Effects of walking trainings on walking function among stroke survivors: a systematic review

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Physical function is often compromised as a result of stroke event. Although interventions propose different strategies that seek to improve stroke survivors' physical function, a need remains to evaluate walking training studies aimed at improving such physical function. The aim of this review was to assess the available literature that highlights the impact of walking training on enhancing walking for stroke survivors. We performed a systematic literature review of online databases – Google Scholar, PubMed, CINHAL, Cochrane Library, Scopus, and EBSCO – with the following inclusion criteria: manuscript published from 2005 to 2016, written in English, with treatment and control groups, for walking training studies aimed at improving physical function among stroke survivors. Findings indicated that walking speed, walking distance, and gait speed were the most used outcome variables for measuring improved physical function among stroke survivors. Importantly, proposed interventions involved either overground or treadmill walking trainings, if not both. Preserved locomotor improvements were not noted in all interventions at follow-up. Some interventions that used walking treadmill training augmented by auditory stimulations reported significant improvements in physical function compared with overground walking training augmented by auditory stimulations. The imperative to improve physical function among stroke survivors with physical impairment is paramount, as it allows survivors to be socially, emotionally, and physically more independent. In general, we note an insufficiency of research on the interaction between physical function and socialization among stroke survivors.

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Introduction

Stroke is the fourth leading cause of death and the leading cause of long-term disability among adults in the USA (Centers for Disease Control and Prevention, 2016; Mozaffarian *et al.*, 2016). Stroke causes physical impairments such as extremity weakness, fatigue, and postural instability that lead to walking difficulty and physical inactivity (American Stroke Association, 2012; Jeon *et al.*, 2015). In addition, stroke can cause memory loss, language/speech deficits, and aphasia (American Stroke Association, 2012). The economic burden of stroke in the USA is costly, with the mean lifetime cost reaching ~ $140 048, thus making it a top 10 most costly condition (Johnson *et al.*, 2016).

Participation in exercise or physical activity is essential after stroke to prevent secondary complications. Exercise after stroke can improve muscle strength, gait, balance, and may prevent cardiovascular complications (Billinger *et al.*, 2014; Van Duijnhoven *et al.*, 2016). Therefore, it is recommended that stroke survivors begin exercise as soon as possible after stroke (Billinger *et al.*, 2014). Depending on functional ability, it is recommended to exercise at least 3 days/week for 20–60 min or in a series of 10–15 min of moderate-intensity exercise (Billinger *et al.*, 2014). Walking is a low to moderate aerobic exercise that can be performed with or without equipment, alone or with a group, and at one's own pace, making it an ideal exercise for stroke survivors to perform. Treadmill walking offers different intensities and has handrails that may aid the individual's performance. Although level-ground walking does not require equipment, and can be easily incorporated into daily tasks, whether these types of walking training similarly improve physical function in stroke survivors needs to be examined. The aim of this review was to assess the available literature that highlights the impact of walking training on enhancing walking for stroke survivors.

Materials and methods

The initial search yielded 1437 articles retrieved from online databases such as PubMed, Google scholar, EBSCO, and Scopus.

Databases

The following databases were searched to obtain data for this review: Google Scholar, PubMed, Scopus, Cochrane Library, CINAHL, and EBSCO. The search was performed in September and October 2016. The following

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terms were searched consecutively: 'walking' and 'stroke' as Medical Subject Headings (MeSH) that yielded (1437 articles), and then the terms 'effects' (all fields) (476) and 'exercise therapy' (all fields) (151) were added consecutively to the search.

Inclusion and exclusion criteria

We performed a detailed search using filters to limit search to randomized control trials published between 2005 and 2016 and written in English. Articles were included if they fulfilled these criteria and were walking training or exercise studies aimed at improving physical function among stroke survivors. In general, physical function includes activities such as walking and climbing stairs (Tomey and Sowers, 2009). Systematic reviews, meta-analysis, and qualitative studies were excluded from the review. Out of 151 articles, 29 were reviewed and included in our results.

Data analysis

A systematic review of the literature was performed. The review followed the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) statement. Data were collected on the following study characteristics: publication date, hypotheses or research question, study design, sample size, inclusion criteria, demographics of sample, type of stroke, type of walking training, effects of walking on outcomes, stated implications, and recommendations. Two independent reviewers screened all potential articles and the articles were excluded if they did not address the research question.

Results

Using PRISMA guidelines (Fig. 1) and a flow diagram (Table 1), we gathered relevant information from published literature. After screening 1437 articles by title and abstract for inclusion, we selected 29 articles that fulfilled the eligibility criteria for the current review. Of these, only one study was a mixed-method study; the rest were pilot studies, case studies, cross-sectional studies, or retrospective studies.

Intervention types

Two major types of interventions aimed at improving stroke survivors' physical functioning: using a treadmill and over-the-ground walking trainings (Table 1). Although most rehabilitation programs were clinical interventions or clinical trials performed in hospital or university settings, some involved community-based interventions. Most intervention protocols included participating in 30- or 60-min sessions of moderate exercises ranging from 3 to 5 times weekly for 6–16 weeks. Some other interventions lasted for 40 weeks over 12 months with 3 sessions/week (Dean *et al.*, 2012).

Gait training was used as a proxy for improved physical function and locomotion in general. Although some studies found that locomotor training improved daily stepping activity and gait efficiency among poststroke individuals, others highlighted the impact of aerobic treadmill and resistance trainings on cardiovascular fitness. In one case, balance improved by a virtual reality-based stepping exercise; another augmented treadmill and ground walking trainings with rhythmic auditory stimulation. Treadmill walking trainings were also coupled with obstacle-crossing to improve ambulatory habits.

Randomizations

Although randomization reduces the risk of selection bias and eliminates the source of bias in treatment assignments (Suresh, 2011), only some of these interventions were randomized. Among randomized studies, some used either control groups exclusively or control groups but no pretest (Harris *et al.*, 2006); some were single-blind interventions, whereas others were cross-over randomized.

Participants

Participants were assigned randomly to control or intervention groups. Thesex of the participants was mostly male, with some mixed groups, with ages ranging from the early 20s to the late 80s and averages in the 60s. Most of the inclusion criteria were individuals who had at least 6 months poststroke (i.e. either ischemic or hemorrhagic) and were able to walk independently on the ground for the 10-m walk test with or without a walking aid at a walking speed of less than equal to 1.4 m/s. In addition, participants who could walk ~5 min at a self-selected pace on the treadmill were included. Other studies included participants who had 1 month, 12 months, or 5 years poststroke. Similarly, individuals with unstable hemodynamic states, who were unable to walk independently, and had cognitive impairment, aphasia (inability to follow at least two-step commands), or depression were excluded from most interventions. The Mini-Mental State Examination cutoff value of less than 23 was used as an exclusion criterion. Participants with recurrent stroke episodes were also excluded in most of the studies.

Outcome variables

Studies had different outcome variables, including the 6-min timed walk or the 10-min timed walk, the Short Physical Performance Battery, the Berg Balance Scale, the Stroke Impact Scale, the Barthel Index, and the Fugl Meyer Assessment, which measured the impact of walking training on walking function.

Effects of walking training on walking

Overall, most findings suggested that walking training improved walking for stroke survivors. Specifically, different training mechanisms (i.e. overground, treadmill, and conventional physiotherapy rehabilitation) highlighted the improvement in walking function among after stroke individuals (Olawale *et al.*, 2011). In particular,

Fig. 1

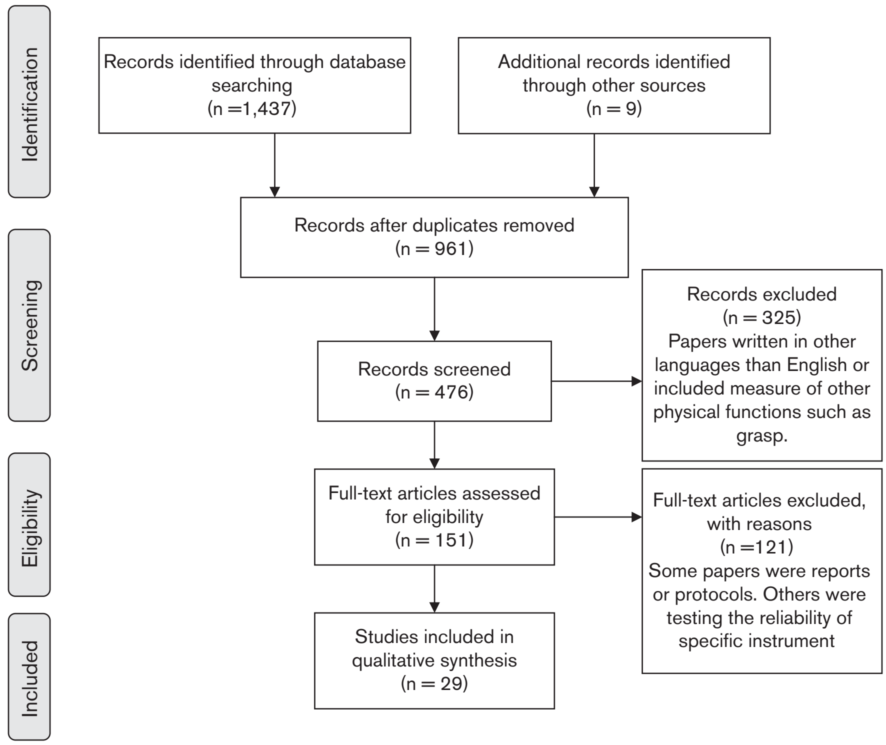

Chart of selected articles.

some interventions – consisting of 30-min walking trainings overground or body weight-supported treadmill – indicated significant improvements (Ada *et al.*, 2013; Combs-Miller *et al.*, 2014).

There seems, however, to be divergent results associated with the use of overground compared with body weight-supported treadmill in walking trainings. For instance, when comparing the impact of overground versus body weight-supported treadmill trainings, overground training showed a more significant impact on improving physical function (Combs-Miller *et al.*, 2014). Conversely, Ada *et al.* (2013) reported that treadmill training performed over 4 months showed significant walking improvements compared with overground training. Mayo *et al.* (2013) found no significant effect on physical function between two groups of participants (i.e. one group exercised on a stationary bicycle and the other group performed brisk walking). In addition, effective walking training did not prevent falls among stroke survivors (Dean *et al.*, 2012).

Walking speed and walking distance increased significantly for a participant who simultaneously performed task-specific and strength training programs after stroke (Sullivan *et al.*, 2006; Ada *et al.*, 2013). Likewise, daily stepping improved among patients who participated in intensive locomotor training (Moore *et al.*, 2010). Participating in walking training not only improved walking functions but also significantly improved emotional well-being among some participants (Stuart *et al.*, 2009).

Gait training through treadmill, especially with biofeedback, not only improved gait and walking function but also gait cycle length, duration of gait phases, and swing phase speed (Drużbicki *et al.*, 2015). Similarly, Sousa *et al.* (2011) reported that gait training performed overground also significantly improved walking function. High-intensity aerobic training significantly improved gait and peak oxygen consumption rate alike (Mackay-Lyons, 2012).

Significantly, although most interventions yielded improvements in physical functioning among poststroke individuals, many studies reported that the maintenance of these improvements faded after a certain period of time (Ada *et al.*, 2013; Severinsen *et al.*, 2014).

Discussion

Physically impaired stroke survivors require interventions that enhance their walking function and lead to an improvement of their overall quality of life and independence. Nonetheless, mixed findings for the use of conventional, overground, and treadmill walking trainings among stroke survivors with physical impairments

Table 1 Methodological characteristics of intervention studies focusing on walking trainings

References	Purpose of study	Study design/data source	Sample size, inclusion criteria, demographics, type of stroke	Type of intervention	Results	Implications and recommendations
Salbach *et al.* (2005)	To evaluate the efficacy of a task-oriented walking intervention in improving balance self-efficacy in persons with stroke and to determine whether effects were task-specific, influenced by baseline level of self-efficacy and associated with changes in walking and balance capacity	Secondary analysis of a two-center, observer blinded, randomized, controlled trial	Ninety-one individuals with a residual walking deficit within 1 year of first or recurrent stroke. Inclusion: clinical diagnosis of first or recurrent stroke; residual walking deficit; mental competency evaluated using Telephone Version of the Mini-Mental State Examination; ability to walk 10 m independently	Three times/week for 6 weeks targeting walking or upper extremity function. Participants asked to participate in 18 training sessions given 3 times/week for 6 weeks in a hospital setting. Walking intervention: progressive program of 10 tasks: walking on a treadmill; standing up, walking.	The walking intervention was associated with a significant greater average proportional change in balance self-efficacy than the UE intervention	Task-oriented walking retraining enhances balance self-efficacy in community-dwelling individuals with chronic stroke. Benefits may be partially the result of improvement in walking capacity.
Sullivan *et al.* (2006)	To describe outcome associated with a therapy program that combines task-specific and strength training in an individual after stroke and to discuss some possible mechanisms and modulating factors that may affect poststroke neurological recovery and responsiveness to intervention	Case study	A 38-year-old women with right middle cerebral artery stroke, evaluated 15 months after onset. Ambulated independently with an ankle-foot orthosis and straight cane.	Body weight-supported treadmill training and a limb-loaded cycling exercise were alternated over 24 treatment sessions (four 1-h treatment sessions) (4 times/week for 6 weeks)	Post-treatment: walking speed increased 18% for free (0.59 m/s) and 14.4% for fast velocity (0.71 m/s); 6 min walking distance increased 4% (184.4 m). At 6 months, continued improvements in all walking outcomes were evident.	For the person in this case clinically meaningful changes in walking function were associated with a combined therapeutic program that included both task-specific and lower extremity strength training
Krishnamoorthy *et al.* (2008)	To describe the application of a novel gait retraining approach to an individual with poststroke hemiparesis	Case study	The participant was a 58-year-old man who had a stroke more than 3 years before the intervention	Underwent gait retraining over a period of 3 days /week for 5 weeks for a total of 15 sessions during which the gravity compensation provided by the gravity-balanced orthosis and visual feedback about walking performance was gradually reduced. Each session lasted approximately two hours.	At the end of the 5 weeks, he decreased the time required to complete the Timed Up and Go test; his gait speed increased during overground walking. Except for gait symmetry, all other improvements were maintained after 1 month after intervention	The case report describes possible advantages of judiciously combining different treatment techniques in improving the gait of chronic stroke survivors
Smith *et al.* (2008)	To explore the secondary benefits of treadmill training for people in the chronic stage of recovery from stroke	Modified random assignment. Matched-pair control group design with repeated measures.	Twenty individuals participated in this study. Participants matched by side hemiparesis and motor impairment. Control group: $N=10$. Treatment group: $N=10$. Inclusion: Individuals who had an ischemic stroke more than 3 months but less than two years before enrolling in the study.	Twelve 20 min sessions of walking on a treadmill or weekly phone call. Control group: received weekly phone calls from the examiner enquiring about the quality of their week and encouraging them to record any life events in the log. Treatment group: received identical questions about the quality of their week and encouragement to use the QoL.	No significant difference was found between groups for any dependent measure. The ANOVA to investigate main effects in each group found no significant findings in control group; however, in the treatment group significant improvements over time for depression, mobility, and social participation were demonstrated.	A task-specific intervention designed to improve gait speed may potentially provide secondary benefits by positively impacting depression, mobility, and social participation for people poststroke
Pang *et al.* (2008)	To identify the determinants of improvement in walking capacity following	Secondary analysis of data obtained from a prospective, single-blind, randomized	Sixty-three community-dwelling individuals (mean age = 65 years, age range = 50–87 years) with a chronic stroke (poststroke	Participants in each group underwent three 1-h exercise sessions/week for 19 weeks	Gain in paretic leg muscle strength and peak oxygen consumption remained independently associated with	Enhancement of cardiorespiratory fitness and paretic leg muscle strength are both significant

	therapeutic exercise in chronic stroke survivors	controlled intervention trial	duration: mean-5.5 years, range = 1–28 years). Inclusion: a single episode of stroke more than one year ago, aged 50 years or more, ability to walk more than 10 m independently, living at home, a mental score > 22, the ability to pedal the cycle ergometer at 60 rpm and increase the heart rate to at least 60% of the maximal heart rate.		gain in walking capacity. Two-way ANOVA indicated that the leg group had significantly more gain in walking capacity ($P = 0.01$), peak VO ($P = 0.01$) and paretic leg muscle strength ($P = 0.01$) than the arm group.	determinants in improving walking capacity among chronic stroke survivors. However, the weak relationship indicates that other factors not measured in this study may also contribute to the improvement in walking capacity.
Moore *et al.* (2009)	To suggest that reduced task-specific walking practice during clinical physical training contributes to limited gains in ambulatory function in those with a perceived plateau after stroke, and suggest that further gains can be realized if intensive stepping, or locomotor training is provided after discharge	Randomized cross-over study	Participants had hemiparesis > 6 months duration who were attending PT after unilateral supratentorial stroke were recruited. Inclusion: walk > 10 m overground without physical assistance at speeds ≤ 0.9 m/s at their self-selected velocity, required medical clearance, a primary stated goal to improve walking ability, and enrolled ~ 1 month before termination of PT services secondary to decreased gain in function, as stated by the treating clinical therapist	Twenty patients with chronic stroke completed a repeated baseline measures, randomized cross-over trial in which walking performance was assessed during the last 4 weeks of clinical PT before discharge secondary to reaching a plateau, followed by 4 weeks of intensive LT and 4 weeks of no intervention	Stepping practice was more than four-fold higher during LT versus clinical PT sessions, with significant improvements in daily stepping and gait efficiency only after LT. Change in daily stepping after clinical PT and intensive LT were correlated with the amount of stepping practice received during these interventions.	Intensive LT results in improved daily stepping in individuals' poststroke who have been discharged from PT because of a perceived plateau in motor function. These improvements may be related to the amount and intensity of stepping practice.
Stuart *et al.* (2009)	To determine whether Adaptive Physical Activity (APA-stroke), a community-based exercise program for participants with hemiparetic stroke, improves walking function in the community	Nonrandomized controlled study	Participants with mild to moderate hemiparesis at least 9 months after stroke. Forty participants completed APA-stroke. Thirty-eight participants completed the usual care. Inclusion: have no comorbid conditions that were contraindication to participation, aphasia with inability to follow two-step commands, symptomatic heart failure, unstable angina, and hypertension (diastolic BP ≥ 95 mm Hg; systolic BP ≥ 160 mm Hg), which would preclude participation in exercise.	APA intervention included walking, strength, and balance training for 1 h, thrice a week in local gym. Outcomes measured: 6-month change in gait velocity (6-min timed walk), Short physical Performance Battery, Berg Balance Scale, Stroke Impact Scale, Barthel Index, Hamilton Rating Scale for Depression	Intervention groups improved whereas controls declined in gait velocity, balance, SPPB, SPPB, and SIS social participation domains. Between group comparisons were significantly at $P < 0.00015$. Individuals with depressive symptoms at baseline improved whereas controls were unchanged ($P < 0.003$).	APA-stroke appears to be safe, feasible, and efficacious in a community setting
Combs *et al.* (2010)	To examine changes in balance, balance confidence, and health-related QoL immediately and 6 months after body weight-supported treadmill training (BWSTT)	Prospective pretest/post-test pilot study with 6-month retention	Only 16 participants completed the study. Inclusion: onset of stroke at least 6 months before the study, aged 40–80 years, living in the community, ambulatory with or without the use of an assistive device or ankle-foot orthosis, able to ambulate at a self-selected comfortable speed of 0.4–0.8 m/s determined by using the 10-m walk test, physician approval to enter the exercise program, and able to follow at least two-step verbal instructions.	BWSTT was provided for 24 sessions over 8 weeks with 20 min of total walking each session	Statistically significant improvements were found from pretest to post-test for Berg Balance Scale, Activities-Specific Balance Confidence, Stroke Impact Scale mobility, SIS stroke recovery, and comfortable 10-min walk test (CWT) scores ($P < 0.05$) and from pretest to retention on BBS, ABC, CWT, and FWT scores ($P < 0.05$)	The findings of this study suggest that effects of BWSTT may transfer beyond gait to positively influence balance, balance confidence, and health-related quality of life. However, for most participants, BWSTT was not sufficient to induce improvements in balance and balance confidence beyond measurement error or long-term retention of enhanced perceptions of QoL.

Table 1 (*continued*)

References	Purpose of study	Study design/data source	Sample size, inclusion criteria, demographics, type of stroke	Type of intervention	Results	Implications and recommendations
Sousa *et al.* (2011)	Investigate the effects of gait training on ground level with partial body weight support in individuals with stroke during overground walking with no BWS	Pilot study	Twelve individuals with chronic stroke (53.17 ± 7.52 years) participated in a gait training program with BWS during overground walking, and were evaluated before and after the gait training period. Inclusion: an elapsed time no longer than one year since stroke and the ability to walk ~ 10 m with or without assistance	BWS training during overground walking (10 m) and measures the amount of weight borne by the system	After gait training, individuals walked faster (F1, $11 = 8.384$, $P = 0.015$), with symmetrical steps, longer and faster strides, and increased toe-clearance. Also, they displayed increased rotation of foot, shank, thigh, and trunk segmental angles on both sides of the body.	Gait training individuals with chronic stroke with BWS during overground walking improved walking in terms of temporal-spatial parameters and segmental angles. The training strategy might be adopted as a safe, specific and promising strategy for gait rehabilitation after stroke.
Olawale *et al.* (2011)	To evaluate the effects of treadmill walking and overground walking exercise training on recovery of walking function in an African group of stroke survivors	Prospective, randomized controlled trial	Outpatient stroke rehabilitation unit in tertiary hospital. Sixty patients with chronic stroke (≥3 months not > 24 months). Group A: Treadmill Walking Exercise Training ($N = 20$) (age: 56.8 ± 6.4). Group B: Overground Walking Exercise Training ($N = 20$) (age: 56.8 ± 8.3). Group C: (control) ($N = 20$) (57.2 ± 5.9). Able to walk 10 m independently with or without a walking aid.	All participants received individual outpatient conventional physiotherapy rehabilitation for 12 weeks. Participants in group A received treadmill walking exercise training. Participants in group B received overground walking exercise training. Participants in group C received conventional physiotherapy rehabilitation only.	TWET (A): recorded $22.6 \pm 1.5\%$ decrease in 10 MWT and $31.0 \pm 4.3\%$ increase in 6 MWT. OWET (B): made $26.8 \pm 1.3\%$ and $45.2 \pm 4.6\%$ improvement in 10 MWT and 6 MWT, respectively. CG: made $2.2 \pm 0.7\%$ and $2.9 \pm 0.8\%$ improvement in the two functions. Changes were significant for the TWET and OWET ($P < 0.05$).	Treadmill and overground walking exercise training programs, combined with conventional rehabilitation, improved walking function in African group of adult stroke survivors
Billinger *et al.* (2012)	Examine whether an 8-week aerobic exercise intervention would improve cardiovascular health and physical performance in participants with subacute stroke	Prospective study	Ten patients were enrolled and nine completed the study. Aged 61.2 ± 4.7 years old, were 66.7 ± 41.5 days' poststroke, and had minor motor performance deficits (Fugul-Meyer score, 100.3 ± 29.3). Inclusion: between 50 and 70 years of age, diagnosis of first time, unilateral stroke that occurred less than 6 months before enrollment, ability to walk with or without an assistive device and need only stand-by assist, and ability to travel for all testing and exercise sessions.	Aerobic exercise training session 3 times/week for 8 weeks. Preexercise vital signs, ten stretching exercises, 5-min warm up, intensity increased to prescribed workload (started at lower end of targeted HR range then increased to the upper portion of THRR). Duration was increased but did not exceed 40 min and intensity did not exceed THRR but was adjusted according to physiological response.	At baseline, we identified between-limb differences in brachial artery flow-mediated dilation (FMD) and low VO_2 peak values. After the intervention, significant improvements were observed in FMD in both arms, resting systolic blood pressure, and the 6 MWT. Although we also observed improvements in the resting diastolic pressure, heart rate, and VO_2 peak values, these changes were not significantly different.	Aerobic exercise in participants with subacute stroke was beneficial for improving cardiovascular health, reducing cardiovascular risk, and improving physical performance (6 MWT)
Mackay-Lyons (2012)	Does high-intensity aerobic exercise improve cardiovascular fitness and gait function in people with chronic stroke?	Randomized controlled trial	Thirty-eight poststroke individuals > 60 years Inclusion: with residual gait impairment, and ability to walk on the treadmill at ≥ 0.3 km/h for 3 min were eligible	A total of 18 people was in the usual care. Intervention group (20 people) underwent treadmill training (3 times/ week) for 3 months. Program intended to achieve 30–50 min of treadmill training at 60–80% of the maximum heart rate reserve as determined by a maximum effort exercise test.	After 3-month training period, change in peak oxygen consumption rate was significantly more in the treatment group, by 6.3 ml/kg/ min 6 MWT. Change in distance was significantly more in treatment group.	A high-intensity treadmill training program improves cardiovascular fitness and gait in older adults with chronic stroke

Dean *et al.* (2012)	Investigate whether an exercise intervention can enhance mobility, prevent falls, and increase physical activity among community-dwelling people after stroke	Randomized trial	Experimental group program ($n=76$) aimed to improve walking, prevent falls and increase physical activity. The control group program ($n=75$) aimed to improve upper-limb and cognitive functions. Age, mean (SD; range): EG: 66.7 (14.3; 31–91). CG: 67.5 (10.2; 40–85). Inclusion: suffered one or more strokes, were able to walk 10 m independently with or without a mobility aid, gained medical clearance.	Both groups, on average, 5.9 years poststroke, received exercise classes (40 weeks over 12 months; 3 times/week), advice, and a home program for 12 months. Each class and home program designed to take 45–60 min EG received an exercise intervention designed to enhance mobility, prevent falls, and increase physical activity.	Twelve months, EG: walked 34m further in 6 min and 0.07 m/s faster over 10 m than the CG. EG: 129 falls. CG:133 falls. There were no differences in proportion of fallers (relative risk = 1.22; 95% CI = 0.91–1.62; $P=0.19$) or the rate of falls between groups (incidence rate ratio = 0.96; 95% CI = 0.59–1.51; $P=0.88$).	The experimental intervention delivered through stroke clubs enhanced aspects of mobility but had no effect on falls
Mayo *et al.* (2013)	To estimate the relative effectiveness in improving walking ability and other mobility and health outcomes after stroke of two home-based exercise programs – stationary cycling and an exercise and walking outcomes	An observer blinded, randomized, pragmatic, trial with repeated measures	People (ages 67.7 ± 14.4) within 12 months of acute stroke who were able to walk > 10 m independently and healthy enough to engage in exercise. Total of 87 individuals (cycle group, $n=43$; exercise group, $n=44$).	Two dose-equivalent interventions, one involving stationary cycling and the other disability-targeted interventions were tested. Both protocols required daily moderate-intensity exercise at home building up to 30 min/day. One group exercised on a stationary bicycle, the second group carried out mobility exercises and brisk walking.	No significant effects of group or time were found for the 6 MWT. Significant effects for role participation was found in favor of the exercise group (global odds ratio for cycling vs. exercise was 0.51; 95% CI: 0.27–0.95).	Both programs were equally effective in maintaining walking capacity after discharge from stroke rehabilitation; or were equally ineffective in improving walking capacity
Mackay-Lyons *et al.* (2013)	To compare the effectiveness of body weight-supported treadmill to dose-equivalent usual cause in improving cardiovascular fitness and walking early after stroke	Single site, randomized controlled trial	Fifty individuals (mean age, 60 ± 14 years; mean event-to-randomization, 23 ± 5 days; 29 men) participated. Inclusion: enrolled men and women who were older than 18 years, within 1 month of first ischemic stroke, inpatients in the stroke rehabilitation unit, and able to walk 5 m with or without use of ambulatory aids, ankle orthoses, or stand-by assistance.	All individuals participated in 60-min physiotherapy sessions five times weekly as inpatients for 6 weeks and three times weekly as outpatients for another 6 weeks	BWSTT improved VO_2 peak by 30% which was significantly greater than the 8% improvement observed for UC ($P=0.004$ between groups)	BWSTT elicits greater improvements in cardiovascular fitness and walking endurance than UC in the subacute poststroke period. These gains are largely sustained for 1 year.
Ada *et al.* (2013)	To determine if a 4-month treadmill and overground walking program is more effective than a 2-month program, compared with control, at improving walking in community-dwelling people with stroke who walk slowly	Prospective randomized trial. Ambulate trial	A total of 102 people living with stroke in community. Experiment 1: $n=34$ (mean age: 70). Experiment 2: $N=34$ (mean age: 64) Control group: $N=34$ (mean age: 63) Inclusion: were within 5 years of their first stroke, Mini-Mental State Exam > 23, were community-dwelling and walked slowly (walk 10 m across flat ground bare feet without any aids taking more than 9 s).	Experimental group 1 (EG1): 30 min of treadmill and overground walking thrice/ week for four months. Experiment 2 (EG2): training for 2 months. Control group: no intervention.	EG1 and EG2: Improved 6-min walk distance compared with control group. EG1: Improved further than EG2; walking 38 m (95% confidence interval 15–60) more than the control group and 29 m (95% CI: 4–53) more than EG2. After 12 months: Both experimental groups returned to near baseline levels.	Four months of treadmill training results in better walking. However, these effects disappear once training ceases. Therefore, training should be ongoing.

Table 1 (*continued*)

References	Purpose of study	Study design/data source	Sample size, inclusion criteria, demographics, type of stroke	Type of intervention	Results	Implications and recommendations
Combs-Miller *et al.* (2014)	To compare the effects of body weight-supported treadmill training and overground walking training when matched for task and dose (duration/ frequency/intensity) on improving walking function, activity, and participation after stroke	Single-blind, pilot randomized controlled trial with 3-month follow-up.	Convenience sample of participants ($N=20$) at least 6-month poststroke (ischemic or hemorrhagic) and able to walk independently were recruited. Between the ages of 21 and 80 years, community dwelling, able to walk with or without an assistive device or orthosis at a self-selected gait speed of <1.0 m/s over 10 m, medically stable, and able to follow two-step verbal instructions.	Thirty-min walking interventions (body weight-supported treadmill training or overground walking training) were administered five times week for 2 weeks. Intensity was monitored with the Borg Rating of Perceived Exertion Scale at 5-min increments to maintain a moderate training intensity.	Overground walking training group: significant greater improvements in comfortable walking speed compared with body weight-supported treadmill group immediately (change of 0.11 vs. 0.06 m/s, $P=0.047$) and 3 months (change of 0.14 vs. 0.08 m/s, $P=0.029$) after training. OGWTG: improved comfortable walking speed ($P=0.001$).	Overground walking training was more beneficial than body weight-supported treadmill training at i mproving self-selected walking speed for the participants in this study
Severinsen *et al.* (2014)	Compare the effects of aerobic training with progressive resistance training after stroke to determine whether AT-induced fitness gains or RT-induced fitness gains translate into improved ambulation across 12-weeks intervention and whether gains are retained 1-year after cessation of formal training	Randomized controlled 12-week intervention trial with 1-year follow-up	Fourty-three community-dwelling independent walkers with chronic stroke. Inclusion: Nonhemorrhagic stroke; 6–36 months have elapsed after stroke; aged 50–80 years; muscle strength of more than three on the Medical Research Council scale at the paretic lower limb; and walking velocity of less than 1.4 m/s at fast 10 MWT, allowing assistive walking devices.	Participants performed exercise 3 times/week for 12 weeks. Individually adapted high-intensity AT consisted of 15 min of strenuous cycle ergometer exercise, three times at each session. If heart rate scales were unreliable Borg Scale was used. High-intensity progressive RT of both lower limbs consisted of three sets of eight repetitions targeted at an intensity of 80% of one repetition maximum. Self-assessments of physical activity were estimated monthly using Danish version of the Physical Activity Scale.	Comparison between AT, RT, and sham training showed no clinically relevant effects on walking velocity or walking distance. Muscle strength improved after RT ($P<0.0001$) and was preserved at 1-year follow-up ($P<0.001$). Aerobic capacity increased after AT ($P<0.001$) but was lost during the follow-up observation period.	Improvements in muscle strength or aerobic capacity using non-task-specific training methods does not result in improved ambulation in patients with chronic ischemic stroke. Muscle strength gains were maintained at follow-up, whereas all improvements of aerobic capacity were lost, indicating a long-lasting effect of intensive RT even without maintenance training.
Park *et al.* (2015)	To investigate the effect of external cues using vibratory stimulation on spatiotemporal gait parameters in patients with chronic stroke	Cross-sectional study	Thirty patients who had suffered a stroke (men = 18 women = 12). Inclusion: 6 months since the diagnosis, ability to walk for a minimum of 10 m, no problem in gait by contracture of the foot and ankle, and no musculoskeletal disease.	Each participant was subjected to six walking trials: three trials were vibratory stimulation of the tibialis anterior muscle and three trials without stimulation.	Gait velocity under vibratory stimulation of the tibialis anterior muscle (50.22 ± 17.42 cm/s) was significantly higher than that of general gait (46.59 ± 15.09 m/s; $P<0.05$). Gait cadence under vibratory stimulation of the tibialis anterior muscle (79.26 ± 15.76 step/min) was significantly higher than that of general gait (76.32 ± 13.13 step/min; $P<0.05$).	These results indicate that the application of external cues using vibratory stimulation during gait may control gait parameters and improve gait performance. Intervention could be used for gait rehabilitation in chronic stroke patients.
Srivastava *et al.* (2015)	To ascertain whether rehabilitation interventions improve locomotion beyond 6-months poststroke	A prospective, repeated-measure study	Forty participants. Inclusion: patients with first ever supratentorial stroke, with an age range of 16–65 years, with more than 6 months of poststroke duration, with an ability to follow three-step commands, and having an impaired balance and gait with an intact ability to walk with or without support.	Twenty sessions of task-specific interventions consisting of lower limb resistive exercises and treadmill gait training to locomotor abilities (90 min/ day, 5 days/week for 4 weeks). Evaluations were performed at the beginning and end of training and at follow-up of 3 months.	At the beginning, the end of training, and follow-up, the mean Scandinavian Stroke Scale scores were 0.41, 0.53, and 0.51; and Barthel Index scores were 77.34, 89.06, and 92.32.	Rehabilitation interventions significantly improve locomotor outcome even in the chronic phase following a stroke

Park *et al.* (2015)	To compare the gait abilities in chronic stroke patients following either treadmill walking training with rhythmic auditory stimulation or overground walking training with rhythmic auditory stimulation (ORAS)	Pilot study	Nineteen patients: TRAS: $N=9$ ORAS: $N=10$ Inclusion: patients who had a stroke more than 6 months after the onset of stroke and less than 2 years, the ability to walk for 10 min or longer on a treadmill, no amblyopia, vertigo, and abnormal vestibular function, cognitive function allowing an understanding of researchers' instructions, and after 6 min of walking, no blood pressure, pulse, or breathing problems.	Both the TRAS group and ORAS training group received neurodevelopment therapy and then performed walking training for 30 min Five times a week for 3 weeks. 10 m distance on the ground and let patients walk at a convenient speed. Tempo of rhythmic auditory stimulation was increased from 90% (first week) to 100% (second week) to 110% (third week). TRAS: metronome was used for auditory rhythmic stimulation. Before walking training, patients were asked to beat foot along with metronome to adapt to the rhythm for 2 min.	After the training period, the TRAS group showed a significant improvement in walking speed, step cycle, step length of the unaffected limb, coefficient of variation, 6 MWD, and FGA when compared with the ORAS group. After the training results showed that the TRAS group's walking speed statistically significantly increased compared with the ORAS group ($P<0.05$).	Treadmill walking training during rhythmic auditory stimulation may be useful for rehabilitation of patients with chronic stroke
Druzbicki *et al.* (2015)	To evaluate the effects of gait training using a treadmill with or without visual biofeedback in patients in the late period after stroke, and to compare both training methods	A single-blind, randomized, control group investigation, conducted among patients treated at the Clinical Rehabilitation Unit.	Fifty people [(18 women, 32 men; mean age 62 years (range 38–79 years)] at least 6 months after stroke, independent walking (walking speed > 0.4 m/s), Brunnstrom recovery stage 3–4, muscle tone of a paretic lower limb (Ashworth ≤ 1 plus), and a level of disability according to the Rankin Scale: 3. Randomly enrolled into groups with a rehabilitation program of treadmill training with or without visual biofeedback. Intervention group: $n=25$. Control group: $n=25$.	Group 1 (control) received treadmill training without visual biofeedback and basic physiotherapy consisting of 1.5-h sessions for 10 days (every Monday to Friday for 2 weeks.) Group 2 (intervention group) received treadmill training with visual biofeedback and basic physiotherapy consisting of 1.5-h sessions for 10 days (Monday–Friday) for 2 weeks.	Intervention group: greater improvements in the shortening of stance phase ($P=0.0045$) and lengthening of the swing phase of the unaffected limb ($P=0.0042$) and increase in unaffected limb cycle length ($P=0.0021$). No significant differences between groups in other spatiotemporal parameters of gait or additionally assessed parameters.	Gait training using a treadmill resulted in improvements in the gait and functional capacity of patients. The use of biofeedback gives better results in improving gait cycle length, duration of gait phases and swing phase speed compared with exercise on a treadmill alone.
Llorens *et al.* (2015)	To study clinical effectiveness and the usability of a virtual reality-based intervention compared with conventional physical therapy in the balance recovery of individuals with chronic stroke	Randomized controlled trial	Twenty individuals with chronic stroke. Experimental group: $n=10$ Control group: $n=10$. Inclusion: hemiparesis, age ≥ 40 years old and ≤ 70 years old; chronicity > 6 months; Mini-Mental State Examination cutoff > 23; able to follow instructions; ability to maintain stride-standing position for 30 s without assistance.	Intervention consisted of 20 1-h sessions, 5 sessions/week for 4 weeks. Experimental group: combined 30 min with the virtual reality-based intervention with 30 min of conventional training. Control Group: underwent 1 h conventional therapy.	Group-by-time interaction in the scores of the BBS ($P<0.05$) and in the 10 MWT ($P<0.05$)	Virtual reality interventions can be an effective resource to enhance the improvement of balance in individuals with chronic stroke
Bang *et al.* (2016)	To investigate the effects of body awareness training on balance and walking ability in chronic stroke patients	Randomized controlled trial	Patients were randomly assigned to a body awareness training group ($N=6$) and a control group ($N=6$). Inclusion: hemiparesis stroke (first hemorrhage or infarction), event occurring > 6 months previously and ability to walk a distance of 100 meters with or without assistance.	BAT: received body awareness training for 20 min, followed by walking training for 30 min a day, 5 days a week for 4 weeks. Control group: received walking training for 30 min a day, 5 days a week for 4 weeks.	After intervention, both groups showed significant differences compared with before the intervention in the BBS ($P=0.036$) and TUG ($P=0.037$) between the two groups/no significant intervention in the 10 MWT	The results of this study suggest that body awareness training has a positive effect on balance in patients with chronic stroke

Table 1 (*continued*)

References	Purpose of study	Study design/data source	Sample size, inclusion criteria, demographics, type of stroke	Type of intervention	Results	Implications and recommendations
Boyne *et al.* (2016)	To assess the feasibility and justification for a definitive randomized controlled trial comparing high-intensity interval training and moderate-intensity, continuous aerobic training in people with chronic stroke	Feasibility study preliminary RCT was conducted	Nineteen participants. HIT group: $N=13$, MCT group: $N=5$. Inclusion: (i) age 35–90 years, (ii) unilateral stroke experienced > 6 months before enrollment, able to walk 10 m overground with assistive devices as needed without physical assistance, able to walk 3 min on the treadmill at ≥ 0.3 mph (0.13 m/s) with no aerobic exercise contraindications, stable cardiovascular condition.	Both groups trained 25 min, 3 times/week, for 4 weeks. HIT strategy involved 30-s bursts at maximum-tolerated treadmill speed alternated with 30–60 s rest periods. MCT strategy involved continuous treadmill walking at 45–50% of heart rate reserve.	Baseline VO_2 peak and fractional utilization were significantly different between groups	Although further protocol optimization is needed to improve overground translation of treadmill gains, a definitive RCT comparing HIT and MCT appears to be feasible and warranted
Murata *et al.* (2016)	To investigate the efficacy of stepping-in-place training using a foot lifting assist device on the walking gait of chronic hemiparetic stroke patients	Cross-sectional sample	Seven patients with chronic hemiplegic stroke (age: 80.9 ± 4.9 years) participated in the study. Inclusion: able to maintain the standing position independently, and able to walk at least 10 m on flat ground with or without minimum assistance in walking balance.	Participants had 2 or 16 weeks of intervention. Evaluations were performed before the baseline period and before and after the intervention period (two-dimensional motion analysis of walking and stepping-in-place exercises and a clinical evaluation).	Walking speed increased in three participants after 2 or 16 weeks of intervention. Swing phase percentage increased in the paretic gait cycle. A walking speed gain was found in three participants, and, furthermore, a cadence gain was found.	The transition from the support phase support to the swing phase was shortened after the intervention. The stepping-in-place exercise using the device designed for this study may improve the muscle strength of the lower limb and coordination in the pre-swing phase of the paretic limb.
Jeong *et al.* (2016)	To investigate the effects of treadmill walking combined with obstacle-crossing on the walking ability of ambulatory poststroke patients	Pilot randomized controlled trial	Twenty-nine patients randomly assigned to one of the following: experimental group treadmill walking training : ($N=15$) or CG (TWT): $N=14$. Inclusion: first stroke (6 months to <1 year); 24–80 years of age; hemiplegic stroke with gait disturbance; independent ambulation with or without walking aids for over 10 m and a score of 4 or 5 on the Functional Ambulation Classification; sufficient cognition to participate in the training.	Participants had 30 min of active/passive exercises and 30 min of gait training in the form of treadmill walking. They participated in daily sessions of regular intervention for 1 h/day, 5 times/week, for 4 weeks, with 30 min of active/passive stretching exercises as well as upper and lower extremity training (active exercises and strengthening) and 30 min of gait training. Only the 30 min allocated for gait training differed in content between the groups (TWT vs. TWT-OC).	Significant differences were found in 6 MWT and BBS scores between the groups after adjusting for baseline value, but not at the 10 MWT, timed up and go, and Activities-Specific Balance Confidence scale scores, with the TWT-OC group demonstrating significantly greater BBS scores of the two groups. Both groups demonstrated significant improvements in all variable.	Treadmill walking combined with obstacle-crossing training may help improve the walking ability of patients with hemiplegic stroke and can possibly be used as an adjunct to routine rehabilitation therapy as a task-oriented practice on the basis of community ambulation
Danks *et al.* (2016)	To determine preliminary efficacy and to identify baseline characteristics predicting who would benefit most from fast walking training plus a step activity monitoring program (FAST + SAM) compared with fast walking training (FAST) alone in persons with chronic stroke	Randomized controlled trial with blinded assessors	A total of 37 participants. Inclusion: had sustained a stroke > 6 months before; were able to walk without assistance; were able to walk 5 min at a self-selected pace on the treadmill; were able to walk outside the home before stroke; walked <10 000 steps/day; and were able to communicate with the investigators	Subjects were assigned to either FAST, which consisted of walking training at their fastest possible speed on the treadmill (30 min) and overground 3 times/week for 12 weeks	There was a significant effect of time for both groups, with all outcomes improving from pretraining to post-training (all $P<0.05$). The FAST + SAM was superior to the FAST for 6 MWT ($P=0.018$), with a larger increase in the FAST + SAM group. The intervention had differential effectiveness on the basis of baseline step activity.	The addition of a step activity monitoring program to a fast walking training intervention may be most effective in person with chronic stroke who have initial low levels of walking endurance and activity. Regardless of baseline performance, the FAST + SAM intervention was more effective for improving walking endurance.

Vahlberg *et al.* (2016)	To evaluate the effects of progressive resistance and balance exercise on physical and psychological functions of poststroke individuals	Randomized controlled trial with follow-up at 3, 6, and 15 months	Sixty-seven community-living individuals (76% male; 65–85 years) with a stroke 1–3 years previously were allocated to an intervention group (IG, $n=34$). Control group (CG, $n=33$). Inclusion: stroke of within the previous 1–3 years, ability to walk a minimum of 10 m and either a lack of outdoor walking for at least 5 days/week.	IG: PRB exercises combined with motivational group discussions twice for 3 months. Training performed in classes that were conducted twice weekly over 3-months period and consisted of different work stations with functional exercises.	At 3 months, the IG showed significant improvements in balance and comfortable walking speed relative to the CG. A faster walking speed persisted at 6 months.	In chronic stroke patients, 3 months of PRB exercise and motivational discussions induced improvements in balance at 3 months and in walking speed at 3 and 6 months. Progressive resistance and balance exercise program supported by motivational group discussions and one home-based exercise appears to be effective for short-term balance and walking speed in individuals with chronic stroke.

ABC, Activities-Specific Balance Confidence; ANOVA, analysis of variance; APA, Adaptive Physical Activity; BAT, body awareness training; BSS, Berg Balance Scale; BWS, body weight support; BWSTT, body weight-supported treadmill training; CWT, comfortable 10-min walk test; LT, locomotor training; MWT, meter walk test; FGA, functional gait assessment; FWT, fast 10-m walk test; OWET, Overground Walking Exercise Training; PT, physical training; SIS, Stroke Impact Scale; SPPB, Short physical Performance Battery; THRR, targeted heart rate range; TUG, the timed up and go test; TWET, Treadmill Walking Exercise Training; UE, upper extremity; QoL, quality of life.

were found in this review. Although most of the studies found significant improvements associated with these training approaches, still others reported no improvement. This is in agreement Rensink *et al.* (2009), who note significant walking function improvement for groups of individuals using overground and treadmill training, but no significant difference between those groups.

Nonetheless, the majority of studies reported improvements among poststroke individuals, consistent with previous studies. For instance, An and Shaughnessy (2011) found that gait training was effective in improving walking function after stroke, especially when it was initiated early, similar to the findings obtained by Mackay-Lyons *et al.* (2013). Early initiation of rehabilitation may also improve the overall quality of life of stroke survivors (Chaiyawat *et al.*, 2009; An and Shaughnessy, 2011), although perhaps only for certain types of rehabilitation, for example, gait training (Combs *et al.*, 2010).

Maintenance of rehabilitative gains remains a challenge for after stroke interventions. Although the benefits of rehabilitation can help stroke survivors become independent by facilitating more ambulatory and social lifestyles (Dowla and Chan, 2010; Ada *et al.*, 2013). Further, Severinsen *et al.* (2014) reported that stroke survivors who had gained muscle strength or aerobic capacity during non-task-specific training lost those improvements after the program was over.

These temporary gains could signal three major situations: (a) that there is a lack of programs for stroke survivors to participate to maintain their improvements; (b) that after stroke survivors lack the personal motivation to continue engaging in intervention programs; (c) or that stroke survivors may have other priorities in terms of what they would like to experiance improvements in terms of their after stroke condition. For instance, Combs *et al.* (2013) reported that 76% of stroke survivors would like to observe improvements in their walking distance rather than their walking speed. This underscores the importance of knowing the goals or aspirations of poststroke individuals in relation to walking function before implementing rehabilitation.

Like other research, which reported gait speed and spatiotemporal parameters as the most used outcome measures (Mudge and Stott, 2007; Van Bloemendaal *et al.*, 2012), the current review similarly reported such outcome measures across different walking trainings. In so doing, this review also highlights the relationships between specific walking trainings and related outcomes to propose new intervention strategies and potential outcome measures for use in future research. Hancock *et al.* (2012), for example, have reported beneficial effects on balance, physical function, and muscle strength in stroke survivors through the use of reciprocal pedaling exercise. In a subsequent review by Obembe and Eng

(2016), they found a small beneficial effect from physical intervention trainings on socialization. Overall, these kinds of outcome measures – balance, physical function, muscle strength, and socialization – range across physical and emotional outcomes that suggest improvements to quality of life. In general, these findings and our review alike point to a need for maintained improvement of quality of life and physical function following rehabilitation participation after stroke.

There are many limitations to this review that we would like to highlight. One is related to the fact that we relied on studies that have been published in English, ignoring other major studies published in languages other than English. In addition, participants were exposed to several treatments that make it difficult to focus solely on the impact of walking trainings alone. We did not identify a single longitudinal study that could effectively capture the impact of participating in walking trainings.

Conclusion

This study reviews the impact of different types of walking training interventions on walking function among stroke survivors. Although such a rehabilitation intervention has a positive impact in improving stroke survivors' walking function and quality of life, it remains a challenge to maintain the gains of rehabilitation over time after the cessation of the rehabilitative interventions. Moreover, differences in rehabilitative intervention, as well as proxies for measuring rehabilitative gains such as walking speed, walking distance, balance, and so forth, make objective assessments of the value of different approaches difficult at best. Programs to maintain – or research to identify ways to better maintain – improvements gained from rehabilitation even after rehabilitation ceases are needed, as well as a more standardized measure of after stroke walking function improvement overall.

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Conflicts of interest

There are no conflicts of interest.

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