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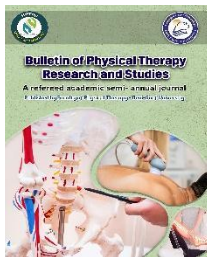

Robot-Assisted Gait Training Is a Promising Novelty In The Neurorehabilitation: Narrative Review

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Running Title: Robot-Assisted Gait Training Is a Promising Novelty In Post-Stroke Rehabilitation: Narrative Review

Abstract

Background: A major cause of long-term disability on the word wide scale is stroke, and gait is among the most demanding outcomes because of which people become stricken. Conventional physical therapy has been questioned to restore functional ambulation particularly in cases of patients with moderate to severe motor impairments. Robot-Assisted Gait Training (RAGT) has been appearing as a new intervention candidate able to provide a repetitive, task-specific intensive locomotor rehabilitation .

Objective: The objective of this narrative review is to outline the existing scenarios of RAGT systems, to report their clinical efficiencies, to examine their neuroplastic mechanisms, and to point out the limitations and future research directions in treating post-stroke conditions by using rehabilitation strategies.

Methods: The search of peer-reviewed articles published in 2008-2025 on the basis of databases, including PubMed, PEDro, Cochrane Library, and Google Scholar was carried out completely. Articles on RAGT-based interventions after stroke with any age were considered, as well as hybrid protocols involving RAGT (combined with any other therapeutic intervention).

Results: Positive outcomes of RAGT have been demonstrated to gait speed, gait symmetry, gait endurance and balance especially when introduced in the subacute and chronic stages of the stroke. Both end-effector and exoskeleton present certain benefits depending on the degree to which a patient

is affected. Multimodal stimulation supplements the outcomes by supplementing hybrid RAGT therapies. Nevertheless, the problem continues to be heterogeneity of protocols, lack of long-term follow-up, and high costs that do not facilitate its universal use.
Conclusion: The application of RAGT forms a useful supplement to standard stroke rehabilitation especially when applied on an individual basis coupled with other treatments. The next steps to increase the universality of the procedures, make them more accessible, and find neuroplastic biomarkers to maximize the results should be aimed.
Keywords: end-effector, exoskeleton, neuroplasticity, rehabilitation, robot-assisted gait training and stroke.

Introduction

Stroke is a major cause of adult disability all over the world and is known to affect more than 12 million individuals annually with a big percentage of the patients' developing sequelae on motor functions. Gait dysfunction is one of the most frequent and disabling sequelae among them, highly restricting the independence, mobility and quality of life of the patients[(1)] .Stroke is an increasingly important issue in terms of public health in Egypt; its increased incidence is determined by the aging populations, ineffective management of vascular risk factors, and inaccessibility to early rehabilitation interventions. Although effective, traditional physical therapy modalities are usually labor intensive, therapist dependent and limited by fatigue and inconsistency of delivery[(2)] · Robot-Assisted Gait Training (RAGT) is a promising novelty in the neurorehabilitation sphere that has appeared in recent years, and highly repetitive, task-specific, and intensive training can be adjusted to the stroke survivor. These robotic devices are fabricated to help patients walk with pre-set, biomechanically correct gait cycles, and they offer real-time feedback to the therapists although they lessen the physical weight of the therapists. It has been hypothesized that RAGT increases neuroplasticity and induces cortex reorganization and motor relearning, especially during the early phases of stroke[(3)] · RAGT devices are roughly divided into 2 distinct categories, namely end-effector systems (where the feet of the patient are guided by motorized footplates (e.g., G-EO System, GT I)) and exoskeleton systems (where the joint motion is controlled by wearable robotic braces (e.g., Lokomat, EksoGT)). Training intensity, patient engagement, set up time and cost are unique benefits and drawbacks of each system. Their effect on various stages of stroke recovery. Clinical trials have been conducted on their effect on stroke recovery at acute inpatient hospitalization through to chronic outpatient care with mixed results based on patient selection, time of intervention, and training methodologies[(4)] Although the clinical utility of RAGT has been supported by evidence in high-income countries in terms of its effectiveness in improving walking ability, balance, and functional mobility, there is still little adoption of the treatment in low-resource settings, including Egypt and other countries in the Middle East. Obstacles are that it is expensive, there is inadequate trained staff and it is not well integrated into national rehabilitation plans. Nevertheless, as the interest in technology-assisted care is increasing, RAGT has a chance to become a game-changer in stroke rehabilitation services provision in the area--provided that it is introduced in a strategic way .Thus, the purpose of this narrative review is to summarize the existing evidence base on robot-assisted gait training in stroke patients, as well as what types of systems are present, how they work, their clinical effectiveness at different stages of stroke, and any practical limitations to their use. Future directions and the possible role of RAGT in the increase of rehabilitation capacity in Egypt and other health care settings alike are also discussed in the review[(5)] ·

Methodology

The presented narrative review was performed to investigate and synthesize the existing evidence concerning robot-assisted gait training (RAGT) application in stroke rehabilitation patients. The non-systematic search strategy was used to find out relevant peer-reviewed articles between January 2008 and May 2025. Such databases as PubMed, PEDro, Cochrane Library, and Google Scholar were queried using a combination of the following keywords: “robot-assisted gait training,” “stroke,” “exoskeleton,” “end-effector,” “rehabilitation,” and “neuroplasticity.” Preference was provided to randomized controlled trials (RCTs), meta-analyses, systematic reviews, and large cohort studies, which assessed the clinical effectiveness of RAGT among post-stroke populations. Other sources like clinical guidelines, expert opinions, and proceedings of conferences were likewise examined in order to present a clear panorama. Articles were only included if they were in the English language and dealt with adult stroke patients (age ≥ 18 years). Research that utilized pediatric populations or non-stroke neurological disorders were eliminated. The quality of the findings emphasized focusing on the results investigating various kinds of RAGT devices, stroke recovery phases (subacute, and chronic), and outcome measures connected with gait, functional mobility, and quality of life. The information in the chosen articles was then thematically synthesized, taking into consideration the mechanisms of action, treatment procedures, and device features, and practical aspects of applying them in clinical practice in low-resource or developing countries context, including Egypt[6] .

Classifications of Robot-Assisted Gait Training System

There are two main types of robot-assisted gait training systems that may be distinguished in terms of mechanical implementation and the way of interaction with a patient end-effector systems and exoskeleton systems. All these types possess certain distinctive characteristics that determine the way of their therapeutic use, convenience, and clinical efficiency[7] .

1. End-Effector Systems

The functioning of the end-effector systems is based on the movement of the feet of the patient through a guided motion with the help of footplates that provide the sensation of a normal gait pattern. The patient is asked to stand on the footplates, and the system moves the lower limbs through the gait phases. Among them, one can distinguish Gait Trainer GT I, G-EO System, and LokoHelp[8] . These systems mostly strengthen the distal parts (foot and ankle) and depend on posture control and trunk stability of the patient to finish the movement pattern. They are mostly simpler to install and can process patients faster. Research has found end-effector devices to be successful in helping to change gait parameters including walking speed, stride length, and endurance, most so when used with traditional physiotherapy. They are less expensive and less complicated in design which means that they may be more readily available in low-resource environments[9] .

2. Exoskeleton Systems

Exoskeleton systems comprise of a robotic orthosis which the patient wears to assist and constrain the joint motion at the hip, knee, and in some cases ankle. They are more anatomically aligned and have the possibility of having precise control of the joint angles, force, and the range of motion. These are Lokomat, EksoGT, ReWalk, and HAL (Hybrid Assistive Limb) [10] . The systems are generally utilized in combination with a body weight support (BWS) system and a treadmill, whereas others are built to allow overground walking. Exoskeletons can provide very customized gait-patterns and biofeedback, which potentially leads to motor learning and motivation. They are, however, more complicated to use, take longer to set up and much more costly. There is research indicating that exoskeleton-based RAGT holds the potential of generating clinically significant advances in gait function, mostly during stroke rehabilitation early and subacute stages. In addition, the devices can be more helpful to the patients with more severe motor impairments, who cannot independently initiate the gait[11].

3. **Hybrid technologies and Emerging technologies**

More recent progress has given rise to the existence of hybrid systems, i.e., the combination of robotic gait training with other modalities, including virtual reality (VR), functional electrical stimulation (FES), and brain-computer interfaces (BCIs). The technologies are designed to achieve higher patient engagement and active participation, and have a greater capability of stimulating cortical plasticity[12]. Indicatively, the RAGT in combination with FES has proven capable of enhancing muscle activation and decreasing spasticity, whereas the VR integration can positively affect motivation and compliance due to the simulation of the real-life walking conditions. These systems are the future of stroke rehabilitation, even though they are still under research, they are personalized and immersive, and therefore, the future of stroke rehabilitation[13].

Table 1: Robot-Assisted Gait Training Systems

Feature	End-Effector Systems	Exoskeleton Systems	Hybrid/ Emerging Technologies
Mechanism of Action	Moves feet along fixed trajectory using footplates	Controls joint movement via wearable robotic exoskeleton	Combines robotics with VR, FES, or brain-computer interfaces
Examples	Gait Trainer GT 1, G-EO System, LokoHelp	Lokomat. EksoGT, ReWalk, HAL	VR-integrated Lokomat, RAGT+ FES, BCI- enhanced systems
Targeted Joints	Mainly distal (ankle and foot)	Hip, knee ± ankle	Multiple joints and neural pathways
Body Weight Support (BWS)	Often included	Usually required	Varies depending on system
Setup Time	Relatively short	Longer due to fitting and calibration	Moderate to long
Patient Engagement	Passive to moderately active	Active, with biofeedback	Highly interactive and immersive
Customization of Gait Parameters	Limited	High	High, with adaptive learning
Suitability	Subacute and chronic stroke patients	Acute to chronic, especially severe cases	Experimental, tailored for motivated or younger patients
Advantages	Easy to use, less expensive, suitable for clinics	Precise joint control, high intensity, promotes neuroplasticity	Enhanced motivation, multimodal stimulation
Limitations	Less precise control, limited joint training	High cost, requires trained staff	Limited availability, still under research

Is robot-assisted gait training (RAGT) in stroke rehabilitation effective or not?

Robot-assisted gait training (RAGT) is a stroke rehabilitation intervention whose clinical effectiveness has been extensively studied during the last twenty years. Its possible advantages are attributed to its capacity to provide highly repetitive, task-oriented, and intensive training which is identified to facilitate motor recovery and neuroplasticity following a stroke. The evidence of RAGT during stroke recovery is examined in this section at various stages; acute, subacute, and chronic[14] · Rehabilitation of after stroke should begin as early as possible in order to optimize the results of the recovery process. A number of studies have demonstrated that application of RAGT in the acute (within 7 days) and subacute (7 days to 6 months) stages can surprisingly enhance gait-related outcomes when used with traditional physical therapy[15] · Mehrholz et al. (2020) conducted a multicenter randomized controlled trial in which 408 patients participated and revealed that RAGT applied in the subacute phase resulted in significantly more patients improving walking independence and gait speed in comparison with patients treated with conventional therapy alone. The derived benefit of RAGT in regards to cortical reorganization is thought to be due to the capability of early mobilization and regular movement patterns which reduce learned non-use of the affected limb[16] · Furthermore, among patients with severe motor deficits and lack of ability to weight bear or take a step, RAGT allows safe gait training without the need of substantial manual support. This gives the therapists time to concentrate on the adjustments in other functional areas without compromising the safety and motivation of the patients· However, in chronic stroke patients (> 6 months post-onset), RAGT could be used differently, that is, it may not be viewed as the means to relearn how to walk, but to improve endurance, balance and gait symmetry. It is known that neuroplasticity is less in the chronic phase but even then, robotic training provides repetitive and patterned gait cycles which can strengthen functional mobility and lower the risk of falls[17] · According to a meta-analysis carried out by Bruni et al. (2021) RAGT enhanced gait speed and walking distance among chronic stroke survivors, especially those who still had some degree of walking ability. Nevertheless, the extent of improvement was in most cases lesser than those observed during the subacute phase. It indicates that RAGT is not contraindicated in the chronic cases but the sooner it is initiated the greater are the effects[18] ·

Comparisons to Standard Therapy

Although RAGT is not meant to substitute conventional physiotherapy, it can be used to supplement results when used as part of the multidisciplinary rehabilitation programs. Research indicates that RAGT in combination with traditional gait training promotes more progress in gait speed, cadence and walking independence than traditional gait training alone -particularly among non-ambulatory patients, or those at risk of falls due to poor balance. Therapist-directed therapy is, however, still required to work on individual impairments (e.g., coordination, spasticity), as well as to encourage adaptive solutions in real-life walking situations. Hence, in the majority of cases, the most efficient protocols include RAGT in combination with traditional therapy, and the duration, frequency, and progression of the sessions depend on the functional level of the patient[19]·

Effectiveness Factors

Several variables affecting the clinical outcome of RAGT include:

- Post-stroke timing (the sooner the better).
- Baseline motor function and level of impairment of patient.
- The kind of robotic system applied (exoskeleton, end-effector).
- The intensity and the duration of training.
- Patient engagement and Motivation level.

When prescribing RAGT, the patient safety, cognitive status, and medical comorbidities are also of significance[20].

Therapeutic Mechanism of Action of the Robot-Assisted Gait Training (RAGT)

It is majorly implemented through the processes that facilitate neuroplasticity, motor relearning, and sensorimotor integration. These processes are very essential especially in stroke recovery where the brain must re-wire and re-compensate to have some working effect[21].

Neuroplasticity laws

Neuroplasticity refers to the capacity of the brain to reorganize and form new cell connections either because of damage or as a result of training. The motor recovery paradigm in the situation of stroke recovery is activity-dependent plasticity. RAGT applies the key concepts that stimulate neuroplasticity that include:

- **Repetition and Intensity**: RAGT offers hundreds and thousands of step cycles during a single session which imposes uniform motor patterns.
- **Task-Specificity**: The walking patterns repeat actual walking and do task-specific learning.
- **Sensory Feedback**: Apparatus provides proprioception and skin feedback and leads to more participation of sensorimotor loops.
- **Error Augmentation**: In some systems it is possible to apply controlled perturbations to the gait to induce learning through error correction.

These regulations agree with the Kleim and Jones scheme of experience-dependent plasticity whereby the salience, specificity, and use are the biggest drivers of cortical reorganization. [22].

Neuro Chemicals and Activation of Neural Pathways

RAGT was found to activate a series of cortical and sub cortical areas which are related to motor control. Increased activation in has been shown by fMRI and EEG studies to be in:

- Premier motricity cortex (M1).
- Supplementary motor area (SMA).
- Cerebellum.
- Basal ganglia.
- Association areas of sensation

Recovery and functional gains are linked to an increase in activity in the contralesionally hemisphere (priorly in beginnings of post-stroke period) and a reversion to postlesional dominance with training. This change could represent a more efficient and localized process with the progression of recovery·

In addition to cortical modifications, RAGT provokes spinal-level changes, such as:

- Increased central pattern generator (CPG) activity of the spinal cord that facilitates rhythmic locomotor patterns.
- Enhanced sensorimotor coordination, enhanced ability to respond to surface changes, load and perturbation.

Such adaptations are thought to carry over into better gait symmetry, balance and reactive stepping even when there is no conscious motor planning.

Even though neuroplasticity is also encouraged in traditional physiotherapy, RAGT makes it possible:

- Repetitions of gait, more intense, otherwise restricted by the therapist.
- Augmented feedback that is able to CPUs raise cortical involvement and motivation.

All of these advantages in combination position RAGT as especially useful in patients with severe motor deficits, in which voluntary movement is not abundant, but neuroplastic potential is high.

According to recent research, cortical reorganization is improved when RAGT is used in connection with functional electrical stimulation (FES) or virtual reality (VR):

- FES facilitates excitability in the corticospinal tract and somatosensory cortex.
- VR stimulates attentional and reward systems which make task salience and motivation.

A new technology that could enable reinforcement of voluntary effort with robotic action in real time is the brain machine interfaces (BMI) [23].

Clinical Recommendations and Limitations

Robot-Assisted Gait Training (RAGT) has already shown a promising outcome in stroke rehabilitation to offer locomotor training that is targeted, repetitive and intensive. Its clinical usefulness, however, is thoughtful use as a component of rehabilitation process in general. This section underlines key propositions in the light of clinical practice, key limitations and challenges of RAGT application[24].

Clinical recommendations

- **Selection of the Patients**:
    - **Best suited to**: The patients in early subacute phase of stroke (within 3 months), when neuroplasticity is the most elevated.
    - **Assistant Need**: Patients who are ambulatory and non-ambulatory; those with moderate and severe gait deficits in particular.
    - **Caution in**: Patients with severe orthopedic restrictive or mental impairments resulting in the lack of cooperation with spasticity[25].
- **Most Appropriate Time and Span of Duration:**
    - The result is improved when RAGT is used within 46 weeks of a stroke.
    - **It needs to be vigorous**: 3-5 sessions/week, 4-6 weeks are recommended to monitor the functional changes.
    - **Session time**: 30, 45 minutes of active robotic walking tend to be effective[26].

- **Device Matching**
    - **End-effector systems**: Most appropriate in patients that still retain some degree of residual voluntary control and that are willing to ambulate with an improved level of functioning.
    - **Exoskeleton systems**: Recommended in case an individual has a more severe motor loss or needs the assistance of the entire body.
    - **Hybrid systems (e.g., RAGT + FES/VR):** the most suitable in cases when it is wanted to provide cognitive and sensory stimulation to the maximum, in particular, chronic stroke[27].

Combination with Conventional Therapy

RAGT should be applied as an adjunct to, and not as a replacement for standard physiotherapy. Combined approaches improve balance, functional independence and performance of daily activities better than either of the two. Multi-disciplinary Involvement Training of physiotherapists should also be invested in and rehabilitation team should also comprise of biomedical engineer and in some situation occupational therapist so as to maximize device utilization and patient outcome[(28)].

Limitations and restrictions

- **Affordability and Availability**
  - High capital expenditure (generally over 100000 dollars) provides access to specialized centers only.
  - To the long-term operating costs are added maintenance and skilled personnel requirements.
  - The insurance cover is also adjustable in most nations and in most cases, inadequate[(29)].
- **Caution Suitability to Patients Limits**
  - Wearing some types of exoskeletons may be ruled out due to weight, height, or joint deformities.
  - Unstable cardiovascular disease, open wounds, and severe osteoporosis should not be treated with it[(30)].
- **Staffing and Learning Curve**
  - Well-trained staff is required to install and operate and monitor the patients using the devices.
  - Set up can take some time (especially with exoskeletons), so the overall time to work through a therapy regime may be restricted unless well optimized [(31)].
- **Warning Indicators of Variable Evidence Between Phases**
  - Stroke clinical trials lack homogeneity and therefore it is difficult to use the sample results to make conclusions about all stroke populations.
  - In other studies, it states that there are no significant differences between RAGT and standard treatment in chronic stages unless RAGT is used as a compound measure (e. g., FES, VR) [(32)].
- **Technical Limitations**
  - Adaptive real time feedback lacks in most of the systems and therefore limits their ability to dynamically respond towards the performance of the patients.
  - Some exoskeletons would reduce ecological validity because they do not allow natural gait variability [(33)].

Ethical and Practical implications

- Equitability of access to sophisticated rehabilitation technologies ought to be considered in order not to generate disparities between urban and rural or approaches to health between the public and the private sector.
- The ethical use will be characterized by discrete goals of outcome, reasonable anticipation and shared decision between patients and caregivers [(34)].
-

Evidence Aspects and Future of the Study

Although the number of publications in favor of Robot-Assisted Gait Training (RAGT) continues increasing due to its positive role in stroke rehabilitation, a number of knowledge gaps still exist that restrict the wider application of the technology in the clinical setting. Recognizing these gaps helps in improvement of the therapeutic methods in order to maximize patient treatment outcomes and equitable access to treatment [35].

Gaps in the Current Evidence

- **Impoverished Long-Term Outcome Data**

The majority of RCTs and cohort studies evaluate the outcome only in short periods of time (412 weeks). Sound evidence related to the maintenance of gait and balance improvements that persist following the withdrawal of robots training is not available [36].

- **Unpredictable Outcomes in the Various Phases of Stroke**
  Whereas RAGT would seem most effective in a subacute phase, it is less clear in the chronic field. There are some indicators of success when RAGT is combined with other forms of therapy (e.g., FES or VR), but there are no obvious clinical instructions on how to turn to RAGT in case of a stroke in case of permanent ailment [37].
- **Absence of non-individualized protocols**
  One-size-fits-all This approach is common in current studies, where there is little modification of RAGT parameters (e.g.: speed, level of support, feedback) depending on individual neurophysiological profiles and levels of motivation, or on functional objectives to achieve [38].

- **Evidence on Psychosocial and Cognitive Factor**
  Limited data exists on the impact of RAGT on cognitive ability, emotional status, and quality of life, which are vital in comprehensive recuperation following the attack of a stroke. In addition, patients satisfaction and engagement with robotic machines are not always posted [39].
- **Inadequacy of Low-Resource settings representation**
  Published research is largely performed in high-income nations, so conclusions are restricted to resource-limited settings where there is little availability of robotics, trained personnel, or facilitative infrastructure [40].

Conclusion

Future studies must fill these research gaps that will entail interdisciplinary teamwork, technological advancements, and policy support to include RAGT in the regular rehabilitation practice. Robotics and the possibility of advanced robotics rehabilitation of the stroke gait in the future is not the only solution, but the construction of individual care with the peculiarities of the patient is a future oriented approach to this.

Conflict of Interest

The author declares no conflict of interest related to the publication of this article.

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