ORIGINAL ARTICLE

Rehabilitation with robotic glove (Gloreha) in poststroke patients

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ABSTRACT

Background and Objectives: Stroke is a leading cause of long-term disability. Rehabilitation involving repetitive, high-intensity, and task-specific exercise is the pathway to restore motor skills. Robotic assistive devices such as Gloreha are increasingly being used in upper limb rehabilitation. The aim of this study is to explore the efficacy of robotic therapy for upper limb rehabilitation using robotic glove (Gloreha) in patients with stroke. **Materials and Methods:** The patients affected by stroke who were admitted to our rehabilitation unit were studied. Patients were exposed to Gloreha device rehabilitation (30 min/die), physiotherapy (1,5 hours/die), and occupational therapy (30 min/die). We measured the impairment in motor function and muscle tone using the modified Ashworth scale (MAS), the activities of daily living functional independence measure (FIM), and the finger dexterity Nine-Hole Peg test (NHPT). **Results:** Twelve patients (mean age = 64.5 years; male/female: 8:4) were admitted at the rehabilitation training. We found statistically significant differences between admission and discharged in terms of functional recovery using the FIM scale (pre/M = 88.33; post/M = 117.25, $P = 0.01$); hand training showed a better outcome using the NHPT (pre/M = 51.8; post/M = 36.33, $P = 0.01$). No significant changes were observed in terms of spasticity with the MAS (pre/M = 1.25; post/M = 1.08; $P > 0.05$). **Conclusions:** Rehabilitation with robotic glove (Gloreha) can positively promote functional recovery of arm function in a patient with stroke.

Keywords: Rehabilitation, robotic glove, stroke

INTRODUCTION

Stroke is the second leading cause of mortality and the third leading cause of long-term disability worldwide, with 33 million stroke survivors; its occurrence has been progressively increasing over the years.[1] Depending on the magnitude and severity of the disease, people with stroke experience a variety of motor, sensory, and cognitive disabilities.[2] In terms of the physical effects of stroke, the loss of motor abilities of the limbs presents significant challenges for patients, as their mobility and activities of daily living (ADL) are affected.[3] A majority of patients with stroke are often associated with limitations of the upper limbs more frequently than those in the lower limb.[4] Deficits in the upper limb capacity persist at 6 months poststroke in 30%–66% of hemiplegic stroke patients.[5,6] One year after stroke, upper limb deficits are accompanied by higher levels of anxiety, lower perceived health-related quality of life, and reduced self-reported well-being.[7] A majority of patients have difficulty with independently performing ADL.[8,9] For stroke patients, rehabilitation is the pathway to regain or manage their impaired functions. One of the most challenging aspects of stroke rehabilitation is upper limb intervention. Optimal restoration of arm and hand motor function is essential for stroke patients to

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independently perform ADL.[10,11] Studies on the dose–response relationship in stroke rehabilitation have shown that more intensive therapy is associated with enhanced rate of motor recovery.[12] Neurological rehabilitation is based on the concept of neural plasticity, involving the principles of re-establishment and re-organization of the lost functions of the brain,[13] resolution of diaschisis, and behavioral compensation strategies.[14] Rehabilitative training can shape subsequent reorganization in the adjacent intact cortex, and the undamaged motor cortex may play an important role in motor recover.[14] Positive outcome of physical rehabilitation, in case of neurologically based disorders, depends heavily on onset, duration, intensity, and task orientation of the training[15] as well as the patient's health condition, attention, and effort.[16] Intense repetitions of coordinated motor activities constitute a significant burden for the therapists assisting patients (standard multidisciplinary stroke rehabilitation is labor-intensive and requires one-to-one manual interaction with therapists).[11] In addition, due to economic reasons, the duration of primary rehabilitation is getting shorter and shorter.[17] These problems, as well as the need for intensive training, have prompted the development of technologies in poststroke rehabilitation. Robot-assisted therapy (RT) enhances the recovery process and facilitates the restoration of function.[2] During the last two decades, a growing series of intelligent rehabilitation robots including artificial prostheses and external mechanical auxiliary systems has been successfully developed to help patients achieve functional recovery or compensation for the loss of motor function.[18] Human–machine interaction is an important part of the robot system, which can influence the recovery effect and treatment process largely. It can enhance neuroplasticity by affecting motor learning, including promoting closer attention to a motor task, reinforcing motor behavior, or requiring the activation or deactivation of a specific brain signal.[19] Upper limb motor rehabilitation in stroke patients has conventionally relied on conventional therapies (e.g., physiotherapy and occupational therapy [OT]).[20] Brain–computer interface (BCI) systems seem to have the potential to promote functional recovery after stroke due to its capacity to provide real-time neurofeedback and consequently provide a reward that improves user performance.[20] The use of robotic devices in rehabilitation can provide high-intensity, consistent, and repetitive cycles over long periods and can help patients train their limbs to keep receiving and sending signals to and from the brain and thereby regain their motor abilities.[3] Robotic therapy provides patients with sensorimotor feedback with the use of games to facilitate functional use of upper paretic limb[11,19,21] and is typically supported by games that facilitate functional use of the upper paretic limb, becoming also more challenging and motivating for the patients.[3,10,22,23] The aim of this study is to explore the efficacy of RT for the upper limb using a robotic glove (Gloreha) in patients with stroke.

Gloreha device

Gloreha device [Figure 1] is a robotic glove for rehabilitation which permits customizable and task-oriented therapies. It is composed by a glove and a monitor for the visual feedback. The glove is a sequence of sectors which linked one to the other by the elastic transmissions which remain on the back side of an impaired hand/finger and reflect and follow the hand anatomy in terms of its natural parts and articulations. Each sector, to be effective in terms of movement actuation and transmission, is fixed to the corresponding anatomic part of the impaired hand/finger by a velcro fastening, thus allowing a large degree of wearability on flaccid and/or edematous hand/finger.[24]

Thanks to its simple, modular design, can be used in various, prolonged therapies.[25]

Two dynamic supports allow the arms to move with gravity eliminated to perform functional tasks. A customizable vocal guidance can give the patient the proper instructions during the therapy execution. While the rehabilitation glove mobilizes finger joints, the patient simultaneously observes a three-dimensional (3D) simulation of the hand on the screen. The glove works both in flexion and extension. Even on the patient who has no active residual movement, it is possible to apply passive mobilization from the first stages of treatment. The software offers many possibilities for the customization of the therapy. All the movements of

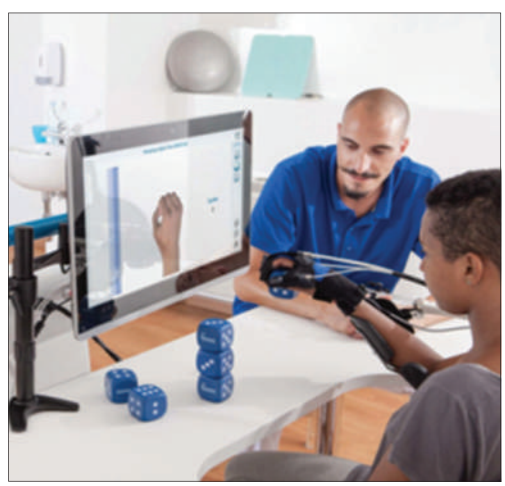

Figure 1: Gloreha device

flexion and extension plus the pinch can be programmed for each patient. The compensation level is calibrated according to the weight of the arm and the residual control and movement abilities of the patient. These supports are particularly useful during functional training because otherwise it often would not be possible without adequate weight relief for the upper limb.

Gloreha offers six different types of exercises and six types of movements. These six movements are (1) flexion–extension of the four long fingers (second, third, fourth, and fifth) simultaneously; (2) flexion–extension of all fingers independently; (3) flexion–extension of the first finger; (4) flexion-extension of all fingers (the entire hand: four long fingers plus first finger); (5) personalized movement (e.g., one finger does not move) in function of the physiological conditions of the treated hand; (6) random actuation of a movement: the surprise, raised in a patient by an unplanned and unexpected movement, has proven to add more stimulus to the crucial relearning process of a movement by the impaired sensorimotor areas of the cortex.[24]

The main innovation of this RT 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. The association of hand and finger movements with audiovisual effects appears to be of particular importance, improving patient motivation in performing task-oriented motor exercises and improving motor learning process. Gloreha is user-friendly and has intuitive software. Video previews, audiovisual effects, and simultaneous 3D animation are all aimed to increase the effects on neural plasticity and actively follow mobilization exercises. The aim of every rehabilitation program is the recovery of ADL.[25,26]

MATERIALS AND METHODS

Poststroke patients consecutively admitted for long-term rehabilitation to the "Istituto Prosperius Tiberino" (Umbertide) were screened and enrolled. We enrolled 12 patients (8 men and 4 women), aged 42–82 years (medium age = 64.5), from September 2018 to December 2018. All of the patients were in the poststroke phase (<30 days); six of the patients had hemorrhagic stroke and six an ischemic stroke. Inclusion criteria were patients aged >18 years, patients affected by stroke from cerebral ischemia or hemorrhage, and patients with Ashworth spasticity index ≤3. Exclusion criteria were Ashworth spasticity index >3; orthopedic limitation (amputations, active rheumatoid arthritis, advanced osteoarthritis, and irreducible articular limitations); severe cognitive and behavioral disorders, neurodegenerative and neuromuscular diseases; peripheral nerve injury; and uncontrolled inflammation. Each patient signed informed consent before being admitted to the study. The hand rehabilitation program lasted for 3 weeks. In particular, poststroke patients were exposed to Gloreha device rehabilitation (30 min/die), physiotherapy (1.5 h/die), and OT (30 min/die).

For each exercise made with Gloreha, a two-stage execution is proposed: at first, the patient observes on the screen a real hand performing the movement; subsequently, the robotic glove will support the motor exercise. In particular, the clinical protocol performed is (1) warm-up exercises that concern passive mobilization with augmented reality that involves the movement of individual fingers in sequence; (2) action observation therapy plus active participation (type of exercises: forceps, thumb + index, count, clamp in sequence); and (3) bimanual therapy in which the patient replies with the healthy hand the movements made by the device on the treated hand (type of exercises: wave, single random fingers).

No ethical issues were noted due to the lack of a control group that did not receive any therapy.

The primary outcome was the impairment in motor function and muscle tone, measured through the modified Ashworth scale (MAS). MAS (score 0–4) assesses the tone of nine muscle groups: shoulder abductors, flexors and extensors of the elbow, wrist, fingers, and thumb. The secondary outcome was the ADL, measured by the functional independence measure (FIM). FIM contains 18 items and is divided into six subscales that measure self-care, sphincter control, transfer, locomotion communication, and social cognition ability. Each item is rated from 1 to 7, which is based on the required level of assistance to perform the basic ADL. The third outcome was finger dexterity, measured through the Nine-Hole Peg Test (NHPT) a task in which the patient has to take pegs and place them in a hole. Data are presented as mean values and standard deviation for each variable. Nonparametric methods were applied due to the small sample size. We tested distribution and normality of variables by Wilcoxon matched pair signed-rank test. The level of significance was set at $P < 0.05$. The statistical analysis was done with Statistica 8.0 (Statsoft.com)

RESULTS

We enrolled 12 patients (mean age 64.5 years; male/female: 8:4), of which six hemorrhagic stroke and six ischemic stroke; five strokes were in the left hemisphere and seven strokes were in the right hemisphere. All of the patients completed the hand rehabilitation training [Table 1].

We found significant differences between admission and discharge in terms of functional recovery using the FIM scale (pre/M = 88.33; post/M = 117.25, $P = 0.01$). Hand training showed a better outcome using the NHPT (pre/M = 51.8; post/M = 36.33, $P = 0.01$). No significant changes were observed in terms of spasticity with the MAS (pre/M = 1.25; post/M = 1.08; $P > 0.05$) [Table 2 and Figure 2].

DISCUSSION AND CONCLUSIONS

This pilot study provides preliminary evidence of the efficacy of the hand rehabilitation program with Gloreha to maintain and improve the functional capacity of the hand in poststroke patients. According to recent literature, the hand rehabilitation program with Gloreha provides an intensive, repetitive, functional, task-oriented, specific, and customizable treatment.[5] Robotic systems and computer interfaces are useful for facilitating functional recovery and reducing impairment of the upper limb.[27,28] The exercises with devices work on plasticity in the central nervous system due to the neuromotor, audiovisual feedback: the multisensory action-observation system enables patients to re-learn impaired motor function through the activation of internal action-related representations.[29,30]

We did not find any differences between ischemic and hemorrhagic stroke patients; there were no differences in age and time of onset of stroke during rehabilitation with Gloreha. Our results showed a great improvement on the ADL and positively marked functional recovery of motor function. An important aspect of our study was the association of robotic therapy with the traditional rehabilitation-based approach of physiotherapy and OT to provide more full and intensive sessions to improve the outcome.

Nonetheless, our findings are similar to the results obtained employing intensive conventional therapy (CT). Additional sessions of robotic training promote better motor recovery in the upper limb of patients with stroke when compared with standard CT.[2]

Our study has some limitations including small sample size, the absence of a control group and consequently the lack of randomization. Specifically, a larger sample could detect more significant results also in MAS measure.

Future research should focus on studies that compared patients that will be treated only by OT and physiotherapy versus patients treated by OT, FKT, and Gloreha; we also need to underline the long-term benefits of the Gloreha intervention: Gloreha can also be used in a laboratory with specialized operator and can also be used "Gloreha Lite"[26] that is the home version of the device. "Gloreha Lite" is the miniaturized version of Gloreha Professional: it is light, convenient to carry, and simple to use. Connected

Table 1: Characteristics of patients

Poststroke patients	Etiology	Age	Gender
1	Hemorrhagic, left	58	Male
2	Ischemic, left	70	Male
3	Hemorrhagic, right	71	Male
4	Hemorrhagic, right	42	Male
5	Ischemic, left	73	Female
6	Ischemic, left	60	Male
7	Ischemic, right	51	Female
8	Hemorrhagic, right	60	Female
9	Ischemic, left	77	Male
10	Hemorrhagic, right	82	Male
11	Ischemic, right	66	Male
12	Hemorrhagic, right	64	Female

Table 2: Outcome at 30 days measured by functional and clinical scales

Evaluation	Session, mean±SD		Wilcoxon results	
	Pre	Post	*Z*	*P*
FIM	88.33±12.34	117.2±7.59	3.06	0.01*
Ashworth	1.25±0.87	1.08±0.9	0.51	0.6
Nine hole	51.58±5.40	36.33±3.67	3.06	0.01*

**P*<0.05 significance. FIM: Functional independence measure, SD: Standard deviation

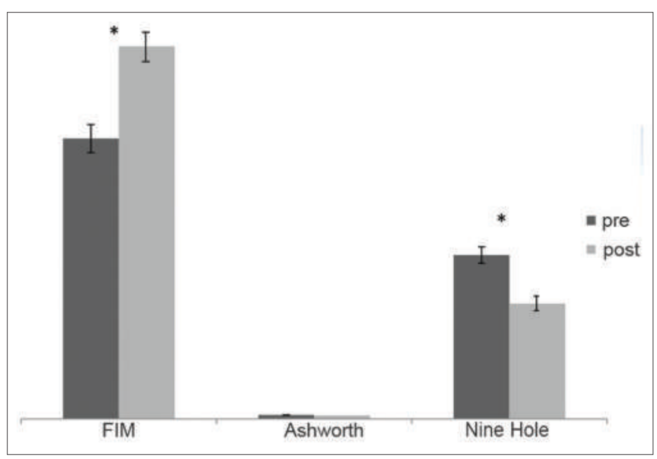

Figure 2: The variations of the clinical scores by means and error bars, used for pretraining and posttraining evaluation (the significant differences are indicated by *Wilcoxon test, $P < 0.05$)

to a personal computer (PC), it allows the patient to view the 3D simulation of the moving hand, while the glove moves his/her finger joints. "Gloreha Lite" allows to continue rehabilitation from the structure to the home.[26]

Future researches should be evaluated if patients can independently use a robotic device without the dedicated supervision of health-care personnel and what cognitive functions poststroke are necessary for this to happen.

Another hint for the future regarding BCI, we suggest a study with randomization into four groups: control (no intervention), only CT, CT with simultaneous real neurofeedback, and CT with sham neurofeedback. Future studies will help elucidate which BCI modalities work best and allow the design of more tailored interventions.

These results reinforce the recommendation to enlarge robotic rehabilitation to a larger clinical practice as a traditional way to rehabilitate.

We can conclude that our hand rehabilitation training can produce satisfying results in poststroke patients.

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Conflicts of interest
There are no conflicts of interest.

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