Strength Training Improves Upper-Limb Function in Individuals With Stroke

A Meta-Analysis

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***Background and Purpose*—**After stroke, maximal voluntary force is reduced in the arm and hand muscles, and upper-limb strength training is 1 intervention with the potential to improve function.

***Methods*—**We performed a meta-analysis of randomized controlled trials. Electronic databases were searched from 1950 through April 2009. Strength training articles were assessed according to outcomes: strength, upper-limb function, and activities of daily living. The standardized mean difference (SMD) was calculated to estimate the pooled effect size with random-effect models.

***Results*—**From the 650 trials identified, 13 were included in this review, totaling 517 individuals. A positive outcome for strength training was found for grip strength (SMD=0.95, P=0.04) and upper-limb function (SMD=0.21, P=0.03). No treatment effect was found for strength training on measures of activities of daily living. A significant effect for strength training on upper-limb function was found for studies including subjects with moderate (SMD=0.45, P=0.03) and mild (SMD=0.26, P=0.01) upper-limb motor impairment. No trials reported adverse effects.

***Conclusions*—**There is evidence that strength training can improve upper-limb strength and function without increasing tone or pain in individuals with stroke. **(*Stroke*. 2010;41:136-140.)**

Key Words: strength ■ rehabilitation ■ arm ■ systematic review

Upper-limb weakness after stroke is prevalent in acute and chronic stages of recovery, with up to 40% never regaining functional use of the upper limb in daily activities.[1] After stroke, maximal voluntary force is reduced, reorganization of the central nervous system takes place, and peripheral muscle changes occur (eg, muscle weakness).[2] Studies have shown that sufficient strength in the upper limb is related to the ability to adequately perform many activities of daily living (ADLs).[3,4] In addition, Pang and Eng[5] found that strength of the paretic upper limb was a determinant of upper-limb bone mineral content. A recent review of upper-limb strength training in stroke[6] found no adverse effects of strength training. Despite this knowledge, there is still controversy surrounding strength training in stroke, as prominent neurologic rehabilitation frameworks hold the view that strengthening the paretic upper limb will increase tone and pain, particularly in the shoulder region.[7]

There have been 6 reviews that reported the effect of upper-limb strength training on upper-limb strength, function, and ADLs.[4,6,8–11] Four of these studies were systematic reviews wherein a search strategy and method of study evaluation were transparent,[4,6,10,11] whereas the remaining 2 provided a synthesis of the literature on strength training in stroke.[8,9] Of the 6 reviews, 4 reported evidence that upper-limb strength training improved strength and upper-limb function.[4,6,8,9] Two studies[10,11] found no effect of upper-limb strength training; these reviews included only a few studies of upper-limb strengthening. No review found a significant treatment effect for ADLs.

However, there are issues with the previous reviews. Morris et al[10] calculated the effect size of 2 upper-limb trials[12,13] and reported a positive effect of strength training on upper-limb muscle strength and function; however, this was in contrast to Van Peppen et al,[11] who reported on the same 2 trials and concluded that there was no evidence for improved strength and dexterity. Ada et al[6] calculated a pooled-effect size from strength trials and found a small but positive effect on strength and functional measures. However, interpretation of their findings is uncertain because pooled estimates combined trials focused on upper- and/or lower-limb function (eg, gait speed, hand use), as well as different modalities (eg, resistance training, robotics, electric stimulation).

Our primary study objective was to examine the evidence for strength training of the paretic upper limb in improving strength, upper-limb function, and ADLs. A secondary objective was to examine the effect of duration of injury (subacute and chronic) and motor severity (moderate and

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mild) on upper-limb function. Adverse effects were also explored.

Methodology

An electronic database search was conducted by using the Cochrane Database of Systematic Reviews, MEDLINE (1950 to April 2009), Cumulated Index to Nursing and Allied Health Literature (1982 to April 2009), EMBASE (1980 to April 2009), and Physical Therapy Evidence Database (PEDro). The key word search used the words "cerebrovascular accident," "stroke," or "hemiparesis" paired with "rehabilitation," "exercise," "strength," "activities of daily living," or "upper limb." We limited the search to human subjects, the English language, and studies published in peer-reviewed journals. Hand searches of relevant journals and reference lists from systematic reviews were completed.

Randomized controlled trials that examined the effect or additional effect of a graded strengthening program compared with uni- or multi-dimensional programs were included. One arm of the trial had to include a component of strength/resistance training as an element of the intervention and comparison with a control group. The control group could include no treatment, placebo, or a nonstrengthening intervention. It was necessary that study authors used the term "strength," "resistance," or "exercise" as part of the intervention description. We defined strength training as an intervention that incorporated voluntary, active exercises against resistance. This may have been accomplished by using resistance bands, weights, or gravity-resisted exercises. Exercises could be isometric, isotonic, or isokinetic. Additional inclusion criteria were (1) confirmed diagnosis of stroke by computed tomography, magnetic resonance imaging, or clinical examination; (2) adult patients; (3) evaluation of 1 of the following: upper-limb strength, upper-limb function (eg, Action Research Arm Test), or ADLs; and (4) experimental and comparison group treatments clearly defined (ie, so a distinction could be made between treatment type).

Studies of repetitive practice (with no resistance), constraint-induced movement therapy, robot-assisted therapy, and electrical stimulation were excluded, and the effectiveness of these modalities on upper-limb function has been recently reported.[14–17] We excluded robot-assisted therapy because it utilizes passive range of motion and guided movement (along a set trajectory) as major components of the therapy, in addition to potentially active and resisted movements. Electrical stimulation was excluded because the physiologic effects may be distinct, as it causes a reverse order of motor unit recruitment from voluntary contractions with a selective facilitation of type II muscle fibers.[18,19] Furthermore, there is evidence that electrical stimulation may cause more intracellular disruption compared with voluntary contractions.[20]

Planned subgroup analysis was performed for duration of injury after stroke (subacute $<$6 months vs chronic $>$6 months) and level of upper-limb motor impairment (moderate and mild). Level of upper-limb motor impairment was determined by using impairment outcomes measured at baseline (eg, Fugl-Meyer or grip strength). Participants who had a baseline score of less than half of the maximum impairment score were classified in the moderate group. Those individuals with moderate impairment generally had little hand movement and were capable of gravity-assisted range of motion on commencing the intervention, whereas those with mild impairment had hand movement and were able to move against gravity. Comparison groups were constructed for grip strength, upper-limb function, ADLs, subacute and chronic participants, and moderate and mild motor impairment.

Two reviewers searched and evaluated each study abstract independently on the basis of the inclusion and exclusion criteria. If there was disagreement regarding eligibility, a third reviewer intervened. Quality was evaluated on the PEDro scale (maximum score of 10).[21]

Statistical Analysis

All of the outcome measures used continuous scales. For all studies, we extracted the mean difference and calculated the pooled (control and experimental) standard deviation of the baseline score. The raw score population standard deviation was used in the effect size calculation rather than the change score standard deviation, which can be very small and result in inflation of the effect size.[22,23] When the median and interquartile range were provided, we converted them to the mean and standard deviation according to the method explained by Hozo and colleagues.[24] Tables of comparison were derived for all outcomes of interest as well as Forest and funnel plots (RevMan 5.0 software).

Weighted effect size (standardized mean difference and 95% CIs) were calculated for all comparisons because we pooled summary data from different measures for comparisons of interest. The degree of heterogeneity was evaluated with the I^2 test for each outcome. Nonsignificance indicates that the results of the different studies were similar ($P>0.05$). We evaluated the pooled treatment effect by using random-effect models to reduce the effects of heterogeneity between studies.[25]

Sensitivity analysis was used to determine the robustness of our results. To assess sensitivity, we compared random-effect models with fixed-effect models. In addition, we examined the effect of deleting low-quality studies ($<$5/10 on the PEDro scale) from the analysis. Funnel plots were used to detect possible publication bias. To illustrate the cumulative effect of strength training on outcome measures, Forest plots were constructed.

Results

We identified 650 studies by using our key search terms, and 390 articles progressed to abstract inspection. Details of the article selection and QUORUM diagram are included in the online data supplement, available at http://stroke.ahajournals.org. Of these, 308 articles did not meet our inclusion criteria (eg, did not have strength training or randomization). We retrieved the full text of the remaining 82 articles and of these, 68 trials did not have an upper-extremity strength training component and 1 trial did not include summary data for their relevant outcome measures.

Fourteen trials were identified as meeting our inclusion criteria.[12,13,26–37] The study by Dickstein et al[28] provided percentage of change in upper-limb function but no measure of variance; therefore, this study was excluded from further review. Quality of the included trials ranged from 2[36] to 8[26,30,32,35] on the PEDro scale. Four trials were below a rating of 5.[13,31,33,36] Funnel plots were constructed for upper-limb function comparisons, as these were the only data sets large enough to produce valid plots,[38] and these showed that negative findings were underrepresented in our meta-analysis. The majority of the included studies utilized isotonic exercises with resistance bands and free weights. Only Bourbonnais et al[12] exclusively used isometric exercises, although Butefisch et al[13] described both isotonic and isometric exercises. On average, treatment commenced for 1 hour/d, 2 to 3 days/wk for 4 weeks. However, 4 studies[29,30,34,36] had considerably longer programs of between 10 and 19 weeks. Several studies used an upper-limb program as the control group when investigating a lower-limb training program,[12,26,27,34] whereas others used prescribed outpatient treatment as the control for investigating upper-limb training.[29,30,32,36] Neurodevelopmental treatment techniques were a control group comparison in several studies.[13,31,33,35,37] Individual study details are included in the supplemental Table I, available at http://stroke.ahajournals.org.

Grip Strength

Six studies[13,27,30,32,34,37] recruiting 306 participants were used to produce the random-effect model of grip strength:

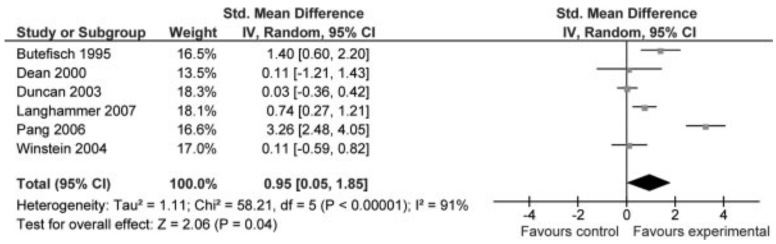

Figure 1. Meta-analysis of upper-limb strength training effect on grip strength (N=306).

SMD=0.95, 95% CI, 0.05 to 1.85, P=0.04, I^2=91% (Figure 1). (For the fixed effect model, SMD=0.67, 95% CI, 0.43 to 0.92, and P<0.001). The study by Bourbonnais et al[12] measured grip; however, appropriate data were not provided to determine effect size.

Upper-Limb Strength

Because only 2 studies[12,33] used strength measures other than grip strength, we report their results descriptively. The study by Logigian et al[33] evaluated a composite manual muscle testing score of the upper-extremity muscles but found no group differences. Bourbonnais et al[12] found significant improvements in shoulder and elbow isometric force over time for the experimental group but did not report or analyze values for the control group.

Upper-Limb Function

Eleven studies recruiting 465 participants were used to produce the random-effect model for upper-limb function.[12,13,26–28,32–37] The article by Logigian et al[33] did not include an upper-limb function test, and Duncan et al[29] provided change scores but no standard deviation. Strength training indicated a significant effect for upper-limb function, with both random- and fixed-effect models producing the same result: SMD=0.21, 95% CI, 0.03 to 0.39, P=0.03, I^2=0% (Figure 2).

Duration of Injury: Subacute and Chronic

The treatment effect for the 8 trials involving 371 participants in the subacute phase of injury was significant for upper-limb function: random-effect model, SMD=0.27, 95%, CI 0.06 to 0.48, P=0.01, I^2=0%. The fixed-effect model produced the same result. The 4 trials involving 169 participants in the chronic phase of injury produced a significant random-effect model: SMD=0.32, 95% CI, 0.02 to 0.63, P=0.04, I^2=0%. The fixed-effect model produced the same result.

Motor Impairment Level: Moderate and Mild

The treatment effect for 5 trials[13,34–37] involving 229 participants with moderate motor impairment was significant: random-effect model, SMD=0.45, 95% CI, 0.05 to 0.84, P=0.03, I^2=53% (fixed-effect model: SMD=0.49, 95% CI, 0.22 to 0.76, P<0.001). Six trials[12,26,27,30–32] including 236 participants produced a significant random-effect model for those with mild motor impairment: SMD=0.26, 95% CI, 0.08 to 0.61, P=0.01, I^2=33%. The fixed-effect model was also significant: SMD=0.20, 95% CI, 0.06 to 0.46, P=0.02.

Activities of Daily Living

Five studies [29,31–33,37] recruiting 210 participants were used to produce the random-effect model for ADLs (Figure 3). All trials involved individuals in the subacute stage of recovery. No treatment effect was found for strength training from either the fixed- or random-effect models: random-effect model: SMD=0.26, 95% CI, −0.10 to 0.63, P=0.16, I^2=39%; fixed-effect model: SMD=0.27, 95% CI, −0.01 to 0.54, P=0.06.

Adverse Effects

Six of the 13 studies reported on adverse effects, and none were found. Of the studies that measured tone at baseline,[12,13,35] none reported an increase in tone over the course of treatment, although all reported a low level of tone at baseline (mean of 1.0 on the Modified Ashworth Scale). Butefisch et al[13] reported a decrease in tone for isometric and isotonic strength training compared with NDT techniques. Several studies reported on pain[32,34,35,37] and found no significant increase in pain for the strength training group. Additionally, Platz et al[35] found that pain increased significantly in the Bobath group compared with impairment-oriented training (BASIS), which utilizes isotonic, graded resistance training. Two studies reported on satisfaction with treatment[27,34] and found high ratings for the upper-limb strength program.

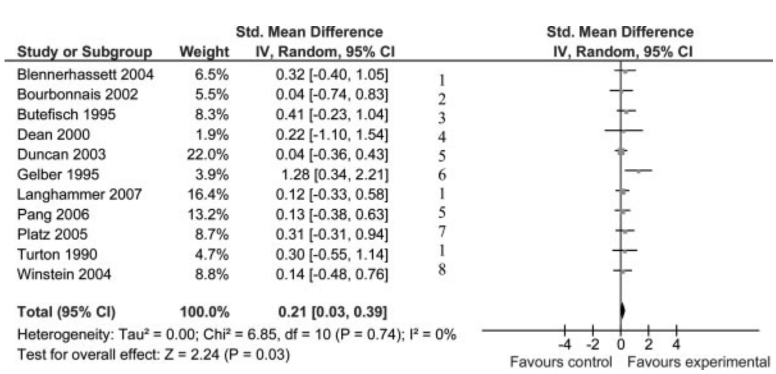

Figure 2. Meta-analysis of upper-limb strength training effect on upper-limb function (N=465). Assessment measures are as follows: 1 indicates Motor Assessment Scale; 2, TEMPA; 3, Rivermead Motor Assessment; 4, Purdue Peg Board; 5, Wolf Motor Function Test; 6, Box and Block; 7, Action Research Arm Test; and 8, Functional Test of the Hemiparetic Upper Extremity.

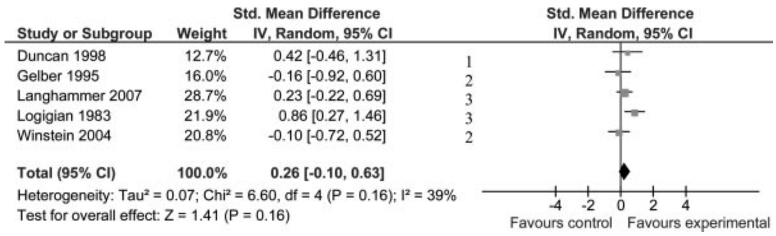

Figure 3. Meta-analysis of upper-limb strength training effect on ADLs (N=210). Assessment measures are as follows: 1 indicates SF-36 Physical Function Subscale; 2, Functional Independence Measure; and 3, Barthel Index.

Sensitivity Analysis

We conducted a sensitivity analysis by using fixed-effect models and by deleting low-quality studies as indicated by a score of <5 on the PEDro scale. Fixed-effect models showed no difference in the significance of the treatment effect for any of our planned comparisons. When we removed the studies with a PEDro score of <5, no difference in the significance of the treatment effect was found for any of our comparisons. These results support the robustness of our findings.

Discussion

Effect of Strength Training on Grip Strength and Upper-Limb Function

We demonstrated a large effect size (SMD=0.95) for strength training on grip strength. Most of the control group treatment in this comparison used methods that were comparable to no upper-limb treatment (eg, lower-limb exercises), passive treatment (eg, transcutaneous electrical nerve stimulation), or standard of care treatment. Comparisons of strength training with other specific upper-limb treatment methods (constraint-induced therapy) and strength training may reveal alternative results. Given that grip strength has been shown to be a predictor of disability and mortality in older adults,[39] remediation of low grip strength by strength training should be an important aspect of treatment for individuals with stroke.

The pooled estimates for upper-extremity function included a large number of participants (n=465), with the majority of included studies representing moderate- to high-quality randomized, controlled trials. Three studies[31,33,35] compared strength training with Bobath treatment for the upper limb. The comparison group for the remaining studies was equivalent to standard of care or minimal upper-limb treatment (eg, lower-limb treatment). Further clarification regarding the treatment effect of strengthening in contrast to specific upper-limb treatment methods needs to be examined.

The magnitude of the effect size was higher for those with moderate (SMD=0.45) compared with mild (SMD=0.26) impairment, which may indicate that strength training for those with moderate impairment may be an important component of upper-limb treatment for this group of individuals. Alternatively, it may suggest that those with mild impairment may require treatment that is focused on the training and integration of complex upper-limb skills, such as fine motor, coordination, and accuracy skills. Regardless, our findings support the effectiveness of strength training for all levels of upper-limb motor impairment. Stage of recovery showed a significant treatment effect on upper-limb function for individuals in the subacute and chronic stages of injury duration. However, the chronic subgroup analysis should be viewed with caution owing to the possibility of a type II error arising from the small number of trials (n=5).

Effect of Strength Training on ADLs

One of the main tenets of treatment outcome in rehabilitation is to promote independence in ADLs. Despite this, only 5[29,31–33,37] of the 13 studies included an ADL outcome. Results of the pooled estimates showed that strength training was not effective in improving ADLs. Daily activities are composed of complex movements that include strength, range of motion, and coordination; therefore, it may be that practice of all components is required for improvement. Additionally, compensatory techniques and use of the nonparetic upper limb may be preferred to complete ADLs; thus, strengthening of the paretic upper limb would not translate into improved ADL performance. Many of the control group comparisons incorporated a component of ADL training, whereas the strengthening groups were not especially exposed to ADL training. Task-specific strength training (eg, wrist weights during ADL tasks) may be an ideal combination of treatments.

In the studies reviewed, there was a lack of description of the progression of the strengthening program (eg, intensity, duration) as recommended by the American College of Sports Medicine.[40] The investigation of Bourbonnais et al[12] was the only study that provided a detailed description of the progression of voluntary effort required during the program. Other studies only provided a brief description of the type of resistance provided (eg, against gravity or free weights) and the number of repetitions and sets completed.[13,34,37] Future studies investigating strength training after stroke should include an appropriate muscle strength prescription to optimize the program.

Limitations

We included studies in our review that described resistance training as a component of upper-limb treatment after stroke. Seven studies[12,13,32–35,37] indicated that strength training was a significant focus of the intervention, with minimal additional modalities (eg, functional activities). The remaining studies described strength training as a component but also included task-focused and ADL practice as part of the intervention. In those latter studies, it is difficult to determine which component or combination of components produced the significant treatment effect.

Conclusions

The findings from this meta-analysis provide evidence that strength training can improve function without increasing tone or pain in individuals with stroke. We recommend that future trials investigate the intensity, frequency, and specificity of strength training required for improved performance in daily activities.

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Disclosures

None.

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