REVIEW ARTICLE

Assessment of two gait training models: conventional physical therapy and treadmill exercise, in terms of their effectiveness after stroke

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Abstract

Background: Rehabilitation provided to patients after stroke mainly aims at improvement in gait function. The most common gait training strategies include treadmill exercise and traditional overground gait training. The study was designed to assess the effectiveness of two models of gait re-education in post-stroke patients, namely conventional physical therapy and treadmill training.

Methods: A systematic literature review was performed, taking into account the online databases of Medline (PubMed), Science Direct, Web of Science, Google Scholar, and clinical trials registries. The following inclusion criteria were applied: studies published from 2008 to 2018, written in English, involving treatment and control groups, investigating conventional physical therapy and treadmill training administered for gait re-education after stroke.

Results: Out of 160 articles identified, 23 met the inclusion criteria and were reviewed and analyzed. One hundred fifteen projects involving clinical trials were identified; out of these nine reports from the last five years are included in the review. The number of participants in all the studies totaled at 1,772. The participants in all the studies represented both sexes, and their age ranged from 18 to the late 80s, with an average of 60+ years of age. In most cases, the patients examined were at a chronic stage post-stroke, i.e., more than six months following stroke onset. The most frequently applied types of treadmill training included: high-intensity aerobic treadmill training and treadmill training with or without body weight support. Most interventions involved participation in 30- or 60-minute sessions, from three to five times weekly, for the duration of six to 16 weeks.

Conclusions: Treadmill training seems to be a valuable and effective method of gait re-education, which can be used at various periods following a stroke, and mainly leads to improvement in walking speed and walking capacity. However, no standard has been defined so far with regard to treadmill-supported recovery of gait function in patients after stroke. We still do not know the optimum duration and frequency of exercise. Further study should investigate long-term effects and the way treadmill training impacts on patients' daily activities. HIPPOKRATIA 2018, 22(2): 51-59.

Keywords: Stroke, gait, treadmill, randomized controlled trials, literature review

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Introduction

Walking is one of the most important abilities, necessary for independent functioning and active involvement in social life. It is estimated that gait-related problems are experienced by approximately 60 % of patients after stroke[1,2]. Although most stroke survivors regain a certain level of independent locomotion, in many cases, they are not able to perform all activities of daily living without assistance. Consequently, rehabilitation programs designed for post-stroke patients primarily focus on gait training[3,4]. Well-known methods applied in gait re-education after stroke include treadmill training, which presents many advantages compared to overground gait training. Most importantly, treadmill training is based on multiple repetitions of the entire gait cycle, with a greater total number of steps and complete control over the patient's gait velocity. Furthermore, treadmill training is carried out in a well-defined area; therefore, the therapist has greater control of and can adequately secure the patient[1,5].

In the literature, numerous studies are reporting that treadmill training contributes to improved ambulation in patients, both at an early and at a chronic stage after stroke. In addition to such benefits as higher walking speed and longer distance covered, increased endurance, and decreased spasticity, treadmill training seems to support mechanisms of neuroplasticity[2,6-13]. Likewise, it has been established that overground gait training is effective in post-stroke patients[14-24]. Therefore, it would be interesting to examine whether or not there are significant differences in the progress achieved by post-stroke patients as a result of treadmill gait training compared to conventional overground gait training. A need to find an answer to the above question was the motivation for this study. The study was designed to assess the effectiveness of two models of gait re-education after stroke, namely interventions based on a conventional physical therapy or a treadmill training.

Material and Method

The search was carried out, in the period from May 2017 to April 2018, in the following databases: Medline (PubMed), Science Direct, Web of Science, Google Scholar, and in the clinical trials registries (https://www.clinicaltrialsregister.eu, https://clinicaltrials.gov). The following medical subject headings (MeSH) search terms were defined in combination: 'gait' and 'stroke', and yielded 1,522 articles, and then the terms 'treadmill training' (all fields) (505 articles), and 'conventional gait training' (all fields) (160 articles) were added to narrow down the search.

Inclusion and exclusion criteria

A detailed search was carried out, and filters were applied to limit the search to randomized control trials published in English, between 2008 and 2018. The articles were taken into account if they met the above criteria and if they focused on gait re-education based on conventional physical therapy or treadmill training administered to patients after stroke. Systematic reviews, meta-analysis, and qualitative studies were excluded from the analysis. Projects involving clinical trials were qualified if their status was identified as ongoing, completed, or terminated and recruiting, within the last five years. Projects based on clinical trials with "unknown" status were excluded from the review. Out of 160 articles identified, 23 met the inclusion criteria and were reviewed and analyzed in the present study. One hundred fifteen projects involving clinical trials were identified; out of these nine reports from the last five years are included in the review.

Data analysis

A systematic review of the research reports was performed in line with the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) statement. The data collected related to the following items: publication date, study type, number of patients, randomization, control, demographics of importance (age, sex, time from a stroke), intervention, training modalities, and main outcome measures. All the potential articles were screened by two independent reviewers and those reports which did not address the research question were excluded.

Results

Relevant information was gathered from the published literature following the PRISMA guidelines and the flow diagram is shown in Figure 1. Titles and abstracts of 1,522 articles were initially screened for inclusion, and 23 articles meeting the eligibility criteria were ultimately selected for the current review (Table 1, Table 2, and Table 3). As for the clinical trials, the screening process took into account 115 projects from 2000-2018, and eventually, nine studies (status: ongoing, completed, terminated, and recruiting) were selected, all published within the last five years (Table 4). All research reports related to randomized controlled studies. All the projects involving clinical trials were interventional/randomized.

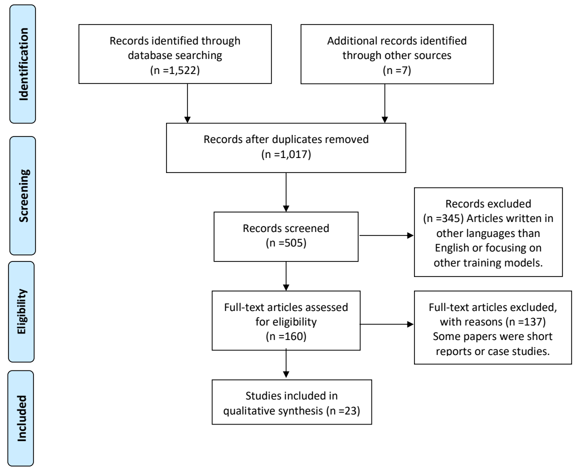

Figure 1: Flow diagram according to PRISMA statement of the systematic review conducted to assess the effectiveness of two models of gait re-education in post-stroke patients.

Participants

The participants were assigned randomly to the intervention group or the control group. The number of subjects participating in all the studies totaled at 1,772. The experimental groups and the controls in all the studies represented both sexes (male/female), and their age ranged from 18 to the late 80s, with an average of 60+ years of age. One clinical trial project focused on pediatric stroke at the age of 5-17 years[25]. In most cases, the patients were at a chronic stage after stroke, i.e., more than six months from stroke onset. Other studies included participants who were one to three months after stroke.

Intervention types

Two major types of interventions applied to improve gait in stroke survivors included treadmill training and conventional physical therapy (Table 1-4). Most interventions involved participation in 30- or 60-minute sessions, three to five times per week, for the duration of six to 16 weeks. Other interventions consisted of 90-minute sessions[26,27], 50-minute sessions[28,29] or 40(45)-minute sessions[30-33]. In some cases, the training was conducted with greater intensity for a shorter period of time, e.g., 180-min sessions for two weeks[34]. The most common types of treadmill training applied included: high-intensity aerobic treadmill training and treadmill training with or without body weight support. Some studies also focused on treadmill training with optic flow, a treadmill based visual cue training, backward walking treadmill training, and asymmetrical treadmill training. Conventional physical therapy (general exercise program/regular physiotherapy) involved stretching, strengthening, endurance, balance, coordination, range of motion activities, and overground walking practice. One study reported a home exercise program, managed by a physical therapist, and focusing on the task-specific walking program, enhancing flexibility, range of motion in joints, the strength of arms and legs, coordination, as well as static and dynamic balance[26].

Table 1: Characteristics of studies indicating advantages of treadmill training in comparison to conventional gait training.

References	RCS	Subjects: N/Mean Age/Sex(females-F/ males-M)	Interventions and training modalities	Main outcomes measures
Yen et al, 2008[29]	Yes	N =14 (Exp =7; Con =7) Age =Exp 57.30; Con 56.05 Sex =M9/F5 Time since stroke (years) =1.96	Exp =BWSTT + general physical therapy (stretching, strengthening, balance, and overground walking training) Frequency general physical therapy =50 min x 2-5/ wk x 4/wk Frequency BWSTT =30 min x 3/wk x 4/wk Con = general physical therapy (stretching, strengthening, balance, and overground walking training) Frequency =50 min x 2-5/wk x 4/wk	Corticomotor activity =focal transcranial magnetic stimulation, motor threshold, map size, the motor map for the tibialis anterior and abductor halluces muscles; Balance =BBS Spatial parameters of gait =GAITRite system (walking speed, cadence, step length) Follow-up =0, 4 wk
Yang et al, 2010[28]	Yes	N =18 (Exp =9; Con =9) Age =Exp 57.15; Con 54.95 Sex =M10/F8 Time since stroke (years) =1.4	Exp =BWSTT + general exercise program (stretching, strengthening, endurance, and overground walking training) Frequency BWSTT =30 min x 3/wk x 4/wk Frequency general exercise program =20 min x 3/ wk x 4/wk Con = general exercise program ((stretching, strengthening, endurance, and overground walking training) Frequency =50 min x 3/wk x 4/wk	Corticomotor activity =motor threshold and map size of the abductor hallucis muscle in the ipsilesional hemisphere Lower extremity motor function =FMA Follow-up =0, 4 wk
Dean et al, 2010[40]	Yes	N =126 Age =Exp 70; Con 71 Sex =M71/F55 Time since stroke (week) =2.4	Exp =BWSTT + assisted overground walking Frequency =30 min x 5/wk until discharge Con =assisted overground walking Frequency =30 min x 5/wk until discharge	Ability to walk independently =15 m, no aid Speed =10-m Walk Test (comfortable, no aids) Capacity =6-min Walk Test Follow-up =1/wk until discharge, 26 wk
Kuys et al, 2011[39]	Yes	N =30 (Exp =15; Con =15) Age =Exp 63; Con 72 Sex =M12/F18 Time since stroke (months) =1.7	Exp =high-intensity treadmill training + usual physiotherapy Frequency =30 min x 3/wk × 6 wk Con =usual physiotherapy Frequency (both) =60 min x 3/wk × 6 wk	Speed =10-m walk test Distance =6-min walk test Follow-up =0, 6, 18 wk
MacKay-Lyons et al, 2013[43]	Yes	N =50 (Exp =24; Con =26) Age =Exp 62; Con =59 Sex =M29/F21 Time since stroke (days) =23	Exp =BWSTT + usual care (active/ passive stretching exercises, upper/lower extremity training, overground gait training) Frequency (inpatients) =60 min x 5/wk x 6/wk Frequency (outpatients) =60 min x 3/wk x 6/wk Con =usual care (active/ passive stretching exercises, upper/lower extremity training, overground gait training) Frequency (inpatients) =60 min x 5/wk x 6/wk Frequency (outpatients) =60 min x 3/wk x 6/wk	Peak oxygen consumption =VO2peak Speed =10-m walk test Capacity =6-min Walk Test Balance =BBS Motor impairment = Chedoke-McMaster Stages of Recovery, Leg and Foot Follow-up =0, 6, 24, 48 wk
Ochi et al, 2015[44]	Yes	N =26 (Exp =13; Con =13) Age =Exp 61.8; Con =55.5 Sex =M20/F6 Time since stroke (days) =24.5	Exp =gait training with a gait-assistance robot + standard physical therapy Frequency =20 min x 5/wk x 4/wk Con =overground gait training + standard physical therapy Frequency =20 min x 5/wk x 4/wk Frequency standard physical therapy (both) =60 min x 5/wk x 4/wk	Walking ability =FAC; Muscle torque =servo-dynamically controlled ergometer; Speed =10-m walk test; Lower extremity motor function =FMA Functional Independence = FIM Follow-up =0, 4 wk
Mao et al, 2015[42]	Yes	N =24 (Exp =12; Con =12) Age =Exp 59.55; Con 60.82 Sex =M5/F19 Time since stroke (days) =48.46	Exp =BWSTT Frequency =30 min x 5/wk x 3/wk Con =assisted overground walking Frequency =30 min x 5/wk x 3/wk	Balance =Brunel balance assessment Lower extremity motor function =FMA Kinematic data =gait capture system; Follow-up =0, 3 wk
Han et al, 2016[45]	Yes	N =56 (Exp =30; Con =26) Age =Exp 67.89; Con =63.2 Sex =M32/24 Time since stroke (days) =19.83	Exp =robot-assisted gait therapy + rehabilitation therapy Frequency robot-assisted gait therapy =30 min x 5/ wk x 4/wk Frequency rehabilitation therapy =30 min x 5/ wk x 4/wk Con =rehabilitation therapy Frequency =60 min x 5/wk x 4/wk	Brachial–ankle pulse wave velocity, cardiopulmonary fitness =oscillometric method Functional Independence =Modified Barthel Index; Walking ability =FAC; Lower extremity motor function =FMA; Balance =BBS; Follow-up =0, 4 wk

RCS: Randomized controlled study, Exp: experimental group, Con: control group, BWSTT: body weight supported treadmill training, FAC: Functional Ambulation Category, FMA: Fugl-Meyer assessment scale, BBS: Berg Balance Scale, FIM: Functional Independence Measure.

Outcome measures

Different outcome variables adopted by the studies included: spatiotemporal and kinematic gait parameters (gait analysis systems), the 6-minute timed walk or the 10-minute timed walk, the Timed Up and Go test, the Dynamic Gait Index, the Functional Reach Test, the Berg Balance Scale, the Activities-specific Balance Confidence Scale, the Stroke Impact Scale, the Barthel Index, the Functional Independent Measure, the Fugl-Meyer Assessment, the Functional Ambulation Category, the Rivermead Mobility Index, the Motor Assessment Scale, the Falls Efficacy Scale, the Medical Outcomes Study Short Form 12, the International Physical Activity Questionnaire, the Health-related Quality of Life Scale, the Frenchay Activities Index, the Scandinavian Stroke Scale, the Depression Scales, the corticomotor activity and the oscillometric, spirometric, accelerometric, and ergometric methods.

Discussion

Advantages of treadmill training in comparison to conventional gait training

Research shows that treadmill walking is an alternative for conventional overground walking, which is linked with new opportunities for the analysis of biomechanics and motor control of gait[35-41]. Kuys et al conducted a comparison of gains achieved by post-stroke patients as a result of treadmill training versus overground gait training. The authors suggested that 30-minute high-intensity treadmill training, three times a week, for six weeks, in addition to

Table 2: Characteristics of studies indicating similar effects of treadmill gait training and conventional gait training.

References	RCS	Subjects: N/Mean Age/ Sex(females-F/males-M)	Interventions and training modalities	Main outcomes measures
Franceschini et al, 2009[53]	Yes	N =97 (Exp =52; Con =45) Age =Exp 71; Con =66 Sex =M50/F47 Time since stroke (days) =15.5	Exp =BWSTT + conventional rehabilitative treatment Frequency =60 min x 5/wk x 4/wk Con =conventional treatment with overground gait training Frequency =60 min x 5/wk x 4/wk	Walking ability =FAC; Functional Independence =Barthel Index; Speed =10-m walk test; Capacity =6-min Walk Test Motor impairment =Motricity Index, Trunk Control test Gait =Walking Handicap Scale Assessments Follow-up =0, 4, 6, 24 wk
Duncan et al, 2011[26]	Yes	N =408 (Exp =282; Con =126) Age =Exp 62; Con 63 Sex =M224/F184 Time since stroke (days) =63.5	Exp =BWSTT Frequency =90 min x 3/wk x 12-16/wk Con =home exercise program (managed by a physical therapist, task-specific walking program enhancing flexibility, range of motion in joints, strength of arms and legs, co-ordination, and static and dynamic balance) Frequency =90 min x 3/wk x 12-16/wk	Proportion of participants in each group who had an improvement in functional walking ability one year after stroke; Speed =10-m walk test; Capacity =6-min Walk Test Activity monitor =number of steps walked per day Self-reported perceived recovery =SIS; Lower extremity motor function =FMA; Balance =BBS; Self-rated balance confidence =ABC; Follow-up =0, 24, 48 wk
Olawale et al, 2011[47]	Yes	N =60 (Exp =20; Con1 =20; Con2 =20) Age =Exp 56.8; Con1 =56.8; Con2 =57.2 Sex =M34/F26 Time since stroke (months) =10.4	Exp =treadmill walking exercise training + conventional physiotherapy (stretching, strength, balance) Frequency treadmill =25 min x 3/wk x 12/wk Frequency conventional physiotherapy =35 min x 3/wk x 12/wk Con1 = overground walking exercise training + conventional physiotherapy (stretching, strength, balance); Frequency =60 min x 3/wk x 12/wk; Con2 =conventional physiotherapy (stretching, strength, balance); Frequency =60 min x 3/wk x 12/wk	Speed =10-m walk test Capacity =6-min Walk Test Follow-up =0, 4, 8, 12 wk
Globas et al, 2012[48]	Yes	N =36 (Exp =18; Con =18) Age =Exp 69; Con =69 Sex =M29/F7 Time since stroke (months) =65	Exp =high-intensity aerobic treadmill exercise Frequency =30 to 50 min x 3/wk x 12/wk Con =conventional physiotherapy (passive, muscle tone-regulating exercises for the upper and lower extremities with elements of balance training) Frequency =60 min x 3/wk x 12/wk	Peak VO2 =during maximum effort treadmill walking Capacity =6-min Walk Test; Self-selected and maximum walking speeds =10-m walk test; Functional leg strength =5CR; Balance =BBS; Self-rated mobility and activities for daily living function =RMI; Physical and mental health measured =SF-12; Follow-up =0, 12 wk
Høyer et al, 2012[52]	Yes	N =60 (Exp =30; Con =30) Age =Exp 52; Con =52 Sex =M38/F22 Time since stroke (days) =97.5	Exp =treadmill therapy (harness combined with a suspension system releasing body weight) + traditional gait training Frequency1 =30 min x 5/wk x 4/wk; Frequency2 =30 min x 1-2/wk x 6/wk; Con =traditional gait training + functional training (selective training of the trunk and extremities, balance and transfer, customised to individual deficits and needs); Frequency =60 min x 5/wk x 10/wk	Walking ability =FAC, EU-walking scale Functional Independence =FIM Speed =10-m walk test Capacity =6-min Walk Test Follow-up =0, 4, 6, 10, 12 wk
Kang et al, 2012[49]	Yes	N =30 (Exp1 =10; Exp2 =10; Con =10) Age =Exp 56; Con =56 Sex =M16/F14 Time since stroke (months) =14.5	Exp1 =treadmill training with optic flow; Frequency =30 min x 3/wk x 4/wk; Exp2 =treadmill training; Frequency =30 min x 3/wk x 4/wk Con =conventional physiotherapy (general stretching added range of motion exercises in the less and more affected sides of the trunk, arms and legs for the same time); Frequency = 30 min x 3/wk x 4/wk	Speed during upright mobility =TUG Balance =FRT Speed =10-m walk test Capacity =6-min Walk Test Follow-up =0, 4 wk
Bonnyaud et al, 2013[51]	Yes	N =26 (Exp =13; Con =13) Age =Exp 50.1; Con =50.3 Sex =M19/F7 Time since stroke (years) =5	Exp =single treadmill training session Frequency =20 min x 1 session Con =single overground training session Frequency =20 min x 1 session	Spatiotemporal, kinematic, kinetic gait parameters =three-dimensional gait analysis (Motion Analysis System) Follow-up =0, immediately after the training and after a 20-minute rest
Bonnyaud et al, 2014[50]	Yes	N = 56 (Exp = 28; Con = 28) Age = Exp 52.5; Con = 49.7 Sex = M42/F14 Time since stroke (years) = 6	Exp =single treadmill training session Frequency =20 min x 1 session Con =single overground training session Frequency =20 min x 1 session	Speed during upright mobility =TUG Follow-up =0, immediately after the completion of each session
Middleton et al, 2014[34]	Yes	N =43(Exp =23; Con =20) Age =Exp 61.39; Con 60.70 Sex =M30/F14 Time since stroke (years) =3.3	Exp =BWSTT + balance activities + strength, coordination, ROM activities Frequency = 80 min x 5/wk x 2/wk Con =overground walking + balance activities + strength, coordination, ROM activities Frequency =180 min x 5/wk x 2/wk	Spatial parameters of gait =GAITRite system (step length differential); Self-selected and fast walking speed = 3-meter walk test; Capacity =6-min Walk Test; Balance =BBS Self-reported balance confidence =ABC; Balance =single limb stance; Speed during upright mobility =TUG Ability to adapt to changing task demands during gait =DGI Lower extremity motor function =FMA; Self-reported perceived recovery =SIS, percent perceived recovery Follow-up =0, 12 wk
Hollands et al, 2015[20]	Yes	N =56 (Exp1 =18; Exp2 =19; Con =19) Age =Exp1=59; Exp2 =56.1; Con =60 Sex =M33/F23 Time since stroke (months) =8.1	Exp1 =treadmill based visual cue training Exp2 =Overground visual cue training Frequency =60 min x 2/wk x 8/wk Con =usual care (task-specific-practice of walking and/or components of gait, exercises for strength balance and coordination; and/or prescription of assistive devices) Frequency =60 min x 2/wk x 8/wk	Walking speed, spatial and temporal symmetry of gait = GaitRite system; Time to turn 180°; Adaptability of gait = success rate in target stepping; Lower extremity motor function =FMA; Falls risk =Falls Efficacy Scale Quality of life =SF–12; Mobility =FAC Speed during upright mobility =TUG Follow-up =0, 8, 12 wk
Srivastava et al, 2016[46]	Yes	N =45 (Exp1 =15; Exp2 =15; Con =15); Age =Exp 58.7; Con = 57.7 Sex =M36/F9 Time since stroke =16.51 months	Exp1 = treadmill training; Exp2 = BWSTT Frequency = 30 min x 5/wk x 4/wk Con = overground gait training Frequency = 30 min x 5/wk x 4/wk	Speed = 10-m walk test; Capacity = 6-min Walk Test Level of disability = SSS Walking ability = FAC Follow-up = 0, 4, 12 wk

Baer et al, 2018[33]	Yes	N =77 (Exp =39; Con =38) Age =Exp 71.23; Con =74.5 Sex =M40/F37 Time since stroke (days) =41.19	Exp =treadmill training + normal gait re-education (assisted / independent activities such as weight transfer, stepping with either leg, walking, step ups and stairs, movement control, strengthening) Frequency =8-16 min x 2/wk x 8/wk; Con =normal gait re-education (assisted/independent activities such as weight transfer, stepping with either leg, walking, step ups and stairs, movement control and strengthening); Frequency = 8-16 min x 2/wk x 8/wk	Motor impairment, level of disability =RMI, MAS Walking ability =FAC Speed =10-m walk test Capacity =6-min Walk Test Functional Independence =Barthel Index Self-reported perceived recovery =SIS Follow-up =0, 8, 24 wk

RCS: Randomized controlled study, Exp: experimental group, Con: control group, BWSTT: body weight supported treadmill training, FAC: Functional Ambulation Category, FMA: Fugl-Meyer assessment scale, BBS: Berg Balance Scale, DGI: Dynamic Gait Index, ABC: Activities-specific Balance Confidence scale, TUG: Timed Up and Go test, ROM: range of motion, SIS: Stroke Impact Scale, 5CR: 5-Chair-Rise, RMI: Rivermead Mobility Index, SF-12: Medical Outcomes Study Short Form 12, FRT: Functional Reach Test, FIM: Functional Independence Measure, NIH: National Institutes of Health, MAS: Motor Assessment Scale, FAI: Frenchay Activities Index, SSS: Scandinavian Stroke Scale.

a conventional physical therapy produces more significant improvement in walking capacity and walking speed than regular physiotherapy alone. Moreover, these effects were still present after 18 weeks, the patients from the study group on average could walk 0.26 m/s faster than the controls[39]. Likewise, Dean et al reported that body weight supported treadmill training (BWSTT) leads to greater improvement in walking capacity than overground gait training. The authors showed that 30-minute BWSTT applied in combination with conventional physiotherapy until the patients achieved the ability to walk without assistance or were discharged from hospital, produced a greater increase in walking capacity, compared to assisted overground walking. The findings, however, did not show differences between the groups related to walking speed, length of the gait cycle, number of falls, or community participation[40]. Mao et al compared changes in balance, lower limb motor function as well as temporospatial and kinematic gait parameters, resulting from BWSTT and conventional overground gait training in patients with subacute stroke. Both types of gait training were conducted on average for 30 minutes per day, five days a week, for three weeks. The authors showed that at the end of the program, both groups achieved improvement in balance and motor function of the lower limb. However, the experimental group presented better temporospatial and kinematic parameters of gait[42]. The study also showed that the BWSTT (60-minutes per day, five times per week, for six weeks) produced more significant improvements in cardiovascular fitness and walking endurance than conventional physiotherapy during a subacute post-stroke period. Moreover, these gains were largely sustained for one year[43]. It was also pointed out that, compared to conventional overground walking practice, gait training with robotic gait assistance more successfully decreased gait disturbances, and improved peak torque on the unaffected side and peak aerobic capacity, peak heart rate, and exercise tolerance in subacute hemiplegic stroke patients[44,45]. On the other hand, Yang et al showed that, in comparison to a general exercise program, the BWSTT (30-minutes per day, three times per week, for four weeks) produced greater increase in cortical reorganization, and consequently more significant improvement in motor control; this effect was observed in the patients both at an early and at a chronic stage after stroke[28]. Yen et al also investigated changes in corticomotor excitability evoked by gait training in patients with chronic stroke. The researchers reported that following conventional gait training alone, the patients showed improvement in gait velocity and cadence, yet no significant changes were observed in this case in corticomotor excitability. However, after the additional BWSTT, the subjects had significantly better scores on the Berg Balance Scale, and in walking speed and cadence. The map size for tibialis anterior muscle was increased in both hemispheres, while the map size for abductor hallucis muscle was increased only on the affected side[29].

Table 3: Characteristics of studies indicating advantage of conventional gait training over equipment assisted gait training.

References	RCS	Subjects: N/Mean Age/Sex(females-F/ males-M)	Interventions and training modalities	Main outcomes measures
Hidler et al, 2009[27]	Yes	N =63 (Exp =33; Con =30) Age =Exp 59.9; Con =54.6 Sex =M39/F24 Time since stroke (days) =24.9	Exp =Lokomat; Frequency =90 min x 3/wk x 8-10/wk Con =conventional gait training (static and dynamic postural tasks, trunk positioning, improving lower and upper extremity range of motion, overground walking) Frequency =90 min x 3/wk x 8-10/wk	Speed =5-m walk test; Capacity =6-min Walk Test Balance =BBS; Walking ability =FAC; Neurologic deficits =NIH Stroke Scale; Motor impairment, level of disability =MAS, RMI, FAI; Quality of life =SF-36 Health Survey Cadence =Gait Rite at NRH (CIR Systems, Havertown, PA) or Gait Mat II at RIC (E.Q. Inc, Chalfont, PA) Follow-up =0, 2, 4, 12 wk
Combs-Miller et al, 2014[54]	Yes	N =20 (Exp =10; Con =10) Age =Exp 56.2; Con =65.5 Sex =M11/F9 Time since stroke (months) =61.15	Exp =BWSTT Frequency =30 min x 5/wk x 2/wk Con =overground gait training Frequency = 30 min x 5/wk x 2/wk	Speed =10-m walk test (comfortable and fast); Capacity =6-min Walk Test; Spatiotemporal symmetry =GAITRite system; Activity and participation =ICF Measure of Participation and ACTivity; Follow-up =0, 2, 12 wk
Gama et al, 2017[32]	Yes	N =28 (Exp =14; Con =14) Age =Exp 58.7; Con =57.7 Sex =M13/F15 Time since stroke (months) =57	Exp =BWSTT Frequency =45 min x 3/wk x 6/wk Con =overground gait training Frequency =45 min x 3/wk x 6/wk	Speed =10-m walk test; Capacity =6-min Walk Test Functional Independence =FIM; Lower extremity motor function =FMA; Step length, step length symmetry ratio, single-limb support duration =gait analysis system (VICON®); Follow-up =0, 6, 12 wk

RCS: Randomized controlled study, Exp: experimental group, Con: control group, BWSTT: body weight supported treadmill training, FAC: Functional Ambulation Category, FMA: Fugl-Meyer assessment scale, BBS: Berg Balance Scale, RMI: Rivermead Mobility Index, FIM: Functional Independence Measure, NIH: National Institutes of Health, MAS: Motor Assessment Scale, FAI: Frenchay Activities Index.

Table 4: Registered clinical trials regarding the topic from the last five years.

ClinicalTrials.gov Identifier Recruitment Status Registration Year	Study type/ Allocation	Subjects	Interventions and training modalities	Main outcomes measures
NCT01789853 Completed 2013[55]	I(CT)/R	N =56; Age =18-75 Sex =All Time since stroke <6m	Exp =high intensity walking training (treadmill, overground, stair training, skilled walking training); Frequency =40 min x 3/wk × 8/wk; Con =conventional physical therapy; Frequency = 40 min x 3/wk × 8/wk	Speed =10-m walk test Distance =6-min walk test Balance =BBS; Follow-up =0, 4, 8, 16 wk
NCT01827436 Completed 2013[25]	I(CT)/R	N =9; Age =5-17 Sex =All Time since stroke =min 6 months post-stroke	Exp =asymmetrical gait training (walking on a split-belt treadmill with the belts moving at different speeds under each leg); Frequency =3/wk × 8/wk; Con =conventional physical therapy (walking practice, muscle strengthening, and balance training); Frequency =3/wk × 8/wk	Walking symmetry, walking speed, excitability of neural motor pathways, patient/parent satisfaction rating, community step activity; Follow-up =0, 8 wk; Walking ability and cortical excitability measure; Follow-up =0, 4 wk, before and after a 4 wk withdraw phase
NCT02132650 Recruiting 2014[58]	I(CT)/R	N =60; Age =18-80 Sex =All Time since stroke =6-18 months post-stroke	Exp = rehabilitation of walking using typical steady state walking speed. Conducted overground and on treadmill; Frequency =60 min x3/wk × 12/wk; Con =rehabilitation of walking using accurate walking tasks (stepping on targets, over obstacles); Frequency =60 min x3/wk × 12/wk	Walking Speed Follow-up = 0, 12, 24 wk
NCT02619110 Completed 2014[56]	I(CT)/R	N =30; Age =60-65 Sex =All Time since stroke =chronic stroke more than 6 months	Exp =backward walking treadmill training + conventional physical therapy (strengthening, postural control, functional mobility and forward gait training program); Frequency treadmill =30 min x 5/wk × 4/wk; Frequency conventional physical therapy =30 min x 3/wk × 4/wk; Con =conventional physical therapy (strengthening, postural control, functional mobility and forward gait training program); Frequency = 30 min x 3/wk × 4/wk	Balance =BBS Pulmonary function test =FVC, FEV1 Speed =10-m walk test Distance =6-min walk test Speed during upright mobility =TUG Follow-up =0, 4 wk
NCT02043574 Recruiting 2014[57]	I(CT)/R	N =50; Age =20 Years and older; Sex =All; Time since stroke =greater than or equal to 6 months	Exp =treadmill exercise; Frequency =15 - 50 min x 2/wk × 24/wk Con =stretching (basic mobility skills, including balance, endurance, sit-to-stand, weight shifting, leg strength, and truncal stability-coordination) Frequency =60 min x 2/wk × 24/wk	Total daily energy expenditure =accelerometer Follow-up =0, 24 wk; Substrate oxidation =open circuit spirometry; Follow-up =0, 2 of dietary education, 24 wk; Tissue oxidative stress =bilateral vastus lateralis muscle biopsies; Follow-up =0, 24 wk
NCT02190734 Recruiting 2014[31]	I(CT)/R	N =12; Age =18-89 Sex =All; Time since stroke = stroke within previous 180 days	Exp =treadmill training with or without BWS; Frequency =30 min x 3/wk × 10/days; Con1 =overground walking with or without BWS;Con2 =sitting in wheel chair (Placebo/control intervention); Frequency =30 min x 3/wk × 10/days	Clinical measure of pushing behaviours in supine position, sitting, standing, walking, and transfers = Burke Lateropulsion Scale; Follow-up =0, after each of 3 treatment sessions (3 separate days) over a maximum of a 10 day period
NCT02550015 Recruiting 2015[59]	I(CT)/R	N =70; Age =18-75 Sex =All Time since stroke = minimum 3 months post-stroke	Exp = supervised high intensity interval treadmill training Frequency =4x4 min x 3/wk × 8/wk Con =standard care (including general information about importance of physical activity as part of a healthy lifestyle)	Maximal Oxygen Uptake =breath ergospirometer; Blood pressure; Speed =10-m walk test; Speed during upright mobility =TUG; Leisure time activity and inactive time =ActivePal monitor; Balance =BBS; Blood tests; Functional Independence =FIM; Self-reported physical activity level =IPAQ; Cognitive function = Montreal Cognitive Assessment; Distance =6-min walk test; New cardiovascular or cerebrovascular incidents; Anxiety and depression after stroke = Hospital and Anxiety and Depression Scale; Self-reported perceived recovery =SIS Degree of disability and dependence =mRS; Health status =EQ-5D-5; Submaximal oxygen consumption; Follow-up =8, 48 wk
NCT02798237 Recruiting 2016[30]	I(CT)/R	N =22; Age =20 Years and older Sex =All Time since stroke =more than 6 months	Exp =aerobic treadmill training Frequency =40 min x 3/wk × 12/wk Con =overground walking Frequency =40 min x 3/wk × 12/wk	Physical activity levels =multisensor monitor, Human Activity Profile; Sedentary behavior =multisensor monitor Cardiorespiratory fitness =cardiopulmonary exercise test Distance =6-min walk test, shuttle walk test; Depression =PHQ-2, PHQ-9; Mobility =gait speed; Quality of life - Stroke specific quality of life; Participation – SIS; Follow-up =0, 12, 16 wk
NCT02680496 Terminated 2016[60]	I(CT)/R	N =14; Age =18 Years and older; Sex =All Time since stroke <1 year	Exp1 =lokomat + treadmill + overground walking (with or without BWS); Exp2 =lokomat + overground + treadmill walking (with or without BWS); Exp3 =treadmill + lokomat + overground walking (with or without BWS); Exp4 =treadmill + overground + lokomat walking (with or without BWS); Exp5 =overground + lokomat + treadmill walking (with or without BWS); Exp6 =overground + treadmill + lokomat walking (with or without BWS); Frequency (all groups) =30 min x single walking trial	Gross, net: oxygen consumption, minute ventilation, respiration rate, heart rate, respiratory exchange ratio, metabolic equivalent of task; Gross, net perceived exertion = Borg Scale; Total walking duration; Paretic, non-paretic: cadence, gait cycle time, stance, swing, double support (variability and symmetry ratio); Follow-up =Minute 5 of 5-minute resting period, Minute 6, 18, 30 of 30-minute walking period

I(CT): Interventional (Clinical Trial), R: Randomized, BBS: Berg Balance Scale, FVC: forced vital capacity, FEV1: Forced expiratory volume in one second, TUG: Timed Up and Go test, SIS: Stroke Impact Scale, PHQ-2, PHQ-9: Patient Health Questionnaire, BWS: body weight support, IPAQ: International Physical Activity Questionnaire, mRS: Modified Rankin Scale.

Similar effects of treadmill gait training and conventional gait training

The above observations are not consistent with findings reported by Middleton et al, who concluded that BWSTT did not produce better effects in patients with chronic stroke than overground gait training. The entire program comprised one hour of gait training (overground or BWSTT), one hour of balance training, and one-hour exercise session focusing on strength, range of motion, and coordination, and was administered for ten consecutive weekdays. The authors did not find any significant differences in the effects between the groups, either immediately after the training or during the follow-up assessment[34]. Given the above it was assumed that 10-day training was insufficient; hence there was a need to conduct further study to assess a more intensive training applied for more than ten days, and a resulting improvement of gait, balance, and mobility in individuals with chronic stroke. Srivastava et al assessed the effects of 4-week BWSTT and conventional gait training programs conducted for 30 minutes per day, five times per week. This study also showed no significant differences in the improvement achieved by chronic stroke survivors[46]. Duncan et al argue that BWSTT is not more effective than progressive exercise at home administered by a physiotherapist. The home exercise program focused on improving flexibility, range of motion in the joints, the strength of upper and lower extremities, coordination, as well as static and dynamic balance. The patients received 36 training sessions, for 12 to 16 weeks, each intervention was 90 minutes long. No significant differences were identified in walking speed, motor control, balance, functional performance and quality of life improvements between the groups (either the early or the late locomotor training)[26]. Studies carried out by Olawale, Globas, and Kang focused on subjects with chronic stroke (up to 24 months from stroke onset) and reported no significant differences in gait capacity improvements (the 6-minute walk test) achieved by patients as a result of treadmill training, high-intensity aerobic treadmill training and with optic flow as compared to overground training[47-49]. On the other hand, Baer et al pointed out that treadmill training was feasible in sub-acute stroke patients, but when compared to normal gait re-education showed no significant difference in outcomes[33]. Bonnyaud et al compared effects of a single treadmill training session and a single overground training session reflected by subjects' performance in the Timed Up and Go test, assessing independent mobility and risk of falls in patients with hemiparesis after stroke. The authors showed that the time needed for completing the Up and Go test was significantly reduced after the 20-minute training session, to a similar degree in both groups[50]. Given the above, it can be concluded that hemiparetic patients should be encouraged to regularly walk overground, when possible for 20 minutes without stopping because this is a simple and inexpensive method of rehabilitation to recover functional walking ability. Bonnyaud et al also undertook a comparison of a single overground practice and a single treadmill gait training session to examine short-term effects reflected by biomechanical gait parameters (spatiotemporal, kinematic, and kinetic) in hemiparetic patients. The authors reported that after gait training, there was a considerable increase in such parameters as walking speed, cadence, duration of stance phase, and peak knee extension on the paretic side. Yet, there were no specific changes dependent on the type of gait training performed by the two groups[51]. Høyer et al investigated the effectiveness of BWSTT combined with traditional gait training in comparison to traditional gait training alone at an early stage after stroke. The authors concluded that the two training strategies (60-minutes per day, five times per week, for ten weeks) lead to similar improvements in walking abilities (speed and capacity) after stroke[52]. Similar issues were investigated by Franceschini et al. The BWSTT combined with a conventional rehabilitation program and the conventional rehabilitation program alone (60 minutes per day, five times per week, for four weeks) produced the same improvement in gait parameters in patients within six weeks from stroke onset[53]. Based on these findings, it can be concluded that, in the case of patients with subacute and with chronic stroke, treadmill training is as effective as a conventional overground gait practice.

Advantage of conventional gait training over equipment assisted gait training

In the literature, we can also find publications suggesting that conventional gait training presents advantages over devices designed to assist gait training in subacute and chronic stroke. Hidler et al reported that patients who received conventional training showed significantly higher improvement in walking speed and distance walked compared to the patients who trained on the Lokomat (90 minutes per day, three times per week, for 8-10 weeks). The differences were maintained at the follow-up, three months later[27]. Also, Combs-Miller et al indicated that overground walking was more beneficial than BWSTT in improving self-selected walking speed in patients at least six months post-stroke and able to walk independently[54]. It was also reported that the step length symmetry ratio was only improved by overground walking practice, which suggested it was essential to integrate overground walking into BWS in individuals with chronic stroke[32].

Clinical trials

Research findings published so far do not provide consistent and robust evidence either for or against the effectiveness of treadmill training in recovery of gait by patients after stroke. Further studies, which are being prepared or are in progress[25,30,31,55-60], should provide information on the effectiveness of novel treadmill training methods, such as backward walking treadmill training[56] and asymmetrical treadmill training[25]. New research also aims at developing methods of gait re-education after stroke, based on various types of gait training. Kerckhofs et al are conducting a study in which gait re-education program combines robot-assisted gait training (Lokomat), treadmill practice, and overground walking[60].

The limitation of the review is the fact that it does not apply strict inclusion criteria taking into account the duration, intensity, and frequency of the programs based on both treadmill training and conventional gait practice.

Conclusions

The present review focuses on the effectiveness of treadmill gait training in comparison to conventional overground gait training in patients with stroke. Studies conducted so far greatly vary in terms of the training methods applied. No standard has been defined yet about the recovery of gait function after stroke. We still do not know the optimum duration and frequency of exercise. The current literature review also allows a conclusion that it is challenging to adopt a uniform definition for the concept of conventional gait training because the relevant studies greatly vary in terms of gait therapy duration as well as the types of exercise applied in gait re-education. Research also seems to suggest that treadmill training mainly produces improvement in walking speed and walking capacity in patients both at an early and at a chronic stage post-stroke. Few of the relevant studies investigated gait changes and the resulting gains in basic and complex activities of daily living. Given the above, further research should focus on assessing long-term effects, and the way they impact the daily activity of subjects after stroke. There is too little evidence confirming that improved gait function (speed and capacity) resulting from treadmill training corresponds to decreased limitations due to disability, and consequently to greater independence and self-reliance.

New studies, which are underway, should provide information on the effectiveness of novel treadmill training methods, such as backward walking treadmill training and asymmetrical treadmill training. New research also aims at developing methods of gait re-education after stroke, based on various types of gait practice.

The problem investigated by these authors remains controversial because the studies published so far provide conflicting information. Some researchers report that treadmill training produces more significant improvement in walking abilities, compared to conventional gait training in patients after stroke, some argue the two methods are equally effective, while others insist conventional gait training presents an advantage over devices designed to assist gait training. Given the above, it can clearly be concluded that the two training strategies produce beneficial effects leading to improved walking abilities in patients after stroke. However, if advanced gait re-education methods, requiring costly equipment, cannot be used for various reasons, a well-designed conventional gait training is an adequate, affordable and straightforward method to achieve the intended effects of rehabilitation after stroke.

Conflict of interest

Authors have no conflict of interest to declare.

References

1. Mehrholz J, Pohl M, Elsner B. Treadmill training and body weight support for walking after stroke. Cochrane Database Syst Rev. 2014; 23: CD002840.
2. Kim TH, Hwang BH. Effects of gait training on sand on improving the walking ability of patients with chronic stroke:a randomized controlled trial. J Phys Ther Sci. 2017; 29: 2172-2175.
3. Ada L, Dean CM, Lindley R, Lloyd G. Improving community ambulation after stroke: the AMBULATE Trial. BMC Neurol. 2009; 9: 8.
4. Murata K, Asai H, Inaoka PT, Nakaizumi D. Walking gait changes after stepping-in-place training using a foot lifting device in chronic stroke patients. J Phys Ther Sci. 2016; 28: 1170-1177.
5. Lee SJ, Hidler J. Biomechanics of overground vs. treadmill walking in healthy individuals. J Appl Physiol (1985). 2008; 104: 747-755.
6. Lau KW, Mak MK. Speed-dependent treadmill training is effective to improve gait and balance performance in patients with sub-acute stroke. J Rehabil Med. 2011; 43: 709-713.
7. Belda-Lois JM, Mena-del Horno S, Bermejo-Bosch I, Moreno JC, Pons JL, Farina D, et al. Rehabilitation of gait after stroke: a review towards a top-down. J Neuroeng Rehabil. 2011; 8: 66.
8. Luft AR, Macko RF, Forrester LW, Villagra F, Ivey F, Sorkin JD, et al. Treadmill exercise activates subcortical neural networks and improves walking after stroke: a randomized controlled trial. Stroke. 2008; 39: 3341-3350.
9. Chen IH, Yang YR, Chan RC, Wang RY. Turning-based treadmill training improves turning performance and gait symmetry after stroke. Neurorehabil Neural Repair. 2014; 28: 45-55.
10. Langhammer B, Stanghelle JK. Exercise on a treadmill or walking outdoors? A randomized controlled trial comparing effectiveness of two walking exercise programmes late after stroke. Clin Rehabil. 2010; 24: 46-54.
11. Patterson SL, Rodgers MM, Macko RF, Forrester LW. Effect of treadmill exercise training on spatial and temporal gait parameters in subjects with chronic stroke: a preliminary report. J Rehabil Res. 2008; 45: 221-228.
12. Mehrholz J, Elsner B, Werner C, Kugler J, Pohl M. Electromechanical-assisted training for walking after stroke. Cochrane Database Syst Rev. 2013; (7): CD006185.
13. Ada L, Dean CM, Vargas J, Ennis S. Mechanically assisted walking with body weight support results in more independent walking than assisted overground walking in non-ambulatory patients early after stroke: a systematic review. J Physiother. 2010; 56: 153-161.
14. States RA, Pappas E, Salem Y. Overground physical therapy gait training for chronic stroke patients with mobility deficits. Cochrane Database Syst Rev. 2009; 8: CD006075.
15. States RA, Salem Y, Pappas E. Overground gait training for individuals with chronic stroke: a Cochrane systematic review. J Neurol Phys Ther. 2009; 33: 179-186.
16. Lewek MD. The value of overground gait training for improving locomotion in individuals with chronic stroke. J Neurol Phys Ther. 2009; 33: 187-188.
17. Park HJ, Oh DW, Kim SY, Choi JD. Effectiveness of community-based ambulation training for walking function of post-stroke hemiparesis: a randomized controlled pilot trial. Clin Rehabil. 2011; 25: 451-459.
18. Barclay RE, Stevenson TJ, Poluha W, Ripat J, Nett C, Srikesavan CS. Interventions for improving community ambulation in individuals with stroke. Cochrane Database Syst Rev. 2015; (3): CD010200.
19. Hollands KL, Pelton TA, Tyson SF, Hollands MA, van Vliet PM. Interventions for coordination of walking following stroke: systematic review. Gait Posture. 2012; 35: 349-359.
20. Hollands KL, Pelton TA, Wimperis A, Whitham D, Tan W, Jowett S, et al. Feasibility and Preliminary Efficacy of Visual Cue Training to Improve Adaptability of Walking after Stroke: Multi-Centre, Single-Blind Randomised Control Pilot Trial. PLoS One. 2015; 10: e0139261.
21. Veerbeek JM, van Wegen E, van Peppen R, van der Wees PJ, Hendriks E, Rietberg M, et al. What is the evidence for physical therapy poststroke? A systematic review and meta-analysis. PLoS One. 2014; 9: e87987.
22. Dickstein R. Rehabilitation of gait speed after stroke: a critical review of intervention approaches. Neurorehabil Neural Repair. 2008; 22: 649-660.
23. Kuys SS, Brauer SG, Ada L, Russell TG. Immediate effect of treadmill walking practice versus overground walking practice on overground walking pattern in ambulatory stroke patients: an experimental study. Clin Rehabil. 2008; 22: 931-939.
24. Dobkin BH, Duncan PW. Should body weight-supported treadmill training and robotic-assistive steppers for locomotor training trot back to the starting gate? Neurorehabil Neural Repair. 2012; 26: 308–317.
25. Asymmetrical Gait Training After Pediatric Stroke. ClinicalTrials.gov Identifier: NCT01827436. Available at: https://clinicaltrials.gov/ct2/show/NCT01827436, last accessed: 12/01/2018.
26. Duncan PW, Sullivan KJ, Behrman AL, Azen SP, Wu SS, Nadeau SE, et al. Body-weight-supported treadmill rehabilita-

tion after stroke. N Engl J Med. 2011; 364: 2026-2036.
27. Hidler J, Nichols D, Pelliccio M, Brady K, Campbell DD, Kahn JH, et al. Multicenter randomized clinical trial evaluating the effectiveness of the Lokomat in subacute stroke. Neurorehabil Neural Repair. 2009; 23: 5-13.
28. Yang YR, Chen IH, Liao KK, Huang CC, Wang RY. Cortical reorganization induced by body weight-supported treadmill training in patients with hemiparesis of different stroke durations. Arch Phys Med Rehabil. 2010; 91: 513-518.
29. Yen CL, Wang RY, Liao KK, Huang CC, Yang YR. Gait training induced change in corticomotor excitability in patients with chronic stroke. Neurorehabil Neural Repair 2008; 22: 22-30.
30. Effects of Aerobic Training Post-stroke. ClinicalTrials.gov Identifier: NCT02798237. Available at: https://clinicaltrials.gov/ct2/show/NCT02798237, last accessed: 12/01/2018.
31. Pushing Behaviors in Individuals Post-stroke. ClinicalTrials.gov Identifier NCT02190734. Available at: https://clinicaltrials.gov/ct2/show/NCT02190734, last accessed: 13/01/2018.
32. Gama GL, Celestino ML, Barela JA, Forrester L, Whitall J, Barela AM. Effects of Gait Training With Body Weight Support on a Treadmill Versus Overground in Individuals With Stroke. Arch Phys Med Rehabil. 2017; 98: 738-745.
33. Baer GD, Salisbury LG, Smith MT, Pitman J, Dennis M. Treadmill training to improve mobility for people with sub-acute stroke: a phase II feasibility randomized controlled trial. Clin Rehabil. 2018; 32: 201-212.
34. Middleton A, Merlo-Rains A, Peters DM, Greene JV, Blanck EL, Moran R, et al. Body weight-supported treadmill training is no better than overground training for individuals with chronic stroke: a randomized controlled trial. Top Stroke Rehabil. 2014; 21: 462-476.
35. Kautz SA, Bowden MG, Clark DJ, Neptune RR. Comparison of motor control deficits during treadmill and overground walking poststroke. Neurorehabil Neural Repair. 2011; 25: 756-765.
36. Tesio L, Rota V. Gait analysis on split-belt force treadmills: validation of an instrument. Am J Phys Med Rehabil. 2008; 87: 515-526.
37. Goldberg EJ, Kautz SA, Neptune RR. Can treadmill walking be used to assess propulsion generation? J Biomech. 2008; 41: 1805-1808.
38. Watt JR, Franz JR, Jackson K, Dicharry J, Riley PO, Kerrigan DC. A three-dimensional kinematic and kinetic comparison of overground and treadmill walking in healthy elderly subjects. Clin Biomech (Bristol, Avon). 2010; 25: 444–449.
39. Kuys SS, Brauer SG, Ada L. Higher-intensity treadmill walking during rehabilitation after stroke in feasible and not detrimental to walking pattern or quality: a pilot randomized trial. Clin Rehabil. 2011; 25: 316-326.
40. Dean CM, Ada L, Bampton J, Morris ME, Katrak PH, Potts S. Treadmill walking with body weight support in subacute non-ambulatory stroke improves walking capacity more than overground walking: a randomised trial. J Physiother. 2010; 56: 97-103.
41. Ada L, Dean CM, Lindley R. Randomized trial of treadmill training to improve walking in community-dwelling people after stroke: the AMBULATE trial. Int J Stroke. 2013; 8: 436-444.
42. Mao YR, Lo WL, Lin Q, Li L, Xiao X, Raghavan P, et al. The Effect of Body Weight Support Treadmill Training on Gait Recovery, Proximal Lower Limb Motor Pattern, and Balance in Patients with Subacute Stroke. Biomed Res Int. 2015; 2015: 175719.
43. Mackay-Lyons M, McDonald A, Matheson J, Eskes G, Klus MA. Dual effects of body-weight supported treadmill training on cardiovascular fitness and walking ability early after stroke: a randomized controlled trial. Neurorehabil Neural Repair. 2013; 27: 644-653.
44. Ochi M, Wada F, Saeki S, Hachisuka K. Gait training in subacute non-ambulatory stroke patients using a full weight-bearing gait-assistance robot: A prospective, randomized, open, blinded-endpoint trial. J Neurol Sci. 2015; 353: 130-136.
45. Han EY, Im SH, Kim BR, Seo MJ, Kim MO. Robot-assisted gait training improves brachial-ankle pulse wave velocity and peak aerobic capacity in subacute stroke patients with totally dependent ambulation: Randomized controlled trial. Medicine (Baltimore). 2016; 95: e5078.
46. Srivastava A, Taly AB, Gupta A, Kumar S, Murali T. Body-weight-supported treadmill training for retraining gait among chronic stroke survivors: A randomized controlled study. Ann Phys Rehabil Med. 2016; 59: 235-241.
47. Olawale OA, Jaja SI, Anigbogu CN, Appiah-Kubi KO, Jones-Okai D. Exercise training improves walking function in an African group of stroke survivors: a randomized controlled trial. Clin Rehabil. 2011; 25: 442-450.
48. Globas C, Becker C, Cerny J, Lam JM, Lindemann U, Forrester LW, et al. Chronic stroke survivors benefit from high-intensity aerobic treadmill exercise: a randomized control trial. Neurorehabil Neural Repair. 2012; 26: 85-95.
49. Kang HK, Kim Y, Chung Y, Hwang S. Effects of treadmill training with optic flow on balance and gait in individuals following stroke: randomized controlled trials. Clin Rehabil. 2012; 26: 246-255.
50. Bonnyaud C, Zory R, Robertson J, Bensmail D, Vuillerme N, Roche N. Effect of an overground training session versus a treadmill training session on timed up and go in hemiparetic patients. Top Stroke Rehabil. 2014; 21: 477-483.
51. Bonnyaud C, Pradon D, Zory R, Bensmail D, Vuillerme N, Roche N. Does a single gait training session performed either overground or on a treadmill induce specific short-term effects on gait parameters in patients with hemiparesis? A randomized controlled study. Top Stroke Rehabil. 2013; 20: 509-518.
52. Høyer E, Jahnsen R, Stanghelle JK, Strand LI. Body weight supported treadmill training versus traditional training in patients dependent on walking assistance after stroke: a randomized controlled trial. Disabil Rehabil. 2012; 34: 210-219.
53. Franceschini M, Carda S, Agosti M, Antenucci R, Malgrati D, Cisari C. Walking after stroke: what does treadmill training with body weight support add to overground gait training in patients early after stroke?: a single-blind, randomized, controlled trial. Stroke. 2009; 40: 3079-3085.
54. Combs-Miller SA, Kalpathi Parameswaran A, Colburn D, Ertel T, Harmeyer A, Tucker L, et al. Body weight-supported treadmill training vs. overground walking training for persons with chronic stroke: a pilot randomized controlled trial. Clin Rehabil. 2014; 28: 873-884.
55. Very Intensive Early Walking in Stroke (VIEWS). ClinicalTrials.gov Identifier: NCT01789853. Available at: https://clinicaltrials.gov/ct2/show/NCT01789853, last accessed: 13/01/2018.
56. The Effect of Backward Walking Treadmill Training on Balance in Patient With Chronic Stroke. ClinicalTrials.gov Identifier: NCT02619110. Available at: https://clinicaltrials.gov/ct2/show/NCT02619110, last accessed: 14/01/2018.
57. Nutrition and Aerobic Exercise in Chronic Stroke (NEXIS). ClinicalTrials.gov Identifier: NCT02043574. Available at: https://clinicaltrials.gov/ct2/show/NCT02043574, last accessed: 14/01/2018.
58. Rehabilitating Corticospinal Control of Walking (ABC of Walking). ClinicalTrials.gov Identifier: NCT02132650. Available at: https://clinicaltrials.gov/ct2/show/NCT02132650, last accessed: 15/01/2018.
59. High Intensity Interval Training After Stroke. ClinicalTrials.gov Identifier: NCT02550015. Available at: https://clinicaltrials.gov/ct2/show/NCT02550015, last accessed: 15/01/2018.
60. Energy Consumption and Cardiorespiratory Load During Walking With and Without Robot-Assistance. ClinicalTrials.gov Identifier: NCT02680496. Available at: https://clinicaltrials.gov/ct2/show/NCT02680496, last accessed: 15/01/2018.