to use her hand, and she stated that the improvement stopped in the last 3 years. The patient applied to our clinic since she was getting tired and suffering from limited ability while using her hand although she was able to use it to perform daily activities. The patient's Modified Rankin Score<sup>14</sup> was 1.

Until she applied to our department, she had received treatments including neurophysiological approaches and electrotherapy applications, but she had never undergone robotic rehabilitation. The patient did not have any limited range of motion, spasticity, or any orthopedic problems that would affect the upper extremity or cause cognitive problems to prevent robotic rehabilitation. Her total sensory score, passive joint motion and joint pain scores were full according to Fugl Meyer UE assessment.

### Outcome measures

All assessments were based on ICF classification. For the body structures and functions, we used the Cup Test for the evaluation of EMG and force signals, the Fugl-Meyer Assessment of Upper Extremity Scale (Fugl-Meyer UEA) for the development status of the upper extremity. We employed the Motor Activity Log (MAL) to evaluate activities, the Canadian Occupational Performance Measurement (COPM) and the Visual Analog Scale (VAS) for the evaluation of patient's participation. The cup test was performed before the first treatment session, after the 5th, 10th sessions and at the end of the treatment (4 times in total). Other measurements were undertaken before and after the treatment.



Fig. 1. Cup test.

### Tests for body structures and functions

**Cup test:** It was performed in order to evaluate the improvement in muscle activity for grasping a cup (Fig. 1). For this purpose, surface EMG signals from flexor digitorum superficialis (FDS) muscle, and the force exerted to grasp the cup were measured. The patient was asked to grasp a cup for 4 seconds after being given the verbal and auditory stimulus; meanwhile, EMG signals and the grasp force were recorded. The EMG sensors (SX230, Biometric Ltd) were placed according to Hand of Hope (HOH) manual.<sup>15</sup> The EMG signals were amplified and bandpass filtered at 20–460 Hz. The force signal was detected by load cells (F2812, 5 kg, TECSIS Co Ltd), then amplified and bandpass filtered at 5–100 Hz. The EMG signals from FDS and ED muscles and the force signal were digitized by a 14-bit DAQ (USB6009, National Instrument) with a sampling rate of 2000 Hz and stored on a computer. The cup test was repeated 3 times with at least 2-minute intervals between grasping movements on the unaffected and affected sides. The data were collected and analyzed with Matlab (ver 2018a, Mathworks).

After the experiments, the EMG onset, and EMG offset for FD, force onset, force offset, and the first peak of force were manually selected. The average EMG amplitude, average force, and the rate of force development were calculated as given below.

The average amplitude of EMG (mV) was calculated as the Root Mean Square (RMS) value of the acquired EMG signal between the onset and offset time with a 100 ms moving window.

The average Force (N) was calculated as mean value of force between the onset and offset time with a moving average window of 100 ms.

The rate of force development (RFD) was calculated as half of the magnitude of the 1st peak force divided by the time for force to reach half value of its first peak.

$$RFD50\% = \frac{\frac{1}{2} \text{Force}|_{1st\ peak}}{(t|_{F=\frac{1}{2} 1st\ peak} - t|_{Force\ Onset})}$$

Fugl-Meyer UEA (0–66 points) was used to assess movement performed in and out of synergy patterns, coordination, speed, and reflexes. A greater than %10 change in Fugl Meyer motor score represents a minimal clinical importance difference (mcid).<sup>16</sup>

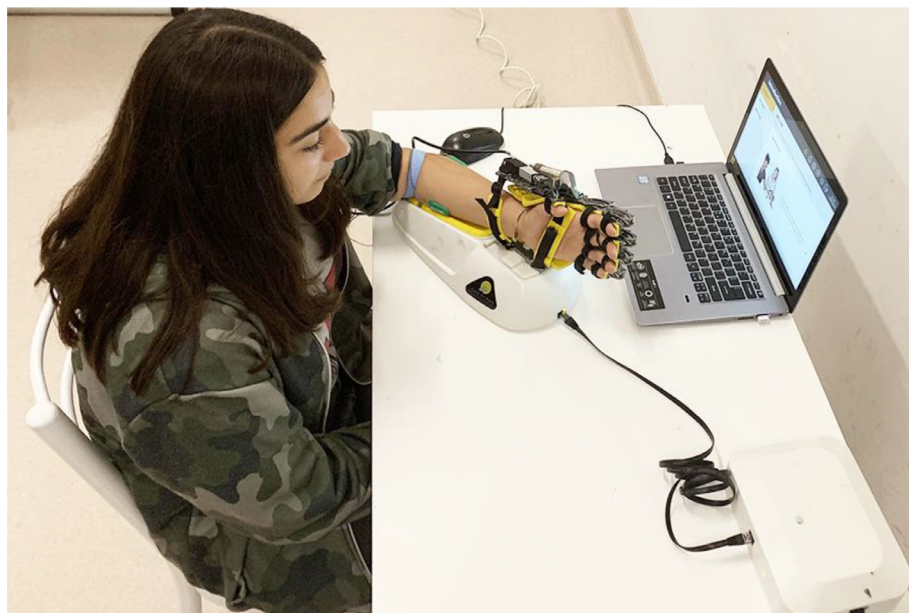


Fig. 2. Application of hand of hope.

### Tests for activity

The MAL is a scale used for patients with hemiparetic stroke to assess the amount of use (AOU) and quality of movement (QOM) of paretic arms and hands during daily activities.<sup>17</sup> A change of %10 of the range of the scale was proposed as mcid.<sup>18</sup>

### Tests for participation

The COPM was used to assess the performance and satisfaction of the case in daily activities.<sup>19, 20</sup> In the literature, clinically importance value of COPM has shown 2-points change.<sup>21</sup> Holding onto grab rails and handles in the bus, washing her hair in bath, chopping vegetables and holding a tablet were identified as the activities that our patient had difficulty in.

VAS: The VAS which is commonly used to measure pain intensity was also employed to assess fatigue severity.<sup>22, 23</sup> The VAS is originally a 100 mm horizontal line used in various modified versions.<sup>24</sup> Numerically rated version (0-10) was used to assess fatigue severity in our study.

### Physiotherapy interventions

The patient received 15 sessions of robot-assisted training 3 times per week by using the Hand of Hope (HOH)<sup>25</sup> (Fig. 2). After FDS and ED EMG sensors were placed as described previously the patient was seated comfortably on a chair and the hand of the patient was placed on the HOH. The shoulder was positioned in slight abduction and internal rotation and the elbow was positioned at 90° flexion. The hand and fingers were fixed with velcro straps in the hand brace.

At the beginning of each session, the maximal voluntary contraction (MVC) was recorded for 6 seconds in the HOH system. Each robot-assisted training session lasted for approximately 1 hour. Three training modes were used in all sessions: The CPM mode, trigger, and go mode and trigger and maintain mode. Within all these modes; hand grasping, hand opening, and hand grasping and opening can be performed.<sup>26</sup> Our treatment protocol was

Table 1

Patient Scores for the Fugl-Meyer UEA, Motor Activity Log, COPM, and VAS.

Measure	Before the treatment	After the treatment
Fugl-Meyer UEA		
• Upper extremity sub-score	56	59
Motor Activity Log		
• QOM	3.93	4.13
• AOU	3.5	3.13
COPM		
• Performance	5.25	7.25
• Satisfaction	4.5	8.25
VAS	6	4

MAL = motor activity log, AOU = amount of use, QOM = quality of movement, COPM = canadian occupational performance measurement, VAS = visual analog scale.

as follows: Initially, the treatment started in the CPM mode and lasted 10 minutes for warming up, then hand opening and grasping in the trigger and go mode, hand opening in the trigger and maintain mode and hand grasping in the trigger and maintain mode were performed; each lasted 10 minutes and each was applied sequentially with 2-minute intervals between the sequences.

### Results

There were improvements in the force and EMG values obtained from the cup test. While the average force on the affected side increased by 114%, the force on the unaffected side increased by 42% as well (Fig. 3). In addition, the affected and/or unaffected side force ratio increased dramatically from 54%-82%. The average RFD on the affected and unaffected side increased by 27% and 83% respectively (Fig. 4). While the average amplitude of FD EMG on the affected side increased by 41%, average amplitude of FD EMG on the unaffected side increased by 81% (Fig. 5).

The values obtained via the Fugl-Meyer UEA Scale are given in Table 1. The upper extremity sub-score improved from 56-59, while no changes in the remaining sub-scores were observed.

The COPM performance scores of the patient for the impaired activities increased from 5.25-7.25 and the average satisfaction

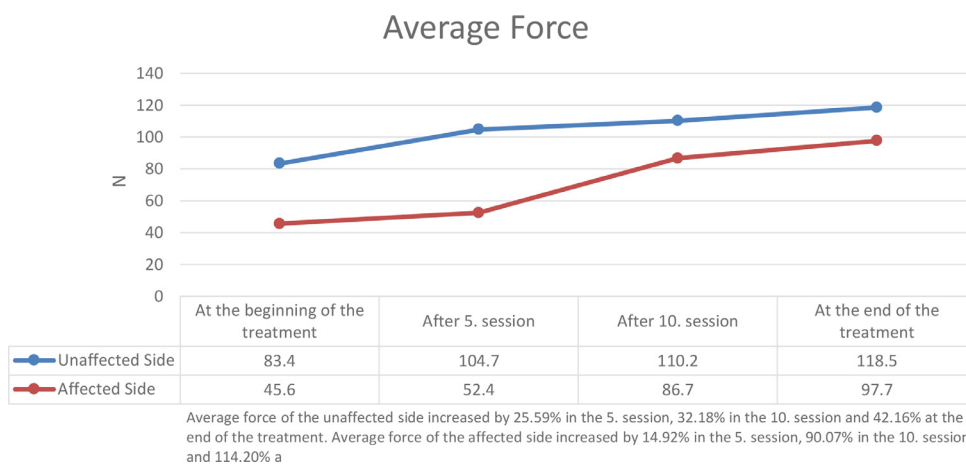


Fig. 3. Improvement of the average force in the CUP test.

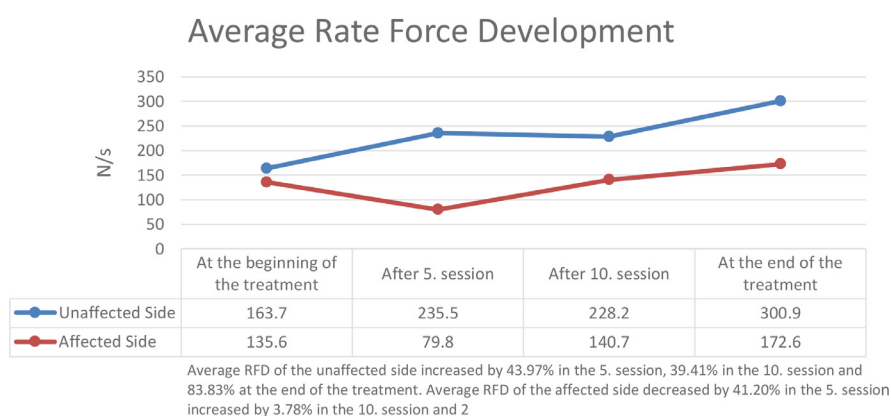


Fig. 4. Improvement of the rate force development in the CUP test.

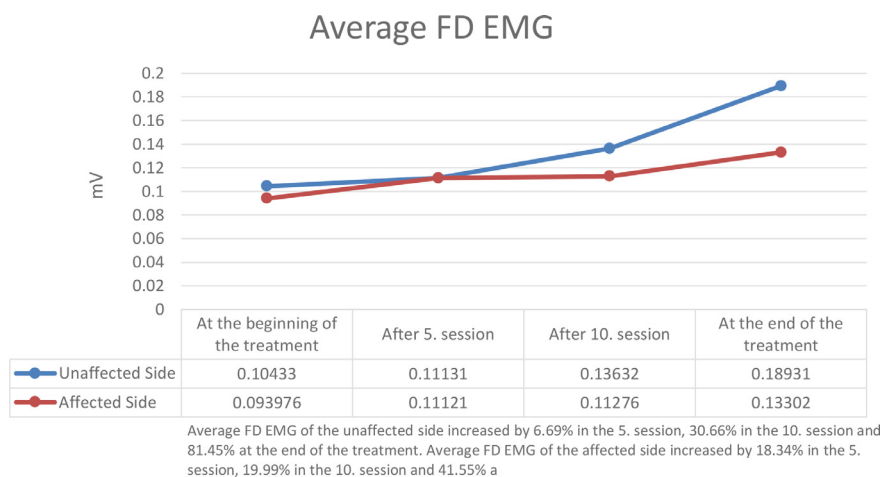


Fig. 5. Improvement of the average FD EMG in the CUP test.

score increased from 4.5-8.25 after the treatment (Table 1). The activities reported by the patient as problems are provided in Table 2. In the MAL test, QOM increased from 3.93-4.13 and AOU decreased from 3.5-3.13 (Table 1). When the patient was asked to rate the severity of fatigue on the VAS, she rated 6 before the treatment but it decreased to 4 after the treatment (Table 1).

## Discussion

We presented the effect of robotic rehabilitation on the hand functions of an 18-year-old female with a 9-year history of stroke. Improvement was observed in her muscle strength, ability to use her hand in activities, and performance and satisfaction of her activities after 15 sessions of a robotic rehabilitation program. To the

**Table 2**  
The activities reported by the patient as problems.

Goal	Level of importance	Before the treatment		After the treatment	
		1.PS	1.SS	2.PS	2.SS
Bathing	7	6	5	7	8
Cutting and/or Chopping	7	7	5	8	9
Holding the bus handle	6	4	5	7	7
Holding tablet	5	4	3	7	9

PS = performance score, SS = satisfaction score.

best of our knowledge, the presented case is the first report showing the effect of robotic rehabilitation after 9 years of stroke.

In this study, we observed an improvement in the results of force-EMG test evaluating the gross finger muscle strength. It is stated in the literature that repetitive and high-intensity practice contributes to functional improvement by increasing the muscle strength in patients with chronic stroke.<sup>8,27,28</sup> In the light of this studies, it can be argued that robotic rehabilitation performed with a total of 450 repetitions and 50%-60% intensity of MVC within the scope of our study may be responsible for the increase in finger muscle strength reflected in the force-EMG test. Furthermore, our results support Liao et al. who found improvements in muscle strength and motor functions in chronic stroke patients treated through robotic systems<sup>9</sup>.

As it is very well defined in the literature, training 1 side of the body increases strength in the same muscle on the untrained side which is called as the 'cross-education effect'.<sup>29</sup> The fact that there was an increase in muscle strength in the unaffected side as well as in the affected side may be due to this cross-education effect.

In this study, we observed a progress in the Fugl-Meyer UEA and a clinically significant improvement in satisfaction and performance on the COPM (+ 3.75 and +2, respectively) after the treatment. Previous robotic rehabilitation studies have shown improvements in Fugl-Meyer assessment,<sup>30,31</sup> 9-hole peg test<sup>30</sup> and COPM<sup>31</sup> outcomes. There are a number of studies showing that robotic rehabilitation increases the performance of motor functions and daily life activities.<sup>7,27</sup> Considering our results along with these previous studies, robotic rehabilitation in chronic stroke survivors shows significant promise.

It is also noteworthy that those progress in the sub-items of the Fugl-Meyer UEA is compatible with the increase in the QOM in the activities that require wrist circumduction in MAL (lathering and rinsing hands, putting on the cream on face, open a door by turning a door knob and/or handle) and in COPM (washing hair during bath). It has been observed that the changes seen in the MAL are due to partial differences in a few items rather than radical changes in a single item. Considering all the outcomes, it was seen that improvement in COPM is reached in clinically importance level. Despite the progress of Fugl-Meyer UEA and MAL scores, they were not reached in clinically importance level. The patient had a higher baseline manual dexterity score compared to most of the patients with chronic stroke. Thus, our results support Hsieh et al. who suggest that chronic stroke patients with high dexterity have clinically significant functional and motor gains after robotic rehabilitation.<sup>32</sup> Although the decreases detected in AOU score of MAL after the treatment could not be understood at first glance, it was revealed in the detailed questioning that the patient stayed in someone else's house during the treatment. Therefore, she could not perform every activity she did in her own home, such as using a TV remote control. This might explain the decrease in the frequency of hand use of the patient.

Before our treatment, one of the main reasons for the decrease in her performance during daily activities was fatigue, which most

patients after stroke complain about. After 15 sessions of robotic rehabilitation, the fatigue score decreased from 6 to 4 in VAS in our case and the patient stated, "I now feel less tired in the activities in which I use my hand". It made us believe that the decrease in VAS score associated with the increase in muscle strength and this was reflected in daily activities.

It is stated that RFD, which is often used to diagnose muscle strength and to monitor the effectiveness of the training, is highly sensitive to acute and long-term fatigue and is used to estimate the degree of fatigue.<sup>33</sup> In our study, there was a 37.01 increase in RFD value after the rehabilitation and a decrease (2 units) in the fatigue complaints that the patient reported subjectively during activities of daily living. There are a limited number of studies in the literature about the effect of robotic rehabilitation on fatigue. Since fatigue is a common problem for patients after stroke and adversely affects the quality of life, clarifying the effects of robotic rehabilitation on fatigue can be beneficial.

Stroke rehabilitation is actually a never-ending process and it can be said that the best results are achieved when the gains obtained during rehabilitation sessions are transferred to daily life. Which rehabilitation approach leads to functional gains in real life is still an unanswered question. We believe that determining the effect of treatments on neuroplasticity will be effective in answering this question. In this context, we think that the data provided through the EMG-driven systems used in this study indirectly give an idea about neuroplasticity, and we believe that the studies that will be supported by neurophysiological methods and conducted in the form of a case study will light the way for science and may open up new horizons. Although the short-term effects of the intensive treatment we applied had a positive impact on daily life, the reflection of the treatment on the long term had remained a matter of concern. In this context, our study has raised a research question for future studies. Although the patient in our case is young, it is not easy to achieve improvement after a period of 15 sessions in a stroke patient of 9 years by means of motor functions their reflections in daily life. The present study revealed questions to be answered by prospective studies like "Is robotic rehabilitation more effective than traditional neuro-rehabilitation studies in chronic cases?", "At what stage and intensity should robotic rehabilitation be added to chronic stroke treatment?", "Do application of robotic rehabilitation with other treatments effect the impact of treatment?" and "Should robotic rehabilitation be applied in combination with other treatments?" Limitations:

Several potential limitations of the present study should be mentioned. Firstly, our case is young and it should not be forgotten that the same effect cannot be achieved in all ages since capacity of improvement changes with age.

Moreover, intensive, and long therapy was used because of age and the performance capacity of the patient. On the other hand; it may consider as a preliminary study so the results cannot be generalized. But the results obtained may light the way for future studies.

Lastly; in this study immediate effect was shown, we couldn't do that but, it would be more helpful to assess the patient a couple of months later for seeing carry-over effect.

Take-home messages:

- 1- There is a need for new studies in stroke cases that are quite chronic.
- 2- It may be beneficial to support subjective evaluations used in stroke rehabilitation with objective evaluations such as electro-physiological measurements.
- 3- The robotic rehabilitation system has some advantages, such as providing high repetitive activities, compared to the traditional rehabilitation approaches.
- 4- In stroke rehabilitation, it should be aimed to transfer the gains obtained after the treatment to daily life.

## Conclusion

This early study presents improvement in objective measurement (force and EMG) and the quality of hand use, and the increase in patient satisfaction and the decrease in fatigue during hand use in daily activities after 15 sessions of robotic rehabilitation in the case with 9 years stroke. The findings support the assumption that robot therapy can significantly influence therapy outcomes and transfer the gains to everyday life in chronic stroke. Our give an evidence that, even if in a chronic period not to abandon rehabilitation, especially in young patients with stroke. These critical results will be promising in future studies.

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