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Original Article

# Changes in skeletal muscle perfusion and spasticity in patients with poststroke hemiparesis treated by robotic assistance (Gloreha) of the hand

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**Abstract.** [Purpose] The purpose of this case series was to determine the effects of robot-assisted hand rehabilitation with a Gloreha device on skeletal muscle perfusion, spasticity, and motor function in subjects with poststroke hemiparesis. [Subjects and Methods] Seven patients, 2 women and 5 men (mean ± SD age: 60.5 ±6.3 years), with hemiparesis (>6 months poststroke), received passive mobilization of the hand with a Gloreha (Idrogenet, Italy), device (30 min per day; 3 sessions a week for 3 weeks). The outcome measures were the total hemoglobin profiles and tissue oxygenation index (TOI) in the muscle tissue evaluated through near-infrared spectroscopy. The Motricity Index and modified Ashworth Scale for upper limb muscles were used to assess mobility of the upper extremity. [Results] Robotic assistance reduced spasticity after the intervention by 68.6% in the upper limb. The Motricity Index was unchanged in these patients after treatment. Regarding changes in muscle perfusion, significant improvements were found in total hemoglobin. There were significant differences between the pre- and posttreatment modified Ashworth scale. [Conclusion] The present work provides novel evidence that robotic assistance of the hand induced changes in local muscle blood flow and oxygen supply, diminished spasticity, and decreased subject-reported symptoms of heaviness and stiffness in subjects with post-stroke hemiparesis.

**Key words:** Near-infrared spectroscopy, Robotic rehabilitation, Stroke

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## INTRODUCTION

After a stroke event, only 5 to 20% of patients demonstrate complete functional recovery, while 80% reveal a variable degree of impairment and inability to attend to daily life activities1). Pain, spasticity, joint constraint, and skin or vascular damages are typical consequences observed in stroke survivors with upper limb disability and represent a paramount rehabilitation challenge either in the subacute and chronic phase2, 3). In relation to the increasing prevalence of stroke cases in an aging societies, there is a compelling need for innovative rehabilitation strategies.

One of the most promising approaches intended to recover upper limb function after stroke, is robotic rehabilitation (RR)4).

The effectiveness of robotic devices for the treatment and rehabilitation of poststroke upper limb disorders is recognized by the scientific community5–7). Understanding of the regulatory principles of clinical, neurophysiological, and biomechani-

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*Corresponding author. Jorge Hugo Villafañe (E-mail: mail@villafane.it) cal adaptations of each of the available means of RR is the key to achieving the best outcomes when treating the various and specific upper limb disorders affecting stroke patients[5–7]. Many researchers have tried to identify the concurrent and reciprocal influence of all of the different factors that lead to the final results of the treatments[8–11]. Study of the biological and functional adaptations during and after RR in this population would be of particular interest in light of their intrinsic correlation with postural modulation of the upper limb and in relation to neuroplasticity harnessing, even in chronic poststroke patients[12].

With the aim of contributing to post-stroke functional recovery of the hand, a newly designed RR device named Gloreha has recently been introduced in the field of rehabilitation. This new device consists of a soft exoskeleton similar to a glove that envelops the wrist and fingers of the paretic hand with Velcro attachments and straps. Passive mobilization of the fingers is provided by a hydraulic system that generates force transmitted through semirigid cables. The main innovation of this new RR device is that it enables well calibrated sequential movement of each single finger while the patient is observing the action induced by the device in a synchronous modality. Different exercises and ranges of motion can be selected through the dedicated software.

At present, the biological and functional adaptations of the upper limb structures and tissues induced by the Gloreha glove in patients with poststroke hemiparesis have not been fully explored. Studies are needed to determine the changes in local tissue blood flow and oxygen supply, the degree of spasticity, and the patients' perception of heaviness and stiffness during and after passive hand mobilization with the Gloreha glove.

## SUBJECTS AND METHODS

Seven consecutive patients, 2 women and 5 men, from 18 to 70 years old who presented poststroke hemiparesis in the nondominant hand were recruited from the waiting list of physical therapy department. The causes of stroke were ischemia in 3 patients and hemorrhage in 4 patients; all patients had a left-sided lesion. Diagnosis was performed by computed tomography (CT) or magnetic resonance imaging (MRI) scan. The study was limited to patients in the chronic phase of stroke (more than 6 months after the onset of acute injury)[13]. The inclusion criteria included preserved cognitive capacities according to age (Mini-Mental State Examination score >24)[14], primary ischemic or hemorrhagic stroke, mild to moderate paresis of the upper limb, and absence of pain on movement. The exclusion criteria included subjects that had a spasticity score of greater than three on the Modified Ashworth Scale (MAS)[15], a pain score greater than four on the Visual Analogue scale (VAS)[16], presence of finger flexion contracture, De Quervain's tenosynovitis, and degenerative or non-degenerative neurological conditions in which pain perception could be altered[17]. Participants with apraxia, anxiety, or depressive disorders were also excluded. Informed consent was obtained from all participants, and all procedures were conducted according to the Declaration of Helsinki. An institutional ethical committee approved the experimental protocol.

Each patient received 10 sessions with the Gloreha device over a period of 3 weeks. Treatment sessions were scheduled on separate days and were at least 48 hours apart. The sessions were performed at the same time of day (morning), although circadian patterns modulating neural and vascular functions can be profoundly altered and highly variable in stroke patients[18]. Just before and immediately after the first and last sessions of treatment, upper limb muscle strength, spasticity, and pain have been detected. Muscle perfusion of the flexor carpi was measured during the first and last sessions of treatment.

Each patient received treatment with the Gloreha exoskeleton device for passive mobilization of the affected hand after the therapist performed passive range of motion therapy for the hand during a one-hour session. The RR treatment session was half an hour and consisted of the following: "isolated" (each finger was mobilized individually) and "synchronous" (mobilization (the 2nd to 5th fingers are mobilized simultaneously, while the thumb was mobilized individually). The fingers of the patients were hooked to individual thimbles connected through a nylon thread to a device fixed on the glove that interfaced with a hybrid system (compressed air and oil) causing passive flexion-extension movement of the fingers.

Evaluation of the patient's response to therapy was monitored by use of the following assessment tools: A probe of near-infrared spectroscopy (NIRS) for noninvasive measurements of the forearm regional blood supply was placed on the flexor carpi belly for determination of the muscle tissue oxygenation level and regional blood supply[19], the MAS was used to measure spasticity in the shoulder, elbow, wrist, and fingers, and motor function was assessed using the Motricity Index section for upper limb evaluation (MI)[20]. Raters reviewed charts to gather the self-reported levels of the subjects (visual analogue scale of 0–100) for wrist-finger, elbow, and shoulder heaviness and stiffness[21]. A NIMO system (Nirox Optoelectronics, Brescia, Italy) was employed to study local muscle oxygenation and perfusion dynamics. To study the changes in local blood flow and tissue oxygenation induced by passive mobilization of the hand through the Gloreha system, the profiles of total hemoglobin (THb) and tissue oxygenation index (TOI, related to concentration of $O_2Hb$) were gathered. With reference to baseline (average value during a 30 second of rest just before the intervention with the Gloreha device), the values corresponding to the largest variation in THb and TOI dynamics (average value of the delta calculated for each passive movement) during robot-assisted mobilization were quantified. Care was provided to place the probe in the same position during the first and last treatment sessions.

Data were analyzed using IBM SPSS Statistics version 20.0 (IBM Corp., Armonk, NY, USA). The normality of the distribution was examined by using the Kolmogorov-Smirnov test. A one-way analysis of variance (ANOVA) with repeated measurements and the Bonferroni test was used as a post hoc test to evaluate statistical significance. Within-group effect sizes

**Table 1.** Characteristics of the impaired subjects

| Patients | Age | Gender | Type of stroke | Impaired arm | Time since stroke |
|---|---|---|---|---|---|
| 1 | 55 | Female | Ischemic | Left | 8 years, 5 months |
| 2 | 58 | Male | Ischemic | Left | 7 months |
| 3 | 59 | Male | Ischemic | Left | 7 years, 11 months |
| 4 | 67 | Male | Ischemic | Left | 1 year, 3 months |
| 5 | 68 | Male | Hemorrhagic | Left | 1 year |
| 6 | 63 | Male | Hemorrhagic | Left | 2 years, 5 months |
| 7 | 51 | Female | Ischemic | Left | 8 months |

**Table 2.** Mean (SD) for outcome at all study visits, mean (SD) difference within group

| Outcome | | Group | | Difference within groups |
|---|---|---|---|---|
| | | Day 0 | Day 21 | Day 21 minus Day 0 |
| | | Before | After | |
| | | (n=7) | (n=7) | (n=7) |
| NIRS | TOI | 68.5 (12.3) | 71.2 (10.8) | 2.6 (0.09) |
| | THb | 95.4 (5.1) | 101.5 (4.3) | 6.1* (0.03) |
| MAS | Elbow | 1.3 (0.5) | 0.7 (0.5) | −0.6* (0.03) |
| | Wrist | 1.7 (0.9) | 0.6 (0.5) | −1.1* (0.005) |
| | Fingers | 1.4 (1.0) | 0.3 (0.5) | −0.3* (0.01) |
| | Supination | 1.0 (0.6) | 0.3 (0.5) | −0.7* (0.047) |
| MI | Shoulder | 16.4 (6.1) | 16.4 (6.1) | 0.0 |
| | Elbow | 17.4 (9.1) | 18.7 (6.6) | 1.3 (0.4) |
| | Pinch | 14.7 (6.4) | 16.4 (7.2) | 1.7 (0.2) |

NIRS: near-infrared spectroscopy; MAS: modified Ashworth Scale; MI: Motricity Index
*Significantly different within the same group, p<0.05 (95% confidence interval)

were calculated using Cohen's d coefficient. Cohen considers an effect size greater than 0.8 as large, around 0.5 as moderate, and less than 0.2 as small. For all the data of the study, p values lower than 0.05 were considered significant.

## RESULTS

Seven patients with poststroke hemiparesis, 2 women and 5 men, aged 51 to 69 years (mean, 60.1; SD, ±6.2 years), were included in this study. The anthropometric and clinical characteristics of the subjects included in the present case series are listed in Table 1. No subjects dropped out during the different phases of the study, and no adverse effects were induced by the treatment. None of the subjects began any drug therapy during the course of the study.

THb improved (F=14.095, p=0.03) after the treatment cycle. After the 10 sessions, a small within-group effect size (d<0.2) was found between before and after treatment (Table 2).

Regarding the results of spasticity measured with the MAS, a significant interaction was found for time in the extension elbow, wrist, and fingers was found, and supination of the forearm (F=8.0, p=0.03; F=19.2, p=0.005; F=11.294, p=0.015; and p=0.047, respectively). In addition, there were significant differences between before and after treatment (all, p=0.03). Also, a small within-group effect sizes (d<0.2) was found between before and after treatment (Table 2).

Regarding abduction of the shoulder, flexion of the elbow, and key pinch as assessed by the MI, there was no significant interaction for time in the shoulder (F=errors; p=errors), elbow (F=1.0; p=0.4), and pinch strength (F=2.077; p=0.2) (Table 2).

A significant time interaction (F=11.413; p=0.02) was found for subjects who perceived shoulder heaviness after 10sessions of treatment. The post hoc analysis revealed significant differences between the 10 sessions (p=0.02).

For subject who reported perceptions of elbow and wrist-fingers heaviness, there was no significant finding for time (F=2.4, p=0.2, and F=3571, p=0.1, respectively).

We also found a significant change with time (F=21.833, p=0.03) for subject who perceived wrist-finger stiffness. The post hoc analysis revealed significant differences between the 10 sessions (p=0.003). For subjects who reported perceptions of shoulder and elbow stiffness, there was no significant finding for time (F=5.426, p=0.59, and F=4.395, p=0.08, respectively) (Table 3).

**Table 3.** Mean (SD) for Outcome at all study visits, mean (SD) difference within group

| Outcome | | Group | | Difference within groups |
|---|---|---|---|---|
| | | Day 0 | Day 21 | Day 21 minus Day 0 |
| | | Before | After | |
| | | (n=7) | (n=7) | (n=7) |
| Perception of heaviness | Shoulder | 45.0 (33.0) | 20.0 (17.1) | −25.0* (0.015) |
| | Elbow | 28.6 (28.0) | 12.9 (9.1) | −15.7 (0.2) |
| | Wrist-Fingers | 34.3 (39.9) | 9.3 (14.3) | −25.0 (0.1) |
| Perception of stiffness | Shoulder | 27.9 (30.5) | 7.1 (12.5) | −20.7 (0.06) |
| | Elbow | 20.7 (27.5) | 5.7 (9.8) | −15.0 (0.08) |
| | Wrist-Fingers | 47.1 (28.1) | 19.3 (22.4) | −27.8* (0.003) |

*Significantly different within the same group, p<0.05 (95% confidence interval)

## DISCUSSION

This novel study found that specific robot-assisted mobilization (Gloreha) of paretic hand and wrist decreased spasticity after treatment (10 sessions) in subjects with poststroke hemiparesis. Skeletal muscle THb in the flexor carpi muscles of the forearm increased during the intervention, and major deviation from baseline was found for the levels of THb, suggesting a beneficial effect of robot-assisted therapy on patients presenting stroke in terms of improved regional blood flow during the passive movements, and favored washout of the catabolites accumulating in the tissues of the poorly active upper limb.

It is known that NIRS detects variations in oxygenated and deoxygenated hemoglobin amounts at the microcirculation level and that it is therefore able to specifically monitor muscle capillary supply. Improved local perfusion changes represent a fundamental mechanical factor (shear stress) for angiogenesis at the capillary level, suggesting remarkable implications for muscle tissue functions and circulatory homeostasis[22, 23)]. Muscle disuse due to hemiparesis may significantly impair this balance, leading to oxygen supply/uptake mismatch: if less oxygen is available than required, effort intolerance and early onset of fatigue as well as impairments in muscle functions will inevitably occur.

This study is in agreement with randomized controlled trial of Sale et al.[24)] that found that robotic rehabilitation produced positive results in the recovery of hand function following stroke. The innovative robotic rehabilitation device (Gloreha Idrogenet) intervention spasticity in the subjects, and all subjects reported a perceived improvement in hand stiffness. This can translate into improved functional use of the hand for completion of activities of daily living.

The sample size in the present study was small, but it was sufficient to determine significance . we also did not have a control group. However, since this pathology is often accompanied by depression and neurodegenerative disorders and we excluded patients with neurodegenerative and non-neurodegenerative disorders, there was a number of important patients with poststroke hemiparesis that were excluded from the study. We are aware that we only examined the mid-short-term effects of arm joints mobilization directed at post stroke hemiparesis. Therefore, we cannot affirm that the positive results would remain over time. Finally, the study was not a randomized controlled trial, and the assessor of the outcomes was not blinded. Therefore, there may exist some study bias that was not controlled.

The present work provides novel evidence that robotic assistance of the hand induced changes in local muscle blood flow, diminished spasticity, and decreased subject-reported symptoms of heaviness and stiffness in subjects with post stroke hemiparesis.

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