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# Resistive strength training for arm rehabilitation after stroke (Protocol)

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# Resistive strength training for arm rehabilitation after stroke

Susan Hoegg[1], Bernhard Elsner[2], David H Saunders[3], Frederike van Wijck[4], Jan Mehrholz[1]

[1]Department of Public Health, Dresden Medical School, Technical University Dresden, Dresden, Germany. [2]Department of Public Health, Dresden Medical School, Technical University Dresden, Dresden, Germany. [3]Physical Activity for Health Research Centre (PAHRC), University of Edinburgh, Edinburgh, UK. [4]Institute for Applied Health Research and the School of Health and Life Sciences, Glasgow Caledonian University, Glasgow, UK

**Contact address:** Susan Hoegg, susan.hoegg@mailbox.tu-dresden.de.

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## ABSTRACT

### Objectives

This is a protocol for a Cochrane Review (intervention). The objectives are as follows:

To determine the effects of resistive arm strength training after stroke on strength and arm-hand movements, compared to no therapy or to any other intervention.

# BACKGROUND

## Description of the condition

Hemiparesis (muscle weakness on one side of the body) is the most common impairment after a stroke (Cawood 2016; Lawrence 2001). It affects more than 70% of patients, and the loss of strength is more common in the arms than the legs (Lawrence 2001). Arm weakness leads to significant limitations in activities of daily living for people after stroke (Cawood 2016), and can also have a negative impact on participation in self-care (Faria-Fortini 2011). Arm weakness reduces autonomy and independence, such that after discharge from the rehabilitation hospital 41% of stroke survivors need help with daily activities and 20% require care from relatives or friends (Chen 2019). Even five years after stroke, almost 20% of patients have been found to be restricted in outdoor activities, at work, and in education (Palstam 2019).

When people who have had a stroke are asked about their research priorities in relation to life after stroke, the most frequently mentioned topics are arm and leg problems and the impact of physical activity on stroke rehabilitation, along with balance and walking problems, and fatigue after stroke (Rudberg 2021). Because of the extensive limitations resulting from post-stroke arm weakness, and the increasing prevalence of stroke, finding the best treatments for arm recovery is an important research priority related to life after stroke (Pollock 2012). The UK's Stroke Association has also recently listed finding the best exercises to improve strength as one of the top research priorities in stroke rehabilitation (Stroke Association 2021).

## Description of the intervention

Strength training is an intervention that attempts to increase the ability to produce and sustain force through repeated resistive muscle contractions (Kraemer 2002). The American College of Sports Medicine (ACSM) characterises it as repetitive resistive movements, with progressively increasing exercise demands (ACSM 2018). There are different types of muscle contractions used in strength training. For instance, muscles can generate force while they are shortening (concentric contraction), lengthening (eccentric contractions), or even when the muscle length does not change (isometric contractions) (ACSM 1998).

The ACSM recommends adherence to specific training characteristics for successful and safe muscle training in healthy people (ACSM 1998): The training sessions should be carried out on two to three days per week. Strength training should be performed through a full range of motion. A minimum of one set of eight to 12 repetitions for healthy individuals, or 10 to 15 repetitions for older and more frail people, are recommended. The intensity should be sufficiently high that the muscle is close to fatigue at the end of a set. The training demands should be increased, for example by progression of the weight load or repetitions, by shortening the rest period between exercises and sets, or by increasing the number of sets completed. Resistance can be applied by free-weights, weight machines, bodyweight, elastic devices, masses or isokinetic devices. Robotic devices and everyday objects of different weights can also be used to create resistance during movement. The same training approach as for healthy people is also recommended for people with stroke (i.e. utilising the same muscles, same training frequency, same number of repetitions, sets and exercises, Billinger 2014). Classical strength training exercises can be performed in the context of restricted and predetermined movements (e.g. machine-guided training). However, the exercises can also be performed as functional or task-related training, as long as the movements are always performed against resistance.

For our review, we will look for randomised controlled trials (RCTs) that investigated strength training with the exercise features described above. We will exclude other interventions that can increase strength but do not follow this systematic strength training methodology.

## How the intervention might work

Stroke results in a reduction in muscle strength. It leads to a lack of oxygen supply to the nerve cells, causing them to become damaged and lose their function (Gund 2013). As the associated muscles receive less neuronal input due to the neuronal damage, muscle weakness develops (Hara 2000). There is a stroke-related restructuring of the muscle architecture (Gray 2012), and sarcopenia (Li 2020), which affects the functional capacity of the muscles. Loss of muscle strength is also related to limitations in terms of arm movements (Harris 2007), activities of daily living (Bae 2015), and quality of life (Aidar 2016). If muscle weakness after a stroke leads to complications such as pain, contractures, or muscle or joint injuries, this has an additional negative impact on arm movements.

There are concerns that strength training in stroke rehabilitation may increase spasticity. However, the influence of strength training on spasticity has been investigated in several reviews and the review authors found that neither in the first weeks nor in the later course after a stroke spasticity was increased by strength training (Harris 2010; Salter 2016). There may also be risks associated with strength training in neurorehabilitation, such as exercise-related soft tissue injuries, altered muscle tone, pain, or an increase in blood pressure, which should be considered in therapy.

Strength training could prevent neural and muscular adaptations that occur after stroke (Andersen 2011; Clark 2013; Ryan 2011), and improve strength in stroke survivors (Dorsch 2018; Fasoli 2003; Pang 2006). Such structural adaptations (enlarged muscle fibres) and increased muscle strength after strength training could also be found in patients with multiple sclerosis (Dalgas 2010). In a population of healthy adults, a dose-response relationship was found for strength training (Borde 2015). The increase in strength was obtained with a training intensity of 70% to 79% of the one repetition maximum (1RM, the maximum amount of weight a person can move for one repetition) and a duration of six seconds per exercise repetition. Additionally, the measured strength gains were greater the longer the training period lasted. To our knowledge, a dose-response effect in stroke patients has not yet been found, but resistive strength training has also been shown to be effective in increasing strength (Dorsch 2018). As strength training can increase muscle strength, it therefore has potential to improve arm movements, activities of daily living, and quality of life. Several RCTs have described that arm strength training has led to improved arm movements (Corti 2012; Fasoli 2003; Lin 2015; Pang 2006) and activities of daily living (Lin 2015) in chronic stroke survivors. However, a systematic review found no improvement in activity, despite increasing strength (Dorsch 2018). Dorsch and colleagues discussed that strength training might have a benefit at the activity level if the exercises are task-specific and thus address co-ordination deficits (Dorsch 2018). Thus, strength training with

free weights or everyday objects might be more likely to produce improvements in activities than machine training.

Increasing muscle strength can reduce the consequences of problems after stroke. Compared to functional task practice, greater improvements in shoulder flexion and elbow extension range of motion could be achieved through strength training (Corti 2012). Studies on people with stroke show that as arm muscle strength increased, shoulder subluxations and rotator cuff tears were less frequent (Yi 2013). Therefore, rotator cuff strength exercises are recommended for stroke survivors to prevent shoulder subluxations (Kumar 2010). High blood pressure (an important risk factor for cardiovascular disease) can be lowered by isometric grip strength training (Loaiza-Betancur 2020; Smart 2019), and could therefore also be used in secondary stroke prevention.

In summary, strength training may not only increase muscle strength, but may also be beneficial in improving arm and hand movements, the ability to perform activities of daily living, and quality of life, as well as lowing blood pressure, and combating comorbidities.

### Why it is important to do this review

So far, we have identified eight literature reviews investigating the effect of arm strength training for people who have had a stroke. An overview of the published reviews is presented in Table 1. The training effects found in these reviews differ from each other. By using different search strategies and analyses, the authors of three reviews concluded that arm strength training had a positive effect on strength (Ada 2006; Harris 2010; Veldema 2020). There were different conclusions about the effectiveness of arm strength training on arm-hand movements (Harris 2010; Veldema 2020) and activities (Ada 2006; Dorsch 2018), and in some reviews no conclusions could be drawn (Dorsch 2018: Hammami 2012; Morris 2004; Salter 2016; Saunders 2020). All eight reviews we found investigated the effects of strength training in stroke survivors, but only one examined resistance training according to the ACSM recommendations (Dorsch 2018). Only one review focused on arm strength training (Harris 2010); the other reviews also examined leg strength training (Ada 2006; Dorsch 2018; Hammami 2012; Morris 2004; Salter 2016; Saunders 2020; Veldema 2020), strengthening interventions that did not involve resistance training (Ada 2006), or other forms of fitness training (Saunders 2020). While leg strength training has been well studied by previous reviews, this review focuses on the effects of arm strength training, and it will incorporate more recent RCTs that make it possible to evaluate some arm strength training outcomes for the first time and increase the accuracy of other outcomes. Although arm strength training for stroke survivors seems to have a beneficial effect on increasing strength, the training effects on arm-hand movements and activities and the effect of strength training according to the ACSM criteria remains insufficiently investigated.

Strength training is a well-known intervention in stroke rehabilitation. It is recommended that management of stroke rehabilitation includes strength training (Billinger 2014; Hebert 2016; National Clinical Guideline Centre 2013; Stroke Foundation 2021; Zhang 2020) but the clinical effects of resistive arm strength training are unclear. Although strength training potentially impacts arm and hand movements after stroke, the present data is heterogeneous and insufficient for evidence-based rehabilitation. However, strength training in stroke rehabilitation is a rapidly growing area of research; and in an initial handsearch we identified four new RCTs that investigated arm strength training (Pomeroy 2018; Milot 2018; Gambassi 2019; Ellis 2018). This new research, and the fact that no judgement on the effects of resistive arm strength training was possible in previous reviews, justifies a current review.

## OBJECTIVES

To determine the effects of resistive arm strength training after stroke on strength and arm-hand movements, compared to no therapy or to any other intervention.

## METHODS

### Criteria for considering studies for this review

#### Types of studies

We will include RCTs with a parallel-group design. We will also include randomised cross-over studies, provided that relevant outcomes have been reported.

#### Types of participants

We will include people of any age who have experienced one or more strokes, irrespective of the time since stroke onset. If studies include other diseases besides stroke, and the data are not reported separately for each condition, we will contact the study authors about this. We will exclude these studies if the data are not available for people with stroke.

#### Types of interventions

We will include trials comparing strength training (experimental group) with no therapy or other arm interventions (control group). The interventions can be undertaken in isolation or in addition to conventional therapy, as long as both groups receive this. Interventions of both comparison groups can be for the hand, arm, or the entire arm.

##### *Resistive strength training*

This represents training primarily performed to improve strength. The strength training programmes of the included studies should be characterised by moderate-to-high exercise intensity, small-to-moderate number of repetitions in several consecutive sets, and progression of training (Prentice 2015). These variables vary in dependence on trained population (e.g. elderly or more frail people) and the goals of training. We will consider concentric, isometric, or eccentric contractions of any muscle group. The resistance during strength training can be varied using different training equipment such as machine weights, free weights, robotic devices, or everyday objects. Training programmes may focus the training on either arm or hand. To improve the certainty that the effect we will evaluate in this review can be attributed to strength training, we will only include trials in which strength is trained specifically, as described in the Background. If strength training is embedded in a broader training concept, such as circuit training or a general fitness programme, we will include that study in this review if strength training made up the majority of time of the intervention affecting the arm (i.e. more than 50%). In Table 2, we have compiled the characteristics of resistive strength training that are relevant to this review and have provided examples of interventions.

***Other arm interventions***

These interventions may include mobilisation, stretching, therapeutic positioning, robot-assisted therapy, virtual reality training, movement therapy, functional training, task-specific training, physical therapy interventions related to activities of daily living, or electrostimulation. Control conditions may also include activities through which an increase in strength could be achieved. We will use a sensitivity analysis to assess the impact of these studies on the outcome measures.

### Types of outcome measures

Assessments of the outcomes listed below will occur at the end of intervention (end of a training period) and/or the end of follow-up, which we define as any period of time after the training intervention was completed. We expect that the RCTs will use different instruments to evaluate the outcome measures of interest. We will extract data if the trials report the outcome using the scales listed below, or if they report the data using a comparable rating scale. We list below those measures that have been rated most important in the international consensus recommendations for the selection of outcome measures in trials of arm rehabilitation after stroke (Duncan Millar 2021).

According to the International Classification of Functioning, Disability and Health (ICF) (WHO 2001), our primary outcome measure 'strength' refers to 'functions' associated with the power of arm-hand muscles whilst the other primary outcome measure 'arm-hand movements' refers to voluntary movements such as reach-to-grasp, grip, or pinch. The secondary outcome measure 'activities of daily living' refers to 'self-care', by which tasks in the context of life situations are meant (e.g. feeding, dressing, bathing, toileting, and transfers).

***Primary outcomes***

- Strength: measured by isokinetic and hand-held dynamometry (Bertrand 2007; Stark 2011); the Medical Research Council (MRC) Scale for Muscle Strength (Medical Research Council 1943); Motricity Index (arm section) (Collin 1990); and the One-Repetition Maximum Test (Seo 2012)
- Arm and hand movements: measured by the arm section of the Fugl-Meyer Assessment of Sensorimotor Recovery after Stroke (FMA-UL; Fugl-Meyer 1975); Wolf Motor Function Test (WMFT; Wolf 2001); Action Research Arm Test (ARAT; Lyle 1981); Box and Block Test (BBT; Desrosiers 1994; Mathiowetz 1985); Motor Activity Log (MAL; Uswatte 2006); and Nine-Hole Peg Test (NHPT; Kellor 1971)

***Secondary outcomes***

- Activities of daily living: measured by the Barthel Index (BI; Mahoney 1965); or modified Barthel Index (mBI; Collin 1988)
- Quality of life: measured by EuroQoL (EQ-5D; Balestroni 2012); and SF-36 Health Survey (Bullinger 1995)
- Reporting of death
- Changes in blood pressure (systolic, diastolic, and mean arterial pressure)
- Reporting of adverse events: pain, muscular and tendon injuries, and changes in muscle tone, measured by the Ashworth Scale (Ashworth 1964), or Modified Ashworth Scale (Bohannon 1987)
- Compliance to study protocol: can be judged by attendance at training sessions and by compliance with exercise instructions during training sessions

## Search methods for identification of studies

See the methods for Cochrane Stroke's 'Specialised register'. We will search for trials in all languages and arrange for the translation of relevant articles where necessary.

### Electronic searches

We will search Cochrane Stroke's trials register and the following electronic databases.

- Cochrane Central Register of Controlled Trials (CENTRAL, Cochrane Library, latest issue) in the Cochrane Library.
- MEDLINE Ovid (from 1946, Appendix 1).
- Embase Ovid (from 1974).
- CINAHL EBSCO (Cumulative Index to Nursing and Allied Health Literature, from 1982).
- SPORTDiscus EBSCO (from 1892).
- ProQuest Dissertation and Theses Global.
- Physiotherapy Evidence Database (PEDro, from 1900).

The subject strategies for databases will be modelled on the search strategy designed for MEDLINE (Appendix 1) by Cochrane Stroke's Information Specialist. The stroke and intervention subject searches have been linked to the 'Cochrane Highly Sensitive Search Strategy' for identifying randomised trials in MEDLINE: sensitivity- and precision-maximising version (2008 revision) (lines 23-30), as referenced in the *Cochrane Handbook for Systematic Reviews of Interventions* (Lefebvre 2021).

### Searching other resources

We will search the following ongoing trials registers.

- US National Institutes of Health Ongoing Trials Register, ClinicalTrials.gov (www.clinicaltrials.gov/).
- World Health Organization (WHO) International Clinical Trials Registry Platform (www.who.int/clinical-trials-registry-platform).

In an effort to identify further published, unpublished and ongoing trials, we will do the following.

- Check the bibliographies of included studies and any relevant systematic reviews identified for further references to relevant trials, and use Google Scholar (https://scholar.google.co.uk/) to forward-track relevant references.
- Contact study authors for clarification and further data if trial reports are unclear, or to obtain additional information on relevant trials.

## Data collection and analysis

### Selection of studies

Two review authors (SH, JM) will independently screen titles and abstracts of the references obtained as a result of our searching activities, and will exclude obviously irrelevant reports. We will retrieve the full-text articles for the remaining references and two review authors (SH, JM) will independently screen the full-text

articles and identify studies for inclusion. They will also identify and record the reasons for excluding the ineligible studies. We will resolve any disagreements through discussion or, if required, we will consult a third review author (BE). We will collate multiple reports of the same study so that each study, not each reference, is the unit of interest in the review. We will record the selection process and complete a PRISMA flow diagram. We will use Covidence for text screening and de-duplication of the citations (Covidence).

### Data extraction and management

Two review authors (SH, JM) will independently extract data from included studies using an extraction form. We will use Covidence for data extraction (Covidence). We will extract data for our primary and secondary outcomes, details of methods and information relating to methodological quality, as well as the following.

- Participants: number, age (mean, standard deviation (SD)), sex, stroke type, time after stroke at the start of the intervention (mean, SD), first or recurrent stroke, stroke severity at baseline (by means of the National Institutes of Health Stroke Scale (NIHSS) or comparable scale), arm activities at baseline (according to Fugl-Meyer Assessment of the Upper Extremity scores: severe = 0 to 27, moderate = 28 to 41, and mild = 42 to 60 impairments; Woytowicz 2017), comorbidity at baseline, differences in groups at baseline.
- Interventions: brief description of activity or exercise type, training frequency, training duration, number of sets and repetitions, training intensity, progression, programme duration, supervised or self-lead, evidence of compliance and adherence (adherence to training protocol; compliance or non-compliance with the training parameters), description of usual care.
- Setting: inpatient or outpatient.
- Outcome data: assessments applied, time points at which assessments are recorded, number of participants, mean and SD or standard error (SE) for continuous variables.

We will record whether studies are multicentre and collect information on their geographical location and setting. We will use the mean time since stroke plus the intervention period to classify trials according to the following post-stroke phases (Bernhardt 2017). The mean time post stroke and the period of intervention must be within one of the phases listed below if we are to consider the study for analysis by phase after stroke.

- Acute: from within the first 24 hours up to seven days.
- Subacute: from more than seven days up to six months.
- Chronic phase: more than six months post-stroke.

To enhance transparency, we will use the Consensus on Exercise Reporting Template (CERT) checklist for each included intervention, to provide details of the experimental therapy (Slade 2016). We will also assess whether the interventions should comply with the ACSM guidelines ('yes', 'possibly yes', 'possibly no', 'no'; ACSM 1998). We will present all outcome data in additional tables for both the intervention and control group.

### Assessment of risk of bias in included studies

Two review authors (DS, FW) will independently assess risk of bias for each study using the criteria outlined in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2011). We will resolve any disagreements by discussion or by involving another review author (SH). We will assess the risk of bias according to the original version of the Cochrane 'Risk of bias' tool for randomised trials, evaluating the following domains.

- Random sequence generation.
- Allocation concealment.
- Blinding of participants and personnel.
- Blinding of outcome assessment.
- Incomplete outcome data.
- Selective outcome reporting.
- Other bias.

For each study, we will judge the risk of bias for each domain to be 'high', 'low', or 'unclear', and provide information from the study report, together with a justification for our judgement, in the 'Risk of bias' tables. Review authors will not evaluate the risk of bias for studies in which they participated as an author.

### Measures of treatment effect

For dichotomous data, we will calculate the individual and pooled statistics and report them as risk ratios (RRs) with 95% confidence intervals (CIs). For continuous outcomes we will calculate pooled mean differences (MDs) with 95% CIs when all studies used the same measurement tool. Where different scales are employed by different studies for the assessment of the same outcome (e.g. arm activities or activities of daily living) we will calculate standardised mean differences (SMDs) with 95% CIs. MDs provide more clinically relevant information, so we will conduct a separate analysis to combine data for any outcomes where more than six trials used the same specific outcome measure, and display results as MD with 95% CIs.

To ensure that meta-analysis is clinically meaningful, we will only combine trials when participants, interventions, and outcomes are judged to be sufficiently similar. Should this not be the case, we will include a narrative summary of trials instead. We will extract or calculate mean change score and SDs from the pre- and post-intervention time point and for the end of the follow-up time point for each available outcome measure. If a study provides the data as median and interquartile range, we will convert the data to mean change score and SD (Wan 2014). We will use adjusted data for baseline imbalances as available by data provided by the authors.

### Unit of analysis issues

We will give special attention to the design of cross-over studies, repeated measures on the same participants, or multiple intervention groups. For cross-over studies, we will extract only results from the first randomisation phase. When repeated measures are reported, we will define several outcomes based on different periods of follow-up and will analyse these separately. If trials include multiple interventions, we will only include the results if the trial presents data of the different interventions that are relevant to this review separately. In a multi-armed trial, the comparison with an active intervention will be preferred over a comparison group with no intervention or passive intervention, and will be considered the principle intervention arm. To avoid 'double counts', we will not include a study with multiple interventions in the same forest plot. If both interventions are relevant, we will pool the groups by combining the means and SDs

to create a single pair-wise comparison, as recommended in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2021).

### Dealing with missing data

Where the article does not contain sufficient information, we will contact the study authors to complete the quality assessment, to verify key study characteristics, and to obtain missing numerical outcome data.

### Assessment of heterogeneity

We will calculate the $I^2$ statistic to measure statistical heterogeneity among the trials in each analysis (Higgins 2021). We will use a random-effects model, regardless of the level of heterogeneity. We will investigate statistical heterogeneity by creating subgroups and undertaking sensitivity analyses. Additionally, we will look for extreme outliers in our forest plots to see if there was something different about the trials with markedly different results from the others.

### Assessment of reporting biases

We will avoid reporting bias primarily by using an extensive search strategy of databases and handsearching of reference lists. Furthermore, we will evaluate reporting bias for the outcome measures where we include more than ten trials by visual inspection of funnel plots. In case doubt remains, and if more than 10 trials are included in a meta-analysis, we will conduct Eggers' Regression Test for funnel plot asymmetry (P value less than 0.05) (Sterne 2005).

### Data synthesis

We will pool the results of all eligible studies to present an overall estimate of the effect of strength training on all outcome measures and according to phase after stroke, where possible. We will split the meta-analyses for each outcome. A first analysis will include studies investigating the effect of (additional) experimental training versus no control training. A second analysis will investigate the effect of (additional) experimental training versus (additional) control training. We will perform statistical analyses within Cochrane's Review Manager software (RevMan Web). We will apply random-effects models for continuous and dichotomous data.

### Subgroup analysis and investigation of heterogeneity

To explore heterogeneity, we will conduct the following two subgroup analyses for the primary outcomes. We will use the test for subgroup differences to evaluate whether the two subgroups differ (P value less than 0.05). We will only consider a subgroup analysis if we include at least six studies for continuous data and four for categorical data (Fu 2011).

- Different phases after stroke: we will group outcomes according to the phases indicated earlier in the protocol.
- Different interventions after stroke: we will assess the influence of different intervention types (hand training only, arm training only, hand and arm training) on outcomes.

### Sensitivity analysis

We will perform a sensitivity analysis for risk of bias for the primary outcomes, to assess the robustness of our results. We will exclude all trials with a high risk of bias in one or more of these domains: random sequence generation, allocation concealment, blinding of participants, blinding of outcome assessment, incomplete outcome data, and selective outcome reporting.

We will assess the impact of including interventions that may meet ACSM criteria (as described in Data extraction and management, e.g. training without progression) by performing a sensitivity analysis excluding studies that do not meet the criteria.

### Summary of findings and assessment of the certainty of the evidence

We will create four 'Summary of findings' tables comparing resistive strength training after stroke versus no control intervention, and versus any other intervention, at the end of the training period and at the end of follow-up. The 'Summary of findings' tables will include the following outcomes: strength, arm and hand movements, activities of daily living, and adverse events (for an example, see Table 3). We will use the five GRADE considerations (study limitations, consistency of effect, imprecision, indirectness, and publication bias) to assess the certainty of evidence as it relates to the studies that contribute data to the meta-analyses for the prespecified outcomes (Atkins 2004). We will use methods and recommendations described in the *Cochrane Handbook for Systematic Reviews of Interventions* (Higgins 2021), and GRADEpro GDT software, to create the tables. We will justify all decisions to downgrade the quality of studies using footnotes, and we will make comments to aid the reader's understanding of the review where necessary.

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## ADDITIONAL TABLES

**Table 1. Overview of published reviews on strength training**

| Review | Morris 2004 | Ada 2006 | Harris 2010 | Hammami 2012 | Salter 2016 | Dorsch 2018 | Saunders 2020 | Veldema 2020 |
|---|---|---|---|---|---|---|---|---|
| **Aim** | To examine the effects of strength training on impairments, activity and participation after stroke | To examine the effects and safety of strength training after stroke | To examine the effects of arm strength training on strength, arm function, and activities of daily living after stroke. | To examine the effects of isokinetic arm strength training in people with hemiparesis | To examine the effects and safety of strength training on activity in people within the first 3 months after stroke | To examine the effects of strength training on strength and activity after stroke | To examine the effects and safety of fitness training on death, death or dependence, and disability after stroke | To examine the effects of strength training on recovery after stroke |
| **Experimental group** | Strength training | Strength training; electrical stimulation; biofeedback; muscle re-education; mental practice | Arm strength training; mixed interventions (arm strength training with an additional intervention and combined leg and arm strength training) | Strength training | Strength training | Strength training | Cardiorespiratory training; strength training; mixed interventions | Strength training |
| **Control group** | Other intervention | Other intervention; sham intervention; no intervention | Other intervention | Not applicable | Other intervention; no intervention | Other intervention; sham intervention; no intervention | Other intervention; sham intervention; no intervention | Other intervention |
| **Study design (studies investigating arm strength training)** | RCT<br>Single group pre–post trial<br>(2 studies, 52 participants) | RCT<br>Quasi-RCT<br>(13 studies, 430 participants) | RCT<br>(13 studies, unknown number participants) | Case report<br>Open study<br>(2 studies, 21 participants) | RCT<br>(2 studies, 90 participants) | RCT<br>(2 studies, 47 participants) | Strength training: RCT<br>(4 studies, 131 participants)<br>Mixed training: RCT<br>(13 studies, 516 participants) | RCT<br>(6 studies, 385 participants) |
| **Evaluation of quality of evidence** | PEDro scale | PEDro scale | PEDro scale | No | Downs And Black Checklist | PEDro scale | GRADE | PEDro scale |
| **Performed meta-analysis for** | No | No | Yes | No | Yes | No | No | Yes |

**Table 1. Overview of published reviews on strength training** *(Continued)*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **upper limb outcome** | | | | | | | | |
| **Last search date** | 2002 | January 2005 | April 2009 | Unknown | August 2014 | August 2016 | July 2018 | April 2020 |

RCT: randomised controlled trial

**Table 2. Characteristics and examples of strength training for this review**

| | |
|---|---|
| **Repetition** | • A minimum of one set of 8 to 12 repetitions for healthy individuals or 10 to 15 repetitions for older and more frail people<br>• 2 to 3 days per week |
| **Resistance by** | • Free-weights<br>• Weight machines<br>• Bodyweight<br>• Elastic devices<br>• Masses<br>• Isokinetic devices<br>• Robotic devices<br>• Everyday objects of different weights |
| **Progression** | • Of the weight load<br>• Of the repetitions<br>• By shortening the rest period between exercises and sets<br>• By increasing the number of sets completed |
| **Muscle contractions** | • Concentric<br>• Eccentric<br>• iIometric |
| **Range of motion** | • Full range of motion |
| **Intensity** | • High intensity (that the muscle is close to fatigue at the end of a set) |
| **Examples for strength training** | • Weight training<br>• Machine-guided training<br>• Kettlebell training<br>• High Intensity (Interval) Training (HIT or HIIT)<br>• Functional strength training<br>• Functional or task-related training against resistance |
| **Examples for interventions that aim to increase strength but do not meet the ACSM criteria for strength training** | • Electrical stimulation<br>• Biofeedback<br>• Mental practice<br>• Assisted movements (by machines, robots or therapists) |
| **Examples for interventions that may meet the ACSM criteria for strength training, depending on the therapeutic goal and the training methodology** | • Functional training<br>• Bilateral arm training<br>• Repetitive task training<br>• Task-specific training<br>• Virtual reality training |

ACSM: American College of Sports Medicine

**Table 3. Template for 'Summary of findings' table**

| |
|---|
| **Strength training compared to control intervention for people after stroke** |
| **Patient or population**: people after stroke |

**Table 3. Template for 'Summary of findings' table** *(Continued)*

**Setting**: hospital, clinic, inpatient rehabilitation centre, outpatient

**Intervention**: all types of strength training

**Comparison**: other arm interventions

| Outcome | Anticipated absolute effects (95% CI)* | | Relative effect (95% CI)* | Number of participants (studies) | Certainty of the evidence (GRADE) | Comments |
|---|---|---|---|---|---|---|
| | Risk with control intervention | Risk with strength training | | | | |
| Strength | | | | | | |
| Arm and hand movements | | | | | | |
| Activities of daily living | | | | | | |
| Adverse events | | | | | | |

*__The risk in the intervention group__ (and its 95% CI) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).

**CI:** confidence interval

**GRADE Working Group grades of evidence**
**High certainty:** We are very confident that the true effect lies close to that of the estimate of the effect
**Moderate certainty:** We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
**Low certainty:** Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect
**Very low certainty:** We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

## APPENDICES

### Appendix 1. MEDLINE search strategy

1. cerebrovascular disorders/ or exp basal ganglia cerebrovascular disease/ or brain ischemia/ or exp brain infarction/ or ischemic attack, transient/ or vertebrobasilar insufficiency/ or exp carotid artery diseases/ or cerebral small vessel diseases/ or cerebral amyloid angiopathy, familial/ or stroke, lacunar/ or cerebrovascular trauma/ or vertebral artery dissection/ or intracranial arterial diseases/ or cerebral arterial diseases/ or cerebral amyloid angiopathy/ or infarction, anterior cerebral artery/ or infarction, middle cerebral artery/ or infarction, posterior cerebral artery/ or moyamoya disease/ or intracranial aneurysm/ or intracranial arteriosclerosis/ or exp intracranial arteriovenous malformations/ or exp "intracranial embolism and thrombosis"/ or intracranial hemorrhages/ or exp cerebral hemorrhage/ or intracranial hemorrhage, hypertensive/ or exp subarachnoid hemorrhage/ or stroke/ or vasospasm, intracranial/
2. stroke rehabilitation/
3. (stroke or poststroke or post-stroke or cerebrovasc$ or (cerebr$ adj3 vasc$) or CVA$ or apoplectic or apoplex$ or (transient adj3 isch?emic adj3 attack) or tia$ or SAH or AVM or (cerebral small vessel adj3 disease)).tw.
4. ((cerebr$ or cerebell$ or arteriovenous or vertebrobasil$ or interhemispheric or hemispher$ or intracran$ or intracerebral or infratentorial or supratentorial or MCA$ or ((anterior or posterior) adj3 circulat$) or lenticulostriate or ((basilar or brachial or vertebr$) adj3 arter$)) adj3 (disease or damage$ or disorder$ or disturbance or dissection or lesion or syndrome or arrest or accident or lesion or vasculopathy or insult or attack or injury or insufficiency or malformation or obstruct$ or anomal$)).tw.
5. ((cerebr$ or cerebell$ or vertebrobasil$ or interhemispheric or hemispher$ or intracran$ or corpus callosum or intracerebral or intracortical or intraventricular or periventricular or posterior fossa or infratentorial or supratentorial or MCA$ or ((anterior or posterior) adj3 circulation) or basal ganglia or ((basilar or brachial or vertebr$) adj3 arter$) or space-occupying or brain ventricle$ or subarachnoid$

or arachnoid$) adj3 (h?emorrhage or h?ematoma or bleed$ or microh?emorrhage or microbleed or (encephalorrhagia or hematencephal $))).tw.
6. ((cerebr$ or cerebell$ or arteriovenous or vertebrobasil$ or interhemispheric or hemispher$ or intracran$ or corpus callosum or intracerebral or intracortical or intraventricular or periventricular or posterior fossa or infratentorial or supratentorial or MCA$ or ((anterior or posterior) adj3 circulation) or basal ganglia or ((basilar or brachial or vertebr$) adj3 arter$) or space-occupying or brain ventricle$ or lacunar or cortical or ocular) adj3 (isch?emi$ or infarct$ or thrombo$ or emboli$ or occlus$ or hypoxi$ or vasospasm or obstruct$ or vasculopathy or vasoconstrict$)).tw.
7. ((carotid or cerebr$ or cerebell$ or intracranial or basilar or brachial or vertebr$) adj3 (aneurysm or malformation$ or dysplasia or disease or bruit or injur$ or obstruct$ or occlusion or constriction or presclerosis or scleros$ or stenos$ or atherosclero$ or arteriosclero$ or plaque $ or thrombo$ or embol$ or arteriopathy)).tw.
8. hemiplegia/ or paresis/ or exp gait disorders, neurologic/
9. (hemipleg$ or hemipar$ or paresis or paraparesis or paretic).tw.
10. or/1-9
11. exercise therapy/ or endurance training/ or muscle stretching exercises/ or plyometric exercise/ or resistance training/ or exp physical conditioning, human/
12. (((resistance or strength$ or fitness or circuit or circuit-based or high intensity or high-intensity or intermittent or interval or ballistic or power or endurance or compound or isolation or submaximal) adj3 (train$ or intervention$ or protocol$ or program$ or therap$ or activit $ or exercise$ or workout$)) or HIT or HIIT or HIIE).tw.
13. (((anaerobic or bodyweight or plyometric$) adj3 (train$ or intervention$ or protocol$ or program$ or therap$ or activit$ or exercise$ or workout$)) or powerlift$ or calisthenic$ or weightlift$ or (weight$ adj3 (train$ or lift$))).tw.
14. ((isometric or isotonic or eccentric or concentric) adj3 (contraction$ or exercise$ or action$)).tw.
15. (dumbbell$ or barbell$ or kettlebell$ or (Indian adj2 club$) or battle ropes or (weighted adj2 cloth$) or ((elastic$ or resistance) adj2 (cord$ or rope$ or band$))).tw.
16. ((weight$ or exercise or Smith or cable$) adj3 (equipment or machine$)).tw.
17. (squat$ or deadlift$ or push-up or pulldown or chest fly or pull-up or chin-up or ((bent$ or upright) adj2 row$) or ((push or bench or shoulder or military or overhead) adj2 press$) or (lateral adj2 raise$) or (tricep$ adj2 extension$) or ((bicep$ or hammer) adj2 curl$) or power cleans or "clean and jerk" or plank$).tw.
18. (progressive overload or one rep max or forced reps or heavy loading or repetitions or ((muscle or muscular) adj3 failure) or "stress recovery adaptation cycle" or "SRA cycle" or supercompensation or "dynamic effort" or "maximum effort" or "accommodating resistance" or "contractile force" or ((relative or general or speed or starting or submaximal or grip or hand or leg) adj3 strength) or "rate of perceived exertion" or "reps in reserve").tw.
19. or/11-18
20. exp upper extremity/
21. ((upper adj3 (limb$ or extremit$)) or arm or arms or shoulder$ or hand$ or elbow$ or forearm$ or finger$ or wrist$).tw.
22. 20 or 21
23. randomized controlled trial.pt.
24. controlled clinical trial.pt.
25. randomized.ab.
26. placebo.ab.
27. randomly.ab.
28. trial.ti.
29. groups.ab.
30. or/23-29
31. 10 and 19 and 22 and 30

## CONTRIBUTIONS OF AUTHORS

SH wrote the protocol and designed the search strategies.
BE wrote the protocol and designed the search strategies.
DS wrote the protocol.
FW wrote the protocol.
JM wrote the protocol and designed the search strategies.

## DECLARATIONS OF INTEREST

SH: none known.
BE: none known.
DS: none known.
JM: none known.
FW: see below.

- Grants and contracts: external funding for a research project on physical activity for non-ambulatory stroke survivors (Chief Scientist Office, Scotland). This study did not focus on upper limb strength as such, but it included an outcome that measured upper limb force.

- Royalties or licences: co-editor and author of a book on exercise and fitness training after stroke (Churchill Livingstone Elsevier); royalties.
- Payments for a fellowship: PhD studentship for a research project on physical activity for non-ambulatory stroke survivors (Glasgow Caledonian University). This PhD did not focus on upper limb strength as such, but it included an outcome that measured upper limb force.
- Published opinions: authored an opinion piece on physical activity after stroke in peer-reviewed scientific journal (*International Journal of Stroke*). This article did not focus on upper limb strength as such, but discussed general physical activity (which includes strength training). Reference: van Wijck F , Bernhardt J, Billinger SA, Bird M-L, Eng J, English C, Fuscaldi Teixeira-Salmela L, MacKay-Lyons M, Melifonwu R, Sunnerhagen KS, Solomon JM, Thilarajah S, Mead GE. Improving life after stroke needs global efforts to implement evidence-based physical activity pathways. International Journal of Stroke 2019 (14):5;457-459. [Available online] DOI: 10.1177/1747493019840930.
- Affiliation to an organisation that has a declared opinion or position on the topic: co-authored online educational content for third sector organisation, Chest Heart Stroke Scotland, on keeping active. This resource did not focus on upper limb strength as such, but discussed general physical activity (which includes strength training). See: Self Help 4 Stroke
- Involvement in eligible studies: Chief Scientist Office, Scotland (declared above). This was a research project on physical activity for non-ambulatory stroke survivors, which included a PhD student funded by Glasgow Caledonian University. This study did not focus on upper limb strength as such, but included outcomes that measured upper limb strength.

## SOURCES OF SUPPORT

### Internal sources

- No sources of support provided

### External sources

- No sources of support provided