Impact of Robotic Assisted Rehabilitation in Post-Stroke Motor Recovery

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***Abstract*—**
Background
Robot-assisted rehabilitation therapy has the potential to provide high-intensive and goal-based training post-stroke. The biggest unanswered question here is how effective the technology is compared to traditional training. This review paper aims to study the impact of robot-assisted rehabilitation devices on post-stroke patients based on the recent literature and summarize the features that make it distinct from traditional therapy.

Methods
Relevant literature was identified in the Scopus platform using the relevant keywords search. The focus was to gather clinical trials, review papers, user validations and system overview papers to develop a knowledge base. Upper limb rehabilitation and lower limb rehabilitation studies were included in this review to create a more general understanding of robot-assisted therapy and its impact.

Results
A total of 50 studies were filtered from the total of 72 studies. Twenty studies were considered to understand the impact of robot-assisted technology on traditional therapy.

Conclusion
Currently, there is no evident information available that suggests robot-assisted therapies provides better results than traditional therapies. On the other hand, the combined treatment plan of robot-assisted devices and therapists results in an improved motor recovery for the patient.

***Index Terms*—robot-assisted rehabilitation, stroke, neuro-rehabilitation, physiotherapy, robot-assisted gait training (RAGT)**

I. Introduction

With the improvement of medical technologies and medical science, the world has seen a rise in population. UN projection shows the population to grow from 7.7 billion in 2019 to 9.7 billion in 2050, a 26% growth, with a 16% growth in the age group of 65 and over, raising the world average age [51]. A larger older population invites other medical related challenges to society, such as strokes, which is more prominent in older age groups. Stroke is defined by the World Health Organization (WHO) as ”rapidly developed clinical signs of focal (or global) disturbance of cerebral function, lasting more than 24 hours or leading to death, with no apparent cause other than of vascular origin” [1]. In the UK, around 100,000 people suffer from stroke every year leading to 38,000 annual deaths, and the rest survives with some physical disabilities [38]. After surviving strokes, it is common for the patient to experience physical conditions such as Hemiparesis, weakness or paralysis on one side of the body, which make it difficult for them to conduct daily living tasks [5]. Studies indicate that the initial first week and onset months are crucial for motor recovery treatments [9] [15], [19]. Rehabilitation therapies play a significant role in recovering the lost motor control in patients. Research has suggested that an active training of a muscle with intensive goal-based exercises trains uses the neuroplasticity nature of the brain to regain control of motor movements [4].

The traditional method of rehabilitation is appointing a physiotherapist to look after the patient performing the required exercises at a particular interval. But an increased number of stroke patients has developed an imbalance in the number of a caregiver or physiotherapists, making providing adequate rehabilitation to every patient difficult [49]. Robot-aided rehabilitation devices have reduced the stress on the shortage of therapists. Robot-aided therapies have shown the potential to cope with the required demand and promise to provide better treatment than traditional approaches. These robots are designed specifically to train the particular muscles of the patient repetitively by taking input of patients through sensors.

The demand of robotic-assisted stroke therapy has increased in past few decades. These devices are distinct into two categories: social rehabilitation and neurorehabilitation [13]. The major distinction between social rehabiliation and neuro rehabiliation is that social rehabiliation tries to provide a substitute technology such as prostheses to recover lost motor abilities so that a person may do daily regular tasks and retain basic social connections. Neurorehabiliation, on the other hand, tries to recover motor ability following a stroke [14]. Neurorehabiliation takes into account the adaptability of the brain and hence comprises a variety of workouts and therapies to restore brain ability to regain control.

Further, neurorehabiliation robots can be divided into two groups - manipulator and exoskeleton. Manipulator

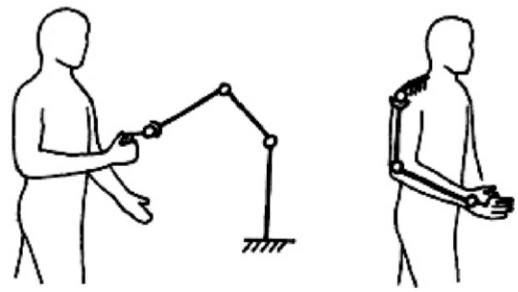

Fig. 1. a. Manipulator Robot b. Exoskeleton Robot, artwork by [12]

or end effector devices hold the hand of the patient and impart strengths at the interface fig 1 a. This type of robot are simple to design and fabricate and can be adjusted for numerous patients. The only shortcoming of such device is controlling the posture of the patient's upper limb. Additionally, it is impossible to control the torque at joints of patient's arm resulting in unpredictive force transfer. The range of motion of manipulators are also very limited, limiting the number of exercises performed by the devices. Rigorous clinical experiment has been performed on clinically available manipulator devices such as MIT-MANUS [17], the ReJoyce [23], and HandMentor [24]. Exoskeletons are wearable devices with structures comparable to a patient's arm and joint axes parallel to the patient's joint axes, fig 1 b. Exoskeleton gives the device more control over applying torques to individual joints, allowing it to target specific muscles and joints for training. The only disadvantage is that the technology is not adaptable to different arm lengths. The study of exoskeleton is new majority of the devices are still in prototype or in research phase. Some of the commercially available exoskeleton are ARMin III [37], CADEN-7 [41], and the RUPERT IV [2]. The results has shown reduced motor impairment for patients who received robotic therapy. Compared to traditional therapies, robotic aided devices have shown the potential to provide the more efficient rehabiliation for a longer duration [18].

Recent development in the technology has motivated researchers to study the actual impact of the robot aided devices into the motor recovery of the patients. Many studies compares the traditional rehabiliation approach with the manipulator and exoskeleton rehabiliation. Additionally, studies involving virtual interfaces with the devices has also attracted focus of researchers. [11] discuss the importance of implementing more rehabiliation robotics into clinical trial to develop a balance healthcare system. Recently published reviews provides us the opportunity to obtain a general analysis of impact of robotic devices for rehabiliation after stroke.

In particular, in this review paper we will address whether using robotic devices provides better results than the traditional rehabiliation methods or not. Keeping focus on devices developed for upper limb rehabiliation and on lower limb rehabiliation after stroke and try to provide an overall usefulness of the technology. Reported studies will be divided into lower-limb rehabiliation and upper-limb rehabiliation.

This paper reviews the recent development into the lower-limb rehabiliation and upper-limb rehabiliation robots for stroke. The flow of this paper would be: first will discuss the method used to filter out the require literature papers than third section will discuss the results developed on the review of literature, moving to the fourth section of discussion and finally completing the study with a conclusion.

II. Methodology

To collect sufficient literature for this study, we performed a literature search on Scopus, with the following keywords: Topic = (Rehabilitation OR Assistive) AND (Robot OR Device) AND (Manipulator OR Exoskeleton OR Wearable Device) AND Topic = (Upper Limb OR Upper body or Lower Limb or Lower Extremeties or Gait cycle) AND Topic = (Clinical Trial OR Validation OR Impact) AND Topic = (Post Stroke).

Using the given keywords, we found 3548 papers on Scopus (updated till April 2022). To retain the study's focus on recently created technology, we included literature published after 2000, reducing the number of papers to 2194. Furthermore, it was feasible to exclude literature's that did not have clinical trial data available to research the impact of technology on people. Finally, we were able to add 72 papers pertinent to the investigation, of which 50 were chosen based on citation and publication journal impact factor to complete the study on time.

To extract the impact of robot assisted devices papers were categorised on the basis of area of rehabiliation, such as lower limb or upper limb. The paper shortlisted belonged to the following categories, review papers, clinical trial papers, user validation and system overview.

III. Results

A. Robot-Assisted Devices for Upper Extremity

Researchers have performed an extensive study on post-stroke patients to showcase the effectiveness of robot-assisted therapy on the motor recovery of the patient compared to the traditional method. The upper limb is the most commonly affected area after suffering a stroke, which impacts the daily living activities of the person [46]. The upper extremity devices focus on providing intensive training to the shoulder, wrist and elbow, essential to perform basic daily tasks.

Fasoli et al [10] demonstrate the capability of MIT MANUS, fig. 2, in improving the upper limb motor abilities in a chronic stroke patient with a short term of four months of training. The improvement measured on a Fugl-Meyer

Assessment (FMA) scale evident improvements in motor skills development with reduced shoulder pain, improved motor control and a small effect in muscle spasticity. Klamroth et al [22] in 2014, experimented to study the efficacy of the ARMin Exoskeleton rehabilitation robot. Seventy-seven stroke patients were assigned randomly to either the robot group or conventional therapy group for eight weeks. The result showed that patients trained by ARMin exoskeleton, fig **??**, showed better improvements than the other therapy group, with a mean difference of 0.78 on the Fugl-Meyer scale showing a significant improvement. A similar study was conducted by Staubli [47] with a small group of four patients, using an evolved ARMin II exoskeleton. The results showcase significant improvement in motor impairment of all four patients, indicating the positive impact of using a robotic-aided therapy for upper limb rehabilitation. Similar results showing positive impact of robot-assisted device on rehabilitation can be seen in [[7] [42]].

In spite of these encouraging results, some research investigations show that robotic treatment is ineffective. Lo et al [28] experiments with 127 patients to study the effectiveness of the rehabilitation robot on the upper limb after stroke using MIT MANUS. The study suggests no significant improvement in motor capabilities compared to traditional motor training after a twelve-week therapy, suggesting a similar result between both studies and no superior benefit of robot-assisted therapy. A systematic review by Nourouzi et al [39] concluded that there is no difference between intensive traditional therapy and robot-aided therapy in regards to motor recovery, motor control or strength. Rather, additional repetitive exercises performed by a robot in therapy help restore control of proximal joints of stroke patients. A meta-analysis conducted by Kwakkel et al [25], suggested a significant improvement in the motor function sensitivity after robotic therapy, but no effect in support of improving the daily living activity tasks. This concludes that the traditional therapies are similarly effective to robotic-assisted therapies in improving motor impairment.

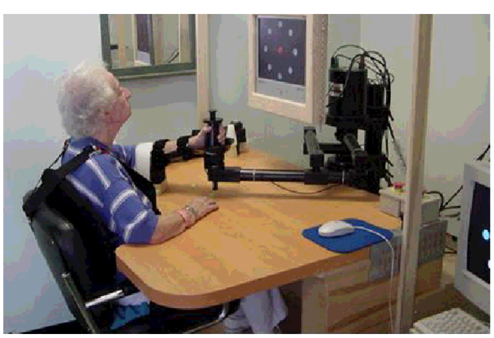

Fig. 2. MIT-MANUS End-Effector Rehabilitation Robot [16]

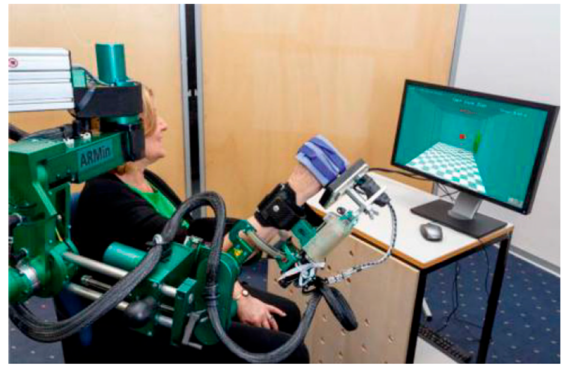

Fig. 3. ARMin Exoskeleton Rehabilitation Robot [20]

Mazzoleni et al [31] studies the impact of combining proximal and distal joints to increase the improvement in recovery. The study suggested the overall improvement in the motor capability of the patient but not any additional improvement in the proximal region. Colombo et al. [6] studied the involvement of time of robot-aided therapy in the stroke patient. The study suggested sub-acute (less than six months) patients showed greater improvement on the Fugl-Meyer scale than chronic (greater than six months) patients.

B. Robot-Assisted Devices for Lower Extremity

Patients with decreased walking capacity due to stroke frequently become reliant on a wheelchair or may even be bedridden [40]. As a result, restoring walking capacity is critical for preserving or regaining quality of life and activities to conduct daily living tasks. Robot-Assisted Gait Training (RAGT) has been popular in recent decades in providing repetitive task training to improve the gait cycle of a patient after stroke [52].

Bang et al. [3] in a recent experiment, compared the effect of RAGT and the conventional treadmill gait training using a Lokomat gait training device, fig 4. In a study conducted on eighteen patients suffering from lower leg impairment after stroke. Results suggested that robotic treatment shows an advantage over traditional training. The group trained with RAGT showed better improvement in gait

Fig. 4. Lokomat Robot-Assisted Gait Training Exoskeleton [44]

speed, cadence, step length and stability. Another study by Schwartz el at [45] conducted a similar experiment for six weeks on a set of sixty-seven patients. The group trained with RAGT blended with traditional physiotherapy showcased a promising gain in independent walking ability in patients. Similar results found by Mayr et al. [30] suggested RAGT treatment using Lokomat provides a better improvement in endurance, velocity, muscle tone and strength than conventional therapy.

While many studies have suggested positive improvements in regaining the gait cycle of a patient after stroke using RAGT, some suggest otherwise. Kelly et al [21] conducted an eight-week study with twenty-one patients to compare the RAGT training using Lokomat to traditional gait training. The study concluded no statically significant difference between the training method. In 2021, Nedergaard et al [36] published a meta-analysis on the effects of RAGT on gait rehabilitation post-stroke. The Meta-analyses revealed improvement in stride length and temporal asymmetry of the patients in the RAGT group but no significant difference in gait speed, cadence, step length or spatial asymmetry between the RAGT and conventional gait training. The given results were aligned with the study conducted by Mehrholz et al [33] and, Tedla et al [48], which showed no significant difference in the RAGT and the conventional gait training.

IV. Discussion

The current review focused on the impact of robot-aided rehabilitation on stroke patients. This review considers the clinical studies of recently developed devices targeted to provide training for upper extremities and lower extremities. We considered systematic reviews, meta-analyses and clinical trial results in this review. This study could be useful for clinical practices, in terms of the potential usability of the robot-aided rehabilitation devices and for engineers to develop solutions fostering improved patients care.

Our study suggests that robot-aided rehabilitation shows a potential benefit in providing a cost-effective use of human resources [43], as it allows a physiotherapist to look after several patients at a time and to provide standardised intensive care. Researchers have shown a mixed mind in utilizing robotic systems for rehabilitation purposes. Out of 20 studies reviewed above, only nine studies have suggested significant improvement in the condition of patients by using robot-assisted devices the rest have reported no significant improvement in condition over traditional treatment, neither in upper extremities treatment nor in lower extremities treatment. The superior results of Robot-assisted therapy can be attributed to the reasons that robotic therapy provides more intense trainings compared to the therapists [[29] [26] [35] [3]]. Moreover, robotic therapy has been shown to improve the range of motion (ROM) of the stroke patient in the upper extremities [[8] [32]] and an improvement in the symmetry of paretic leg step length [53]. Although clinical improvements are observable, the critical issue is the lack of large group clinical trials to measure the true impact of devices over traditional therapies.

The study also suggests that the effectiveness of the therapy depends on the choice of robotic device selected. In a review paper comparing end effector and exoskeleton for upper leg disability, Lee et al. [27] suggested that the usage of an end-effector robot is more effective than an exoskeleton device. However, Moggio et al. [34] in his study reported that the exoskeleton is more significant for functional improvements than the end-effectors. Similarly, for lower extremities, end-effectors devices have shown better performance in the walking velocity and capacity of the patient compared to exoskeleton devices [33]. However, the study also reveals that the impacts of technologically more complex and expensive exoskeleton devices still require proper investigation.

The present study has a lot of scope for future works. Firstly, the study could be divided into two separate parts focusing on upper-limb rehabilitation devices and lower-limb rehabilitation separately, as it could include the detail of literature for both. Secondly, a meta-analysis can be conducted to review the further implications of the research and for more statistical results. Thirdly, the review lacks the study of the impact of visual feedback and gamification as part of therapy. There is proof that the involvement of virtual reality training and game-based training provides better involvement of patients in the therapy and enhances their treatment process [50]. And lastly, based on the study clinical trial could be conducted with a large group of stroke patients to perform the clinical study for validation.

V. Conclusion

This study aimed to investigate the impact of using robot-assisted rehabilitation therapy over conventional therapies for upper-limb and lower-limb impaired patients after stroke. Only twenty relevant studies were identified to evaluate the impact of the recent robot therapy technology. The study demonstrated that robot-assisted therapies have the potential to improve the process of rehabilitation therapies and it allows therapists to provide solutions to training more patients at a time improving the overall gap in demand for physiotherapists at the current time. The robot-assisted devices also provide more intensive therapies than the traditional processes which improve the overall condition of the patient, but apart from that, there is no evident implication that supports that robot-assisted devices help recover patients faster than the traditional therapies. In a long term, technology could be the best solution for rehabilitation. It could be portably accessible for everyone making an impact on the health of stroke patients and carving a path for their fast recovery.

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