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The Use of Robotic Technology in Stroke Rehabilitation – A Review

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ABSTRACT

Stroke is a significant cause of death and disability in the world. It creates problems for families and national economies alike due to its disruptive nature. Rehabilitation is a way to treat disabilities in stroke survivors, a population that is steadily growing into a larger percentage of the population. However, stroke rehabilitation is not standardized as there is no clear evidence-based guideline that can be applied to every person, leading to differences in care. Other problems with rehabilitation include limitations with a therapist's ability to work continuously and consistently over longer periods of time. Robotics can help with solving both types of problems through their ability to record data and work without requiring rest. There has already been development of rehabilitation robots since the 1990s and more advanced robot platforms have begun to emerge in the literature. This article reviews the literature on stroke rehabilitation and how robotics can positively affect a patient's outcome in stroke rehabilitation. It also reviews several rehabilitation robots classified as either exoskeletons or end-effectors.

Introduction

Today, stroke is one of the main causes of adult disability (Stinear et al., 2020). It is the third leading cause of death and disability while also being the second-leading cause of death worldwide (Feigin et al., 2021). Unfortunately, after non-fatal strokes, victims usually face its consequences — in particular, forms of disability. Over 101 million people worldwide are still living with impairments caused by stroke (WSO, 2022). The occurrence of stroke is extremely frequent in the general population, affecting approximately 14% of people worldwide (Aggogeri et al., 2019). Statistically, 25% of the world's population will suffer from strokes in their lifetime. Over the course of the last 17 years, the number of stroke cases has increased by around 50% (WSO, 2022). Though there have been improvements in healthcare and technology, it is projected that the number of strokes will increase because such improvements extend life but do not prevent the incidence of stroke. Studies have shown that older people are more vulnerable to stroke, as strokes are more frequent in the older population (CDC, 2023). As the elderly population increases due to better life expectancy, the occurrences of stroke will likely also increase (Lo et al., 2012). However, recently there has also been a concerning and increasing number of younger people who have suffered from stroke (Katan & Luft, 2018). Thus, as the world population increases and gets older, the number of stroke cases is expected to increase as well.

Stroke is caused by a lack of oxygen in the brain due to either a loss of blood or blockage of blood vessels. The reduction of blood in the brain results in a loss of oxygen and nutrients in the brain, leading to brain cell death (ASA, N.D.). There are two types of stroke: ischemic and hemorrhagic. Ischemic strokes occur when blood clots or when particles such as plaque block blood flow to the brain. Hemorrhagic strokes occur when a blood vessel ruptures and blood either is unable to flow to the brain or puts too much pressure on the brain (CDC, 2023).

A victim of stroke will be deeply affected by it. Stroke survivors are often left with long-lasting disabilities that cause depression. Stroke survivors often cannot complete simple activities associated with daily living (ADLs) as they are unable to move their disabled limbs. Due to their impairments, stroke survivors may not be able to participate in their jobs as they may have to seek rehabilitation and therapy or they may be physically unable to work. They also lose their sense of independence as they usually require assistance after their injury (Winstein et al., 2016).

Stroke impacts not only its victims, but also the people around the victim. People who suffer from stroke usually have to take temporary leaves of absence from their jobs in order to receive rehabilitation (Winstein et al., 2016). Victims of stroke cannot support their families; instead, they have to be supported by their families. Families that are dependent on the patients' jobs may experience struggles and financial hardships due to the injury. They will lose their source of income and may incur heavy additional costs (upwards of over a hundred thousand dollars per patient) such as those associated with treatments (Katan & Luft, 2018).

Rehabilitation

Rehabilitation consists of interventions to be completed by patients to help them regain (or partially recover) the functions they lost due to trauma, disease, or other causes. Rehabilitation often involves a therapist (or other physician) who guides or instructs a patient through specific exercises to help train the patient's injured muscles or nerves. The exercises are specific to a patient's injury, so rehabilitation exercises may be different for each patient (Lubkin & Larsen, 2005). Rehabilitation for any injury should begin as soon as possible. However, rehabilitation should be implemented carefully as incorrect interventions can result in more harm than recovery. Rehabilitation should begin when the patient can handle the strain associated with different therapies (Winstein et al., 2016). Stroke rehabilitation seeks to recover both a patients' brain and muscle function. Generally, after a stroke, one side of a person's body becomes disabled. The injured part of the brain that causes the disability is generally on the opposite side of the disabled side of the body as each of the hemispheres of the brain controls the opposite side (Andrew et al., 2017). Therefore, complications caused by stroke depend on the side of the brain that was affected: some effects of stroke vary depending on whether the damage was to the left or right side of the brain (AANS, N.D.). Generally, the disabled side of the person's body is the target of stroke rehabilitation. Many people are involved during the rehabilitation of a stroke victim. The patient themselves, friends, immediate family, and therapists are all involved in the patient's recovery from stroke (Lubkin & Larsen, 2005). Additional types of medical workers that can be involved in stroke rehabilitation include "physicians, nurses, physical therapists, occupational therapists, speech-language pathologists, recreation therapists, psychologists, nutritionists, [or] social workers…" (Winstein et al., 2016).

In rehabilitation, conventional therapy refers to the treatment given to patients that is widely accepted and used by the majority of healthcare professionals (NCI, N.D.). Occupational therapy is a type of conventional therapy for stroke rehabilitation. Occupational therapy rehabilitates patients by requiring them to do exercises that relate to activities of daily living (ADLs) (Andrew et al., 2017). In stroke cases, rehabilitation is long, repetitive, high intensity training that simulates real tasks in daily living (Norouzi-Gheidari et al., 2012). Stroke victims are generally given occupational therapy in order to help recover everyday function. It should be noted, however, that conventional therapy is not a single type of therapy given to patients. There are no clear guidelines for conventional therapy for stroke since there are multiple variables that can contribute to the success of a patient's rehabilitation from stroke (Lo et al., 2012). In fact, some guidelines contain general activities or recommendations on different activities for patients but do not label exact activities as "conventional therapy." However, in most countries, there are no evidence-based guidelines for general use. Most of the existing guidelines are highly specialized towards a given field or a given country with its specific resources (Platz, 2019). The type and severity of the impairment can result in different types of therapy administered among patients. A patient who has an injury in their arm will receive different therapy from a person who injured their leg. The financial situation of a patient also comes into play in rehabilitation. One may not be able to afford to go to many therapy sessions, changing the effectiveness of rehabilitation (Norouzi-Gheidari et al., 2012). A person may also not be able to go to the physical therapy sessions due to the location of the facility. Finally, conventional therapy can differ according to each physical therapist since every therapist has a different way of treating his or her patients. There is no clear type of conventional therapy since the type and effectiveness of therapy will change according to each situation and patient. Although there is no conventional therapy for stroke, there are some general types of rehabilitation exercises that can be used to help treat stroke. Some types of exercises for stroke rehabilitation include motor-skill exercises, mobility training exercises, and constraint-induced movement therapy (CIMT) (Mayo Clinic, 2022).

Motor-Skill, Mobility Training, and Constraint-Induced Movement Exercises

Motor-skill exercises are repetitive exercises that are designed to improve muscle strength, range of motion (ROM), and coordination (Mayo Clinic, 2022). They require the injured limb to move from one position to another. There are several ways to classify different motor-skill exercises, and one way to classify them through passive (no resistance or assistance), actively assisted, or actively resisted. Passive motor skill exercises help introduce the patients to the exercises and help establish a baseline for the state of the patient's limb. Actively assisted motor-skill exercises help increase the ROM of the patient using a physical therapist or the unaffected arm. Actively resisted motor-skill exercises help increase strength in addition to increasing ROM. Usually, actively resisted exercises are used after actively assisted exercises since a ROM needs to be established before strength is improved (Yakub et al., 2014). Examples of motor-skill exercises that improve ROM and strength include writing and manipulating physical objects (Levey, N.D.). Motor-skill exercises also help link muscle function with other functions in the body. Motor-skill exercises can help improve dexterity (the ability to do tasks and activities with the hand), hand-eye coordination, and confidence. Examples of motor-skill exercises (see Figure 1) that help improve coordination include putting a pencil in a pencil sharpener, putting a charger in a device, and touching one finger with another (Fairview Rehab & Nursing Home, 2021).

Figure 1. Example of a motor-skill exercise: Grabbing a bottle of water (Yakub et al., 2014)

Mobility training focuses on improving the ROM of the patient in order to improve their mobility. It can help improve strength, coordination, and sensation in the patient's affected muscles (Stroke Foundation, N.D.). Exercises that relate to mobility training include some workouts that require gym equipment (e.g., the kettle arm bar) or most workouts that can be done without the use of equipment (e.g., lunges or squats; see Figure 2) (McLean & Polish, 2023).

Figure 2. Example of mobility training: Lunges (Cronkleton & Tsai, 2019)

CIMT is used to help a person improve upper extremity function by using their impaired muscles through restraining the unaffected muscles (Mayo Clinic, 2022). The healthy muscles can be restrained by using a weight, by tying the limb down with a material (such as string or tape), or any other objects such as a cast, mitt, and sling (Pollock et al., 2014). By restraining the good muscles, the body can focus on weaker arm muscles as seen in Figure 3. The focus on the weaker limb can increase the strength of the limb (especially in the chronic stage of stroke) (Teasell et al., 2020). It can also prevent any unhealthy behaviors that stem from the lack of use of the affected limb, such as learned non-use. As long as the weak side is solely used and the strong side is restrained, most daily activities can be counted as CIMT (Semenko et al., 2021).

Figure 3. Example of CIMT: Restraining one limb while manipulating objects with the impaired extremity (Teasell et al., 2020)

Tracking Levels of Impairment

There are several different ways to track a patient's level of impairment. The Fugl-Meyer Assessment (FMA) is a widely used stroke index that is based on the performance of a patient's motor function after stroke (Norouzi-Gheidari et al., 2012). It tests a patient's senses, motor function, balance, and joints' maximum ROM (without pain) (Teasell et al., 2020; Physiopedia, N.D.). The Functional Independence Measure (FIM) measures a patient's ability to perform ADLs without assistance (Norouzi-Gheidari et al., 2012; Teasell et al., 2020). For example, a patient's ability to take care of themselves, to move, and to understand others are all assessed (Physiopedia, N.D.). These scales are primarily used to compare a robot's treatment to a conventional treatment, although they are not the only ways to measure impairment (Pollock et al., 2014).

Benefits and Obstacles to Rehabilitation and Physical Therapy

There can be many benefits from rehabilitation in stroke patients, and it is generally accepted that stroke rehabilitation helps stroke victims. According to Thomas Platz and his Cochrane review on the effects of stroke care, patients — independent of their race, gender, or other physical factors — generally show a decreased rate of death or a need for future hospital care when they are treated for stroke (Platz, 2019). Rehabilitation usually helps hasten function recovery that was previously lost due to stroke. It works to prevent a disability from becoming a permanent one since 70% of a patient's maximum motor function is achieved after around 6 months of the initial impairment (Teasell et al., 2020). Rehabilitation can recover function that was previously lost due to impairment significantly better than treatment without it. According to Winstein et al. (2006), even the slightest amount of physical therapy helps improve a stroke patient's health. Aerobic exercises, or exercises that increase heart rate, have a tendency to improve many aspects of a patient's body such as bone health or fatigue (Winstein et al., 2016).

Despite the benefits of physical therapy, there can be many obstacles that prevent a patient from receiving vital stroke rehabilitation. As stated before, there is no standard type of conventional therapy in most types of rehabilitation since each patient and their situation is unique. Their own physical therapists may have different remedies from other therapists for the same injury. In terms of physical therapists, there may not be enough physical therapists to treat everyone with stroke. Some occupational therapists may have to take multiple patients at once, lowering the quality of care. In some countries or states within the United States, one may find difficulty gaining access to clinics that provide stroke rehabilitation. For example, in rural areas, there may be a lack of centers because there are not as many people who live in the region. There will be difficulty traveling to rehabilitation centers as patients may live far from these centers. Finally, the cost of physical therapy can also prevent a person from receiving treatment. The worldwide cost for stroke in 2017 was 451 billion dollars (WSO, 2022). In western countries, 3 to 4 percent of total health care costs are due to stroke (Katan & Luft, 2018). Moreover, according to Norouzi-Gheidari et al. (2012), the cost of stroke will increase as the population ages. At the same time, people will be less capable of working at jobs as they grow older. Evidently, some people, especially retired elderly people, may not be able to afford therapy due to their financial situation.

Rehabilitation Robots

Robotics is a branch of technology that designs, creates, and uses machines such as computers and mechanical arms (Yakub et al., 2014). The term "robot" usually refers to a machine that can automatically (or semi-automatically) complete tasks. A robot is able to observe and interpret its surroundings and adjust its actions accordingly. Robots usually gather information and provide real-time feedback autonomously as well. However, it should be noted that some robotic devices can be both autonomous and controlled by humans when they work (Guizzo, 2023).

Over the years, the field of robotics has had an increasing presence in rehabilitation. The first rehabilitation robots were first created during the 1990s (Yakub et al., 2014). Since then, research and development of rehabilitation robots have skyrocketed, while higher quality devices were produced over the past few decades. There have been many trends in the priorities of the developers who create rehabilitation robots for stroke. Strength, safety, simplicity, portability, cost efficiency, adjustability, and efficiency (of the robot) are goals that an ideal rehabilitation seeks to achieve (Aggogeri et al., 2019; Lo et al., 2012). Out of all these requirements, safety has been a top focus for many different devices and their developers (Aggogeri et al., 2019). However, it can be difficult to achieve each criterion as sometimes when one field is improved, another is negatively affected such as in the the employment of lighter materials in robots. Lightweight materials improve safety in devices as they are easier to use. The portability of devices are also increased as the robot has less mass. In some robots, the cost of producing the devices decrease as the lighter materials are not as expensive as the heavier materials. Although safety, portability, and cost are enhanced, strength in some robots worsen as the lighter materials have less integrity than the heavier materials. A robot's degree of freedom (DOF) is also considered when it is produced. Robots with more DOFs are usually more capable of providing care for patients as they can move to a wide array of different positions. Robots that have more DOFs tend to misalign less in relation to the patient, preventing accidents and injuries (Lo et al., 2012). The trends in the development of robotic devices have primarily focused on the capability and convenience of the robots.

Advantages of Rehabilitation Robots

The growing interest for robotics in rehabilitation is primarily driven by the idea that robots can overcome the various problems of modern therapy and produce better outcomes for stroke victims. Various studies have shown that some robotic devices are able to produce results that are similar or greater to the results that conventional therapy provides (Chang & Kim, 2013). There are many needs and uses for robotics in rehabilitation.

One way robots can help with rehabilitation is solving the shortcomings of humans. Many problems associated with physical therapy derive from people. Therapists cannot work continuously for extended periods of time. Therapists need breaks as they cannot work every day for long durations. Their motivation to treat patients can decrease if they are overworked. They can also get injured, sick, or tired, preventing them from properly doing their job. Robots, unlike therapists, can work for long periods of time efficiently without changing their rate of operation. Like therapists, robots can provide periods of high-intensity training to patients, except robots do not experience the same fatigue as therapists, allowing for unfaltering high intensity training (Norouzi-Gheidari et al., 2012). They do not need motivation or take breaks, and they are not influenced by ailments that would affect a person. Sometimes people cannot receive rehabilitation due to a shortage of caregivers. A rehabilitation robot can solve this problem by overseeing multiple patients at once while also being monitored by a therapist (Aggogeri et al., 2019; Norouzi-Gheidari et al., 2012).

In fact, a robot can actually motivate a patient to train further when therapists needs motivation themselves. For example, a robot can use games or virtual reality to motivate patients in going through their exercises (Aggogeri et al., 2019). The games give patients an incentive to do the rehabilitative exercises given to them. Rather than mindlessly repeating several actions, a patient is able to focus on something that they can enjoy while adding more practice (Winstein et al., 2016).

The third way robots can help rehabilitation is through cost efficiency. It costs a lot of money to hire and keep therapists at centers. Using robots, a physician can work with multiple patients at the same time by monitoring them through the robots (Norouzi-Gheidari et al., 2012). Although a robot may require much money initially, treatment centers can recover these up-front costs from having to hire fewer employees. Moreover, it would have a net positive in profit and labor since it is able to reduce required manpower while increasing profits through not having to hire employees (or having them work on other projects) (Aggogeri et al., 2019).

Another benefit to using robots in therapy is telerehabilitation (Aggogeri et al., 2019). There are many cases where a person cannot go for therapy. The rehabilitation center may be too far or the patient may not have the means of transportation. In recent times, COVID-19 and the restrictions that work to prevent its spread have affected most people’s ability to travel to various places. A portable robotic device can be used at a patient's home, so that the patient does not have to travel to the rehabilitation center (Nicholson-Smith et al., 2020). Moreover, a portable robot that works at home would make rehabilitation convenient for the patient.

Finally, a robot can improve rehabilitation by recording data (Aggogeri et al., 2019). Physical therapists and other physicians cannot accurately record data as they provide rehabilitation. Therapists usually track a patient’s progress by tracking how well the patient is able to do the exercise. The only way therapists can watch their patients’ recovery is through visual or physical cues. However, a robot is able to accurately measure a patient’s improvement (Thomson, 2000). For example, it can track the angles a patient makes or how far the patient can reach. It can provide numerical values that a therapist cannot. A robot can also measure the intensity and strength of a patient using sensors, while a therapist can only estimate based on their senses. Based on its values, it can adjust accurately whereas a therapist may have to approximate (Norouzi-Gheidari et al., 2012). Moreover, the use of rehabilitation robots will allow for a standardization of guidelines for stroke as quantitative data becomes available.

Disadvantages of Rehabilitation Robots

However, there are still downfalls to rehabilitative robotic devices. In many cases, there are similar results between the robotic and conventional treatment (Norouzi-Gheidari et al., 2012). There may be signs that robotic treatment is superior, but there is no strong evidence to support this claim. More research is required to confirm if rehabilitation robots are more effective than conventional therapy (Aggogeri et al., 2019). It is often concluded that robotic treatment should be used in addition to conventional therapy instead of replacing it (Chang & Kim, 2013). Another downfall to robots is that they do not always fit desirable requirements (Nicholson-Smith et al., 2020). As mentioned previously, there are certain criteria that help determine whether a robot is ideal for rehabilitation. However, robots today do not achieve every criterion. For example, a hypothetical robot, despite safety and effectiveness, may still cost a lot of money to use. The robot has not only an initial cost, but also operating costs (such as electricity to power it). Maintaining the robot and its parts will create a costly bill as well.

There is potential that a robot can also accidentally provide unsafe environments for the patient (Lum et al., 2006). If a robot malfunctions, a patient can receive an injury that is possibly worse than their initial injury. Moreover, a robot may not be able to adjust itself for every patient (Qian & Bi, 2015). It can be difficult to personalize robots for individual patients as each patient is different. A patient's physique or injury can affect the robot's ability to adjust to them.

Another downfall is the cost of rehabilitation robots. Current rehabilitation robots are costly to produce despite having similar results as conventional therapy (Aggogeri et al., 2019). Eventually, robots may be able to create a net positive profit by paying themselves off in the future (for example, by tending to multiple patients at once as stated before), but currently, many robots are experimental and cost a lot of money to operate (Nicholson-Smith et al., 2020).

Finally, there can be ethical concerns with using robots. A robot must be reviewed by the ORDP (The Orthopaedic and Rehabilitation Devices Panel) and possibly the FDA before it can be used on patients (Qian & Bi, 2015). Some people, especially older patients, may also be uncomfortable with wearing a robotic device around their limb. There is also concern about robots replacing therapists and causing them to lose their jobs — although it is a concern for the future as most robots are not capable of fully replacing therapists (Chang & Kim, 2013).

Rehabilitation Robots Treating Upper Extremities

There are many types of robotic devices that work on various parts of the body. However, most research and the robotic devices that are produced focus on the upper extremities. As a result, this article focuses on robotic devices that work with the upper extremities. Because of this focus, it should be noted that any references to the FMA and the FIM are in relation to the upper extremity version of the assessments. The main categorization of robotic devices in upper extremity rehabilitation are end-effectors and exoskeletons (Aggogeri et al., 2019; Chang & Kim, 2013). Although both types of devices can be used in rehabilitation, there is a current trend that leans more towards exoskeletons (in terms of research and devices) (Lo et al., 2012). End-effectors were developed and produced before exoskeletons. The first rehabilitation robots that were created in the 1990s were end-effectors. Because early end-effectors proved their value in rehabilitation, complex robots such as exoskeletons began to develop (Lo et al., 2012). As technology improved, the ability to create effective exoskeletons also improved. Since exoskeletons are almost always more complex than end-effectors, it takes more time to develop exoskeletons (Aggogeri et al., 2019). Exoskeletons are currently favored over end-effectors since they offer more rehabilitative capabilities. For example, they are able to target multiple joints on the upper limb, unlike end-effectors, which usually only target the hand (Lo et al., 2012).

End-Effectors

End-effectors are usually based on normal robotic manipulators (Qian & Bi, 2015). An end-effector can hold a patient or the patient can grab onto it (Lo et al., 2012). As a result, end-effectors generally have less DOFs than exoskeletons. Due to the nature of the way end-effectors work, a patient with a disability can usually only exercise the muscles in their hand—and additional muscles if it is used along with other rehabilitation devices (Aggogeri et al., 2019). End-effectors generally have three different modes when they are used in rehabilitation: active, passive, and resistive (Qian & Bi, 2015). End-effectors usually apply forces and pressure to distal segments of the hand as a part of rehabilitation (Chang & Kim, 2013). The distal joints and haptic (sense of touch) elements of grabbing an object are ignored while using end-effectors, although ADLs are still successfully mimicked while being used (Aggogeri et al., 2019). However, end-effectors are still a viable option for rehabilitation. End-effectors can be easily adjusted to different patients (Lo et al., 2012). This means that more patients can use the device since it takes less time to set up the device (Aggogeri et al., 2019). Finally, end-effectors tend to be less complex and expensive than exoskeletons (Chang & Kim, 2013).

Table 1. Three Examples of End-effector Rehabilitation Robots

End-effector	DOF	Effectiveness	Notes
MIT-Manus	Seven	Treatment had similar results to intensive care	Some literature change the DOFs on this robot depending on which modules they count
MIME	Six	Improvements in the FMA and FIM	One of the only robots that mimic to good side of patients to rehabilitate the impaired side
GENTLE/s	Six	Improvements in the FMA	Split into two main parts - gimbal mechanism and HapticMaster

The MIT-Manus (see Figure 4) is an end-effector that resembles a traditional industrial manipulator (Qian & Bi, 2015). It was one of the first robotic devices that were developed for rehabilitation (Krebs & Volpe, 2013). The MIT-Manus has four modules that have a total of seven DOFs (Norouzi-Gheidari et al., 2012). The MIT-Manus can help train the abduction, adduction, flexion, extension, pronation, and supination of the wrist (Norouzi-Gheidari et al., 2012). The MIT-Manus has a joystick that the patient grasps onto with the hand of their impaired limb. A patient can also be braced through their arm to the machine, depending on the exercise (Thomson, 2000). Patients are able to move the joystick around like a controller on a game console (Trafton, 2010). In fact, the MIT-Manus is often paired with a screen that displays a game or an activity for the patient in order to motivate the patient in exercises (Thomson, 2000). When it is in use by the patient, it has a passive, resistive, and active mode (Norouzi-Gheidari et al., 2012). It is also able to record data while in use (Thomson, 2000). During tests, it was shown that treatment using the MIT-Manus had similar results to those from intensive therapy administered by humans (Trafton, 2010). Despite the promising results, the MIT-Manus exhibits a few shortcomings. Many patients still prefer to be treated by a human rather than robot therapist (Thomson, 2000). The cost of operating the MIT-Manus also lowers the possibility of using it for the general population (Trafton, 2010).

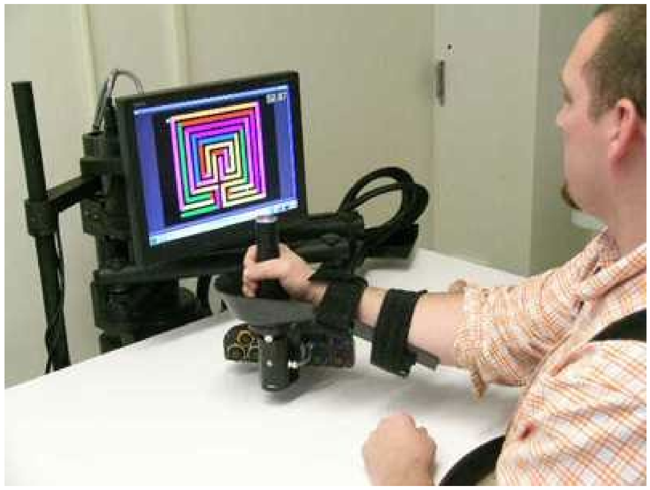

Figure 4. MIT-Manus (Trafton, 2010)

The MIME, or the Mirror Image Movement Enabler, is another end-effector rehabilitation device (see Figure 5). It has six DOFs and replicates the movements of the good limb of the patient (20, 42) . The MIME can also use resistive and assistive forces on the patient during rehabilitation (Norouzi-Gheidari et al., 2012). The MIME has a forearm splint with a handle where the patient can put their hand in (Lum et al., 2006). The limb is secured by straps to prevent it from coming out of the machine. The splint that holds the impaired limb attaches to a robotic arm. The mechanical arm is able to apply various forces to the injured limb since it has several modes like passive and active-assisted movement modes (Lum et al., 2006). Testing in a study revealed that there were improvements in both the FMA and FIM. After six months, however, the control group (intensive conventional therapy) and the group given robotic therapy had similar FMA scores (Lum et al., 2006). In another separate study, the MIME actually had greater improvements than the control group (conventional therapy) in just the FMA, although further testing is required to confirm their findings (Burgar et al., 2000). Both studies indicate that the MIME has similar or greater effects when compared to conventional therapy.

Figure 5. MIME (Amirabdollahian et al., 2007)

The GENTLE/s (also known as the GENTLE/G) is an end-effector system that has a total of six DOFs (see Figure 6). It consists of a 3 DOF robot manipulator (usually the HapticMaster) and a 3 DOF gimbal mechanism (Aggogeri et al., 2019; Amirabdollahian et al., 2007; Kan et al., 2011). It also has a splint with straps to hold the patient in place attached to a mechanical arm, which is part of the larger frame structure (Amirabdollahian et al., 2007). The robot additionally has an operation button that can be used by the therapist or patient to begin exercises (Amirabdollahian et al., 2007; Kan et al., 2011). The robot can also be paired with a screen in order to display a game or activity during an exercise (Amirabdollahian et al., 2007; Kan et al., 2011). The robot can allow a patient to move in several different positions. It allows for the flexion and extension of the wrist, the pronation and supination of the elbow, and flexion and extension of all five fingers (Aggogeri et al., 2019; Amirabdollahian et al., 2007). The robot has three modes: Patient passive, patient active-assisted, and patient active (Amirabdollahian et al., 2007). The GENTLE/s has also demonstrated an ability to track a patient's progress. It was able to record data for analysis after the tests (Amirabdollahian et al., 2007). In a study conducted between the GENTLE/s and a sling-suspension based therapy, there have been small yet noteworthy improvements in the FMA for both types of therapies, indicating encouraging prospects for robotics in the future (Amirabdollahian et al., 2007).

Figure 6. GENTLE/s (Amirabdollahian et al., 2007)

Exoskeletons

Exoskeletons, or orthoses, are wearable robotic devices that usually cover a patient's entire arm (Aggogeri et al., 2019). Exoskeletons, like end-effectors, generally have three different modes when they are used in rehabilitation: active, passive, and resistive (Qian & Bi, 2015). The robotic joints correspond to the patient's actual anatomical joints so that the robot can work with the patient when it is turned on (Aggogeri et al., 2019). Exoskeletons are larger and more complex than end-effectors as they deal with more joints and more parts of the limb (Chang & Kim, 2013). Consequently, exoskeletons take longer to set up than end-effectors (Aggogeri et al., 2019). Moreover, exoskeletons must be adjusted to each patient's anatomical joints, so it will take time to set up the robots. The benefit of using exoskeletons over end-effectors however is that exoskeletons are able to train the entire upper extremity rather than just the hand (Lo et al., 2012). Exoskeletons also generally have more DOFs than end-effectors because they tend to work with more joints than end-effectors. This allows for more mobility in the patient and prevents the patient's arm from misaligning with the motors (Lo et al., 2012).

Table 2. Three Examples of Exoskeleton Rehabilitation Robots

Exoskeleton	DOF	Effectiveness	Notes
ARMin Series	Six to Seven (depending on modules)	ARMin I and ARMin II demonstrated improvements in motor function (FMA) ARMin V has the ability to have input and adjust based on data	Five different versions
HandSOME	One	Has the ability to create realistic environments for patients	Works with ARMin III for better rehabilitative results
T-WREX	Five	Improvements in the arm and recorded for FMA, ROM, and ability to do ADLs	T-Wrex → Therapy Wilmington Robotic Exoskeleton

The ARMin robot series (see Figure 7) produced by ETH Zürich are examples of exoskeletons used in rehabilitation. There have been five different types of ARMin robots, with the ARMin V robot being the most recent robot developed in the series (ETH Zürich, N.D.). The ARMin robots have similar structures to each other, and they all focus on rehabilitating the upper limb. The robots consist of an exoskeleton that goes around the patients' entire limbs and a structural frame that holds the robot (Aggogeri et al., 2019). The robots can also be paired with screens that can display games during exercises (ETH Zürich, N.D.). Every version of the robot other than the first usually has around six to seven DOFs, depending on whether additional modules are attached (9, Aggogeri et al., 2019; Baur et al., 2016; Staubli et al., 2009; Nef et al., 2009). ARMin I was successful in rehabilitating patients' elbows and shoulders, demonstrating improvements in motor function (Staubli et al., 2009). However, distal arm function was missed due to the nature of ARMin I's design and rehabilitation focus. In a pilot study, ARMin II was able to improve the FMA scores for three out of four patients during tests while patients reported that the improvements either stayed the same or improved six months later (Staubli et al., 2009). ARMin III has the capability to be used with other exoskeletons, such as the hand exoskeleton, HandSOME (Brokaw et al., 2011). ARMin V is able to use quantitative data to rehabilitate patients and works best with human therapists as it allows them to put parameters into the robot before or during training (ETH Zürich, N.D.).

Figure 7. ARMin V (ETH Zürich, N.D.)

HandSOME (see Figure 8) is a passive rehabilitative exoskeleton that covers the hand of a patient (Aggogeri et al., 2019). HandSOME only has one DOF since it primarily works on the joints of the hand (Aggogeri et al., 2019). The HandSOME is considered to be a passive exoskeleton since it utilizes linkages to apply force rather than motors or other actuators (Aggogeri et al., 2019). The elastic cords it contains allows the robot to apply extension torques to the patients (Aggogeri et al., 2019; Brokaw et al., 2014). Due to the lack of actuators, it is a lightweight exoskeleton, weighing only 220 grams (Aggogeri et al., 2019). HandSOME can be used with another robot since it only rehabilitates the hand of the patient. As mentioned previously, it was used with ARMin III for rehabilitation (Brokaw et al., 2011). With ARMin III, HandSOME is able to give realistic practice to patients through the employment of virtual reality or of real objects, making it possible for it to be used with conventional therapy (Brokaw et al., 2014).

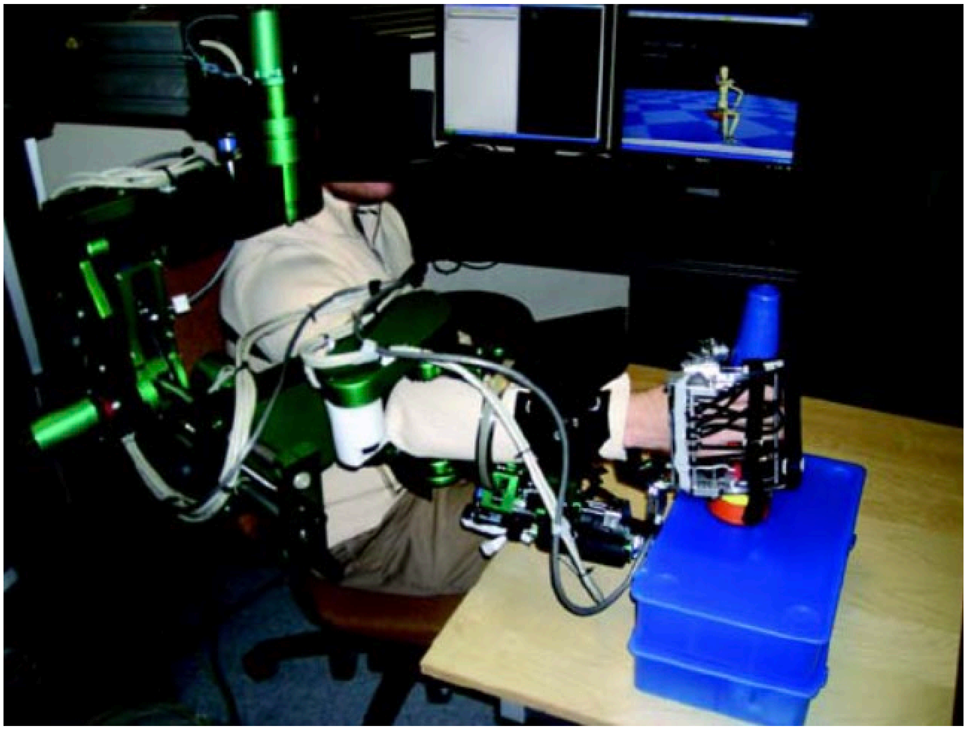

Figure 8. HandSOME and ARMin III (Brokaw et al., 2011)

The T-WREX (The Therapy Wilmington Robotic Exoskeleton – See Figure 9) is an exoskeleton that covers the entire upper limb (Norouzi-Gheidari et al., 2012). It has five DOFs and can be used for either the arm or the body (Norouzi-Gheidari et al., 2012; Housman et al., 2007). It is passive as it has no actuators and uses elastic bands to apply forces to the patient's limb (Housman et al., 2007). It is easily adjustable as its power is based on the number of bands. The T-WREX is able to sense pressure from the patient's hand through the sensor present in its orthoses (Chan et al., 2016). It is also able to simulate ADLs when it is paired with a computer or virtual reality (as used in a version based on the T-WREX called ArmeoSpring) (Chan et al., 2016). In fact, there have been attempts at combining the T-WREX with virtual reality to make rehabilitation more functional (Norouzi-Gheidari et al., 2012; Kan et al., 2011). The T-WREX can also collect data on a patient, providing an opportunity to improve stroke guidelines (Housman et al., 2007). It can also be used at home, providing opportunities for telerehabilitation (Rahman et al., 2006). In one study, the patients who were rehabilitated by T-WREX had improvements in FMA scores (Housman et al., 2007). In another study involving two randomized control trials, one of the trials had larger gains than the control group in arm improvement, ROM, and the ability to do ADLs (Chan et al., 2016). The results of the T-WREX show that it can be effective for general rehabilitation and can be used for clinical use (Chan et al., 2016). In fact, an improved version of T-WREX called ArmeoSpring is commercially available (Chan et al., 2016).

Figure 9. T-WREX (Housman et al., 2007)

Conclusion

Stroke is a terrible illness that negatively impacts the lives of many people. As the human population grows both in number and in age due to the advancements in healthcare and technology, the number of stroke cases will rise as well. Although stroke rehabilitation is a start to combating the disability that follows stroke, there is a clear need for improvement in stroke rehabilitation and, therefore, a need for better research on stroke. For example, there needs to be clear international guidelines for stroke rehabilitation so that patients can receive the best possible treatment. Although a therapist may have good judgment with regards to rehabilitation, they are not perfect. Sometimes, the exercises they give patients do not reflect ADLs nor have the high-intensity level that the victims need to become healthier. Stroke patients also need better access to affordable care in order to improve their quality of life and regain their sense of independence.

This review of several robotic devices and their effects on stroke victims makes evident that robotics has a future in rehabilitation. The developing field of robotics can be used as a tool for therapists to use to help stroke patients. Several studies and trials demonstrated that robot-based therapy can produce similar outcomes to conventional therapy. Since robots can be just as effective as therapists using conventional therapy, they can be used with therapists or even replace them in certain situations. Robots can also help therapists attend to multiple patients at once, allowing more patients to receive therapy. Robotic devices can also be used to help standardize guidelines for stroke rehabilitation through recording data. Robots can measure and record numerical values for the progress of patients. Instead of relying on estimations based on feeling and appearance, a robot can measure the exact improvements of a patient. It is this potential to standardize guidelines for therapy that is particularly meaningful considering the prohibitive costs of using rehabilitation robots for the public. There are still problems in the path for robots in rehabilitation. Many robots are still being developed or are being improved. Robots can still be expensive and there can be ethical concerns over introducing robotics as a standard for rehabilitation. Moreover, robotics has not developed to the point where they can fully replace human therapists. Nevertheless, the benefits of robots in rehabilitation still stand. Robotics likely will be the future for rehabilitation.

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References

Aggogeri, F., Mikolajczyk, T., & O'Kane, J. (2019). Robotics for rehabilitation of hand movement in stroke survivors. *Advances in Mechanical Engineering*, *11*(4), 1687814019841921.

American Stroke Association (ASA). (N.D.). *About Stroke*. American Stroke Association. https://www.stroke.org/en/about-stroke

American Association of Neurological Surgeons (AANS). (N.D.) *Stroke*. American Association of Neurological Surgeons. https://www.aans.org/Patients/Neurosurgical-Conditions-and-Treatments/Stroke#:~:text=One%20side%20of%20the%20brain,left%20side%20of%20the%20body

Amirabdollahian, F., Loureiro, R., Gradwell, E., Collin, C., Harwin, W., & Johnson, G. (2007). Multivariate analysis of the Fugl-Meyer outcome measures assessing the effectiveness of GENTLE/S robot-mediated stroke therapy. *Journal of neuroengineering and rehabilitation*, *4*(1), 1-16.

Andrew, M., Hoessly, M., & Hedges, K. (2017). *Your Guide to Exercise After a Stroke - A Guide for People with Stroke and Their Families*. Stroke Foundation NZ.

Baur, K., Klamroth-Marganska, V., Giorgetti, C., Fichmann, D., & Riener, R. (2016, June). Performance-based viscous force field adaptation in upper limb strength training for stroke patients. In *2016 6th IEEE International Conference on Biomedical Robotics and Biomechatronics (BioRob)* (pp. 864-869). IEEE.

Brokaw, E. B., Murray, T., Nef, T., & Lum, P. S. (2011). Retraining of interjoint arm coordination after stroke using robot-assisted time-independent functional training. *J Rehabil Res Dev*, *48*(4), 299-316.

Brokaw, E. B., Nichols, D., Holley, R. J., & Lum, P. S. (2014). Robotic therapy provides a stimulus for upper limb motor recovery after stroke that is complementary to and distinct from conventional therapy. *Neurorehabilitation and neural repair*, *28*(4), 367-376.

Burgar, C. G., Lum, P. S., Shor, P. C., & Van der Loos, H. M. (2000). Development of robots for rehabilitation therapy: The Palo Alto VA/Stanford experience. *Journal of rehabilitation research and development*, *37*(6), 663-674.

Centers for Disease Control and Prevention (CDC). (2023, May 4). *About Stroke*. cdc.gov. https://www.cdc.gov/stroke/about.htm

Centers for Disease Control and Prevention (CDC). (2023, May 4). *Stroke Facts*. cdc.gov. https://www.cdc.gov/stroke/facts.htm

Chan, I. H., Fong, K. N., Chan, D. Y., Wang, A. Q., Cheng, E. K., Chau, P. H., ... & Cheung, H. K. (2016). Effects of arm weight support training to promote recovery of upper limb function for subacute patients after stroke with different levels of arm impairments. *BioMed research international*, *2016*.

Chang, W. H., & Kim, Y. H. (2013). Robot-assisted therapy in stroke rehabilitation. *Journal of stroke*, *15*(3), 174.

Cronkleton, E. & Tsai, A. (2019, October 18). *11 Benefits of Doing Lunges Regularly*. Healthline. https://www.healthline.com/health/exercise-fitness/lunges-benefits#takeaway

ETH Zürich. (N.D.). *ARMin V*. ETH Zürich. https://sms.hest.ethz.ch/research/current-research-projects/armin-robot/armin-v.html

Fairview Rehab & Nursing Home. (2021, July 19). *Regain Motor Skills: What Exercises Improve Coordination?* Fairview Rehab & Nursing Home. https://www.fairviewrehab.com/rehab/regain-motor-skills/

Feigin, V. L., Stark, B. A., Johnson, C. O., Roth, G. A., Bisignano, C., Abady, G. G., ... & Hamidi, S. (2021). Global, regional, and national burden of stroke and its risk factors, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet Neurology*, *20*(10), 795-820.

Flint Rehab & Tran, A. (2022, October 19). *Stroke Exercises for the Full-Body: How to Recover Mobility at Home*. Flint Rehab. https://www.flintrehab.com/stroke-exercises/

Guizzo, E. (2023, August 9). *What Is a Robot?* IEEE. https://robotsguide.com/learn/what-is-a-robot

Housman, S. J., Le, V., Rahman, T., Sanchez, R. J., & Reinkensmeyer, D. J. (2007, June). Arm-training with T-WREX after chronic stroke: preliminary results of a randomized controlled trial. In *2007 IEEE 10th international conference on rehabilitation robotics* (pp. 562-568). IEEE.

Kan, P., Huq, R., Hoey, J., Goetschalckx, R., & Mihailidis, A. (2011). The development of an adaptive upper-limb stroke rehabilitation robotic system. *Journal of neuroengineering and rehabilitation*, *8*(1), 1-18.

Katan, M., & Luft, A. (2018, April). Global burden of stroke. In *Seminars in neurology* (Vol. 38, No. 02, pp. 208-211). Thieme Medical Publishers.

Krebs, H. I., & Volpe, B. T. (2013). Rehabilitation robotics. Handbook of clinical neurology, 110, 283–294. https://doi.org/10.1016/B978-0-444-52901-5.00023-X

Levey, R. (N.D.). *Exercises and Activities to Improve and Maintain Fine Motor Skills*. Reddy-Care. https://www.reddycare.net/blog/exercises-and-activities-to-improve-and-maintain-fine-motor-skills

Lo, H. S., & Xie, S. Q. (2012). Exoskeleton robots for upper-limb rehabilitation: State of the art and future prospects. *Medical engineering & physics*, *34*(3), 261-268.

Lubkin, I. M. & Larsen P. D. (2005). *Chronic Illness: Impact and Interventions*. Jones & Bartlett Pub.

Lum, P. S., Burgar, C. G., Van der Loos, M., Shor, P. C., Majmundar, M., & Yap, R. (2006). MIME robotic device for upper-limb neurorehabilitation in subacute stroke subjects: A follow-up study. *Journal of rehabilitation research & development*, *43*(5).

Mayo Clinic Staff. (2022, May 18). *Stroke rehabilitation: What to expect as you recover*. Mayo Clinic. https://www.mayoclinic.org/diseases-conditions/stroke/in-depth/stroke-rehabilitation/art-20045172

National Cancer Institute (NCI). (N.D.). *Definition of conventional therapy*. National Cancer Institute https://www.cancer.gov/publications/dictionaries/cancer-terms/def/conventional-therapy

Nef, T., Guidali, M., & Riener, R. (2009). ARMin III–arm therapy exoskeleton with an ergonomic shoulder actuation. *Applied Bionics and Biomechanics*, *6*(2), 127-142.

McLean, S. & Polish, A. (2023, August 9). *The 20 Best Mobility Exercises For Better Movement And Performance*. BarBend. https://barbend.com/best-mobility-exercises/

Nicholson-Smith, C., Mehrabi, V., Atashzar, S. F., & Patel, R. V. (2020). A multi-functional lower-and upper-limb stroke rehabilitation robot. *IEEE Transactions on Medical Robotics and Bionics*, *2*(4), 549-552.

Norouzi-Gheidari, N., Archambault, P. S., & Fung, J. (2012). Effects of robot-assisted therapy on stroke rehabilitation in upper limbs: systematic review and meta-analysis of the literature.

Platz, T. (2019). Evidence-based guidelines and clinical pathways in stroke rehabilitation—an international perspective. *Frontiers in Neurology*, *10*, 200.

Pollock, A., Farmer, S. E., Brady, M. C., Langhorne, P., Mead, G. E., Mehrholz, J., & van Wijck, F. (2014). Interventions for improving upper limb function after stroke. *Cochrane Database of Systematic Reviews*, (11).

Physiopedia. (N.D.). *Fugl-Meyer Assessment of Motor Recovery after Stroke*. Physiopedia. https://www.physio-pedia.com/Fugl-Meyer_Assessment_of_Motor_Recovery_after_Stroke

Physiopedia. (N.D.). *Functional Independence Measure (FIM)*. Physiopedia. https://www.physio-pedia.com/Functional_Independence_Measure_(FIM)

Qian, Z., & Bi, Z. (2015). Recent development of rehabilitation robots. *Advances in Mechanical Engineering*, *7*(2), 563062.

Rahman, T., Sample, W., Jayakumar, S., & King, M. M. (2006). Passive exoskeletons for assisting limb movement. *Journal of rehabilitation research and development*, *43*(5), 583.

Semenko, B., Thalman, L., Ewert, E., Delorme, R., Hui, S., Flett, H., & Lavoie, N. (2021). *An Evidence Based Occupational Therapy Toolkit for Assessment and Treatment of the Upper Extremity Post Stroke*. Winnipeg Health Region Occupational Therapy Upper Extremity Working Group.

Staubli, P., Nef, T., Klamroth-Marganska, V., & Riener, R. (2009). Effects of intensive arm training with the rehabilitation robot ARMin II in chronic stroke patients: four single-cases. *Journal of neuroengineering and rehabilitation*, *6*, 1-10.

Stinear, C. M., Lang, C. E., Zeiler, S., & Byblow, W. D. (2020). Advances and challenges in stroke rehabilitation. *The Lancet Neurology*, *19*(4), 348-360.

Stroke Foundation. (N.D.). *Mobility and exercise after stroke*. Stroke Foundation. https://strokefoundation.org.au/what-we-do/for-survivors-and-carers/after-stroke-factsheets/mobility-and-exercise-after-stroke-fact-sheet

Teasell, R., Hussein, N., Mirkowski, M., Vanderlaan, D., Saikaley, M., Longval, M., & Iruthayarajah, J. (2020). *Stroke Rehabilitation Clinician Handbook 4. Hemiplegic Upper Extremity Rehabilitation*. Heart & Stroke Foundation.

Thomson, E. A. (2000, June 7). *MIT-Manus robot aids physical therapy of stroke victims*. MIT News. https://news.mit.edu/2000/manus-0607

Trafton, A. (2010, April 19). *Robotic therapy helps stroke patients regain function*. MIT News. https://news.mit.edu/2010/stroke-therapy-0419

U.S. Food & Drug Administration (FDA). (2021, November 18). *Orthopedic and Rehabilitation Devices Panel*. U.S. Food & Drug Administration. https://www.fda.gov/advisory-committees/medical-devices-advisory-committee/orthopaedic-and-rehabilitation-devices-panel

Winstein, C. J., Stein, J., Arena, R., Bates, B., Cherney, L. R., Cramer, S. C., ... & Zorowitz, R. D. (2016). Guidelines for adult stroke rehabilitation and recovery: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*, *47*(6), e98-e169.

World Stroke Organization (WSO). (2022). *Global Stroke Fact Sheet 2022*. WSO.

Yakub, F., Khudzari, A. Z. M., & Mori, Y. (2014). Recent trends for practical rehabilitation robotics, current challenges and the future. *International Journal of Rehabilitation Research*, *37*(1), 9-21.