Effectiveness of Body-Weight-Supported Treadmill Training in Improving Quality of Gait among Stroke Survivors: A Narrative Review

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Abstract
Regaining the ability to walk after a stroke improves self-esteem and quality of life of the survivor and as such restoring gait is an optimal goal of stroke rehabilitation requiring different approaches. The purpose of this article was to review the effectiveness of body-weight-supported treadmill (BWST) training in improving gait quality post stroke. An exhaustive electronic search was conducted in Google Scholar, PEDro and PubMed databases for studies (from 1999 to 2019) on the effectiveness of BWST training in improving quality of gait among patients with stroke. Included studies were those published in English language, conducted on stroke patients using treadmill as the primary intervention to assess gait parameters. Of the 26,237 articles identified from the overall search, only 9 articles met the inclusion criteria and were independently screened and reviewed. The results showed that BWST training could elicit significant improvement in cadence (range: 3.2 to 4.2% gait cycle), paretic step length (6.7 cm), walking speed ($p < 0.02$) and walking capacity ($p < 0.001$). While walking velocity increased by 22%, stride length increased by 13% and a medium to large effect sizes of 0.7 and 1.16 standard deviation units were observed for gait energy expenditure. A significant improvement in walking speed and walking distance ($p < 0.005$) which remained better after follow-up (mean difference 0.22 m/sec, 95% CI 0.05 to 0.39) was observed. It was concluded that BWST training is effective in improving quality of gait and in enhancing functional recovery of stroke survivors.

Keywords: *Treadmill; Body-weight support; Gait; Stroke; Quality*

Introduction
Low- and middle-income countries (LMICs) are undergoing an epidemiological transition driven by socio-demographic and lifestyle changes (Owolabi *et al.*, 2014). The burden of non-communicable diseases, including cardiovascular risk factors is increasing (Owolabi *et al.*, 2014; Moran *et al.*, 2013). Consequently, the incidence of

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stroke, a cardinal complication of cardiovascular risk factors, appears to be rising in the poor countries of sub-Saharan Africa of which Nigeria occupies a significant position (Moran *et al*., 2013). Recent data show that 86% of all stroke deaths around the world are contributed by LMICs in Africa and other continents (Feigin, 2005; Norrving & Kissela, 2013).

Stroke is one of the leading causes of adult disability; with more than half of stroke survivors losing functional abilities as a sequel to loss of voluntary control and movement in the affected side (Kwakkel, van Peppen & Wagenaar, 2004; McCarron, Armstrong & McCarron, 2008; Pan, Song, Lee & Kwok, 2008). Gait deficit due to stroke is one of the most common disorders treated by physiotherapists using various rehabilitation approaches (Lin, Wu, Wei, Lee & Liu, 2014). The consequences of hemiplegic dysfunctions in people with stroke influence their daily activities, such as self care, feeding, dressing and return to work (Whitall, McCombe, Silver & Macko, 2000; Vincent-onabajo & Shaphant, 2019). Following stroke, the pattern of walking recovery among survivors is quite variable. Previous reports showed that only 22% of the 45 patients who could not walk as a consequence of stroke were able to walk normally within 3 months of recovery (Lin *et al*., 2014).

Traditionally, the interventions used in managing stroke have always included trunk rotations to normalise muscle tone and reduce spasticity, or use of weight-bearing techniques on spastic lower extremity to inhibit spasticity and facilitate normal movements in the extremity to restore gait (Bobath & Bobath, 1984). Clinicians often use conventional techniques such as neurodevelopment therapy (NDT), strengthening exercises, positioning and proprioceptive neuromuscular facilitation to achieve the aforementioned goals. Other clinical options may include walking aids (bars, sticks and canes) which often demand considerable assistance from the therapist to help the patient support body weight and control balance (Inacio *et al*., 2002).

Evidence shows that employing conventional gait training alone often lead to an asymmetrical gait pattern in many stroke patients (Reisman *et al*., 2013), and consequently there has been growing interest in exploring new approaches that will improve gait symmetry and overcome motor limitations while facilitating task-specific activity and reducing cardiovascular stress of walking among stroke survivors (Reisman *et al*., 2013). One approach for which the literature is rapidly expanding involves the use of body weight support during gait training on a motorised treadmill (Awad, Reisman, Kesar & Binder-Macleod, 2014). Body-weight-supported treadmill is a task-specific method conceptualised based on the framework of functional re-organisation of the brain using the concept of neuro-plasticity and science of neuro-rehabilitation (Nudo, Plautz & Frost, 2001). The rationale for this approach is that while partial body weight support removes some of the biomechanical and equilibrium constraints of full weight bearing, walking movements may be facilitated on the treadmill by the activation of spinal locomotion centers of individuals with neurological conditions such as stroke (Awad *et al*., 2014).

Treadmill training has evolved to serve as an adjunct in stroke rehabilitation but many hemiparetic patients are able to train on treadmills within an initial speed of as low as

0.2 to 0.4 km/hr. The impact of speed dependent treadmill on quality and symmetry of gait may remain minimal due to inadequate body weight support and lack of ambulatory independence during training (Silver, Macko, Forrester, Goldberg & Smith, 2000). Therefore, many patients will remain with significant degrees of walking deficits and disabilities. Thus, a better approach for alleviating these deficits is paramount to achieve quality gait rehabilitation for use by clinicians and healthcare providers. Therefore, the aim of this article was to review the effectiveness of body-weight-supported treadmill as it relates to the quality of gait among stroke survivors, thereby offering insights into the clinical benefits of this method of gait training.

Methods

Search strategy

Three electronic databases (Google Scholar, PEDro and PubMed) were searched using keywords including ‘treadmill’, ‘stroke’ OR ‘hemiparesis and gait’ OR ‘walking’ OR ‘ambulation’. The aim of this search was to identify potentially relevant articles that included any or all of these keywords in their titles or abstracts. The PubMed search was performed by entering the keywords ‘stroke’ OR ‘hemiparesis and gait’ OR ‘walking’ OR ‘ambulation’ into the MeSH database in order to obtain common and consistent MeSH terms. The search was limited to studies that were published in 1999 to 2019, and was performed within two months by two of the authors; it was performed separately and independently and it yielded 13 relevant articles.

Study selection

The overall search yielded 13 potentially relevant articles, out of which nine remained after removal of duplicates. The assessment of the studies and removal of duplicates were done independently by two authors (MK & AAW). The duplicates were removed manually, while the remaining relevant articles were printed. The tittles, abstracts and contents of the relevant studies were screened separately by two of the authors (MOA & AYO) for inclusion.

Eligibility criteria

The inclusion criteria in this review include the following:

1. Studies using treadmill as primary intervention on gait or any gait parameter (such as cadence, stride length, speed and so forth) in stroke survivors.
2. Studies including either acute or chronic stroke or both.
3. Studies including left or right hemispheric stroke with either hemorrhagic or ischaemic lesion.
4. Studies with ambulatory or non- ambulatory stroke survivors.
5. Studies with different designs. This is because narrative reviews can be conducted without much rigor and can include different study designs.

The exclusion criteria were treadmill studies with non-stroke patients, studies published in languages other than English, treadmill studies on stroke patients that did not assess gait and if full text was not available. Standardised data extraction tables were created using Microsoft word. Initially, information related to the study (title, year and author, number of participants, intervention parameters and methodology) were extracted by two of the authors (MK & AAW). Two other authors (MOA & AYO) with combined teaching, clinical practice and research experience (including narrative reviews) of over fifteen years later checked the reviews and extractions for accuracy. The reviewer was not blinded to the authors or journals when extracting and assessing the accuracy of the data.

Results

Data synthesis

The titles and abstracts of 13 potentially relevant articles were examined of which 4 were excluded. Of these, 3 were duplicates and one was an abstract which did not give sufficient information on the study. Full text copies of the remaining 9 articles were screened in detail for inclusion criteria. Thus, a total of 9 papers on the effects of treadmill exercise on improving gait among stroke survivors met the inclusion criteria (Figure 1). The eligibly included studies comprised seven RCTs, one descriptive study and a systematic review. The non-RCT studies that were included have provided information on the feasibility and efficacy of body-weight-supported treadmill intervention on gait rehabilitation in stroke survivors.

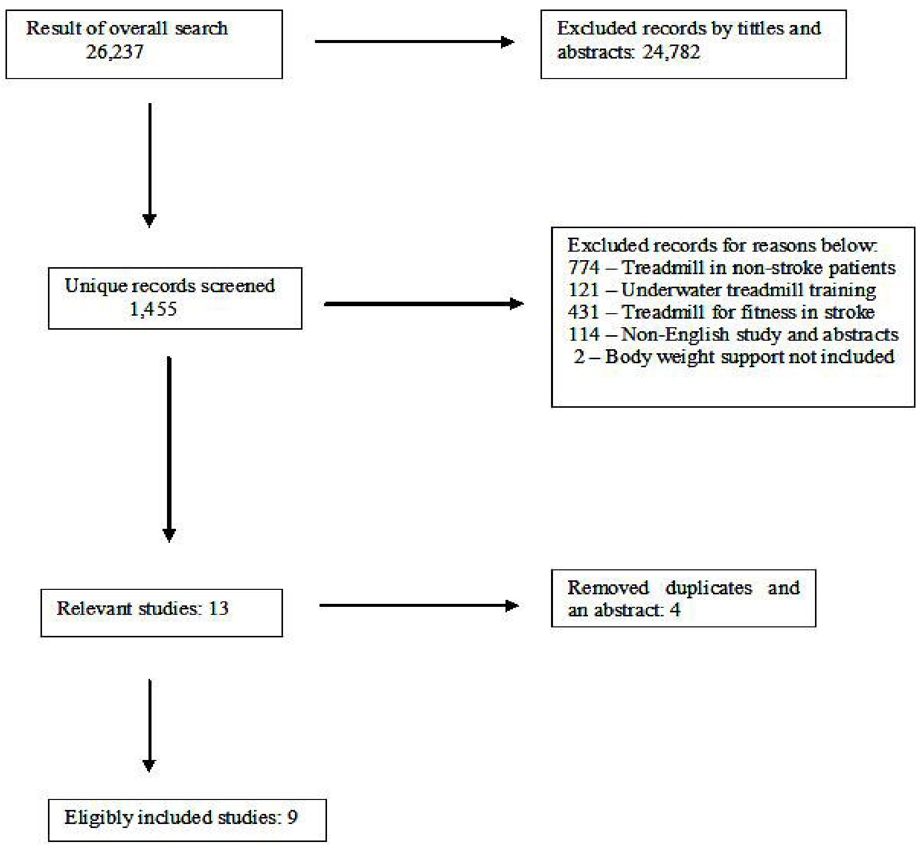

Figure 1: *Flowchart for the included studies*

Study characteristics

Table 1 presents a summary of the studies included in the review

Table1: *Summary of the studies included in the review*

Authors (Year)	**Title**	**Participants and intervention parameters**	**Study design**	**Outcome**
Inacio *et al.* (2002)	Gait outcomes after acute stroke rehabilitation with supported treadmill ambulation training	Experimental group (n = 6) and control group (n = 7). The control group received 1 hour each of regular physical therapy, kinesiotherapy and occupational therapy while the experimental group received supported treadmill ambulation training (STAT) and regular intervention without the usual gait training	RCT-Pilot study	Small sample size did not generate enough power to detect significant difference in any variable after 4 week on 3 times season for 3 hrs
Marcus *et al.* (2002)	Speed dependent treadmill training in ambulatory hemiparetic stroke patients	Three groups speed-dependent treadmill training (STT), limited progressive treadmill training (LTT) and conventional gait training(CGT) (n= 20 each) participated in 12 training sessions	RCT	STT group improve higher than LTT & CGT in over ground walking speed, cadence and stride length
Anne *et al.* (2003)	Treadmill training and body weight support for walking after stroke	Using a priori protocol, two reviewers independently selected and extracted data	Systematic review	A slight trend towards effectiveness of treadmill training with body support was observed. There was a comparative benefit of treadmill exercise with and without body support at the end of follow up
		Ninety-seven subjects were recruited within 6	RCT	

Marco *et al.* (2009)	Walking after stroke: what does treadmill training with body support add to over ground gait training in patients early after stroke	weeks of stroke onset and were randomly assigned to conventional rehabilitative treatment plus gait training with body weight support on a treadmill (experimental group; n = 52) and conventional treatment with over-ground gait training only (control group; n = 45).		All patients were able to walk. No differences were seen between the 2 groups before, during, and after treatment and at follow-up.
Trisha *et al.* (2011)	Minimal detectable change (MDC) for gait variables collected during treadmill walking in individuals post-stroke	Each of the 19 participants with post-stroke hemiparesis walked on a split-belt treadmill within 20-40 seconds duration for two sessions	Descriptive	There were MDC for all temporal variables, paretic step length, and hip, knee and ankle joints. Walking speed and walking capacity increased significantly (P = 0.2 and < 0.001)
Savin *et al.* (2014)	Generalisation of improved step length symmetry from treadmill to over-ground walking in person with stroke and hemiparesis	The experimental group (n= 10) received treadmill training and walked over-ground on Gaitrite mat while the control (n= 10) received the Gaitrite mat walking	RCT	Both group's over-ground gait velocity increased post adaptation due to increased stride length and decreased stride duration
Toshifumi *et al.*	Improvement of gait ability with a short-term intensive gait	Intervention (n = 10) and control (n= 8), BWSTT for 20 minute once a day 3 times a week for 4 weeks at 20% of suspended body weight support.	RCT	4 weeks treadmill training shows improvement in maximum speed,

(2015)	rehabilitation program using body weight support treadmill training (BWSTT) in community dwelling chronic post stroke survivors			cadence and speed length among the intervention group
Srivastava *et al.* (2016)	Body weight-supported treadmill training for retraining gait among chronic stroke survivors	Three groups I, II and III (n = 15 each). Group I received gait training using conventional physiotherapy, II received treadmill without body weight support while III received treadmill with body weight support for 30min/day	RCT	Walking speed and endurance improved in body weight supported treadmill training (BWSTT) group
Gillian *et al.* (2017)	Treadmill training to improve mobility for people with sub-acute stroke	The experimental group (n = 39) received treadmill training plus normal gait re-education and the control group (n= 38) received normal gait re-education only	Phase II feasibility RCT	Treadmill training was feasible for sub-acute stroke but showed no significance difference when compared with normal gait re-education

RCT = Randomized controlled trial

The stroke onset duration varied among the patients included in this review. Of these studies, two comprised patients that were within 4 to 6 weeks of their stroke onset (Marcus, Jan, Claudia & Stefan, 2002; Inacio *et al*., 2002) and six studies on patients with stroke onsets of between 3 and 9 months. One study included patients with stroke duration above one year (Trisha, Stuart, Gregory & Darcy, 2011). Furthermore, the participants recruited were both male and female with either ischemic stroke or intra-cerebral hemorrhage (Toshifumi *et al*., 2015; Marcus *et al*., 2002; Inacio *et al*., 2002). The review included studies among patients with left, right or bilateral sites of stroke affectation (Srivastava, Taly, Gupta, Kumar & Murali, 2016; Abhishek, Arun, Anupam, Sendhil & Thyloth, 2016; Anne, Angela, Ian & Alex, 2003; Gillian, Lisa, Mark, Jane & Martin, 2017; Marco *et al*., 2009). Savin, Morton and Whitall (2014) combined individuals with middle cerebral artery infarcts, brainstem lesions and others with cortical and sub-cortical focal sites of lesion.

The total number of patients in the nine eligible studies was 622 which was arrived at by adding the 191 patients in the eight studies and 458 patients from the systematic review. The mean age of the patients in the included studies varied from 59 to 66 years except two studies that recruited younger patients of 40 years (Gillian *et al*., 2017) and 45 years (Srivastava *et al*., 2016). Some of the patients were non-ambulatory post stroke (Anne *et al*., 2003), while the majority were ambulatory.

The gait variables assessed after the treadmill intervention were cadence (Marcus *et al*., 2002; Trisha *et al*., 2011; Marco *et al*., 2009) and step length (Trisha *et al*., 2011; Savin *et al*., 2014). Similarly, paretic step length and stride length (Marcus *et al*., 2002), as well as gait energy expenditure (Inacio *et al*., 2002) were assessed. Other gait variables assessed in the included studies were walking speed, gait speed and walking velocity (Trisha *et al*., 2011; Inacio *et al*., 2002; Toshifumi *et al*., 2015). Walking distance was also assessed (Srivastava *et al*., 2016; Inacio *et al*., 2002).

The study of Toshifumi *et al*. (2015) on improvement of gait ability with short-term intensive gait rehabilitation programme using body-weight-supported treadmill training recruited eighteen community dwelling chronic post-stroke survivors. The treatment group composed of 10 participants (2 women and 8 men) with a mean age of 59.1±12.5 years and time since stroke onset of 35.3±33.2 months. The control group comprised 8 individuals (3 women and 5 men) whose mean age was 59.8±6.3 years and time since stroke onset of 39.3±27.3 months. The treatment group received body-weight-supported treadmill training, with 20% body weight supported 3 times a week for 4 weeks, with each session lasting for 20 minutes. There was improvement in maximum gait speed, cadence, and speed length post intervention in the treatment group. There were no follow up assessments to determine long term effect of the intervention.

A randomised controlled pilot study conducted by Inacio *et al*. (2002) on gait outcomes after stroke rehabilitation with supported treadmill ambulation training was conducted on six treatment group participants and seven participants in the control group. The six participants (age = 57.8±5.50 years, hours after stroke = 41.8±17.4) received three hours daily for an average of three weeks of physical therapy, kinesiology and occupational therapy plus supported treadmill ambulation training. The control group (age = 58.9±12.9, hours after stroke = 51.0±26.4) received same intervention except the supported treadmill ambulation training. The treadmill training was performed with 30% body weight support and progressively decreased by the therapist that administered the intervention. The decrease in the body weight support was quantified subjectively by the therapist based on observation of the support patients required to achieve the capability of greater self-support. Gait speed, walking distance, gait energy expenditure and gait energy cost were evaluated with no significant difference between the groups. There were no follow up assessments on the lasting effect of the intervention.

A randomised controlled study by Srivastava *et al*. (2016) used body-weight-supported treadmill for retraining gait among stroke survivors. Participants were those with first episode of stroke (right or left hemiparesis) due to an ischaemic or haemorrhagic supratentorial lesion. The participants were between 16 and 65 years with greater than three-month duration of stroke onset. They were randomly allocated to one of three groups. Group I received over-ground task-oriented gait training by a conventional physiotherapy approach. Group II received gait training on a treadmill without body weight support while group III received gait training on a treadmill with body weight support. The gait training was given for 30 minutes per day, five days per week for a period of 4 weeks. On completion of 20 sessions of the training, walking speed and walking endurance improved in the body-weight-supported treadmill training group. The body weight was supported by 40%; the patients were followed up to three months while improvement was sustained up to the period.

In a randomised controlled trial, Marcus *et al*. (2002) randomly selected 60 ambulatory post-stroke patients, and grouped them into three to receive one of three gait therapies - speed-dependent treadmill training (STT), limited progressive treadmill training (LTT) and conventional gait training (CGT) with each group consisting of 20 participants. The first group received STT for 30 minutes, the second group received 30 minutes of LTT and the third group received 30 minutes of CGT. These interventions covered 12 training sessions each, while all groups received eight sessions of conventional physiotherapy for a period 45 minutes. Body weight was supported with an overhead harness bearing no more than 10% of the patient's weight during first three training sessions of treadmill training. The treatment outcomes were assessed on the basis of over-ground walking speed, cadence and stride length and were found to be significantly higher in the STT than in the LTT and CGT groups. The outcomes were measured at two weeks and at the end of the study and there were no follow up assessments.

In the Gillian *et al*. (2017) phase 2 feasibility randomised controlled trial, 77 patients with sub-acute stroke within the first three months of stroke onset were trained on treadmill. The patients were group into 2 groups - intervention and control. The intervention group comprised 39 participants that received treadmill training plus gait re-education. In all, 49% of the patients that received treadmill training used a body weight support harness in week one which was reduced to 23% in week eight. The control group consisted of 38 participants that received normal gait re-education only. The treadmill training was performed twice a week with weekly median times spent on the treadmill equating to between 8 - 16 minutes a week, at a median speed of 0.6 m/s. The primary outcome measures were mobility and activities of daily living. These were assessed at eight weeks and at six months follow up interval. The outcomes were found to be better and feasible for the treadmill group.

The Savin *et al*. (2014) study on generalization of improved step length symmetry from treadmill to over-ground walking in persons with stroke and hemiparesis was conducted on 20 participants. The treatment group had 10 participants with stroke or hemiparesis among which seven were females (aged 62.8±9.40 years). The controls were gender matched non-stroke patients (aged 61.8±9.30 years). The participants undertook four consecutive testing conditions - over-ground baseline, treadmill baseline, and treadmill adaptation and over-ground generalization. During the treadmill training, a weight equal to 1.25% of the participants' body weight that was rounded to the nearest 0.11 kg was used for support by the participants. This was provided using a set of pulleys in order to resist forward movement of the legs during the swing phase. The primary outcome variables considered were step length symmetry, rates of step length symmetry adaptation on treadmill, over-ground gait velocity, stride length, and stride cycle duration. These were assessed after the intervention and were found to enhance generalisation of step length symmetry and prolong over-ground aftereffects. There were no any follow up assessments to determine long term after effect.

Trisha *et al*. (2011) computed minimal detectable change (MDC) for post-stroke gait kinematics, ground reaction force (GRF) indices, as well as temporal and spatial measures during treadmill walking. Nineteen individuals with chronic post-stroke hemiparesis (12 males aged 47 to 75 years, 72.5±63.4 months since stroke) participated in 2 testing sessions separately. The outcome showed an excellent test-retest reliability for all gait variables tested (intraclass correlation coefficients = 0.799 to 0.986). MDCs were reported for hip, knee and ankle joint angles (3.8^{o} for trailing limb angles to 11.5^{o} for hip extension), peak anterior GRF (2.85% body weight), mean vertical GRF (4.65% body weight), all temporal variables (range 3.2 to 4.2% gait cycle) and paretic step length (6.7 cm). There were no follow up assessments to determine long term effect of the intervention.

In a systematic review on treadmill training and body weight support for walking after stroke, Anne *et al*. (2003) investigated walking speed and walking dependence as primary outcomes. The study included randomised controlled trials and randomised crossover trials that used treadmill training and body weight support for the treatment of walking after stroke. The amount of body weight support was tailored to the patients' propensity and was between 10% and 25% of the patients' body weight in the eleven included trials. There was a slight trend toward effectiveness of treadmill training with body weight support for participants who could walk independently at the start of the intervention (weighted mean difference: 0.24 m/sec, 95% CI: -0.19 to 0.66 for speed; random effects). No statistically significant differences were found between treadmill training with body weight support and other interventions for walking dependence for participants who were dependent walkers at the start of the treatment (RR: 1.05%, 95% CI: 0.84 to 1.31; fixed effects).

The effect of treadmill training with body weight support on stroke patients was assessed in Marco *et al*. (2009) who recruited ninety-seven individuals within six weeks of stroke onset. The patients were randomly assigned into two groups. Group I received body-weight-supported treadmill and conventional gait rehabilitation (n = 52), while group II had conventional gait rehabilitation only (n = 45). The quantity of body weight support was tailored to the participants' capability and was limited to 40% of body weight. Participants were all treated for 60 minutes per session within a week for a period of four weeks and were assessed at baseline, after 20 sessions of treatment, two weeks post-intervention and were followed up to six months after stroke. All the participants were able to walk post-treatment and there was improvement in the outcome measures ($p < 0.0063$) both at the end of the treatment and during the follow-up. No differences were observed between the groups before, during, and after treatment and at follow-up.

Discussion

This narrative review comprised nine eligible studies that were conducted to assess the effects of body-weight-supported treadmill on gait in stroke survivors. Of these studies, seven were randomised controlled trials; the others were a systematic review and a descriptive study. Of the seven randomised controlled trials, four studies assessed some parameters of gait including maximum gait speed, gait speed and walking speed as well as stride length, cadence and walking endurance (Srivastava *et al*., 2016; Inacio *et al*., 2002; Marco *et al*., 2009; Toshfumi *et al*., 2005). These studies were at variance in the patients' characteristics (sample size, stroke onset duration, age and affected side), treatment duration and frequency, as well as the percentage of the body weight supported. Notwithstanding, the gait parameters showed improvement in the experimental groups. This implies that body-weight-supported treadmill offers some degree of weightlessness which facilitates some free degree of motion at the hip, knee and ankle joints. Similarly, the withdrawal of the usual physical assistance offered with non body-weight-supported treadmill training may enhance patients' endurance. This may offer the patient a sense of independence that can improve ambulatory performance.

Three randomised controlled trials (Savin *et al*., 2014; Gillian *et al*., 2017; Marcus *et al*., 2002) assessed other gait parameters. These parameters were rate of step length, step length symmetry, walking capacity, paretic step length, hip, knee and ankle joints range of motion. These parameters showed improvement in body-weight-supported treadmill group. It is obvious that the motion of treadmill alone enforces the mere appropriate stretching of the tendons around the joints (Hashidate, Shiomi & Sasamoto, 2011). The presence of body weight support in the treadmill often ensures that the joints extend more due to non-weight bearing effect during the interchange between the swing and the stance phases and overall propulsion. This often improves gait recovery, promotes walking independence, and reduces walking asymmetry by incorporating both agonist and antagonistic muscles in the various phases of gait. This outcome corroborates the findings of Macko *et al*. (2005) which showed that body-weight-supported treadmill produced substantial reduction in energy expenditure and cardiovascular demands of walking, thereby improving gait recovery and ambulatory functions.

Our findings show improvement in maximum walking speed, walking endurance and walking capacity among patients in the suspended treadmill groups. It implies that body-weight-supported treadmill can be an adjunct intervention during gait rehabilitation. In a study by Mulroy *et al*. (2010), body-weight-supported treadmill training (2 to 4 times per week for 6 to 12 weeks) was found to improve muscle strength, balance and gait symmetry. A slight trend of effectiveness in body-weight-supported gait training was reported in a systematic review (Anne *et al*., 2003). This means that body-weight-supported treadmill training could be used an intervention to improve walking dynamics. If physiotherapists are able to secure adequate time to train stroke patients using body-weight-supported treadmill, the patients get the odds of assorted therapeutic benefits. Therefore, ensuring functional and quality stroke rehabilitation requires adjunct interventions including supporting the weight of the patient either manually or using advance technology that incorporates hang up shelve in a suspended treadmill machine.

The major limitation of this review was lack of specificity as we combined different studies with different designs and heterogeneous characteristics of patients in terms of stroke onset duration, age, type of stroke and the side affected.

Conclusion

Body-weight-supported treadmill training improves quality of gait among stroke survivors who are able to walk independently. It can be used to enhance gait symmetry, improve speedy gait and reduce gait energy expenditure and walking disabilities among stroke survivors. Based on the findings of the review, we recommend that further reviews should be carried out in a sub-set of stroke survivors to determine the specificity of the effectiveness of the intervention. Future reviewers should also use intervention specific studies to establish the efficacy and judicious application of the intervention in clinical practice.

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