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Efficacy of assisted locomotor training and conventional physical therapy for gait recovery in stroke survivors: Review

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Abstract:
Background*: Stroke is considered one of the most deadly and disabling diseases in the world. People with neuromotor sequelae after a stroke require rehabilitation to help them to recover independence and to have a better quality of life. However, the process to obtain a functional recovery is not simple. Many variables influence the progress. Different studies have shown that robot-assisted training, locomotor training, and conventional physiotherapy help to improve gait parameters and balance ability in acute and chronic stages after the stroke. However, people's ability to recover varies widely; because of this, it is necessary to find different treatment options that are effective and help to improve their quality of life.*
Contents*: This review integrates data from the literature about robot-assisted training, locomotor training, and conventional physiotherapy for gait recovery after acute and chronic stroke. To calculate the efficacy of these approaches, data on treatment frequency and intensity, time since stroke, and motor functionality outcomes as the Berg Balance Scale, 10 Meters Walk Test, 6 Minutes' Walk Test, and Timed Up and Go test were analyzed.*
Conclusion: *Locomotor training using a high-intensity mode improved motor function of lower limbs in patients with acute and chronic stroke. The results also suggest that treadmill approaches improve balance, gait, mobility, and spasticity to improve motor function and contribute to get independence and a better quality of life.*
Key Word*: Disability; Gait; High-Intensity; Locomotor Training; Physiotherapy; Stroke.*

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I. Introduction

Stroke is considered one of the deadliest and disabling diseases globally [1-2]. In 2019, ischemic heart disease and stroke were the leading causes of disability-adapted life years (DALY's) in people 50 years old and over. Feigin et al. (2015), in their work about the global burden of disease attributable to stroke from 1990 to 2013, estimated that people who survived a stroke added 113 million Disability Adapted Life Years (DALY´s) [3]. Notable the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) reported the increase to 143 million in 2019. If we consider that, in 2004, the WHO published that the DALY´s attributable to stroke was 46.6 million years, what it suggests that the DALY's had an approximate increase of 300% in 15 years [4]. Interestingly, the study by Ovbiagele et al. in 2013 reported projections to the year 2030, reporting that annual costs per stroke would increase substantially. Direct medical expenses are expected to increase from $ 71.55 billion to $ 184.13 billion. At the same time, indirect expenses (loss of productivity) will increase from 33.65 billion to 56.54 billion during the same period. In addition, they estimated a total increase in expenses of 129% in the following two decades [5].

Research on post-stroke sequelae have gained interest in recent years. Most people experience a loss of motor function on the affected lower limb related to deficits in balance, gait, mobility, spasticity, muscle atrophy, fatigue, and force generation [6-10]. In addition, the reduction in motor function restricts mobility and functional ability, their daily life activities and may reduce the quality of life, causing frustration [11]. Although there have been many different therapeutic approaches to improve balance, muscle control, and gait, such as electrical stimulation [12,13], virtual training [14], treadmill training [15], and robot-assisted training [16], most of these therapeutic approaches have proven to be effective treatments. However, none has proven to be superior to the others.

Furthermore, it is understood that none is entirely adequate. Additionally, some of these approaches are not fully accessible to the entire population due to the cost of equipment and interventions. Therefore, it is essential to look for new rehabilitation options that effectively reduce subsequent deterioration and restore the functional capacities of people after a stroke.

The present review evaluates the efficacy of three intervention models for the re-education and relearning of gait in post-stroke patients through conventional physiotherapy, robot-assisted treadmill, and locomotor training. These therapeutic approaches appear to be valuable and practical methods used in acute or chronic periods after stroke. However, to our knowledge, no parameters or standards have been defined so far regarding improvement in speed, walking ability, or gait function. Thus, the optimal duration or frequency of interventions to improve motor function in acute or chronic conditions after a stroke is unknown.

II. Practical approaches to improve locomotor function after stroke

The widely recognized impairment caused by stroke is motor impairment, a loss or limitation of function in muscle control, movement, or mobility. As a result, a wide range of rehabilitation interventions has been developed. Interestingly, some studies reported that interventions and rehabilitation training for stroke survivors improve their functional recovery after the injury [17,18]. Various studies using robotic training and conventional physiotherapy have reported benefits in recovering motor function, especially gait, cadence, speed, kinematics, and muscular endurance [19-23].

In this review, six of the nine selected studies were randomized and controlled, in which the benefits on motor function were compared between robot-assisted therapy and conventional physical therapy. Both types of interventions improved outcomes measures (Berg Balance Scale [BBS], 10 Meters Walk Test [10MWT], 6 Minutes Walk Test [6MWT]) [20-22, 24-27]. However, the results were similar when both approaches were compared, and there were no statistically significant differences. These results suggest that robot-assisted training does not provide additional benefits to traditional physiotherapy interventions, both in acute and chronic strokes (Table I).

One of these articles selected was a randomized and controlled crossover study. The authors reported as main outcome that the hybrid assistive limb (HAL-robot-assisted) training in subjects with chronic stroke did not improve balance and gait parameters compared to the traditional physiotherapy intervention. Each intervention was provided five times a week, for six weeks (30 sessions in total), and 30 min per session[22]. Authors also reported no significant differences between conventional physical therapy and the HAL with body-weight–supported treadmill training (BWSTT) on balance functions during the crossover intervention [22]. In addition, a randomized and controlled pilot study with 30 stroke survivors showed an increase in the speed achieved in a 10 meters distance and stride speed test with 30 min of robotic training for four weeks [19]. Furthermore, this study showed that training with a robot (Lokomat®) and traditional physiotherapy increased motor function, with no differences between two treatments. Therefore, they suggested that both types of intervention had the same effectiveness in recovering motor function [19].

Table I. Therapy interventions for motor function recovery in stroke survivors.

Reference	**Methods**			**Results (before/after)**
	Subjects: N/Mean Age/Sex (females-F/ males-M) Time since stroke	**Interventions and training modalities**	**Main outcomes measures**	
Sczesny et al., 2019 [22]	Crossover study HAL-CPT n=9/63y.o./ N=18; 63/66 y.o. (3F/6M). Time since stroke:62 months. CPT-HAL n=9/66 y.o. (2F/7M). Time since stroke: 102 months.	Conventional Physiotherapy (CPT)/ HAL-BWSTT. Crossover study. Training sessions: 30. Frequency: 5/wk. Total duration training: 6 wk. Session time: 30 min.	10MWT TUG 6MWT	10MWT: HAL-CPT 25.29s/19.34s * Crossover 21.72s CPT-HAL 27.15s/23.28s *Crossover 13.68s. N.S. TUG: HAL-CPT 34.54s /27.22s Crossover 29.32s CPT-HAL 37.20s /25.65s. Crossover 23.83s. N.S. 6MWT: HAL-CPT 169.33 m/203.25m Crossover 190.38m CPT-HAL 242.50m/236.78m Crossover 243.06m N.S.
Nilsson et al., 2014 [21]	N=8/ 56y.o (8M) Time since stroke= 35 days	Training with HAL Frequency=5/wk, Total duration training was individualized. Training sessions: 6-31. Time sessions mean: 25 min.	Bergs balance scale (BBS), TUG, 10MWT.	BBS 8.5/ 28. Timed up and go 44s/33.5s. 10MWT, maximal speed 111.5s/30s.

Kawamoto et al., 2013 [20]	N=16/ 61y.o. (4F/12M) Time since stroke: 47.1 months	Training with HAL Training sessions: over 16 Frequency: 2/wk. 20-30 min/day. Total duration training: 6 wk	BBS, 10MWT and TUG	10MWT: Speed (m/s): 0.41/0.45. Cadence (steps/min): 68.6/ 72. Number of steps (steps): 37.5/33.1 BBS: 40.6/45.4 TUG: 36.0/34.0
Hidler et al., 2009 [24]	Lokomat® experimental group: n=33/59.9 y.o. (12F/21M) Time since stroke: 110.9d CPT group: n=30/54.6 y.o. (12F/18M) Time since stroke: 138.9d	Training sessions: 24 Frequency: 3/wk. 60 min/day Total duration training: 8wk	Walking speed (m/s) 6MWT (m) cadence (steps/m) BBS	Walking speed: Lokomat® 0.34 m/s/postraining increase 0.12 m/s.* CPT 0.35 m/s/ post-training increase 0.25 m/s.* 6MWT (m): Lokomat® 387.8 m/ post-training increase 274 m. N.S. between groups. CPT: 440.7m/ post-training increase 274 m Cadence: N.S. between groups. BBS: N.S. between groups.
Taveggia et al., 2016 [26]	Lokomat® experimental group: n=13/71 y.o. (6F/7M) Time since stroke: 60.1d CPT group: n=15/73.6 y.o. (5F/10M) Time since stroke: 39.4d	Training sessions: 25 Frequency: 5/wk. 60 min/day CPT+30 min Lokomat® Total duration training: 5wk	6MWT 10MWT	6MWT: Lokomat® 124.8 m/184.9m* CPT:171.4m/295.6m* No statistically significant difference between groups 10MWT (m/s) Lokomat®: 0.27/0.53m/s* CPT: 0.46/0.72 m/s* N.S. between groups.
Watanabe et al., 2017 [27]	HAL experimental group: n=12/66.9 y.o. (4F/8M) Time since stroke: 57d CPT group: n=12/76.8 y.o. (4F/8M) Time since stroke: 48.1d	Training sessions: 12 Frequency: 3/wk. 20 min/day Total duration training: 4wk	6MWT 10MWT maximal gait speed cadence stride TUG	6MWT: HAL 92.4m/166.7* CPT:106.9m/131m* N.S. between groups. 10MWT (m/s) HAL: 0.56/0.84m/s* CPT: 0.45/0.57 m/s* N.S. between groups. Stride (m): HAL: 0.37/0.46m* CPT: 0.29/0.36m Cadence (steps/min): HAL: 81.5/99.3* CPT: 75.1/88.9 TUG (s): HAL: 33.9/23.1* CPT: 46.6/27.3
Molteni et al., 2021 [25]	RGAT experimental group: n=38/62.13 y.o. (17F/21M) Time since stroke: 35.68d CPT group: n=37/68.24 y.o. (19F/18M) Time since stroke: 34.14d	RGAT experimental: Frequency=5/wk; 60min/d. Total duration training: 15 sessions/3wk. CPT control group: Frequency=5/wk; 60min/d. Total duration training: 15 sessions/3wk	6MWT 10MWT	6MWT: RGAT 48.6m/139.24m* CPT 44.29m/149.43m* N.S. between groups. 10MWT (m/s) RGAT 0.25/0.48 CPT 0.20/0.59 N.S. between groups.

HAL: Hybrid Assistive limb (robot), RGAT: Robot Gait Assisted Training, BBS: Berg Balance Scale, 10 MWT: 10 Meters Walk Test, 6MWT: 6 Minutes Walk Test, TUG: time up and go test, CPT: convencional physiotherapy, F: female, M: male. *: Statistically significant difference $p<0.05$. N.S.: No statistically significant difference between groups.

On the other hand, a case study reported that an-8-week training with Hybrid Assistive Limb (HAL system) improved walking speed and balance function in a subject with chronic stroke [23]. Taken together, conventional physiotherapy and robot-assisted training are effective improving motor function of lower limbs in patients with acute and chronic stroke. The results also suggest that both therapeutic approaches improve balance, gait, mobility, and spasticity to improve motor function and enable patients to get independence and improve their quality of life. However, neither of them proved to be more effective than the other.

III. Locomotor training to improve motor function

The locomotor training using body-weight support on a treadmill assisted by a therapist is a scientifically evidenced activity-based rehabilitation therapy focused on retraining the injured nervous system driven by neural plasticity through task-specific training. During retraining, the set of sensory information is essential in providing a clear picture of the walking task to be synthesized and integrated by the nervous system to generate an effective motor response (see Figure 1). The sensorimotor experience of locomotor training approximates the task of walking with increasing demands or challenges placed on the nervous system to adapt [28]. *Locomotor training* is a physical therapy modality that has been used in the world with different methodologies. The knowledge of physiological basis and the scientific evidence of therapeutic interventions have evolved and have been constantly updated [28]. Since the changes in the motor cortex related to plasticity, which was reported by Karni et al., (1998), show that learning motor skills was associated with a neuronal reorganization and representation of movements in the motor cortex of rodents [29]. The repetition of activity stimulates neurobiological control and plasticity of the nervous system has redirected therapy interventions after neurological damage [30].

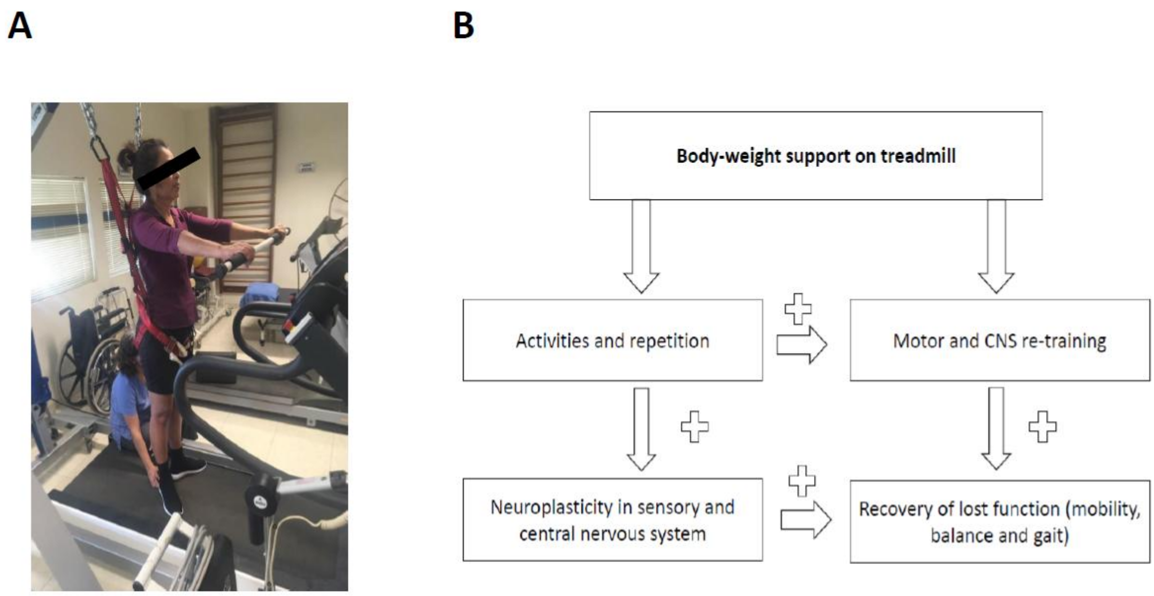

Figure 1. Locomotor training with body-weight support on a treadmill. A) Locomotor training on the treadmill maximizes weight-bearing on the legs. In addition, the therapeutic approach optimizes sensory cues (principles 1 and 2 of locomotor training by Harkema et al.,2011 [28]) and maintains proper posture at trunk and position of pelvis and leg balance. B) Process to recover lost function since neuroplasticity using BWS activities and repetition (gait).

The physical therapy modalities named locomotor training on the treadmill have been published since 2007. However, until 2011, Harkema et al. published a book with a proposal for the evidence-based methodology. Harkema et al. (2011) define a treadmill training as a rehabilitation therapy based on repetitive activity focused on retraining gait [28].

Several studies showed evidence of the benefits of locomotor training. These include randomized controlled trials and studies with a single case experimental design that have evaluated endless treadmill training with body-Weight – Support (BWS) in patients after a stroke. Although the results have been variable, significant changes have been reported in at least four functional assessment scales: parameters of speed, endurance, muscle strength, and balance.

Concerning these, Lang et al. (2007) reported that the repetition of a frequency of up to 2000 times in gait training is sufficient to promote plasticity of motor neurons and achieve a recovery of locomotor function [31]. Furthermore, a study by Veerbeek et al. (2014) concluded that physical therapy interventions based on repetition of tasks and training of a specific task in all recovery phases of patients with stroke sequelae have strong scientific evidence [32].

A meta-analysis study that included six studies and a sample of 549 subjects showed that walking on a treadmill with body weight support was significantly more effective than the intervention of assisted walking on the ground. In addition, the authors of this study show that most of study subjects walked independently at four weeks and walked further and faster at six months of intervention [33].

Studies with different training methodologies for gait include the number of treatment sessions and distribution of sessions per week. Training time on the treadmill, training time on the ground, start of the post-stroke intervention, training speed, and intervals are reported in Table II. According to the table, studies of clinical trials that compared benefits of LT in stroke survivors report that early interventions (2 months after stroke) proved to be more effective than late interventions (6 months after stroke) [34-36], and Exercises Home Programs [37]. In addition, the results of training using maximum speed are superior too [38].

Table II. Locomotor training interventions for motor function recovery in stroke survivors.

Reference	Frequency	Time	Speed	Results
Duncan et al., (2007) [34]	36 sessions - 12 weeks.	20 – 30 min on treadmill. 15 min on ground. Warming, stretching, cold exercise.	3.2km/hr (0.89m/s [2.0 mi/hr].	Early Intervention 20% than Home Exercise Program, and 0-1m/s superior to late intervention.
Duncan et al., (2011) [35]	36 sessions - 12 weeks.	20 – 30 min on treadmill. 15 min on ground. Warming, stretching, cold exercise.	3.2km/hr (0.89m/s [2.0 mi/hr].	After 6 months of stroke, Early Intervention and Home Exercise Program reported improvement 0.25+/-0.21m/s y 0.23+/-0.20m/s. After 1 year of stroke, Early intervention improved 0.23+/-0.20m/s and late intervention improved 0.24+/-0.23m/s.
Nadeau et al., (2013) [37].	36 sessions - 12 weeks.	20 – 30 min on treadmill. 15 min on ground. Warming, stretching, cold exercise.	3.2km/hr (0.89m/s [2.0 mi/hr].	18% of subjects improve range >0.4m/s to >0-8m/s and increased the speed on 0.13m/s. Using early and late interventions, versus Home Exercise Programs.
Rose et al., (2017) [36] .	30-36 sessions – 12-16 weeks.	90 min.	NS	Subjects improved the speed and distance after 12 sessions with early intervention, the average to improve each session was 0.011m/s.
Boyne et al., (2020) [38]	12 sessions on 4 weeks.	10 min on field, 20 min on treadmill with therapist assistance and 10 more min on ground.	Shorts Intervals (30s maximum speed and 30-60s to rest) Long Intervals (4 min with 90% reserve frequency and 3 min with 70%).	On the ground, shorts intervals were superior to long intervals with 0.75m/s vs 0.67m/s, same order results on treadmill 0.90m/s vs 0.51m/s respectively.

(*) NS. No specified.

IV. High-intensity training approach

Horby et al. (2011) presented physiological evidence that the specificity, amount, and intensity of walking practice are thought to be critical variables of rehabilitation interventions that can facilitate the plasticity of neuromuscular and cardiopulmonary systems and improve the performance of the locomotor function [39]. They claim the evidence and physiological rationale for providing large amounts of high-intensity locomotor training to improve ambulatory function in individuals poststroke.

The “frequency” of training sessions in the Moore et al. (2010) study was dictated by the schedule of PT sessions before discharge (2-5 times per week, for a minimum of 4 weeks) [40]. The speed of stepping during training was determined by the “intensity,” set at a limit up to 85% of predicted maximum HR and varied by the subject’s walking speed and cardiovascular efficiency. Total “time” of training was limited to an amount similar to conventional CPT sessions (45 minutes), and the “type” of training provided in this study was LT on a treadmill without physical assistance by a therapist with minimal Body Weight Support provided by a safety harness system. Authors refer that using this structured intervention; subjects received a relatively substantial amount of stepping practice (2,000-6,000 steps/session, 2–5 times/wk over four weeks), which markedly improved stepping activity at home and community as compared to conventional physical therapy sessions.

Hornby et al., (2019) researched the interventions of either high intensity stepping (70-80% heart rate [HR] reserve) of variable, difficult stepping tasks (high- variable), high intensity stepping performing only forward walking (high-forward), and low intensity stepping in variable contexts at 30-40% HR reserve (low-variable), in survivors with stroke, who received up to 30 sessions over 2 months [6]. All walking gains were significantly greater following high-intensity group vs low-variable training.

Ardestani et al. (2020) detailed those changes in locomotor kinematics and kinetics following three different LT paradigms in patients’ post-stroke, revealing consistent differences in treadmill speed, stride length, and cadence between high- versus low-intensity training [41]. Participants were randomized to receive up to 30 one-hour HV, LV or HF training sessions over two months, stepping up to 40 minutes per session. They conclude that providing stepping training at higher intensities resulted in significant gains in spatiotemporal parameters, kinematic consistency, and power generation compared to lower intensity activities.

According to the American Physical Therapy Association on the Clinical Practice Guideline, after a chronic stroke, incomplete spinal cord injury, and brain injury (2020), improving gait function requires many task-specific (i.e., locomotor practice) [42]. Although only higher cardiovascular intensities or with augmented feedback to increase patient engagement. Lower intensity walking interventions or impairment-based training strategies demonstrated questionable or limited efficacy. The guideline suggests that task-specific walking training should be performed to improve walking speed and distance in those with acute-onset central nervous system injury. Future studies should clarify the efficiency of specific training parameters that lead to improved walking speed and distance in these populations in both chronic and subacute stages following injury.

V. Conclusion

Locomotor training as a therapy for stroke survivors represents a therapeutic option that has demonstrated benefits in the recovery of motor function, especially gait, improving cadence, speed, kinematics, muscular endurance, among other characteristics. However, it has also been evidenced to be effective in balance and improving daily living activities. Specifically, the benefits of this therapy have been evidenced through randomized clinical trials and scientific evidence in favor of high-intensity training (70-80% of the reserve heart rate). In this review, strong scientific evidence of the benefits above in chronic patients after a stroke has been found. Therefore, future research should be oriented towards the benefits of this therapy in stroke survivors within the first six months, which is associated with the more significant potential for neuronal plasticity and its critical periods in terms of neuromotor recovery of stroke patients. In the same way, future research should include the combination of locomotor training with virtual reality, transcranial electromagnetic stimulation, biofeedback, and fitness, with the specificity of managing high-intensity therapy in stroke survivors in the first six months.

On the other hand, the cost-benefit analysis is a section that we should not omit. Further efforts are considered to identify the best modalities of therapies, timing, intensity, and frequency to improve the cost/benefit on stroke patients' rehabilitation and increase treatment effectiveness. Just with it, people will have a real opportunity to enjoy a better quality of life after a stroke.

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