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Original article

Muscle strengthening for hemiparesis after stroke: A meta-analysis

Sophie Wist *, Julie Clivaz, Martin Sattelmayer

School of Health Sciences, University of Applied Sciences and Arts Western Switzerland Valais (HES-SO Valais-Wallis), Leukerbad, Switzerland

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A B S T R A C T

Introduction: Muscle weakness is a common consequence of stroke and can result in a decrease in physical activity. Changes in gait performance can be observed, especially a reduction in gait speed, and increased gait asymmetry, and energy cost is also reported.
Objective: The aim was to determine whether strengthening of the lower limbs can improve strength, balance and walking abilities in patients with chronic stroke.
Method: Five databases (Pubmed, Cinhal, Cochrane, Web of Science, Embase) were searched to identify eligible studies. Randomized controlled trials were included and the risk of bias was evaluated for each study. Pooled standardized mean differences were calculated using a random effects model. The PRISMA statement was followed to increase clarity of reporting.
Results: Ten studies, including 355 patients, reporting on the subject of progressive resistance training, specific task training, functional electrical stimulation and aerobic cycling at high-intensity were analysed. These interventions showed a statistically significant effect on strength and the Timed Up-and-Go test, and a non-significant effect on walking and the Berg Balance Scale.
Conclusion: Progressive resistance training seemed to be the most effective treatment to improve strength. When it is appropriately targeted, it significantly improves strength.

1. Introduction

1.1. Background

In industrialised countries, stroke is the most frequent cause of disability among adults. The death rate following stroke is set to decrease as a result of better care provision as soon as the problem occurs. It can therefore be expected that the number of people surviving with a disability following a stroke is liable to increase [1]. In addition, the incidence of stroke has increased dramatically among younger subjects, with over 20% of people affected being under the age of 65 [2].

After a stroke, hemiparesis is a serious motor impairment, affecting 65% of stroke victims [3].

Muscular weakness is a conspicuous symptom [4] and appears as one of the main factors slowing the recovery of normal physical abilities among patients [5]. It appears in several forms, the most significant being paresis of the body on the contra-lateral side to the cerebral lesion [6], although correlation has also been observed between strength deficits on the ipsilesional side and walking speed [7]. Paresis is defined as an alteration in the ability to generate a normal level of muscle strength [8]. This results in abnormal posture and stretching reflexes, and a loss of voluntary movement [9].

Muscle weakness can lead to immobilisation or to markedly reduced physical activity [2]. In the study by Hsu et al. [10], the authors show how the walking performances of stroke patients, in comparison with healthy subjects, is characterised by reduced walking speed and residual left-right spatial and temporal asymmetry. According to these authors, the strength of the hip flexor muscles and the knee extensor muscles of the hemiplegic limb are the most important factors determining comfortable or fast walking speed. However, the spasticity of the ankle plantar flexors also appears as an important factor in this asymmetry. Plantar flexor muscles also affect walking speed [5]. Other characteristics are observed in stroke patients on the ten-metre walking test, such as a decrease in step length and in swing phase speed of the hemiplegic limb, longer single support time on the healthy side and prolonged double support phase [11] (time of transfer from hemiplegic to healthy side). It has also been shown that the pathological gait of a hemiplegic subject may have double energy cost compared to that of a healthy subject [12].

* Corresponding author. Tel.: +41797998149.
E-mail address: sophie.wist@gmail.com (S. Wist).

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1.2. Intervention

It should be noted that since the 1990s there have been studies showing that neither activities requiring effort nor strength training increase spasticity among stroke patients [2,13,14], this having previously been a subject of controversy. Given this absence of negative effects, and the positive consequences reported, these treatments are now included in post-stroke rehabilitation programmes [6].

In case of marked muscle weakness, strengthening exercises are required to alleviate the effects of atrophy [15], but it seems that the gain in strength results mainly from an adaptation of the nerve tissues [16].

Muscle strengthening uses the principle of maximum strength (1 RM) defined by DeLorme in 1948 [17]. For healthy subjects, this consists in one to three series of eight to twelve repetitions at 60–80% of the 1 RM, twice or three times a week [5]. For post-stroke subjects, some authors [18] prescribe exercising entailing more numerous repetitions, between 10 and 15, but with a reduced workload (percentage of 1 RM). Different authors have assessed gains in strength for workloads mainly between 50% and 80%, but it seems that a workload of only 40% also has positive effects [5].

Given the different methods of muscle strengthening available, we provide below a description of certain types of exercise used among patients in rehabilitation after a stroke.

1.2.1. Progressive resistance training (PRT)

Muscle strengthening by progressive resistance exercises is based on a workload of 70–80% maximum strength (1 RM) or more [14]. This means that 1 RM should be measured regularly so as to adapt the workload to the constant improvements in the patient [19] by way of isokinetic devices [20], manual dynamometers [21] or manual testing [22]. There is no consensus to date on the duration or the frequency of treatments. However, it seems that treatment lasting at least sixteen hours provides an improvement in functional capacities [23].

1.2.2. Task-specific training (TST)

Functional, i.e. task-specific training has shown its efficacy in improving walking when delivered intensively [24] In addition, it should always be integrated in therapies, since functional improvement is their final purpose [6].

For instance, standing up from a chair (known as chair-rise) is a complex motor task that requires adequate postural control and dynamic movement. The movement mainly requires muscular strength, coordination and balance. The main muscles involved in getting up from a chair are the quadriceps and hamstring muscles [25]. When the movement is performed rapidly, it shows better symmetry in standing position, and improvement in postural stability and in directional control [26].

1.2.3. Intensive aerobic exercising

It has been demonstrated that the combination of muscle strengthening and aerobic exercising have a positive effect among elderly subjects. In addition, as a result of this type of exercising, an improvement is observed in the recruitment of motor units [27] and in walking speed [28].

The intensity of exercising can be calculated with the Karvonen formula, which uses the heart rate reserve (HRR) to define the exercise heart rate. Among stroke patients, the target intensity of aerobic exercising is 50 to 70% of the HRR [29].

1.2.4. Functional electrical stimulation (FES)

Functional electrical stimulation is a tool that uses the transmission of electrical signals to the muscle [30]. This type of training mobilises more muscular fibres and thus increases their metabolic activity [31].

Certain articles report on electrical stimulation combined with cycling [31–33]. This appears more beneficial for patients than manual guidance with FES when walking. This technique enables the patient to re-learn a correct, complete movement and to increase the sensory feedback from the movement as a result of the bilateral cycling motion [33].

1.3. Measures

Two walking tests recur regularly in the literature. The Six Minutes Walking test (6MWT) [34] has exhibited a significant, positive relationship with strength of the lower limbs [35]. Among stroke patients, a difference of 50 metres between two tests on the same patient is required to conclude to substantial improvement [36]. The second widely-used test is the 10-Metre Walking test (10MWT) which assesses fast walking [7]. For this test, a substantial improvement corresponds to a difference of 0.10 metres a second [36].

There are different ways of measuring strength among stroke patients. One of them consists in calculating maximum strength (1 RM) [37]. In untrained subjects, the maximum load can be calculated using a formula such as that proposed by Brzycki [38].

The Manual Muscular test (MMT), which is applied using the Medical Research Council scale (MRC) has been validated for use among stroke patients [22,35,39].

Regarding the manual dynamometer, reliability and precision seem good, provided the test is applied by one and the same investigator [21,40].

The Timed Up-and-Go (TUG) is a quantitative test [41,42] enabling the assessment of balance, fall risk and walking [34]. The minimum detectable change is 23% [43]. A fairly similar test is the five times sit-to-stand test. The minimum detectable change for this test is 3.6 seconds. These two tests have excellent reliability among stroke patients [21].

The Berge Balance Scale (BBS) also measures functional activity capacities, testing balance in 14 tasks. Its validity and reliability have been repeatedly established [34]. This test carries a total of 54 points. A significant change is observed from 5.8 points difference with the same tests taken previously [44].

2. Methods

2.1. Inclusion criteria for studies in this review

The aim of this work was to analyse the effect of muscle strengthening on walking, strength and balance among chronic hemiplegic patients following a stroke, and to observe results in the long-term. A systematic review of the literature was performed, followed by a meta-analysis.

The inclusion criteria targeted solely randomised controlled trials (RCTs) published up to January 20th 2014 in French, English or German. RCT follow-up studies were also considered. The participants were to be adults (over 18 yrs) following stroke and presenting hemiparesis. They were to be in chronic post-stroke phase. On account of disagreement on this subject, only studies including patients 3 months post-stroke or more were considered, or studies that stipulated that they included patients in subacute and chronic phase.

In the search, we included strengthening methods aiming to improve motor function in the lower limbs via specific, intensive exercises for particular muscle groups.

The exclusion criteria were the use of robotic devices, since in most rehabilitation centres they cannot be used on account of their cost, and the use of medication. Articles concerning the upper limbs and trunk were also excluded.

2.1.1. Outcomes and measures

To measure the effect of strengthening on walking, two tests were considered, the 6-Minute Walking test (6MWT) and the 10-Metre Walking test (10MWT). Then, to observe the effects of muscle strengthening on strength in the hemiplegic limb, we divided up the results according to the muscles tested. Priority was given to isokinetic tests, followed by manual dynamometers and MMT. As maximum strength was targeted, excentric tests took priority [45].

We also looked at balance in the course of functional activities as measured by the Berg Balance Scale (BBS) and the Timed Up-and-Go test (TUG). The five times sit-to-stand test was included with the TUG in our analyses.

2.2. Search strategy

Our literature search was performed on the databases Pubmed, Cochrane, Cinhal, Web of Science et Embase. The following search strategy was implemented: (stroke OR ''cerebrovascular accident'' OR ''cerebrovascular disease'' OR CVA OR hemipleg* OR hemipar*) AND (strength* OR power OR force OR ''muscle performance'' OR ''resistance training'' OR ''task oriented training'' OR ''task specific training'' OR FES OR ''functional electrical stimulation'') AND (gait OR walk OR locomotion OR ambulation OR 6MWT OR ''Berg balance scale'' OR BBS OR ''timed up-and-go'' OR TUG OR ''Barthel index'' OR strength OR 1 RM OR isokinetic OR 10MWT). The last search on these databases was on January 20th 2014.

Methodological filters were combined with this search strategy so as to target clinical studies as described by Wong et al. [46] for Embase and Web of Science. For PubMed and Cinal, we used the ''clinical queries'' proposed by Haynes [47].

2.3. Data collection and analysis

After completion of the electronic searches, articles were sorted in three distinct steps, first individually by two reviewers [48], and then disagreements were solved conjointly. In the first stage, duplicates were removed. The second stage consisted in perusing titles and abstracts for inclusion and exclusion criteria. Finally, the full articles were perused, and unsuitable studies were removed.

The evaluation of risk of bias was performed using the Cochrane Collaboration Risk of Bias (ROB) tool [49]. The results are presented in a table with different colours. Green indicates low risk, red indicates high risk, and yellow indicates that the risk of bias could not be estimated for lack of information.

Means and standard deviations for the different groups were then extracted for continuous measures, using the result at the end of the intervention for all outcome measures. The results of follow-up studies were extracted for walking measures, strength and TUG. For the meta-analyses, the results of continuous measures were calculated from the standardised mean difference (SMD) and the corresponding 95% confidence interval. A randomised effect model was used for all the meta-analyses. The value of the effect was established according to the method described by Cohen [50] (where 0.8 is a marked effect, 0.5 a moderate effect, and 0.2 a small effect).

The I^2 index [51] was used to classify statistical heterogeneity. The guide by Higgins and Green [52] was followed to interpret the I^2 statistics (from 75% to 100% indicates considerable heterogeneity, 50 to 90% substantial heterogeneity, 30 to 60% moderate heterogeneity and 0–40% fairly low heterogeneity). All the statistical analyses were performed on Review Manager 5.2 software. To enhance reporting procedures, the PRISMA guidelines were used [53].

3. Results

3.1.1. Studies included

In all, 2401 articles were identified according to the above search procedure (Fig. 1). Of these, 587 were duplicates, 1725 were excluded on title and abstract, and 79 on full-text perusal. Finally, the 10 studies meeting the inclusion criteria were selected for the systematic review. A critical overview of the data in each study is provided in Table 1.

Following this procedure, only studies covering strengthening by progressive resistance, specific tasks (chair-rise), intensive aerobic exercising (pedalling) and functional electro-stimulation remained, because they were the studies meeting the inclusion criteria. There is however wide disparity in duration and intensity of the exercising reported in these articles: the duration of interventions ranged from two to 12 weeks, and intensity of exercising ranged from twice [8] to five times a week [54].

The mean age of the 355 patients was between 48.8 and 67.2, and the mean time-lapse since the stroke was between 9.4 and 65 months. All the studies included patients in the subacute or chronic phase after stroke.

3.1.2. Interventions

In studies on progressive resistance training (PRT), the patients start with an adapted workload, which increases gradually to a predefined percentage. In some studies [8,19,55], intensity and the number of repeats are comparable with the norms proposed for muscle strengthening of healthy subjects [5]. Other studies use duration, calculated in minutes [54,56].

Task-specific training (TST) [26] comprises chair-rise exercises on different ground surfaces and with different chair heights. The patients start with a simple task and then progress according to their ability to perform the task in a given time.

In the study by Jin et al. [57] where the exercising is on an aerobic cycle, the measurement of heart rate reserve (HRR) is used to define the training heart rate, using the Karvonen formula as described by Ivey et al. [29].

The study involving functional electrical stimulation in a cycling activity [31] entails at least three times five to 10 minutes pedalling against resistance, and requires each patient to reach a predetermined speed, for a total muscle strengthening duration of 25 to 30 minutes. During the test, peak heart rate (HR peak) is measured to estimate the intensity of the maximum training exercise.

3.2. Risks of bias in the studies selected

All the studies selected specify that their groups were formed randomly, but there is a lack of information in the studies by Akbari et al. [55], Janssen et al. [31], and Ouellette et al. [19], because the method used for randomisation is not specified. In the other articles, researchers sometimes used dice, dividing patients between group A if the result was an even number and B if it was an odd number [54]. It is nevertheless possible that the investigator was influenced, as we do not know if he was blinded to the names. The same phenomenon occurs for the study by Jin et al. [57] where the patients were drawn randomly, but the exact procedure is not specified. In the study by Flansbjer et al. [8] the authors used unsealed envelopes for allocation of patients to

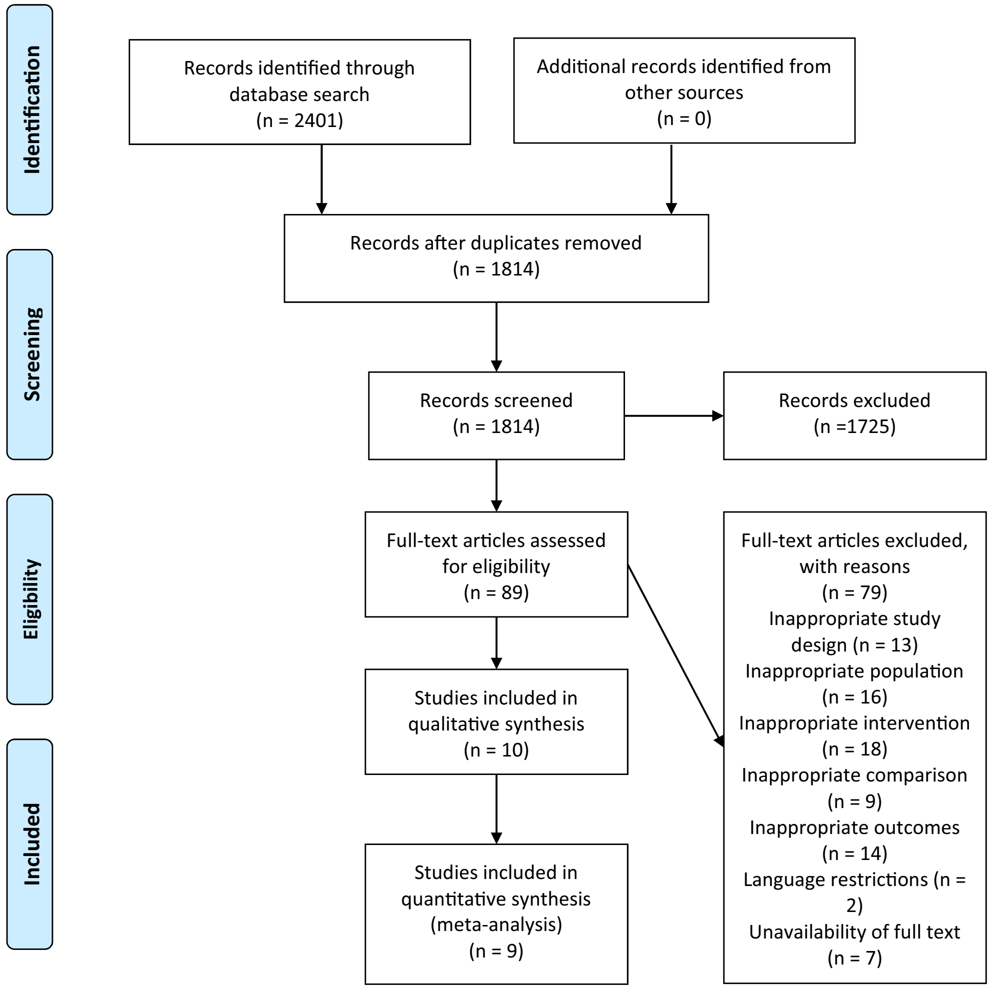

Fig. 1. Flow diagram.

groups, and this was also used in the follow-up study [58]. In the studies by Tung et al. [26] and Lee et al. [56,59], no bias appears in the allocation because the researchers used sealed envelopes and coded cards selected by the patients and prepared by a researchers not involved in the research.

No study was double-blind. The tests were conducted blind by researchers either throughout the study [8,19,31,55] or solely in the preliminary tests to ensure that they were unaware of the allocation [26]. Only one article by Flansbjer et al. [56,58,59], which is a follow-up study, presented the bias of missing data, because a large number of participants left the study in the course of the four years. Other risks of bias can be mentioned, such as results not included in the article or funding bias. The risks of bias for the different studies are shown on Fig. 2.

3.3. *Effects of the interventions*

3.3.1. *Walking*

The effect of muscle strengthening on walking was explored by comparisons across six studies [8,19,31,54,57,59] and two measures, the 6MWT and the 10MWT (Fig. 3). A seventh study [58] was analysed to look for long-term effects, in this case four years after the intervention.

For the 6MWT, the studies on strengthening by progressive resistance, intensive aerobic exercising on a cycle and functional electro-stimulation were analysed, for a total of 289 participants. The results show a statistically non-significant improvement for the intervention groups (SMD = 0.17; $P = 0.25$). The 95% confidence interval is between −0.12 and 0.46, and heterogeneity is low ($I^2 = 25\%$).

In the PRT and aerobic exercising subgroups a non-significant improvement is noted in favour of the intervention group, with a confidence interval between −0.20 and 0.75 and between −0.25 and 0.43, respectively.

The FES subgroup showed a non-significant improvement ($P = 0.75$) in favour of the control group (95% CI = −1.32; 0.95).

In the four-year follow-up in the study by Flansbjer et al. [58], of a total of 18 patients, there was a non-significant improvement ($P = 0.46$) of the 6MWT.

The analysis of the 10MWT concerned three studies [8,19,59] and involved 114 subjects, 60 of whom took part in PRT muscle strengthening. A non-statistically significant improvement ($P = 0.62$) was observed in the intervention group. The confidence interval of 95% was between −0.28 and 0.46. The value of I^2 was 0%, showing a low level of heterogeneity. The standardised mean difference was 0.09 in favour of the intervention group.

The analysis of muscle strengthening on the 10MWT in the long-term [58] comprised 18 subjects. After 4 years follow-up there is a slight improvement in the intervention group ($P = 0.38$). The 95% confidence interval is between −0.53 and 1.39, and the standardised mean difference 0.43 in favour of the intervention group.

Table 1
Summary of studies included.

Type	Study	Population						Intervention				Comparison	Outcomes
		N		Age (SD)		Time Post-Stroke (SD)		Description	Duration	Frequency Length	Intensity		
		I	C	I	C	I	C						
PRT	Akbari et al. (2006) [55]	17	17	49.3 (7.1)	48.8 (3)	34.5 (26.37) months	35.3 (27.5) months	Concentric isotonic muscle strengthening (Flex-Ext-Abd Hip; Flex-Ext Knee; DE-PF) Functional exercises, balance	4 weeks 12 sess.	3×/week 3 h	70% 1 RM	Same exercises without muscle strengthening	Isometric strength (dynamometer) flex + ext + abd H, flex + ext K, DE + PF
	Byun et al. (2011) [54]	15	15	59.1 (10.2)	58.7 (13.8)	9.4 (3.7) months	9.9 (5.4) months	Strength on "sliding rehabilitation machine" + Bobath	2 weeks 10 sess.	5×/week 30 min		Conventional training based on Bobath concept	6MWT, TUGT, BBS, MMT (Knie)
	Flansbjer et al. (2008) [8]	15	9	61 (5)	60 (5)	18.9 (7.9) months	20 (11.6) months	Strengthening on Leg Extension/Curl Rehab machine Passive Stretching of Knee extensors + flexors	10 weeks 20 sess.	2×/week 90 min (PRT 6 min)	5 rep.25% 1 RM 2 × 6–8rep. 80%1 RM	ADL and other training (not PRT)	Dynamic strength K flex + ext, isokinetic strength K flex + ext, TUG, 6MWT, 10MWT
	Flansbjer et al. (2012) [58]	11	7	Follow-up after 4 years. For baseline results, see Flansbjer et al. (2008) [8]									Dynamic strength K flex + ext, isokinetic strength k flex + ext, TUG, 6MWT, 10MWT
	Lee et al. (2008) [59]	24	24	Gr1: 60.5 (10.6)	Gr3: 67.2 (10.6)	Gr1: 63.2 (40.5)	Gr3: 52.4 (2.2)	Gr1: Strengthening on pneumatic resistance equipment ext H + K unilateral; abd-ext-flex K; FP; ED + Active cycling	10–12 30 sess.	3×/week 60 min	PRT 50%–80% 1 RM Active cycling: 50%Vo2max	Gr3 bilateral: exercises without resistance + active cycling	6MWT, 10MWT
	Lee et al. (2010) [56]			Gr2: 62.9 (9.3)	Gr4: 65.3 (6)	Gr2: 44.2 (63.9) month	Gr4: 65.8 (42.3) months	Gr2: same as Gr1 but passive cycling (motorised)				Gr4: like Gr3, but passive cycling	Strength dynamic PF + DE + flex k + ext k + ext H, isometric abd H
	Ouellette et al. (2004) [19]	21	21	65.8 (2.5)	66.1 (2.1)	31.8 (3.3) months	25.6 (4) months	Leg-Press bilateral and Ext k + PF + DE unilateral	12 weeks 36 sess.	3×/week	3 sets of 8–10 × 70% 1 RM	ROM bilateral and upper body exercises	1 RM, 6MWT, stand up, 10MWT
TST	Tung et al. (2010) [26]	16	16	51 (12.1)	52.7 (14.1)	26.9 (16) months	12.8 (12.3) months	Sit-to-stand + global Physio (balance, walking, leg strengthening)	4 week 12 sess.	3×/week 15 min Strength + 30 min global physio		Global physio (balance, walk, leg strengthening)	BBS, isometric strength ext H + k + PF (dynamometer)
Aerobic	Jin et al. (2012) [57]	68	65	57 (6)	56 (7)	18 (5.2) months	17.9 (4.8) months	Aerobic cycling exercise training with additional weight on paretic side Stretching and balance	8 weeks 40 sess.	5×/week 40 min	3% max body weight (hemi-side) 50–70% HRR	Low intensity walking Stretching and balance	6MWT, excentric strength ext k, BBS
FES	Janssen et al. (2008) [31]	6	6	54.2 (10.7)	55.3 (10.4)	12.3 (5.4) months	18.3 (9.9) months	ES-LCE	6 weeks 12 sess.	2×/week 25–30 min		LCE	Isometric strength ext K, 6MWT, BBS

PRT: progressive resistance training; TST: task-specific training; FES: functional electrical stimulation; N: number; I: intervention; C: control; SD: standard deviation; Flex: flexion; Ext: extension; Abd: abduction; ED: ankle dorsal extension; FP: ankle plantar flexion; K: knee; H: hip; VO2max: maximum oxygen volume; LCE: leg cycling exercise; ES: electric stimulation; Sess.: sessions; Min.: minutes; 1 RM: repetition maximum; ROM: range of motion (= amplitude); ADL: activities of daily living; Rep.: repetitions; HRR: heart rate reserve; BBS: Berg Balance Scale; 6MWT: Six Minutes Walking test; 10MWT: Ten Meter Walking test; MMT: Manual Muscle test; Gr1/2/3/4: group 1/2/3/4.

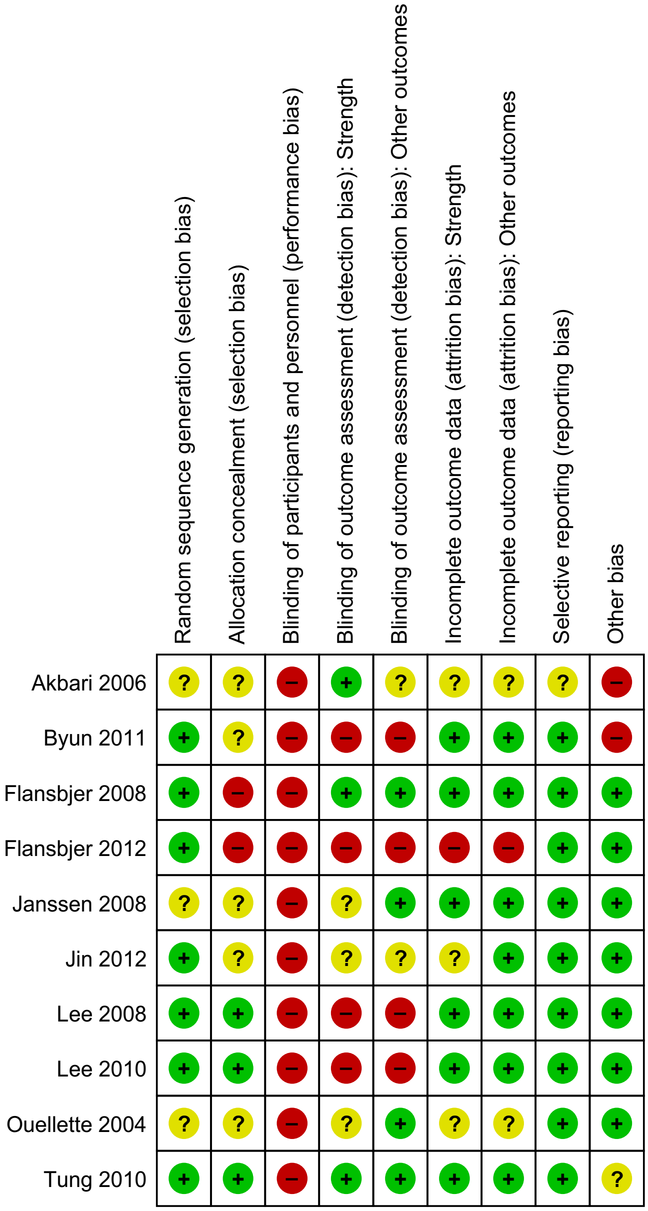

Fig. 2. Risk of bias.

3.3.2. Strength

Tests for different muscle groups of the lower limbs were analysed, and the results are given in the form of a forest plot (Fig. 4). To produce this, we used the data from seven studies [8,19,26,31,54,56,57]. For the analysis of dorsiflexor muscles, only one study [19] on PRT strengthening was considered. This concerned 29 patients in all. There was a significant improvement ($P = 0.00001$) in the intervention group. The 95% confidence interval was between 2.25 and 4.65. The standardised mean difference of 3.45 indicates positive effects in favour of the experimental group. The same type of result is observed in the study by Akbari et al. [55].

The results of three studies were compared [19,26,56] to explore the effect of muscle strengthening on plantar flexion – two studies using PRT [19,56] and one using task-specific training (TST) [26]. The analysis overall concerned 109 patients, and showed an improvement that was statistically significant ($P = 0.04$) in favour of the intervention group. The confidence interval was between 0.04 and 1.87. However, marked heterogeneity was observed ($I^2 = 79\%$). The standardised mean difference was 0.95 in favour of the intervention group.

PRT yielded significant results in favour of the intervention group (95% CI = 0.91, 1.93), which is also reported in the study by Akbari et al. [55]. TST evidenced no improvement (95% CI = −0.64, 0.75 and $P = 0.88$).

To analyse the effects of muscle strengthening on the knee extensor muscles we assessed seven studies [8,19,26,31,54,56,57] for a total of 303 subjects. A statistically significant improvement ($P = 0.01$) was observed in favour of the experimental group, as in the study by Akbari et al. [55]. The 95% confidence interval was between 0.23 and 1.79. The value of I^2 was 87% showing marked heterogeneity. The standardised mean difference was 1.01 in favour of the intervention group.

In the PRT subgroup [8,19,54,56], a statistically significant improvement is noted ($P = 0.004$) in favour on the intervention group (95% CI = 0.52, 2.27). The same effect, but more pronounced, was observed in the aerobic exercising group ($P < 0.00001$ and 95% CI = 1.07, 1.84).

In the FES [31] and TST [26] subgroups, the improvement was slightly in favour of the control group, with a 95% confidence interval between −1.09 and 0.31 and between −1.58 and 0.72, respectively.

The PRT follow-up study [58] performed on 18 patients four years after the initial study showed non-significant improvement ($P = 0.18$) in favour of the experimental group. The 95% confidence interval was between −9.12 and 49.32. The mean standardised difference was 20.10 in favour of the intervention group. This study also returns to the follow-up that took place five months after the intervention, and describes a non-significant improvement ($P = 0.33$) in favour of the experimental group.

For hip extension effects, three studies [19,26,56] including 122 patients in all, were analysed. A statistically non-significant improvement ($P = 0.06$) was observed in favour of the experimental group. The 95% confidence interval was between −0.10 and 3.40. The value of I^2 was 94%, showing considerable heterogeneity. The standardised mean difference was 1.65 in favour of the intervention group.

The PRT subgroup showed a significant improvement ($P < 0.0001$) in favour of the intervention group (95% CI between 1.27 and 3.69) in line with the results of Akbari et al. [55]. The TST subgroup showed no improvement in either the intervention group or the control group (95% CI = −0.72, 0.67).

3.3.3. Balance

The effects of muscle strengthening on balance were analysed via the TUG and BBS tests (Fig. 5). For the Timed Up-and-Go test (TUG), three studies on leg-press machines [8,19,54] were analysed, with a total of 92 participants. There was a statistically significant improvement in favour of the intervention group. The 95% confidence interval was 0.14 to 1.89 and the standardised mean difference was 1.00 in favour of the experimental group.

The long-term analysis of muscles strengthening (not shown on Fig. 5) for TUG comprised 18 subjects in a single study [58]. There was a statistically non-significant improvement at five months and four years in favour of the experimental group. The standardised mean difference was −7.20 in favour of the intervention group in both instances.

Four studies [26,31,54,57] totalling 207 patients were compared to explore the effects of muscle strengthening on the Berg Balance Scale (BBS). There was a statistically non-significant improvement ($P = 0.65$) in favour of the intervention group. The 95% confidence interval was between −0.67 and 1.07. There was marked heterogeneity ($I^2 = 83\%$). The standardised mean difference was 0.20.

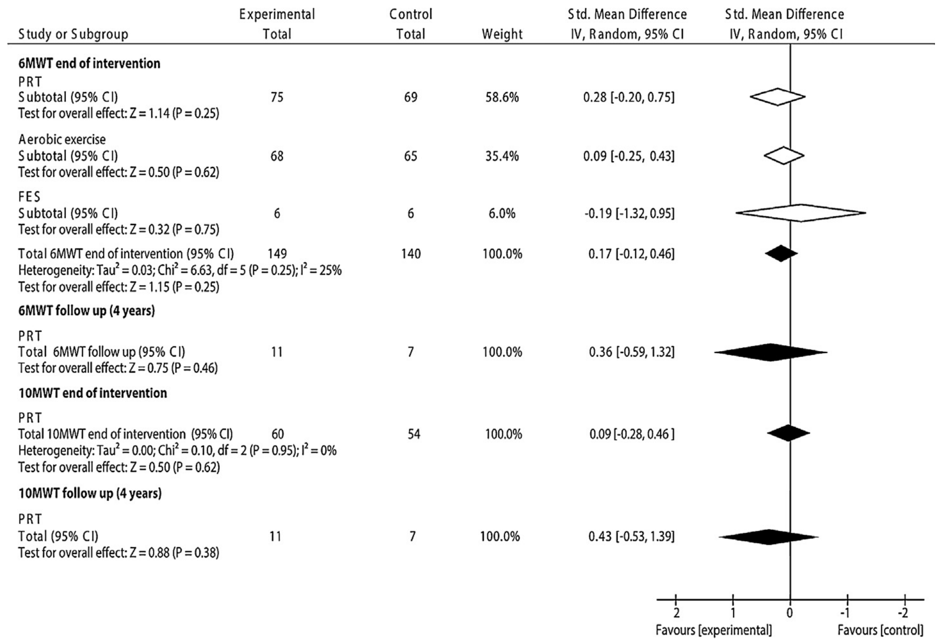

Fig. 3. Forest plot: walking (end of intervention and follow-up). 6MWT: Six Minutes Walking test; FES: functional electrical stimulation; PRT: progressive resistance training. Black diamonds describe the estimated overall results of the different analyses (e.g. 6MWT at the end of the intervention). The white diamonds describe the estimated overall results for subgroups (e.g. estimated effect of FES in 6MWT analysis at the end of the intervention). The results for the individual studies are given in Appendix 1.

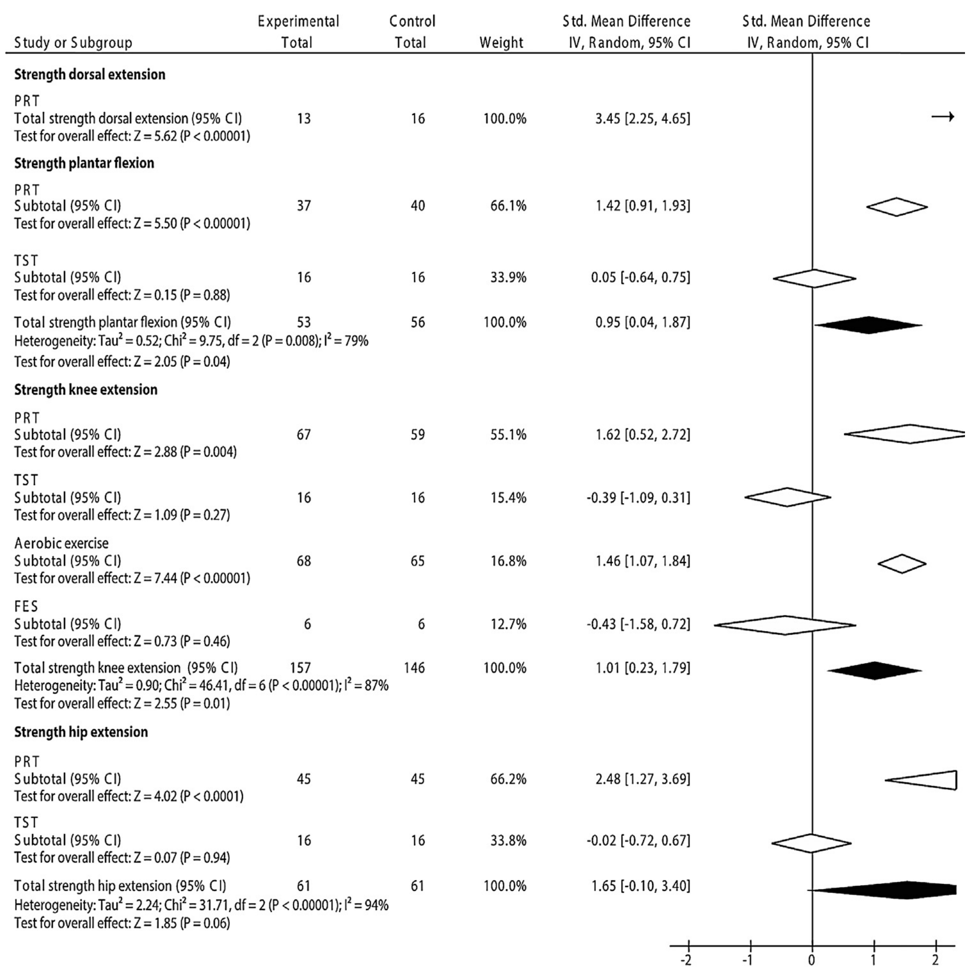

Fig. 4. Forest plot: strength (end of intervention). FES: functional electrical stimulation; PRT: progressive resistance training; TST: task-specific training. The black diamonds describe the estimated overall results for each analysis (e.g. strength dorsal extension end of intervention). The white diamonds describe the estimated overall results for subgroups (e.g. estimated effect of PRT in strength analysis for plantar flexors at the end of the intervention). The results for the individual studies are given in Appendix 1.

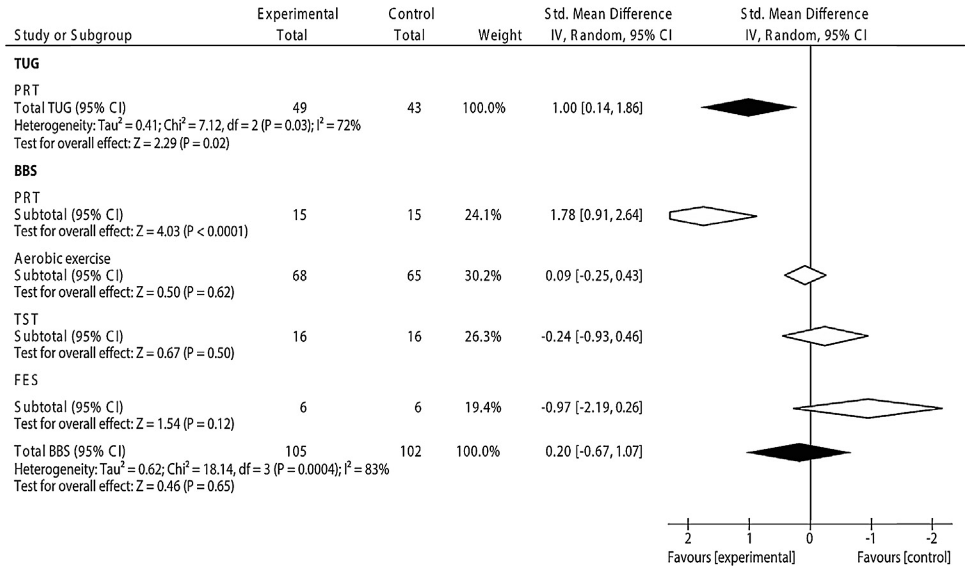

Fig. 5. Forest plot balance (end of intervention). BBS: Berg Balance Scale; FES: functional electrical stimulation; PRT: progressive resistance training; TUG: Timed Up-and-Go test; TST: task-specific training. The black diamonds describe the estimated overall results for each analysis (e.g. BBS end of intervention). The white diamonds describe the estimated overall results for subgroups (e.g. estimated effect of PRT in BBS analysis at end of intervention). The results for the individual studies are given in Appendix 1.

The PRT subgroup comprising only one study [54] was the only study to evidence a significant improvement in favour of the experimental group (95% CI = 0.91, 2.64).

TST exercises [26] and aerobic exercising [57] did not demonstrate improvement in favour of one or other group (respectively 95% CI = −0.93, 0.46 and −0.25, 0.43).

The FES subgroup [31] evidenced a marked improvement in favour of the control group (95% CI = −2.19, 0.26).

4. Discussion

4.1. Main results

In this meta-analysis, we studied the effects of muscle strengthening on walking, strength and balance among patients having survived a stroke and in the chronic phase. The research led to the inclusion of 10 studies on this subject that met our criteria, nine of which were subjected to statistical analyses.

The main results show that walking (on 6MWT and 10MWT) improved in non-significant manner. A general increase in strength of the lower limbs was noted. Four years after the intervention, these positive results were reduced, but only one study evidenced this [58]. Balance was also improved.

Overall, heterogeneity was either substantial or considerable for the outcomes strength and balance, but low to moderate for walking outcomes. This could be explained by the wide variety of the interventions reviewed, and the diversity of the exercises used. For instance, the number of session ranged from twice to five time a week for a total of 10 [54] to 40 sessions [57]. In addition, the shortest intervention lasted two weeks [54] and the longest 12 weeks [19,56].

4.1.1. Walking

The meta-analysis on the 6MWT evidenced positive results for the intervention group that were statistically and clinically non-significant. The greatest improvement was observed in the study by Byun et al. [54] where the intervention had the longest duration and the greatest intensity, that is to say 10 sessions of 30 minutes over two weeks, in addition to 40 minutes Bobath-type therapy five times a week.

4.1.2. Strength

The analysis of dorsal flexion involved only one study [19] showing a statistically significant improvement (SMD = 3.45) for the intervention group. This study included muscle strengthening of the lower limbs on bilateral Leg-Press and unilateral exercises for the paretic and non-paretic limbs (extension of the knee, plantar flexion, dorsal extension).

Regarding results for ankle plantar flexors, a marked statistically positive result is observed (SMD = 0.95; $P = 0.04$). When plantar flexor muscles were specifically targeted, the results tended to be positive [19,56]. The study by Tung et al. [26], where the implementation of task-specific training consisted in sit-to-stand exercises, evidenced no significant improvement in the strength of the plantar flexor muscles. Indeed, although the triceps surae contract in excentric manner when weight is shifted forwards during extension, they are not the main muscles involved in the sitting-to-standing exercise [60]. One negative aspect is the considerable heterogeneity ($I^2 = 79\%$), which could be explained by the differences in duration of the interventions [19,26,56].

As the analysis concerning knee extension involved a larger number of studies, the results are more robust, and statistically significant ($P = 0.01$) in favour of the intervention group (SMD = 1.01). However, the analysis of the FES subgroup evidences results in favour of the control group. In this study [31], only the strength of the knees extensor muscles was tested. According to Jansen et al. [31], potential effects on the strength of the lower limb may have been under-estimated, because in cycling activities, used in both groups, other muscle groups are also activated. It is therefore not possible to conclude from the analysis of this single study that functional electro-stimulation in combination with pedalling is not efficient in increasing strength in the lower limbs.

The analysis of strength for extension of the hip involved only three studies, with widely varied measurement methods. The most robust results were those obtained by PRT [19,56].

The effects of the interventions tested were positive on the strength of the lower limbs, but they require long durations and considerable intensity, tailored to the patient. The positive results concern only interventions using Leg-Press and cycling. This means that it is not possible to extrapolate these results on muscle strengthening to a wider field.

4.1.3. Balance

The results of the TUG test show statistically significant effects with considerable heterogeneity ($I^2 = 72\%$). The most significant results for the intervention group were those reported by Byun et al. [54] and Ouellette et al. [19] where the training devices used were respectively the Sliding Rehabilitation Machine and Leg-Press. The intensity of the intervention (as with walking) in the study by Byun et al. [54] and the modification of the inclination of the footplate could explain the higher values. Concerning the study by Flansbjer et al. [8], it evidenced no significant difference between intervention and control groups, with only a slight trend towards the intervention group, maintained at five months. In addition, at five months, the control group had returned to baseline values. After four years, the study by Flansbjer et al. [58] noted that the results were reduced in both groups.

The meta-analysis of results on the Berg Balance Scale shows positive results that are statistically non-significant in favour of the intervention group, in particular in the study by Byun et al. [54], while there is only a small difference between intervention and control group in the studies by Jin et al. [57] and Tung et al. [26]. The results of the study by Janssen et al. [31] on FES muscle strengthening are mainly in favour of the control group. The baseline values for the intervention group, lower than in the control group, could explain this effect. In addition, the authors report that improvement on the BBS was more marked in the intervention group than in the control group, 10.4% versus 4.1% [31]. Heterogeneity is considerable ($I^2 = 83\%$). Again, as described above for other outcomes, there is considerable disparity across the types of intervention in the studies included.

4.2. External validity

The validity of this study can be extended to a wide population, since the articles originate from different continents, the only continent not represented being Africa. Although strokes can occur at any age, the majority occur after the age of 65 [61]. The 10 studies included in this review concerned patients aged 27 to 76 [26,56] with mean age ranging from 48.8 to 67.2. They included active populations, as often in studies on the subject, this being the case with our review although we did not set any exclusion criterion concerning this aspect.

All the studies included are recent, published between 2004 and 2012, although no exclusion criterion was set for dates of publication. This is a positive aspect, since the interventions and therapies explored are close to those used today in rehabilitation facilities.

4.3. Strengths and limitations

The first step in this research was the determination of a search strategy, which was a difficult task on account of the wide range of interventions that needed to be integrated into the review. We however used the different filters detailed in 2.2 above, which should have avoided bias in the literature search.

One strength of this work is that when articles were screened on title, abstract and full-text, the investigators worked independently, confronting results at completion of each phase. The articles that were not assessed in the same way were discussed one by one to avoid losing important studies.

Our analysis is based on ten studies presenting different forms of bias. The most frequent bias, occurring in all the studies, is the absence of a double-blind design.

The lack of information in the articles is often damaging – the research may or may not have been performed in exemplary manner, but this was not assessed because the information was lacking. For instance, in the article by Akbari et al. [55], there is no table of results, so that it was not possible to compare their results with others for the meta-analysis.

One positive aspect is the use of the intention-to-treat method, which includes patients who were unable to complete certain tests in the results, thus avoiding favouring the intervention. This is beneficial, since any positive results are all the more robust [8,19,59].

4.4. Comparison with the literature

The meta-analysis by Mehta et al. [9] concerns the effects of muscle strengthening on speed and endurance for walking among patients in chronic phase after a stroke. It covers 10 studies among which three [8,19,59] are also included in our review. In the analysis, we note that the authors found statistically significant results in favour of the intervention group for comfortable walking speed and for the 6MWT. This is not in line with our results, given that neither the 6MWT nor the 10MWT (fast walking speed) yielded statistically significant results. This could be explained by the fact that our review included control groups that all had active therapy for the lower limb, while the meta-analysis by Mehta et al. [9] includes studies where the control group only underwent strengthening of the upper limbs, while the lower limbs were either passive or not treated. All this means greater differences between groups, and merely indicates that strengthening is better than no treatment.

The systematic review by Ada et al. [13] concerns muscle strengthening among patients after a stroke, and its effects on strength and functional activity such as walking (10MWT) or upper limb activity (Box and Block test) and independence (Barthel index). Their results concerning strength were significant and positive, using biofeedback or electro-stimulation among chronic patients, but non-significant when interventions were mixed. The same results were obtained for measures of activity. It is only possible to make a global comparison of this review with ours, since it is not specified whether the results assess the upper or lower limbs. However, we observe mainly statistically significant results for strength, and non-significant results for walking.

The study by Pak and Patten [6], which analyses the effect of muscle strengthening on strength and walking among stroke patients in subacute or chronic phase, reports roughly the same results as our meta-analysis. This review included eleven articles two of which [8,19] were also included in our study as well as in the review by Metha et al. [9]. As the main aims of this study were to observe whether muscle strengthening counteracted muscle weakness, and above all, whether there were positive or negative effects on spasticity, the inclusion and exclusion criteria were very different from ours.

5. Conclusion

5.1. Implications for practice

This work has demonstrated the impact of lower limb muscle strengthening among stroke patients in chronic phase, between 9.4 and 65.8 months (means) after the stroke. Effects are observed on muscular strength when training is intensive and tailored to its purpose. The results show a statistically significant gain in dorsal and plantar flexion and knee extension, and a non-significant gain for hip flexion. Progressive resistance training (PRT) appears as the most efficient in improving strength in the lower limbs, walking distance, fast walking and balance.

5.2. Implications for research

It seems that muscle strengthening improves strength when tailored to the needs of the patient. However, we were not able to establish clear-cut results for its effect on balance and endurance walking. We were therefore not able to determine whether it was genuinely beneficial. It would consequently be worthwhile determining what type of intervention might yield improvement in strength, walking and balance combined. In addition, given the heterogeneous nature of our results, we consider that research should be oriented towards ideal training models, taking into consideration the number of sessions required for maximum benefit to the patient. It would also be interesting to determine how long the effects last after the intervention, since the analysis of a single study on this aspect [58] did not enable robust conclusions. We consider it is essential to pursue research in order to draw up recommendations for the follow-up of chronic patients after a stroke, in the form of a therapeutic guide.

Disclosure of interest

The authors declare that they have no competing interest.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.rehab.2016.02.001.

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