# The Impact of Two Robotic-Assisted Devices on the Functional Hand Recovery in Post-Stroke Adult Rehabilitation: A Review

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## Abstract

Hand movement impairment is a common complication after a stroke that impedes patients from performing Activities of Daily Living [ADLs] independently and returning to the workplace. It diminishes their quality of life and imposes a substantial socioeconomic burden. Therefore, regaining hand movement after a stroke has meaningful quality-of-life and quality-of-work-life outcomes for patients. Treatments aimed at full hand function are leading strategies for stroke recovery programs.

The effects of implementing robotic devices as a form of rehabilitation alone or in combination with other rehabilitation strategies, such as conventional treatment, have been investigated in several articles. This review explains the role of rehabilitation robots and summarizes recent advances in stroke survivors' hand rehabilitation when using Gloreha or Tyrosolution robots. We conclude that robotic devices improve post-stroke hand recovery, especially in terms of motor function and activities of daily living.

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# PREFACE

This review explores a novel approach to stroke rehabilitation: robotic-assisted devices to promote hand rehabilitation. Five chapters are included in this document. Chapter 1 covers three main themes. First, it reviews stroke as a disease, its prevalence, and its outcomes. Second, how hand function is measured, and what is the definition of successful rehabilitation in functional hand recovery. Lastly, what are robot-assisted devices, and how do they work. Chapter two reviews robots as a novel therapy for stroke rehabilitation, emphasizing two brands targeting hand therapy: Gloreha and Tyrosolution. Operation and manufacturer's claims will be covered here.

Chapter three will systematically examine the papers this author could find on these two robotic devices, to compare the methods used and any differences detected compared to baseline in motor function or activities of daily living tests, as well as any differences detected between robotic therapy and conventional therapy. Summary Tables are provided to directly compare these devices and the research projects that studied them.

Chapter four will summarize my findings from this review.

The final chapter (five) concludes with a discussion about each Robot and whether the manufacturer's claims are valid, comparing the efficacy of the two robots to each. As well as a limitation section to highlight general challenges in assessing these devices with patients.

Therefore, the purpose of the paper was to: i) describe stroke and assess the use of robotic hand rehabilitation as adjuvant therapy, ii) assess the effects of two robots with different mechanisms of action (Tyrosolution and Gloreha) with conventional therapy, and iii) compare these robots for their impact on motor and functional recovery.

# 1. INTRODUCTION

Stroke is the third leading cause of death and the leading cause of acquired adult disability worldwide, and in Canada (Stroke Canada [Fact sheet], 2020). Based on statistical reports, someone in Canada has a stroke every 10 minutes, and ~300,000 Canadians live with stroke complications (Stroke statistics [Fact sheet], n.d.).

This results in a medical and economic burden, with an estimated global cost of over US$721 billion (Feigin et al., Global Stroke [Fact sheet], 2022). The rapid onset and significant personal and economic burden of stroke, especially among young people of working age, underlines the need to improve outcomes through rehabilitation, as nearly 90 percent of stroke survivors currently have some disability (Feigin et al., Global Stroke [Fact sheet], 2022).

## 1.1 Stroke Definition

Stroke is defined as a sudden onset of focal or global neurological deficits lasting more than 24 hours. It is attributable to vasculopathy and can impose a lethal outcome (World Health Organization [WHO], 2020).

There are three main types of strokes. The most common form, which accounts for about 87% of all strokes, is ischemic stroke: when a blood vessel to the brain is occluded. Hemorrhagic stroke accounts for about 13% of strokes; and occurs when a weakened blood vessel ruptures. Lastly, a transient ischemic attack (T.I.A.), or mini-stroke, is caused by a temporary clot (American Stroke Association, 2020). All types impair blood flow, and therefore oxygen flow, to brain regions, which causes neurological damage.

## 1.2 Immediate-Onset Stroke Symptoms:

According to the American Stroke Society, ‘F.A.S.T. Warning Signs’ should be checked when a patient is suspected of having a stroke. “F” indicates Face drooping; the patient is asked to smile and show signs of an uneven smile. “A” refers to one side arm drop that means weakness or numbness in an arm; to check them, the patient is asked to raise both arms. “S” refers to the patient’s Speech ability and is assessed by listening for slurred speech. If any of these signs exist, the American Stroke Association instructs that this is an emergency, and “T” points it is time to call 911 (American Stroke Association, 2020).

Depending on the stroke location in the brain, there may be other signs and symptoms, including but not limited to numbness or weakness of the leg, especially on one side of the body; confusion; trouble in understanding speech; difficulty seeing with one or both eyes; trouble walking; dizziness, loss of balance or coordination; or severe headache with no known cause (American Stroke Association, 2020).

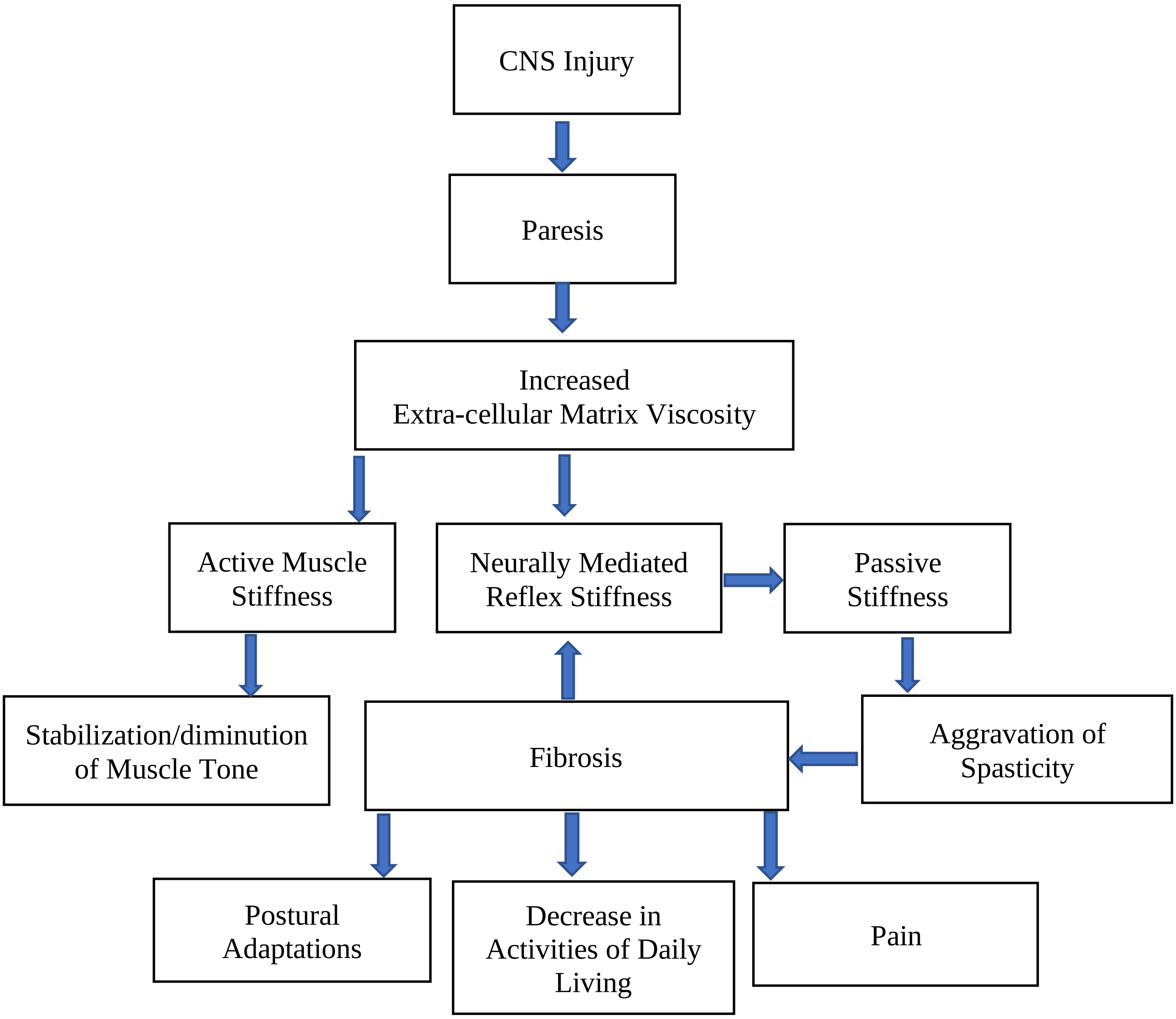
### 1.3 Sub-acute and Chronic, Post-stroke, Upper Extremity Impairments

After a stroke, impairments in the upper extremity, including loss of functional movement, paresis, and abnormal muscle tone, may persist (Hunter & Crome, 2002). Hemi-paresis of an upper contralateral limb is the most common form of post-stroke deficiency, which is why 50 to 70% of stroke survivors experience dissatisfaction and functional dependency after a stroke, and almost 40% complain of chronic hemiparesis (Hatem et al., 2016).

Regarding post-stroke hand motor impairment, two main hypotheses are provided. The first explains that motor execution deficit is due to stroke complications such as weakness, spasticity, as well as abnormal coactivation of muscle groups (muscle synergies dysfunction) (Raghavan, 2007). The second hypothesis is that impairment in higher-order processes like motor planning and learning causes motor dysfunction (Raghavan, 2007).

**Figure 1**

*Model of the contribution of weakness, paresis, and immobility to the progress of spasticity.*




Note: Adapted from Stecco et al., 2014, Current Physical Medicine and Rehabilitation Reports

In the initial stage after stroke, damage to descending motor pathways causes flaccid and weak upper extremities (Brunnstrom, 1970). In the later stage, excessive tone develops with a flexor synergy pattern; clinical signs, including exaggerated resting tone, stretch reflexes, and spasticity, are observed during patient examination (Brunnstrom, 1970). Spasticity is defined as a motor disorder represented by an increase in muscular tone with exaggerated tendon jerks resulting from the hyper excitability of the stretch reflex (one of the upper motor neuron syndrome components) (Lance, 1980). Weakness or paralysis is the paramount issue that leads to post-stroke dysfunctions and is a direct complication of impaired signaling from the brain cortex to the spinal cord, which sends the signal to execute contraction in related muscles (Canning et al., 2004; Wagner et al., 2007). Impaired signaling may affect selective muscles or all muscle groups in a limb. Weakness can result in immobilization, which is the starting point of the subsequent impairment cascade, as shown in Figure 1.

Stroke occurrence also impairs the mutual balance of influence and communication between the two brain hemispheres (Laver et al., 2017). The injured cortical area is unable to retain functional communication with the peripheral muscles, which results in decreased ability to transmit descending motor command signals and thereby leading to weakened motor function in the affected body segments. Further inhibition of neuron repair mechanisms resulting from injured cerebral circuitry, will inhibit and interfere with the functional elements in the neurons in the healthy hemisphere through the Corpus Callosum (the brain's primary commissural region). Effective rehabilitation strategies can have an impact in diminishing the inhibition between the two cerebral hemispheres, thereby improving limb function (Laver et al., 2017).

From a functional perspective, three main outcomes observed in individuals who have sustained a stroke affecting the upper extremity are: learned non-use, learned bad-use, and forgetting (McCrea et al., 2005). Learned non-use develops because often, the initial experience of the patients is to avoid using the affected limb due to weakness, paralysis, or loss of sensation. Over time, this habit may persist, although the patient can move the affected part; this stage is learned non-use. Learned bad-use occurs due to the development of compensatory actions instead of normal movements observed in healthy individuals due to weakness, pain, and/or sensory impairment. For example, stroke patients use wrist flexion rather than an extension to orient the hand to grasp; likewise, they use metacarpophalangeal (MCP) flexion rather than proximal interphalangeal (PIP) flexion for grasping objects. Though these actions seem beneficial in the short-term, tend to compensation lower the chance of returning to normal performance of tasks in the long-term (Raghavan et al., 2010). Therefore, besides spasticity, the lack of correction and suitable feedback can increase the chance of learned bad-use, indicating the effectiveness of early interventions. Lastly, forgetting: where after prolonged disuse, the patient learns not to use the affected part anymore (Raghavan et al., 2010).

Humans rely extensively on hand functions for everyday tasks involving activities of daily living, including health-related activities, such as personal hygiene, preparing and eating food, and engaging in other complex tasks. As such, regaining hand movement after a stroke has meaningful quality-of-life and quality-of-work-life outcomes for stroke patients. Therefore, treatments aimed at regaining full hand function are leading strategies for stroke recovery programs. ‘Hand Therapy’ is defined as using occupational and physical therapy that combines knowledge of structure, function, and activity; to prevent dysfunction, create restorative function, reverse the progression of the disease, enhance a patient’s ability to do daily tasks, and participate fully in life (Panel, 2011). The focus of this paper is on understanding a new hand therapy strategy, i.e. Robotic-assisted therapy.

### 1.4 Hand Function Outcome Measure Definitions

Various assessment tools are used to help clinicians better understand the effects of rehabilitation, as they can show the baseline functionality of the affected area and any improvements, with intervention, over time. Currently, a wide range of these tools are available to assess rehabilitation outcomes in stroke survivors with hand impairment; the measures covered in this paper are those measurements that are used to assess the two identified hand therapy robots of interest. Detailed information regarding these tools are provided in Appendix A.

**1.4.1 Motor function testing.** These tools are used to assess gross motor movements and general impairment measures when a patient uses the upper limb (Teasell et al., 2020).

***Fugl-Meyer Assessment (FMA).*** FMA is a gold standard for assessing motor recovery in the upper extremity (Fugl-Meyer et al.,1975). This measure assesses motor outcomes in stroke survivors and has been shown to have good reliability and construct validity. In this test, locomotor function (physical actions that allow us to move) and control comprising sensation, balance, and joint pain are assessed. The highest motor performance for the upper limb is 66 points (Nilsson et al., 2001; Sanford et al., 1993).

***Motricity Index (MI).*** MI measures the overall strength of the upper and lower extremities in stroke patients with good reliability and validity (Fayazi et al., 2012). It includes six functional movements, including shoulder abduction, elbow flexion, and pinch grip, which all relate to the upper extremity assessment. An ordinal scale of six points is considered for each task, from unable to complete movement (0 points) to completing the task (6 points).

***Wolf Motor Function Test (WMFT).*** This measure enables care providers to quantify stroke patients' upper limb motor abilities and has been shown to have good reliability and validity (Wolf et al., 2005). It includes 17 tasks related to three fields: strength measurement, functional tasks, and movement quality of the upper extremity (Teasell et al., 2020).

***Action Research Arm Test (ARAT).*** This measure is an arm-specific test that helps to assess the ability to handle various objects of different sizes, shapes, and weights with good test-retest reliability and internal validity in chronic stroke survivors (Ward et al., 2019; Nomikos et al., 2018).

**1.4.2 Spasticity testing.** This test is used to assess spasticity. Spasticity is an increase in muscle tone, interfering with muscle function (Lance, 1980).

***Modified Ashworth Scale (MAS).*** To assess muscle spasticity with good reliability and validity in a stroke patient. It includes 20 functional movements for the upper and lower extremity (Stroke Engine, n.d.).

**1.4.3 Activities of Daily Living.** These tests assess the level of independence and the patient's performance in different tasks (Teasell et al., 2020).

***Barthel Index (BI).*** The BI assesses a patient's ability to do daily living activities by measuring ten items (each has a 5-stage scoring); They include personal hygiene, toilet use, bathing, feeding, dressing, ambulation or wheelchair mobility, and bed/chair transfer, stair climbing, bowel, and bladder control. This measure's maximum score is ten and has high inter-rater reliability (Park, 2018).

***Motor Assessment Scale (MAS).*** This performance-based measure helped to assess everyday motor function using eight tasks (each has a 7-points scale) and was shown to have good reliability and concurrent validity (Simondson et al., 2003).

***Functional Independent Measure (FIM).*** It consists of 13 motor and five cognitive assessment subscales (each is a 7-points item). Each subscale measures the required assistance level to do an activity of daily living. This measure has excellent reliability and concurrent validity in its full form (Stineman et al., 1996). The higher score indicates more independency.

***Frenchay Arm Test (FAT).*** This test measures upper limb motor control with good reliability and validity in its full form (Heller et al., 1987). It assesses stroke patients through 5 common tasks (2-point scale), including comb hair, drinking from a glass and setting it down, grasping a cylinder, stabilizing a ruler/drawing a line, and clipping a clothespin onto the table edge.

**1.4.4 Quality of Life.** These tests assess the quality of life of participants.

***Medical Outcome Trusts' Short Form Health Survey (SF-36).*** It includes 36 items encompassing eight subscales: physical function, physical role limitations, general health, body pain, emotional role limitations, mental health, social functioning, and vitality. It was shown to have high reliability and convergent validity in stroke survivors (Guilfoyle et al., 2010).

**1.4.5 Disability Assessment.** This test assesses the level of independency in stroke patients (Stroke engine, n.d.).

***Modified Rankin Scale (MRS).*** This scale is used to measure functional independence in stroke patients; it is a 30–45-minute interview by a trained clinician who asks questions regarding overall health, carrying ADLs, and other factors about their life. This is a 6-point scale (from 0=bedridden to 5=function at the level of before stroke) and has good reliability and validity (Quinn et al., 2009; Wilson et al.,2002)

**1.4.6 Muscle Strength**. These tests assess muscle strength and power during tasks and movements (Teasell et al., 2020). They include but are not limited to the hand grip strength and Medical Research Council Scale (MRCS).

**1.4.7 Range of Motion.** To assess the free movement upper limb in different joints, including active and passive ones (Teasell et al., 2020).

**1.4.8 Dexterity.** These tests are used to assess fine motor and manual skills via hand tasks. Nine-hole peg test and Box and block test are in this category (Teasell et al., 2020).

***Nine Hole Peg Test (9HPT).*** This measures the overall dexterity in stroke patients and has good reliability and concurrent validity (da Silva et al., 2017). To do this, patients should take nine pigs out of a container and insert them into a pegboard, and once it is completed, they should place the pigs back in the container as fast as possible. A faster function (less time) indicates a better outcome.

***Box and Block Test (BBT).*** This test measures gross unilateral dexterity in stroke survivors with good reliability and validity (Higgins et al., 2005). The patient is asked to move wooden blocks as possible from one end of a partitioned box to the other in 60 seconds, and the number of transferred blocks shows the score (Teasell et al., 2020).

### 1.5 The Rationale for Hand Rehabilitation

In stroke survivors, the recovery of upper extremity function, especially the hand, is complicated and, in most cases, needs intensive therapeutic approaches (Kwakkel et al., 2003). The rationale behind hand rehabilitation is to regain movement, and improve function by enhancing neural plasticity and diminishing spasticity. Neural or brain plasticity is defined as the "capacity of neurons and neural networks in the brain to change their connections and behaviors in response to new information, sensory stimulation, development, damage, or dysfunction" (Rugnetta, 2020).

According to the Evidence-Based Review of Stroke Rehabilitation (EBRSR), rehabilitation has various advantages for stroke patients. It is associated with reduced mortality, disability, and institutionalization, shortening the length of hospitalization, improving function, and cost-effectiveness (Teasell et al., 2020).

The stroke rehabilitation process includes four main stages: initial assessment, goal setting, intervention, and reassessment. The initial assessment is used for goal setting; whose aim is to set attainable and realistic goals for stroke survivors. The intervention includes task-oriented training sessions, with the concept of implementing adaptive ways to compensate for impaired hand movements. Reassessment will determine the success of the intervention; however, evidence exists to show positive effects (Kwakkel et al., 2004; Langhorne et al., 2009; Levin et al., 2009).

Based on the current published literature, the effects of rehabilitation on neuroplasticity and perilesional penumbra are responsible for the benefits that ischemic stroke patients can achieve through various therapies (Stinear et al., 2020) performed by therapists (Hatem et al., 2016) or using robotic devices (Gassert & Dietz., 2018). Therefore, Rehabilitation is considered a necessary process for recovery and acts as an adjuvant to medical therapy in stroke survivors.

Presently, robotic-assisted rehabilitation is considered a novel alternative to manual therapy. These devices provide advantages, such as an increase in regular use, with suitable instructions, and minimum supervision.

### 1.6 Robotic-assisted Rehabilitation

Robotic-assisted rehabilitation is an emerging, evidence-based approach that offers comprehensive rehabilitation by integrating the practical elements of physical therapy with modern technology, i.e., robotics (Oujamaa et al., 2009; Platz & Roschka, 2009; Stein et al., 2001). The need for intensive management in hand rehabilitation was a key reason for developing robotic-assisted rehabilitation (Vanoglio et al., 2017 & Masiero et al., 2014).

Based on the current published literature, the practical elements of motor learning using robotic devices include: taking advantage of the affected limb’s residual force to do rehabilitative exercises (Sale et al., 2014; Woldag et al., 2003); enabling patients to perform a higher number of repetitions compared to conventional physiotherapy (Winstein et al., 2004; Byl et al., 2008); ability to train patients based on the patient-determined performance limit (Byl et al., 2008; Ng & Shepherd, 2000); implementing an external focus of attention instead of internal ones, which was shown to improve outcomes (Wolf et al., 2006; Wulf et al., 1998); the ability to integrate with virtual reality rehabilitation (Wolf et al., 2006; Wulf et al.,1998); increasing task difficulty to improve motor learning outcomes (Woldag et al., 2003); and implementing visual- or acoustic-cues during the rehabilitation program to guide or persuade patients to continue the exercises (Taub et al., 1993).

Therefore, Robots and automated systems are considered advantageous in many ways; however, their main advantage is their ability to engage patients to perform high-intensity and high-dose interventions to facilitate successful outcomes (Hatem et al., 2016). Importantly, automated systems can replace aspects of the treatment process and optimize outcomes, such as reducing the need for continuous physical monitoring and accessing therapy results outside the clinic (Parre & Sujatha, 2021). They also provide patients with movements that cannot be run by the therapist's hand (Braun & Wittenberg, 2021).

Robots have been shown to improve self-efficacy and self-reflection via adaptation and engagement (Riva et al., 2016). Using robots and virtual reality, overcoming challenges such as low compliance and motivation seems more accessible (Riva et al., 2016).

Given that it is expected that there will be 70 million stroke survivors by 2030 (Feigin et al., 2014), the need for more therapists to manage intensive programs, has promoted the development of novel rehabilitation techniques, including robotics. Using robotic devices, the healthcare system could decrease the imbalance between the patient's needs and the supply of therapists (Jackob et al., 2018) and allow for longer, more intensive therapy sessions for patients (Hatem et al., 2016).

## 2. ROBOTIC DEVICES

Active-assisted robots take advantage of movement and position monitoring sensors and use this feedback to interact with patients' actions (Tyromotion, 2020). Fundamental elements of a robotic device that are used for rehabilitation include:

- an interactive computer program for patient progression control,
- a mechanical part for training, and
- a component for giving visual feedback based on the patient's performance.

There are various classifications for robotic devices; for instance, based on how robots act, they are sub classified into end-effector-based or exoskeleton-based. Both are worn by patients; they provide high safety against injury during training and movement control to achieve better outcomes and offer forms of feedback (Huang et al., 2018). However, there are some differences between these two groups.

End-effector devices work with simple control mechanisms, meaning a single interaction point between therapist and patient is needed; the location of this interaction point can be in the forearm or hand. The part of the device aligning with the patient's hand is the end-effector part. (Huang et al., 2018). Conversely, exoskeleton-based robots resemble human limbs and are used such that the mechanical joints align with the patient joints. Thus, muscle-specific treatment is possible at calculated torque (Huang et al., 2018). In contrast to exoskeletons that are portable and can be used for home-based rehabilitation, end-effector's portability is not prioritized (Aubin et al., 2014).

Limitations exist with these robots; for example, in end-effector devices, when end-point control activates from the end of the fingers, there is a misalignment aggravation risk, likewise with using exoskeletons; working with a higher degree of freedom can contribute to malalignment (Yurkewich et al., 2020). Glove deformation due to user forces that perturbs the original robot's kinematics is another concern with exoskeletons. Moreover, structural limitations in a glove can impede wire tension from reflecting the joint's torque summation exactly. Arm and wrist movements also can disturb wire tension (Jeong et al., 2013).

Two brands of robotic devices widely used for hand rehabilitation after stroke employing the End-effort approach and the Exoskeleton approach are TYROSOLUTION (AMADEO and PABLO) and Gloreha, respectively.

## 2.1 Tyrosolution Robotic Device

Tyromotion was founded in 2007 in Austria and then developed into Tyrosolution. It comprises four separate and mutually complementary robotic-, computer-, and virtual reality-assisted therapy equipment: AMADEO, TYMO, DIEGO, and PABLO (Tyromotion, 2020). Among them, AMADEO and PABLO target hand rehabilitation.

**2.1.1 AMADEO (Robotic- and Computer-assisted Finger-Hand Rehabilitation).** This assistive rehabilitation device is purported for use in all phases of rehabilitation, at any age, for both the left and right hand, and even in stroke survivors who suffer spasticity and hypertonicity. AMADEO can be adjusted for: table height, hand unit position, and finger movement spread. Finger supports are usually fastened to the tips of the thumb and fingers. Patients will train the digits in active, assistive, or active/interactive forms based on the defined purpose, consecutively or alternatively (Tyromotion, 2020).

AMADEO simulates the hand's natural grip with precise intensity-based exercise to cater to the patient's performance ability. It provides assistive and interactive therapies for independent finger and thumb movement. Wrist dorsal flexion and finger abduction/adduction are finger and hand movements that AMADEO assists with, in addition to shoulder movements. This system has ten different settings for task difficulty, different shaping variants, as well as programs with the aim of cognitive or attention-deficits management via finger movements. It also can offer Surface Electromyography (EMG-based) training (Tyromotion, 2020).

***Advantages of AMADEO.*** AMADEO has been designed to consider some essential factors during rehabilitation. It offers support at the appropriate intensity by establishing limitations for Range of Motion (ROM), force limits, and activity speed. It can also integrate different therapy items, including shaping, movements such as grasping, repetitions, task-oriented treatment focus, and muscular tone control. Various bio-feedbacks options (acoustic, visual, and tactile) are available for the assessment and therapy phases. A potential benefit is that it motivates patients through games, targeted workouts, and proprioception training. Moreover, cognitive training modules and functional movements can be done simultaneously (Tyromotion, 2020).

Even in the lack of muscular strength, AMADEO is helpful as it offers active therapy using EMG-based training. It also helps address spasticity through the application of vibration and continuous movements. Moreover, AMADEO can objectively assess factors like ROM, strength, spasticity, and tone and record these details to help with a detailed report. It is helpful to train patients to perform ADLs effectively. Therefore, Tyromotion claims that this device benefits therapy and patient assessment (Tyromotion, 2020).

**2.1.2 PABLO (Computer-assisted rehabilitation of the shoulder, arm, and hand).** PABLO is a flexible computer-assisted system with the ability to rehabilitate the upper extremity and a part of the lower extremity. The basic device has a sensor grip to perform various force measurements and can also use belts and a balanced pad to attach the hand grip to the torso, arm, or leg (Tyromotion, 2020).

***Advantages of PABLO.*** PABLO provides special assessments for all grips, finger extensions, strength, and upper extremity joint mobility. Performing various force measurements, including bending, stretching, pinch, and cylinder movements, as well as arm mobility range, is possible. Due to the deficit-related design, patients highly affected by spastic paresis or hypertension can take advantage of Multiball and Muliboard options (hand grip with sensors inserted into the board or ball). The software implements various one-or two-dimensional exercises needed in daily activities. Like AMADEO, cognitive training modules and functional movements can be done simultaneously in patients using PABLO (Tyromotion, 2020).

### 2.2 Gloreha Device

Gloreha is self-claimed to be a helpful device for patients in every stage of stroke and post-surgery. It is proposed to rehabilitate the upper extremity and promote neural plasticity stimulation. An innovation in Gloreha is the ability to perform calibrated sequential movement while a patient observes activity (Gloreha, 2019). It takes advantage of a simple, modular device and enables therapists to offer stroke survivors prolonged, repetitive movements (Bissolotti et al., 2015).

Types of exercises that Gloreha offers are independent finger flexion and extension, including the thumb as well as the entire hand; simultaneous flexion ad extension of fingers 2, 3, and 4; personalized movement and randomized movement. The latest pattern was shown to add more stimulus to the relearning movement process (Borboni et al., 2016).

Gloreha comprises two main components, a glove and a monitor. The monitor enables the patient to watch a three-dimensional simulation while fingers and hands are flexed and extended by gloves (Gloreha, 2019). The glove allows task-oriented, customized rehabilitation programs and consists of sectors linked to each other through the elastic transmissions on the back of the impaired hand (s) and fingers and follows hand anatomy. Each sector is fixed to the related anatomic part of the hand by Velcro and permits a high degree of wearability on impaired hands, such as those impacted by edema or flaccidity (Borboni et al., 2016).

**Advantages of Gloreha.**

Gloreha is a user-friendly device. Dynamic supports of the Gloreha device permit the patient's arm to train for functional tasks with gravity elimination. A vocal guide enables therapists to give patients instructions while using this device**.** Gloreha can provide practical, repetitive, customizable, intensive, and task-oriented treatment sessions. A main advantage is the ability to offer passive movements like flexion, extension, and pinch to mobilize fingers or hands, even in cases without active residual activity. Using this device, the compensation level can be calibrated based on residual movement to enable patients to perform functional training (Milia et al., 2019).

Audiovisual effects, video previews, and 3D animation used with this system may help with motivating the patient, enhance motor learning progress, and potentially improve neural plasticity.

Gloreha's website and advertisements claim that the benefits of the robot include: improvement in visual-spatial and attentive abilities, proprioception stimulation, functional independence, ease of pain, edema reduction, coordination improvement, grip and force improvement, increased joint range of motion, prevention of adhesion and contracture caused by immobilization and regaining ADL (Gloreha, 2019). A detailed literature review is required to determine reliability for these claims.

# 3. LITERATURE REVIEW

The literature databases searched for articles relevant to this paper were Google, Google Scholar, and Medline. Search terms were selected to include at least one keyword: 1) study population (stroke, CVA), 2) device (robotic device, robots, Tyromotion, Tyrosolution, AMADEO, PABLO, Gloreha, assistive device, assistive technology), and 3) activity (exercise therapy, rehabilitation, daily living activities, upper limb, upper extremity, wrist, hand, finger, evaluation, motor function, and motor recovery).

## 3.1 Outcome Indicators

There are various recovery indicators for the upper extremities to determine the effectiveness of the robot. We considered the most common ones, including the FMA, MI, BI, and mBI. ARAT for assessing motor function and MAS, FAT, and FIM for ADLs were also used in fewer studies.

Assessment of ***motor function,*** as outlined in the introduction, can be performed using the following tests: Fugl Meyer (FMA), Motricity Index (MI), Wolf Motor Function Test (WMFT), and Action Research Arm Test (ARAT). Among them, FMA-UE is a gold standard for assessing motor recovery in the upper-extremity version (Fugl-Meyer et al., 1975) and is widely used in rehabilitation studies. In addition, regaining the ability to do ***Activities of Daily Living (ADLs)*** was assessed by the Barthel index (BI), Motor Assessment Score (MAS), Functional Independent Measure (FIM), and Frenchay Arm Test (FAT).

First, we will consider the literature results in stroke patients who underwent robotic hand rehabilitation with Tyrosolution (AMADEO, PABLO), and then we will consider Gloreha.

**3.2 Tyrosolution Robotic Device**

Among the studies on Tyrosolution in stroke hand rehabilitation, eleven original articles met the inclusion criteria to review.

Four examined aspects of implementation for Robots, including the ability of the Tyrosolution Robots to differentiate between a healthy and stroke patient, the ability to implement the Robot into a clinical setting, and the use of gaming as a feature of Tyroslution robots.

First, Germanotta et al. (2020) concluded that AMADEO could reliably distinguish between hand movements performed by a healthy person and those who had suffered from a stroke (Germanotta et al., 2020). In this study, 120 stroke patients underwent physical therapy using an AMADEO device with three assessment methods to assess: tone, spasticity, and strength; the aim was to investigate whether these methods discriminate stroke patients from healthy ones and test re-test reliabilities. Participants were assessed clinically using MRC, MAS, and FAT; test selections were based on a published protocol (Franceschini et al., 2015). All measures could discriminate stroke patients from healthy ones ($p<0.001$) (Germanotta et al., 2020). Hand force in flexion and extension, assessed by AMADEO, strongly correlated with the clinical strength measures. However, no significant correlation was observed between muscle tone and the MAS, nor between robotic and clinical spasticity assessment. Finger strength measured by AMADEO correlated positively with the clinical scales ($ICC>0.9$); therefore, finger strength (in both flexion and extension) and muscle tone at rest (r of about 0.7 with MRC, and about 0.5 with FAT), provided by robotic devices, were determined to be sensitive & reliable measures of predictors of stroke patient hand recovery (Germanotta et al., 2020).

Second, Aprile et al. (2019) conducted a study on the efficacy of robotic rehabilitation using AMADEO, PABLO, and MOTORE (Aprile et al., 2019). This observational study aimed to examine the feasibility verification of rehabilitation dose (assessed by training time duration) and participant satisfaction (measured by VAS) in a new organizational model, where one therapist supervised treatment sessions for one, two, three, and four robotic sessions. Patients with different neurologic diseases/disorders participated including spinal disorder, trauma, Multiple sclerosis, Charcot Marie Tooth, Guillain-Barre syndrome, Parkinson; among them, 41 patients were stroke survivors. No differences were detected in patients' satisfaction (Aprile et al., 2019). Also, the number of patients whom each therapist could supervise in accordance with their disability (measured by mBI), upper limb impairment (measured by MI), mobility (assessed by DI), and comorbidity (measured by CIRS) were studied. Therapists could supervise two to four patients simultaneously, and no serious adverse events were detected. Aprille et al. (2019) concluded that the selected devices were easy to set up compared to more complex exoskeleton devices; the average time needed for set-up was 3.3±1.3 min. Moreover, for each treatment session, patient satisfaction was reported to be high (8/10), with no differences between groups of two, three, and four members. Thus, the feasibility of patients' satisfaction and rehabilitation dose reported in this study indicated that each therapist could supervise up to four patients without treatment dose reduction. This is important because there is an intensity-effect relation between motor recovery outcome and the total duration of therapy; multi-patient supervision could enhance the duration and increased frequency of therapy (Kwakkel et al., 2004 & Byl et al., 2008). Results from Aprille et al (2019) also indicated that mean disability could significantly predict the therapist/patient group ratio, which means the level of autonomy (measured by BI) is the most crucial variable influencing this ratio. The cut-off point for BI was detected as 57 in this study, meaning patients with severe disability (BI<57) can be allocated to two to three-member groups. In contrast, patients with moderate disabilities can be allocated to up to four-member groups. In addition, it was concluded that better human resource allocation could be achieved as the ratio of rehabilitation sessions/day can be reduced by 1/3 in these settings (Aprile et al., 2019).

Third, Jakob et al. (2018) conducted a pilot study to investigate the utility of robotic devices, including Tyrosolution (AMADEO, DIEGO, and PABLO), in clinics and compared robotic hand therapy with conventional therapy in post-stroke patients. Patients in the robotic group were treated using all four robots in a parallel study design for both proximal and distal parts of the upper limb. Both groups underwent equal treatment sessions of 30 sessions. Significant improvements in disability (measured by BI) and function (assessed by FMS), with more progress in the robotic group, were detected (Jakob et al., 2018).

In this article, some hardware and software rehabilitation limitations were also reported. Hardware limitations included: technical limitations in robot engineering, material cost, and needed space that could limit usability and require extensive effort for any slight technological improvement. Software limitations were insufficient and limited knowledge in the robotic rehabilitation area, since most clinical studies did not adequately explain and/or report the specifics associated with robotic therapy, including intensity, frequency, dose, and time of exercises, and the session frequency. Moreover, it was discussed that the cost of robotic therapy per session was less than half in Germany compared to standard arm therapy with similar outcomes. They concluded that robotic therapy is a likely option to ensure the most significant number of patients have access to high-quality therapy and lower costs (Jakob et al., 2018).

Lastly, Seitz et al. (2014) conducted a randomized trial on 69 participants, including 30 patients with neurologic disorders [15 post-stroke and 15 Parkinson patients] and 39 healthy subjects as the control group; this study aimed to investigate improvements in visuomotor coordination of both hands rotations resulting from the training of the dominant hand using the PABLO robotic device in stroke survivors and mid-stage Parkinson cases (Seitz et al., 2014).

Virtual reality gaming was implemented to train hand function in participants. All participants completed training sessions, including trials to improve hand functions: hand grip force, pinch grip of index and thumb, and wrist supination/pronation. Assessment sessions were conducted before and after training sessions (three consecutive training days); the result showed that all groups successfully performed visuomotor tracking tasks. They concluded that implementing visuomotor device training improved visually guided hand coordination in both patients (p=0.026) and healthy subjects (p=0.001). However, the mean hand grip force, pinch force, and rotation angle did not show change neither in healthy, nor in patients (Seitz et al., 2014).

Seven other articles examined the therapeutic benefits of Tyrosolution robots. Two studies only looked at the clinical effects of Robot Therapy alone: Dziemian et al. (2018) and Butt et al. (2021).

Dziemian et al. (2018) conducted a pilot study on 10 participants with hand impairment due to stroke. They employed FMA, Nine Hole Peg Test (NHPT), Box and Block test (BBT), as well as surface Electromyography (sEMG) to maintain optimal hand kinematics. Surface EMG transmitted the muscle contraction to the amplifier to activate the robot mechanism. Results indicated that upper limb function improved significantly; in FMA (p=0.038) and BBT (p=0.027), but not in NHPT (p=0.59). They concluded that robotic-assisted rehabilitation, assisted by surface EMG, impacts upper limb function positively in stroke survivors with severe hand motor deficits.

Butt et al. (2021) assessed the effects of using AMADEO for hand training in seven stroke survivors to investigate changes in their electroencephalograms (EEG), as well as some clinical and kinematic tests. They assigned patients into two groups based on the brain lesion location (group A: four patients with the lesion(s) in the supratentorial region and group B: three patients with lesions in the infratentorial region). All patients underwent motor training using AMADEO for eight weeks, as well as the assessments tests, including the Fugl-Meyer Assessment (FMA), Motor Assessment Scale (MAS), Range of Motion (ROM), and EEG (to record brain activity), before and after, four and eight weeks of the intervention termination. Although the training protocol and total exercise time (30 minutes) were identical for both groups, only group A could participate in all four training modes. In contrast, group B could not perform one mode: the active assisted training mode (Butt et al., 2021).

At week four of the intervention, patients in group A had statistically significant improvements in FMA-wrist (p=0.006), FMA-hand (p=0.043), and MAS-hand movement (p=0.035). In contrast, patients in group B only showed statistically significant improvement in FMA-hand (p=0.035). Group B showed significant motor recovery after training extension to eight weeks. This study indicated that patients with infratentorial lesions showed slower improvement in clinical tests, suggesting they need more extended intervention periods for change. They also concluded that clinical outcome improvement is associated with reduced movement-related cortical potential signal amplitude (Butt et al., 2021).

Two studies directly compared Robot-only therapy (RT) with Conventional Therapy alone (CT): April et al. (2020), and Orihuela-Espina et al. (2016).

Aprile and colleagues (2020) conducted a second, clinical study on 247 participants, including 123 stroke patients and 124 controls, taking advantage of different types of Tyrosolution programs: AMADEO, PABLO, and DIEGO, to rehabilitate stroke survivors with hand impairments. This study aimed to evaluate the efficacy of a robotic hand treatment by comparing it with conventional therapy. The primary outcome was Upper Limb (UL) motor function changes from baseline after rehabilitation, which was measured by FMA to assess the treatment effect. The secondary outcomes were changes from baseline in MI, MRC, MAS, DN4, NRS, mBI, FAT, ARAT, SF-36, PCS, and MCS. Results showed that the mean FMA score improvement in the robotic and control group was 8.5 and 8.57, respectively. No significant differences between groups were detected (p = 0.948). Changes in all secondary outcomes in both groups were identical, except for MI in the robotic group, which indicated better results (p= 0.037). The persistence of training effects was re-assessed three months after the treatment termination using these same assessment tools. Stroke survivors who underwent robotic therapy alone or conventional therapy alone, with a similar amount of treatment showed significant improvement in upper limb motor function and participation in various subjects and activities regardless of arm treatment and as such there were no between-group differences (p= 0.90 for both subgroups).

Orihuela-Espina et al. (2016) conducted a study to determine motor recovery with AMADEO when used during the subacute phase (<4 months) after stroke. All participants completed 40 therapy sessions based on the participant's abilities. Patients were randomly assigned to Robot-only Therapy (RT) or Classical Occupational Therapy (CT). The primary outcomes were sensorimotor recovery (assessed by FMA), motor recovery (assessed by MI), and their progress. Both groups showed significant improvement over time in the mentioned parameter. When it comes to comparing two groups, compared to the baseline, significant improvement in FMA (p<0.01) for the hand training with the robot was detected while in the CT group, FMA did not show insignificant improvement (p=0.09). MI indicated a greater improvement (size effect) in hand prehension for the robotic group (p=0.08), but it was not statistically significant.

The remaining three articles examining clinical outcomes for Tyrosolution Robots compared Robot + Conventional Therapy (RC) with CT.

First, Calabro et al. (2019) conducted a study on 50 stroke patients to evaluate the clinical and neurophysiological effects of intensive robotic therapy and to compare it to intensive conventional therapy during the chronic recovery phase (i.e. stroke had occurred at least six months before treatment). Patients were randomly assigned to either RC or CT alone. Both groups underwent 40 hand therapy sessions, 5 times a week for 8 weeks, and 45 min for each. The RC group used AMADEO, while the control group received intensive conventional hand therapy. Results indicated that Fugl-Meyer scores in the robotic group improved significantly more than the conventional hand therapy group ($p<0.001$). The authors concluded that intensive robotic hand therapy had positive neurophysiological effects on hand function recovery (Calabro et al., 2019).

Second, Youssef and colleagues (2021) compared the effects of advanced robotic hand therapy with AMADEO on upper limb function in stroke survivors (Youssef et al., 2021). In this study, 45 male, chronic stroke patients were divided into three groups of 15 persons each. Group A (6 months-2 years after stroke), and B (patients more than 2 years after stroke) received robotic therapy in addition to conventional therapy, which consisted of 4 weeks of training, with 3 sessions per week. Group C received conventional therapy treatment only for 4 weeks. This article failed to report the time from stroke for Group C patients. All patients were assessed before and after 4 weeks of treatment. The Fugl-Meyer assessment tool measured sensorimotor function and the AMADEO device was used to assess grip strength. Results indicated significant improvement in FMA score ($p=0.001$) and grip strength ($p=0.001$) in all three groups, with larger improvement in group A (under 2 years from stroke event), compared to B (over 2 years) and C (unknown): In FMA, $p=0.03$ for A vs B and $p=0.001$ for A vs C; in the flexion grip strength, $p=0.02$ for A vs B and $p=0.001$ for A vs C; in the extension grip strength, for A vs B: $p=0.001$ and for A vs C: $p=0.001$. They concluded that using robots in addition to conventional therapy improved motor function and grip strength in chronic stroke patients' upper limbs, when interventions were used as early as possible (Youssef et al., 2021).

Lastly, Rodriguez-Perez et al. (2022) conducted a non-randomized clinical trial on 18, subacute (between three to six months after stroke) and chronic patients (after six months of stroke). They aimed to evaluate high-frequency vibration treatment effects of AMADEO on motor function (FMA) and patient's perceived quality of life, among other parameters (Rodriguez-Perez et al., 2022). Patients were divided into either RC or CT, based on their geographical location (nine persons each). When it comes to the motor function, the intra-group results indicated that the combination of robotic rehabilitation with conventional therapy led to significant improvement in FMA (p=0.028) and perceived quality of life (p=0.008), compared to the baseline while in the control group, they were not statistically significant (p=0.2 and p=1.0, respectively). In addition, significant differences were reported in their motor performances as estimated by the motor activity log (MAL) (p=0.021 in quantity and p=0.037 in quality) between the two groups; but not in motor function (FMA: p=0.8) or perceived quality of life (p=0.5).

### 3.3 Gloreha Robotic Device

Among the published research studies on Gloreha Robotic System in stroke hand rehabilitation, six original articles met the inclusion criteria to review. One examined aspects of implementation for Robots, including the safety of Gloreha and the ability to implement into a home setting, in addition to its effectiveness in the functional recovery.

Beroncchi et al. (2018) investigated hand rehabilitation's safety, feasibility, and effectiveness with the Gloreha robotic device in 21 hemiplegic stroke survivors. Finally, 17 patients for the first visit (at the end of the second month), and 14 patients for the 2-month follow-up visit remained. This study aimed to verify the maintenance of clinical improvements two months after the implementation of home rehabilitation program using Gloreha. During this time, exercises were planned to move the patient's impaired hand passively; patients' program was consisted of 45-minutes sessions 6 days a week for 2 months. During this time, they did not attend any clinical hand rehabilitation program and had good adherence to their home program. The goals of this study were to investigate the feasibility of the home program, in terms of the number of patients included, the exercise duration used and the number of sessions patients engaged in. Measures of pain (VAS), edema (using flexible tape to measure the circumference of fingers, wrist, and forearm), and spasticity (MAS) were used to determine program safety. For efficacy evaluation, functional ability changes were assessed using MI, NHPT, and Grip tests (Bernocchi et al., 2018).

No significant changes in the mean VAS score of hand pain, mean hand circumferences, and mean MAS index (P=1.0) were detected. Significant improvements were achieved in MI (p=0.002), Grip test (p=0.002), and NHPT (p=0.01) compared to the baseline. The authors concluded that the Gloreha device improved the patient's functional capacity and was safe and feasible for home rehabilitation. It was also concluded that, over time, intensive training sessions might maintain favorable results on dexterity and strength. Thus, they concluded that cyclic home rehabilitation with robotic devices might be helpful in providing hand function rehabilitation. However, some technical issues were reported: requiring robotic glove replacement with a smaller size because of edema reduction in two patients and difficulty putting on gloves by three.

Five other articles also examined the therapeutic benefits of Gloreha robots. Among them, three studies looked at the clinical effects of Robot Therapy alone in pilot studies: Millia et al. (2019), Micinilli et al. (2020), and Cordella et al. (2020),

Millia and colleagues (2019) piloted robotic use with 12 stroke survivors for a larger clinical study to come; as such, they had neither a control group nor randomized enrollment.

They experimented with different treatments, including the Gloreha device, to investigate the efficacy of robotic-assisted hand therapy: patients underwent Gloreha 30 min/d, physiotherapy 90 min/day, and occupational therapy 30 min/day. For using Gloreha, first, patients observed a real hand movement on the screen, and then, robotic hand-supported exercises were done, including passive mobilization, active participation, and bimanual therapy while patients were observing the screen. Results indicated significant differences compared to the baseline in the Functional Independent Measurement to assess ADL (FIM) scale (p=0.01), significant results in dexterity assessed by the Nine Hole Peg Test (NHPT) (p=0.01), however no significant changes in spasticity, measured by Modified Ashworth Scale (MAS) (p=0.6) at the admission and termination session were reported. They concluded that using Gloreha, the patient's ADL improved significantly, similar to the effects of intensive conventional therapy in the previous studies. The robotic device seemed to promote motor recovery compared to the standard format of occupational therapy. Moreover, no differences between ischemic or hemorrhagic stroke patients were detected (Millia et al., 2019).

Second, Miccinilli et al. (2020) assessed robotic devices in 13 chronic stroke patients who were assigned to two groups of active-assisted robotic or passive robotic treatment based on their ability to do at least 20 degrees of wrist extension. This trial evaluated Gloreha robotic glove efficacy in hand motor recovery after 20 treatment sessions. Each group underwent either active-assisted (the patient has some level of control of the movement) or passive robotic treatment (all movements are done by the robotic device and the patient does not exert effort). Participants were assessed before, immediately after the 20 sessions, and again after one month of treatment course termination. Motor performance was evaluated by FM and MAS, and significant improvement was recorded for each item in both groups of participants (Miccinilli et al., 2020).

Lastly, Cordella et al. (2020) tested Gloreha on ten stroke patients. The aim of this study was the quantitative evaluation of Gloreha in patients' motor performance improvement. Participants were assigned into two groups based on their ability, or inability, to perform a 20-degree wrist extension; both groups underwent 20 consecutive daily exercise of 40 minutes each session 5 days a week. The first group (those able to perform a 20-degree wrist extension) performed active exercises using Gloreha, including water pouring, cube skating, tri-digital grip, and opening/closing; where the robotic hand only assists motion when needed. The second group (those unable to perform a 20-degree wrist extension) also underwent passive training including flexion, extension, passive counting, passive opposition of thumb and fingers, hand opening and closing, random flexion, and extension of every finger with Gloreha. Results indicated a strong correlation between FMA-UE and ROM improvement at T1 (r=0.63) on all the fingers, which means that the increase in FMA is correlated with ROM increment. Significant differences in the FMA-UE (p=0.002) and the ROM (p=0.003) before and after the treatment were also reported for all the sujects. Based on these results, the authors concluded that Gloreha robotic hand's camera-based procedure helped fingers regain their joints' angular values from bending sensors and thereby improved motor performance and a correlation between the ROM and FMA.

The remaining two articles examined clinical outcomes for Gloreha Robots with Conventional Therapy.

First, Lee et al. (2021) conducted a randomized, crossover-controlled, assessor-blinded study on 24 subacute or chronic stroke survivors with moderate motor and sensory deficits. They assigned patients into two groups: robotic-first (n=14) and conventional-first group (n=10). Each patient participated in 12 robotic training and 12 conventional therapy sessions lasted 60 minutes each. This was a six-week crossover study with a one-month washout period between arms. In this study, Gloreha simulated ADLs and supported hand movements partially or completely according to the residual patient's motor skills. The conventional occupational therapy was consisted of task-oriented bilateral hand movements, which were the same as activities used in robotic-assisted rehabilitation. Researchers assessed patients' performance four times; before and after robotic therapy and before and after conventional therapy. They assessed participants using various parameters, including FMA, mBI, Box and Block test, EMG, and Grip dynamometer. Using robotic therapy, significant time effect for FMA–UE proximal ($p = 0.030$) and FMA-total ($p = 0.046$), and mBI ($p = 0.038$) of the post-test scores were reported in robotic-first group. There were found no significant time effects in the conventional-first group in FMA-UE proximal ($p=0.9$), FMA-total ($p=0.8$), and ADL ($p=0.07$). Patients' EDC muscles showed more efficacy in the Box and Block test grasping task after robotic therapy than conventional therapy ($p = 0.050$). No significant changes were reported for the other measures BBT, EMG, grip strength in any groups. They concluded that the Gloreha device facilitated the function of the upper limb, including motor function and ADL ability in patients with subacute and chronic stroke history. They also concluded that combining the Gloreha robotic device with a task-oriented approach can improve functional patient recovery.

Second, Crema et al. (2022), in their study (Pseudo-randomized open-label multi-arm trial), recruited 60 stroke survivors to examine the effects of various technological devices, including Gloreha, compared with conventional therapy in restoring sensory and motor functions. they included the robotic glove Gloreha (GR) and a new wearable neuromuscular electrical stimulation system Helping Hand (HH), as well as mixed therapy of Gloreha and helping hand (GRHH). The HH system had been designed for this study and offered peripheral motor activation and increased cutaneous sensation (Crema et al., 2022). Patients were divided into four dose-matched groups (15 persons each): Control (Conventional Therapy), HH, GR, and GRHH, and each group received 27 treatment sessions. Participants in the GRHH group received 50% HH and 50% GR training. Various clinical tests, including MI for motor recovery assessment and ARAT, were employed to assess the patients before (T0), halfway through week 5 (T1), week 9 (end of the intervention, T2), and week 13 (Follow-up, T3). Force recovery (assessed by MI total and MI pinch) was detected at each time (Wilcoxon, all groups, T0 versus T1, T0 versus T2, T0 versus T3, all $p<0.001$). Improvement were reported significant in MI total using HH for T0 versus T1 and T0 vs T2, while significant improvement occurred in all treatment groups for T0 versus T3. ARAT pinch improved over time in HH and GR ($p<0.05$) but not in the mixed training group ($p>0.1$). The authors hypothesized that this occurred because HH and GR were used in combination with standard therapy that offered specific functional skills rather than impairment recovery. When analyzing the changes over time, patients who used HH showed earlier benefits in MI than those who used the Gloreha device (GR); the functional improvement was greater in the GRHH and HH compared to Gloreha alone. These two groups improved perceived dimensions and changed feelings about the affected limb. This study advocated that in stroke survivors with unilateral motor deficits, using HH, induces sensory and motor stimulation through enhanced cutaneous sensation, resulting in improved bodily perception and sensorimotor function and remaining stable in follow-up.  Regarding Gloreha, they concluded that it improved only at follow-up (T0 versus T3, $p=0.025$).

### 3.4 Review articles on Robots for Stroke Rehabilitation

Nine research studies have been published examining the use of robots in hand rehabilitation, and included studies with Gloreha and/or Tyrosolution are also summarized below.

Huang and colleagues (2022) conducted a systematic review, which included 15 studies (1081 subjects) with a meta-analysis of the results of physical, therapy-based rehabilitation on hand recovery in post-stroke adults. They excluded published articles that used combination therapy. This review indicated that various kinds of physical therapy, including robotic rehabilitation (used in four studies), significantly improved all parameters, including FMA score, FIM, ARAT, and BBT (Huang et al., 2022). Therefore, the authors concluded that taking advantage of physical therapy-based rehabilitation, including robotic therapy, in these patients can result in muscle strength and upper limb movement improvement, pain reduction, as well as improvement in quality of life.

A meta-analysis of randomized controlled trials by Zhang et al. (2022) included 46 RCTs that compared the impact of robotic device rehabilitation and conventional treatment on stroke-related hand impairment in adults. Based on this meta-analysis, Fugl-Meyer Assessment and activity function were significantly improved compared to the control group in the robotic group. However, in patients' follow-ups, this difference was not significant (Zhang et al., 2022).

Proietti et al. (2022) analyzed research studies using wearable robots for hand rehabilitation, and concluded that most studies (69%, 82% when it comes to stroke patients) indicated improvement in FMA score (Proietti et al., 2022).

Kabir et al., (2022) compared robotic hand devices, where they reviewed end-effector devices and exoskeletons (Kabir et al., 2022). Most devices resulted in FMA improvement by 2–4 points. The devices that increased the FMA scale by at least 7 points were Gloreha, Amadeo, HEXORR, and My-HERO.  This paper found that the AMADEO robotic device can actuate each finger separately and, based on recorded results of EMG sensors and linear rail system, has been capable of ameliorating the FMA scores in several patients. This review considered Gloreha and its capability of activating each finger using a cable-driven system and improving in FMA score by eight by using this pneumatically actuated exoskeleton (Kabir et al., 2022). These authors concluded that although end-effectors would increase the malalignment risk as they actuate from the end of each finger(s), the end-effectors will have more advantages, like more straightforward control, without overall progress interruption and thereby providing high levels of management and safety without complicated design compared to the other robots, including exoskeletons. Some robots, such as AMADEO, also provided patients with hand neurological profiles during exercise administration (Kabir et al., 2022).

Moggio and colleagues (2022) conducted a systematic review and meta-analysis on exoskeleton versus end-effector robot-assisted therapy for hand and finger recovery in post-stroke patients. They included five RCTs (two articles used Gloreha, and three used AMADEO) for a total of 149 post stroke participants (Moggio et al., 2022). They aimed to compare the relative effects of Gloreha and AMADEO on hand motor function using motricity index (MI) and fugl-meyer (FM-UE) to evaluate the sensorimotor function of the upper limb, as well as a quick version of disability of the arm, shoulder, and hand (QuickDASH) questionnaire (Moggio et al., 2022). In their review, all articles reported significant improvement in MI for the intervention group when compared to the control group. FMA showed a significant improvement in end-effector robot users, while QuickDASH demonstrated a significant reduction in MI for the exoskeleton users. They concluded that for motor recovery, robotic devices are most likely to be the best option, based on reported results from data presented on MI data, especially for exoskeletons (including Gloreha) and thereby concluded it to be the best option for motor recovery (MI) compared to end-effectors and conventional therapy; probability percentage was of 97.3, 48.3, and 4.4, respectively (Moggio et al., 2022).

Baniqued et al. (2021) suggested that Gloreha and AMADEO have met the standards in their related fields of providing rehabilitation intervention. In this article, three specific factors for robotic device assessment were reported based on the International Classification of Functioning, Disability, and Health (ICF), were identified: participation, impairment improvement as well as activity performance support (Oña et al., 2018; Kersten et al., 2004) were identified as primary factors.  These outcomes, besides proper safety, were stated as critical factors when it comes to robotic device selection; that is why this article introduced AMADEO as a gold standard for this application (Baniqued et al., 2021).

Duret et al. (2019) in their study mentioned that for years, superior changes in functional outcomes using robotic therapy were more controversial, since most research articles concluded that robotics did not improve ADLs beyond conventional rehabilitation (Duret et al., 2019). They pointed to a key factor in effective motor rehabilitation: exercise intensity. Several clinical studies indicated intensive motor training and at least 16 hours of exercise-based intervention are required to detect significant changes in ADLs, especially in sub-acute stroke patients (Feys et al., 2004; Kwakkel et al., 2006; Lincoln et al., 1999). One of the main advantages of robotic therapy is the easy quantification of exercise doses in rehabilitation sessions. It is worth noting that plastic changes in human neurorehabilitation were demonstrated to happen only through high repetitions of movements, where more than 300 per/ session for the upper limb provided beneficial effects (Birkenmeier et al., 2010), and repetitions less than 100 per day did not, since plastic changes could not occur (Carey et al., 2007). Thus, a higher dose of exercise administration was shown to improve motor outcomes, compared to lower doses in rehabilitation sessions. However, patients and therapists mentioned that they were exhausted from performing such repetitions, which is probably why they precluded participation in multidisciplinary rehabilitation and, consequently, could not reach rehabilitation goals in terms of ADLs improvement (Duret et al., 2019).

Veerbeek and colleagues, in their study that systemically reviewed the impact of robotic devices on motor control in stroke survivors, meta-analyzed 38 trials on 1026 subjects with hand impairment. Results indicated significant but small improvement in motor control (two points for FMA) and muscle strength without affecting ADLs. They also concluded that robotic therapy can be an adjunct to conventional therapy and is more effective than robotic rehabilitation alone (Veerbeek et al., 2017).

Hung et al., in 2016, conducted a randomized comparative study on 21 stroke survivors with stroke-related hand impairment. Participants underwent 20 sessions of robot-assisted therapy combined with task-specific training (RTT) or impairment-oriented training (RTI). Outcomes were the assessment of Fugl-Meyer, Action Research Arm Test, Stroke Impact Scale (to assess the quality of life), and the Medical Research Council Scale in baseline, post-treatment, and at 3-month follow-up. For both RTT and RTI groups, motor function, muscle power, and life quality indicated significant within-group improvement. In the RTT group, motor function (FMA) and quality-of-life improvement were significantly superior to the RTI group and this improvement was observed to continue at follow-up assessments. Therefore, authors concluded that robotic therapy should focus on the patient's hand impairment and translate them into a function (Hung et al., 2016).

The results of articles introduced in this paper clearly illustrated that hand motor function and ability to do activities of daily living improved using robotic devices. However, as in most studies, robotic devices are assessed in conjugation with conventional rehabilitation, making it difficult to conclude the pure impact of robotic devices on the patients and needs to be considered in future studies.

### 3.5 Original Articles Comparing Robotic Rehabilitation Treatment

**Table I**

*Basic characteristics of the articles on the effects of AMADEO rehabilitation device.*

| Groups | Authors/ Publication Date | Study Type | * Level of Evidence | Participants | Significant Improvement of Motor Function from baseline | Significant Improvement of ADL from baseline | Significant Differences | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | between R and C groups | between RC and C groups |
| A | Dziemian et al., 2018 | Before - after | 3 | 10 | FMA (p=0.038) | N/A | N/A | N/A |
| | Butt et al., 2021 | Before -after | 3 | 7 | FMA (p= 0.006) | MAS (p= 0.035) | N/A | N/A |
| B | Orihuela-Espina et al., 2016 | *RCT* | 2 | 9 R<br>8 Control | FMA (p<0.001)<br>MI | N/A | FMA in R group | N/A |
| | Aprile et al., 2020 | RCT | 2 | 123 R<br>124 Control | FMA-MI-ARAT (p<0.05) | MBI- FAT (p<0.05) | Only MI in the R group (P=0.037) | N/A |
| C | Calabro et al., 2019 | RCT | 2 | 25 R&C<br>25 C | FMA (p<0.001) | N/A | N/A | FMA in R&C |
| | Rodríguez-Pérez et al., 2022 | NRS | 3 | 9 R<br>11 Control | FMA P=0.028 | N/A | N/A | FMA in R&C group |
| | Youssef et al., 2021 | NRS | 3 | 30 R&C<br>15 C | FMA (p=0.001) | N/A | N/A | FMA in R&C |

**Note:**
Groups=indicate our classification for subsections of the studies (A: articles examined the robot therapeutic effects, B: studies compared RT and CT, and C: studies examining outcomes for RC)
ADL=Activities of Daily Living, ARAT = Action Research Arm Test, BI = Barthel Index, C =Conventional rehabilitation, CT = Clinical Trial, FAT = Frenchay Arm Test, FMA = Fugl-Meyer Assessment, mBI = modified Barthel Index, MI = Motricity Index, N/A = Not Applicable, NRS = Non-randomized Controlled study, R= Robotic-assisted rehabilitation, RC=both Robotic and Conventional therapy, RCT = Randomized Control Trial.
*Melnyk Levels of Evidence: Level 1 - Systematic review & meta-analysis of randomized controlled trials, Level 2 - One or more randomized controlled trials, Level 3 - Controlled trial (no randomization), Level 4 - Case-control or cohort study, Level 5 - Systematic review of descriptive & qualitative studies, Level 6 - Single descriptive or qualitative study, Level 7 - Expert opinion (Melnyk & Fineout-Overholt, 2015)

**Table II**

*Basic characteristics of the articles on the effects of the Gloreha rehabilitation device.*

| Groups | Authors/ Publication Date | Study Type | *Level of Evidence | Participants | Significant Improvement of Motor Function from baseline | Significant Improvement of ADL from baseline | Significant Differences | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | between R and C groups | between RC and C groups |
| A | Beroncchi et al., 2018 | Before-after | 3 | 21 | MI (p=0.002) | N/A | N/A | N/A |
| | Millia et al., 2019 | CT | 3 | 12 | N/A | FIM (p=0.01) | N/A | N/A |
| | Cordella et al., 2020 | CT | 3 | 10 | FMA (p=0.002) | N/A | N/A | N/A |
| | Miccinilli et al., 2020 | RCT | 2 | 13 | FMA (p<0.05) | N/A | N/A | N/A |
| B | Lee et al., 2021 | RT | 2 | 24 | FMA first-robotic (p=0.030) | mBI first-robotic (p= 0.038) | No FMA (p=0.8) mBI (p=0.09) | N/A |
| | Crema et al., 2022 | CT | 3 | 15 C, 15GR 15HH, 15GRHH | MI (p<0.001) in all groups, ARAT(p<0.04) in GR | N/A | N/A* | N/A |

**Note:**
Groups=indicate our classification for subsections of the studies (A: articles examined Gloreha therapeutic effects, B: studies compared RT and CT.
ADL=Activities of Daily Living, ARAT = Action Research Arm Test, BI = Barthel Index, C =Conventional rehabilitation, CT = Clinical Trial, FAT = Frenchay Arm Test, FMA = Fugl-Meyer Assessment, GR = Gloreha, GRHH = 50%GR&50%HH, HH = Helping Hand, mBI = modified Barthel Index, MI = Motricity Index, N/A = Not Applicable, R= Robotic-assisted rehabilitation, RC=both Robotic, and Conventional therapy, RCT = Randomized Control Trial.
N/A*: researchers omitted the control group's information
*Melnyk Levels of Evidence: Level 1 - Systematic review & meta-analysis of randomized controlled trials, Level 2 - One or more randomized controlled trials, Level 3 - Controlled trial (no randomization), Level 4 - Case-control or cohort study, Level 5 - Systematic review of descriptive & qualitative studies, Level 6 - Single descriptive or qualitative study, Level 7 - Expert opinion (Melnyk & Fineout-Overholt, 2015)

## 4. Summary of Article Conclusions

Tables I (Tyrosolution data) and II (Gloreha data) summarize the clinical research studies discussed in Chapter 3 above, with an emphasis on the data collected for assessing motor recovery, (FMA, MI, and ARAT), and measures of activities of daily living (ADLs) (mBI, BI, MAS, and FIM). Any statistically significant change is indicated for the following four comparisons: i) improvement in motor function with robot intervention compared to baseline measures; ii) improvement in measures of ADL with robot intervention compared to baseline measures; iii) improvement in motor function between intervention conditions: robot intervention alone vs. conventional therapy alone; iv) improvement in measures of ADL between intervention conditions: robot intervention + conventional therapy vs. conventional therapy alone. If the study did not measure one of these factors, the data cell reads: not applicable (N/A).

The purpose of the paper was threefold: i) describe stroke and assess the use of robotic hand rehabilitation as adjuvant therapy, ii) assess the effects of two robots with different mechanisms of action (Tyrosolution and Gloreha) with conventional therapy, and iii) compare these robots for their impact on motor and functional recovery.

### Robotic Hand Rehabilitation as Adjuvant therapy:

Based on the clinical studies presented in sections 3.2 and 3.3, we cannot conclude at this time whether end-effector or exoskeletal robots can enhance conventional therapy outcomes. However, the review articles (3.4), which incorporate many types of robots and therapy outcomes, suggest that when they can enhance the number of training sessions, they should be included as adjuvant therapy, for better outcomes.

**Assess the effects of two robots with different mechanisms of action (Tyrosolution and Gloreha) with conventional therapy**

Of note, more research was found assessing Tyrosolution robots than the Gloreha robot. Upon examination of the types of research done, both robots had level II and III studies, but only Tyrosolution has had a large, randomized control trial project completed (n=247 patients) (Aprile et al 2020). In addition, the studies conducted using the Gloreha robot did not examine robot-intervention-induced differences in patients' outcomes when compared to either conventional therapy, or robot therapy combined with conventional therapy. Whereas several studies, including the large RCT study by Aprile (2020), found significant improvements in motor function and activities of daily living when patients used the End-Effector Tyrosolution robot alone, compared to conventional therapy and in patients who used both robot and conventional therapy together compared to conventional therapy alone. We conclude that both Tyrosolution and Gloreha robots take advantage of technology to aid hand function rehabilitation after stroke and both can be effective tools for hand function and ADLs improvement. Conventional therapy has also been shown to be effective in functional and ADLs improvement. In fact, a combination of both methods may be most effective in patients' recovery after stroke. It should not be ignored that rehabilitation outcomes vary in different patients based on their individual factors and the designed rehabilitation program.

**Compare these robots for their impact on motor and functional recovery**

When looking at the data from Tables I and II, we observed that all but one study measured motor function as a primary outcome for robot intervention compared to baseline measures. Both the Tyrosolution and the Gloreha robots were able to significantly improve measures of motor function using various assessment tools in patients after using the robot, compared to the baseline in every published study.

Only four studies examined ADL as an outcome measure, but all showed statistically significant improvements in measures of ADL compared to baseline measures after robot intervention. However, no differences between robot therapy and conventional therapy were detected in any of these studies. We conclude that both Robots have meaningful improvements on ADL and Motor function.

# 5. DISCUSSION

Stroke is one of the leading causes of death and acquired adult disability worldwide and in Canada (Stroke Fact Sheet Canada, 2020). Hand movement impairment after a stroke can impede patients from having an ordinary life, performing activities of daily living independently, and returning to the workplace; thus, restoring hand functions is a priority in rehabilitation, and using novel technics like robotic devices has become more widespread to address the need in this area. The purpose of this paper was to: i) describe stroke and assess the use of robotic hand rehabilitation as adjuvant therapy, ii) assess the effects of two robots with different mechanisms of action (Tyrosolution and Gloreha) with conventional therapy, and iii) compare these robots for their impact on motor and functional recovery.

## 5.1 Assessing the use of Robotic Hand therapy as adjuvant therapy

In this paper, results showed that using Tyrosolution and Gloreha robots in rehabilitation, alone or in combination with conventional therapy, significantly improved the function of the hand and wrist motor function and ability to do activities of daily living ***when compared to baseline.*** No studies were found to show that adding robotic therapy to conventional therapy improved outcomes beyond conventional therapy alone. Limited studies to date have been conducted assessing the enhancements of robot intervention alone. However, the ability of all rehabilitation robots to reduce the burden on therapists by providing additional therapy that fulfils the main principles of stroke rehabilitation (i.e. repetition, high intensity, and task specificity) support their continued use at this time.

**5.2 Comparing Tyrosolution & Gloreha, with different mechanisms of action, with conventional therapy**

Of note, more research has been conducted on end-effector robots in general (Lee et al., 2020), and using the Tyrosolution robots specifically, compared to the Gloreha exoskeletal robot.  The studies examined in this review of the Gloreha robot did not examine robot-intervention-induced differences in patients' outcomes when compared to either conventional therapy, or robot therapy combined with conventional therapy. Whereas several studies, including the large RCT study by Aprile (2020), found significant improvements in motor function and activities of daily living when patients used the End-Effector Tyrosolution robot alone, compared to conventional therapy and in patients who used both robot and conventional therapy together compared to conventional therapy alone. As such, the data from this paper suggest that the use of the End-Effector Robot: Tyrosolution; enhances patient outcomes with conventional therapy, in patients with hand immobility issues due to stroke. However, to date, we are unable to determine whether the Exoskeletal robot – Gloreha is equally able to enhance benefits attained from conventional therapy. Future research should address this.

While comparing these devices to conventional therapy, several additional issues were noted which are included here. Specifically issues regarding robotic glove fit and wear challenges, which were reported by participants (Beroncchi et al., 2017). Hardware limitations including technical limitations in robot engineering, material cost, and needed space that limited usability, also reported by Jakob et al. (Jakob et al., 2018). Except for space, these issues are typically not reported for conventional therapy.

### 5.3 Comparing Tyrosolution & Gloreha with outcomes on Motor Function and ADLs

#### 5.3.1 Motor Function

In six studies, FMA was employed to assess participants' motor function; all studies showed significant improvement ($p<0.05$) in motor function after therapy in both conventional and robotic groups compared to the baseline. From this, we conclude that both treatments can improve motor function. In two articles by Aprile et al. (2020) and Orihuela-Espina et al. (2016) using AMADEO, MI was also measured, and they detected significant differences between the robot and showed that the robot was superior in regaining motor function compared to conventional therapy.

One article by Aprile et al. (2020) also measured ARAT for assessing motor function using the AMADEO, and they found that both robotic and conventional therapy improved motor function.

#### 5.3.2 Activities of Daily Living.

In two studies conducted on AMADEO, ADLs improvement was assessed; in one of them, Butt et al. (2021) employed MAS, and in another, Aprile et al. (2020) used MBI and FAT. Significant differences were detected in the measures compared to the baseline. In the article by Aprile et al. (2020), conventional and robotic therapy were compared, and no changes between the two groups were detected in ADLs.

Regarding the comparison between groups, only two studies compared conventional therapy with robotic therapy; In robotic groups used AMADEO, MI was significant in Aprile et al. (2020) study and FMA in Orihuela-Espina et al. (2016) compared to the conventional group.

The designers of other studies used conventional therapy for both control and intervention groups. Three studies compared conventional plus robotic therapy with conventional therapy: Rodríguez-Pérez et al. (2022), Youssef et al. (2021), and Calabro et al. (2019). In all of them, FMA showed significant differences in conventional plus robotic therapy groups compared to conventional therapy.

Six studies employed Gloreha as a robotic device; among them, FMA was used in three articles to assess motor function improvement: Lee et al. (2021), Cordella et al. (2020), and Miccinilli et al. (2020) and indicated significant differences ($p<0.05$) between baseline and after the intervention. Crema et al. (2022) employed MI and ARAT, which were also significant. MI was used by Beroncchi et al. (2017) and indicated a significant difference compared to the baseline, too.

Regarding ADLs improvement, Lee et al. (2021) used mBI, and Millia et al., 2019 employed FIM both showed significant changes from the baseline.

In these six studies, the comparison between groups was not made.

## 5.4 Claims for Tyrosolution &Gloreha

### 5.4.1 Tyromotion

Tyromotion company has claimed that AMADEO and PABLO help regain hand and finger strength and movement, train patients to perform ADLs effectively, and are helpful even in patients with spasticity. They have also claimed that this device benefits patient assessment and enables therapists to supervise more than one client at the same time (Tyromotion, 2020).

This paper summarizes the results of using AMADEO in stroke hand rehabilitation. Table I shows that AMADEO significantly improved participants' FMA from baseline in all studies. The results were also significant in two articles (Aprile et al., 2020& Orihuela-Espina., 2016) that MI used. ARAT in one study (Aprile et al., 2020) was measured and was significant, too. Therefore, it can be concluded that AMADEO successfully improved motor function in this study's participants.

Regarding ADLs improvement, in one study (Butt et al., 2021), MAS, and in another study (Aprile et al., 2020), MBI and FAT were measured and reported significant improvement in the robotic group from baseline.

Only two studies compared robotic and conventional therapy and concluded that in the AMADEO robotic group, improvement of motor function was detected (FMA and MI changed significantly).

Based on the literature reviewed in this paper, these claims are accepted, though more clinical studies need to be performed. We could not find any conflict of interest or evidence of funding the selected articles by the Tyromotion company.

The study by Aprile et al. (2019) showed that the Tyromotion devices were easy to set compared to more complex exoskeleton ones. They also concluded that patient satisfaction was reported to be high, with no differences between groups of two, three, and four members (Aprile et al., 2019).

Germanotta et al. (2020) concluded that AMADEO could reliably distinguish between hand movements performed by a healthy person and those who had suffered from a stroke (Germanotta et al., 2020).

Seitz et al. (2014) concluded that implementing visuomotor device training improved visually guided hand coordination in patients and healthy subjects (Seitz et al., 2014).

### 5.4.2 Gloreha

The Gloreha website and advertisements also claim that the benefits of the robot include: improvement in visual-spatial and attentive abilities, proprioception stimulation, functional independence, ease of pain, edema reduction, coordination improvement, grip and force improvement, increased joint range of motion, prevention of adhesion and contracture caused by immobilization and regaining ADL, and its suitability for home rehabilitation (Gloreha, 2019).

Table II shows the results of articles that use Gloreha in post-stroke hand rehabilitation. In the studies on the effects of Gloreha on motor function improvement, FMA in three articles (Lee et al., 2021; Cordella et al., 2020; Miccinilli et al., 2020) and MI in two studies (Crema et al., 2022&Beroncchi et al., 2018) were significant from the baseline that indicated Gloreha could improve motor function in all participants. Regarding ADLs, two studies were mentioned: significant improvement in mBI (Lee et al., 2021) and FIM (Millia et al., 2019) from the baseline indicated that Gloreha improved ADLs in the mentioned patients.

Cordella et al. (2017) concluded that Gloreha robotic hand's camera-based procedure helped fingers regain their joints' angular values from bending sensors and improved motor performance (Cordella et al., 2020).

Beroncchi et al. (2018) stated that the Gloreha device improved the patient's functional capacity and was safe and feasible for home rehabilitation (Beroncchi et al., 2018).

Except for the article by Bernocchi et al. (2018) that the project's Gloreha Home TC covered the costs of their study, we could not find any support from the Gloreha company or any conflict of interest in the other selected articles.

Therefore, the Gloreha company's claims regarding the effects of this robot can be accepted, though more high-quality studies should be done.

The effectiveness of robotic rehabilitation over physical /occupational therapy is not so clear as in most studies, participants took advantage of both treatments. Regarding the comparison between AMADEO and Gloreha, both robots seem to be effective in regaining and improvement in motor function and ADLs after stroke; we could not find any differences in these two areas between them.

**5.5 Conclusion**

Using robotic devices provide more standardized, consistent, and controllable exercises with multiple patients. This review concluded that rehabilitation robots improve hand recovery in terms of motor function and activities of daily living, compared to the baseline, especially when performed in conjunction with conventional therapy. They can diminish burden on therapists by providing additional therapy that fulfills the main principles of rehabilitation including repetative, functional, and task-oriented sessions. This paper neither concludes whether end-effector or exoskeleton robots can enhance conventional therapy nor whether one is superior to the other.

Effective rehabilitation needs an interdisciplinary team working to provide a comprehensive program for each patient, incorporating the following components: individualized plan and regular participation in the exercises that are varied in type, intensity, frequency, and time; each stroke survivor has specific needs that should be met for their rehabilitation plan. Therefore, stroke rehabilitation should contain various physical/occupational therapies and exercises to restore function in the affected part of the sensory-motor system. In this regard, robots may be considered accessible, somewhat affordable, and persuasive alternatives to traditional physical/occupational therapy or as an adjuvant.

**5.6 Limitations of This Paper**

In most studies, researchers took advantage of conventional therapy in addition to robotic therapy; therefore, concluding the pure effects of robotic devices on participants' function improvement is not possible.

In addition, several general challenges in stroke rehabilitation and rehabilitation studies exist. These include the following:

Too much robot interaction in assisting a paretic hand during training can impose negative consequences (Crespo & Reinkensmeyer, 2009; Schmidt & Bjork, 1999). Assisting in doing exercises would change the learned task dynamics so that it differed from the target movement. Also, the burden on the motor system would diminish due to guiding; this burden is needed to be successful in training. The best solution for this matter has been proposed as assistance as needed, also called faded guidance (Marchal-Crespo & Reinkensmeyer, 2009).

Previous articles indicate that most hand function recovery happens in the first three months post-stroke. However, the recovery process continues slower for an unspecified period, from months to years (Franck et al., 2019). Also, neuroplasticity studies on animals propose that the most training results can be driven in the first month after stroke through the upregulation of growth-promoting factors (Murphy TH & Corbett, 2009). According to current literature, most studies investigated patients in the sub-acute and chronic phases of stroke recovery. Thus, rehabilitation in the acute phase needs to be investigated more in humans.

Moreover, an essential factor neglected in many studies as a valid biological base for training is the need for dose-ranging investigations that should be considered (Craig et al., 2008).

Some professionals have been concerned about muscle hyperactivity or shoulder pain due to the high intensity of robotic exercises. However, various studies have shown the opposite result (Posteraro et al., 2010 & Lo et al., 2010), and results from Lynch et al. (2005) also appear to decrease this concern (Lynch et al., 2005).

The widespread access to robotic devices in rehabilitation has some limitations; one of the major ones is the high cost of devices, estimated to be about 75,000 to 350,000$. However, it can be considered affordable for rehabilitation clinics and hospitals as human labor costs are expected to become more expensive than that for technology. Therefore, when it comes to diminishing the length and price of hospital stays and optimizing human resources, shifting toward robotic devices is expected; they also have the potential to improve productivity and treatment quality in all countries (Duret et al., 2019). In their systematic review of robotic rehabilitation, Lo et al. (2019) also concluded that robotic therapy has brought better economic outcomes than conventional therapy.

Regarding evidence-based rehabilitation in the stroke field, some notable challenges were mentioned in the literature, including the complex essence of interventions and the existing various interrelated components (Craig et al., 2008), the poor establishment of rehabilitation neurophysiology while learning them is important (Murphy TH & Corbett, 2009), the need for managing various problems in participants, as well as an inconsistency between therapists and researchers in describing motor ability changes after a stroke attack (Wade, 1999). Therefore, these challenges should be considered and overcome for designing and conducting research in stroke rehabilitation.

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## Appendix A

**Table I**

*Motor Assessment Scale (Stroke engine, n.d.)*

| | | | |
|---|---|---|---|
| **Motor Assessment Scale (MAS)** | **Scale type** | Performance-based scale | |
| | **Purpose** | Assessing everyday motor function in stroke patients<br>Estimation of muscle tone | 0-6<br><br>4:Normal<br>>4:Hypertone<br><4:Hypotone |
| | **Items** | Supine to side lying<br><br>Supine to sitting over the edge of a bed<br><br>Balanced sitting<br><br>Sitting to standing<br><br>Walking<br><br>Upper-arm function<br><br>Hand movements<br><br>Advanced hand activities | **0-6** |

**Table II**

*Modified Ashworth Scale (Stroke engine, n.d.)*

| | | | |
|---|---|---|---|
| **Modified Ashworth Scale (MAS)** | **Scale Type** | Assessment | |
| | **Items for Upper Limb** | No standardized guidelines for its use.<br>The client is lying supine, with the upper limbs parallel to the trunk, elbows extended, wrists in a neutral position.<br>Moving a client's limb through its full range of motion should be done within one second by counting "one thousand and one | 6 points from 0-4 |
| | **Purpose** | The primary clinical measure of muscle spasticity in patients with neurological conditions. | |

**Table III**

*Medical Research Council (Stroke engine, n.d.)*

| | | | |
|---|---|---|---|
| **Medical Research Council (MRC)** | **Scale Type** | Assessment | |
| | **Purpose** | To evaluate the complaint of weakness, often when there is a suspected neurologic disease through testing key muscles strength from the upper and lower extremities against the examiner's resistance | |
| | **Items for Upper Limb** | Shoulder abductors, elbow flexors, elbow extensors, wrist extensors, finger flexors, hand intrinsic muscles | Scales 0-5 |

**Table IV**

*Fugl-Meyer Assessment and Motricity Index (Stroke engine, n.d.)*

| | | |
|---|---|---|
| **Fugl-Meyer Assessment (FMA)** | **Scale Type** | Stroke-specific, performance-based impairment index |
| | **Purpose** | To assess motor functioning, sensation, balance, joint range of motion, and joint pain in patients with post-stroke hemiplegia<br><br>to determine disease severity, describe motor recovery, and plan and assess treatment. |
| | **Items** | Five domains and there are 155 items in total:<br><br>Motor function (in the upper and lower extremities)<br><br>Sensation (evaluates light touch on two surfaces of the arm and leg and position sensors for 8 joints)<br><br>Balance (contains 7 tests, 3 seated and 4 standing)<br><br>Joint range of motion (8 joints)<br><br>Joint pain |

**Table V**

*Motricity Index (Stroke engine, n.d.)*

| | | |
|---|---|---|
| **Motricity Index (MI)** | **Scale Type** | Assessment |
| | **Purpose** | To assess motor impairment after stroke. |
| | **Items for Upper limb** | (1) pinch grip: using a 2.5 cm cube between the thumb and forefinger:<br><br>19 points: if able to grip the cube but not hold it against gravity 22 points: if able to hold cube against gravity but not against a weak pull, 26 points: if able to hold the cube against a weak pull but strength is weaker than normal<br><br>(2) elbow flexion from 90° so that the arm touches the shoulder<br><br>14 points: if movement is seen with the elbow out and the arm horizontal<br><br>(3) shoulder abduction moving the flexed elbow from off the chest:19 points are given when the shoulder is abducted to more than 90° beyond the horizontal against gravity but not against resistance<br><br>**arm score for each side** = SUM (points for the 3 tests) + 1<br>• minimum score: 0<br>• maximum score: 100 |

Reference: Stroke engine, n.d.

https://strokengine.ca/en/;https://www.ncbi.nlm.nih.gov/books/NBK436008/.

**Table VI**

*Neuropathic Pain Diagnostic Questionnaire **

| | | |
|---|---|---|
| **Neuropathic Pain Diagnostic Questionnaire (DN4)** | **Scale Type** | screening tool |
| | **Purpose** | To estimate the probability of neuropathic pain. |
| | **Questions** | -Interview of the patient: (yes/no) answer<br>1. Does the pain have one or more of the following characteristics? Burning/ Painful cold /Electric shocks<br>2. Is the pain associated with one or more of the following symptoms in the same area?<br>Tingling /Pins and needles/ Numbness/Itching<br>-Examination of the patient: (yes/no) answer<br>3. Is the pain located in an area where the physical examination may reveal one or more of the following characteristics? Hypoesthesia to touch, Hypoesthesia to pinprick<br>4. In the painful area, can the pain be caused or increased by Brushing?<br>YES = 1 point<br>NO = 0 point<br>Patient's Score: out of 10 |

*Reference:

https://aci.health.nsw.gov.au/__data/assets/pdf_file/0014/212900/DN4_Assessment_Tool.pdf