Strength Training Improves Upper-Limb Function in Individuals With Stroke
A Meta-Analysis

Jocelyn E. Harris, PhD, OT; Janice J. Eng, PhD, BSc (PT/OT)

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;41:00-00.)

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. After stroke, maximal voluntary force is reduced, reorganization of the central nervous system takes place, and peripheral muscle changes occur (eg, muscle weakness). Studies have shown that sufficient strength in the upper limb is related to the ability to adequately perform many activities of daily living (ADLs). In addition, Pang and Eng 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 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.

There have been 6 reviews that reported the effect of upper-limb strength training on upper-limb strength, function, and ADLs. Four of these studies were systematic reviews wherein a search strategy and method of study evaluation were transparent, whereas the remaining 2 provided a synthesis of the literature on strength training in stroke. Of the 6 reviews, 4 reported evidence that upper-limb strength training improved strength and upper-limb function. Two studies 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 calculated the effect size of 2 upper-limb trials 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, who reported on the same 2 trials and concluded that there was no evidence for improved strength and dexterity. Ada et al 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...
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 unit 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 non-strengthening 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 groups treatments clearly defined (ie, so a distinction could be made between treatment type).

We excluded 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 was disagreed regarding eligibility, a third reviewer intervened. If there was disagreement 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 I² 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 al28 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 236 to 5/10 on the PEDro scale. Four trials were below a rating of 5.13,33,36 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 al12 exclusively used isometric exercises, although Butefisch et al13 described both isotonic and isometric exercises. On average, treatment commenced for 1 hour/d, 2 to 3 days/wk for 4 weeks. However, 4 studies29,30,34,36 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 data, available at http://stroke.ahajournals.org.

Grip Strength

Six studies13,27,30,32,34,37 recruiting 306 participants were used to produce the random-effect model of grip strength:
SMD = 0.95, 95% CI, 0.05 to 1.85, P = 0.04, I² = 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 measured grip; however, appropriate data were not provided to determine effect size.

Upper-Limb Strength
Because only 2 studies used strength measures other than grip strength, we report their results descriptively. The study by Logigian et al evaluated a composite manual muscle testing score of the upper-extremity muscles but found no group differences. Bourbonnais et al 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. The article by Logigian et al did not include an upper-limb function test, and Duncan et al 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, I² = 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, I² = 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, I² = 0%. The fixed-effect model produced the same result.

Motor Impairment Level: Moderate and Mild
The treatment effect for 5 trials 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, I² = 53% (fixed-effect model: SMD = 0.49, 95% CI, 0.22 to 0.76, P < 0.001). Six trials 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, I² = 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 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, I² = 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, 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 reported a decrease in tone for isometric and isotonic strength training compared with NDT techniques. Several studies reported on pain and found no significant increase in pain for the strength training group. Additionally, Platz et al 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 and found high ratings for the upper-limb strength program.
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, 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 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 529,31–33,37 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. The investigation of Bourbonnais et al12 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 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 specific-
ity of strength training required for improved performance in daily activities.

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Disclosures
None.

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Figure I. QUOROM diagram for decision of trials for inclusion in review. RCT indicates randomized controlled trial.
Table I. Characteristics of Included Studies, N=13

<table>
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<tr>
<th>Study</th>
<th>Participants</th>
<th>Treatment Type</th>
<th>Intensity</th>
<th>Outcome</th>
<th>Results</th>
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<tbody>
<tr>
<td>Logigian et al, 1983; (acute, inpatient); PEDro: 3</td>
<td>N=42; mean age, 61.6 y; 7 wk poststroke</td>
<td>Both groups received inpatient rehabilitation in addition to: EXP (n=21); traditional techniques described as muscle reeducation, volitional control of movement, resistive exercises, and weights OR Facilitation (n=21); Rood, Brunnstrom, Bobath</td>
<td>1 h/d of additional allocated group treatment; no duration of programs given</td>
<td>Manual muscle testing, Barthel Index</td>
<td>Significant difference over time for both measures but no group differences</td>
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<tr>
<td>Turton and Fraser, 1990; (acute, community); PEDro: 2</td>
<td>N=22; mean age, 58.5 y; 20 wk poststroke</td>
<td>EXP (n=12): based on motor relearning, described as exercises, OR outpatient therapy if required (n=10)</td>
<td>2–3 ×/d for exercises; 8–11-wk program</td>
<td>Southern Motor Assessment, 10-Hole Peg Test</td>
<td>Significant between-group difference for peg test in favor of home exercise group; no difference for the Southern Motor Assessment</td>
</tr>
<tr>
<td>Gelber et al, 1995; (acute, inpatient); PEDro: 4</td>
<td>N=27; mean age, 71.8 y; 2–4 wk poststroke</td>
<td>Traditional (n=12): functional tasks, range of motion, resistance exercises OR NDT (n=15); Bobath</td>
<td>No length of treatment sessions was given; 4-wk program</td>
<td>Functional Independence Measure, Box and Block Test, 9-Hole Peg Test</td>
<td>No group differences found; significant difference in favor of traditional for Functional Independence Measure milestones compared with NDT group</td>
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<tr>
<td>Butefisch et al, 1995; (acute, inpatient); PEDro: 4</td>
<td>N=27; mean age, 61.5 y; 3–19 wk poststroke</td>
<td>Both groups received EXP protocol and usual treatment; EXP (n=27): grip strength, isometric and isotonic hand extension; Control (n=15): unspecified standardized treatment with TENS</td>
<td>EXP: 2 times/d for 15-minute periods; TENS: 2 ×/d for 15 min for 2 wk, then received EXP treatment</td>
<td>Rivermead Motor Assessment Scale, grip strength, measured at baseline and start and end of training phases</td>
<td>Decreased muscle tone for EXP; significance found for EXP for Rivermead Motor Assessment, grip strength, peak force, and acceleration</td>
</tr>
<tr>
<td>Duncan et al, 1998; (acute, community); PEDro: 7</td>
<td>N=20; mean age, 67.5 y; 9 wk poststroke</td>
<td>EXP (n=10): home-based treatment to improve strength, endurance, and ADL performance of upper limb (lower-limb exercises as well); Control (n=10): outpatient treatment as required</td>
<td>EXP: 1.5 h ×3/wk ×8 wk; supervised, then on their own for 4 wk; Control: visit every 2 wk by research assistant</td>
<td>Fugl-Meyer Motor Impairment Scale for Upper Limb, Barthel Index, SF-36</td>
<td>EXP improved more on Fugl-Meyer and SF-36 physical scales; no group differences on Jepsen or Barthel Index</td>
</tr>
<tr>
<td>Dean et al, 2000; (chronic, community); PEDro: 5</td>
<td>N=12; mean age, 64.3 y; 1.8 y poststroke</td>
<td>EXP (n=6): strengthening and mobility activities for lower limb; Control (n=6): upper-limb strengthening, dexterity, range of motion</td>
<td>Treatment for both groups was 1 h/d, 3 ×/wk ×4 wk</td>
<td>Grip, Purdue Peg Board; after and 2-month follow-up assessment</td>
<td>Upper-limb group did improve more on arm measures; group differences for these measures not reported, as focus was lower-limb outcomes</td>
</tr>
<tr>
<td>Duncan et al, 2003; (acute, community); PEDro: 8</td>
<td>N=100; mean age, 69 y; 11 wk poststroke</td>
<td>EXP (n=50): strength, range of motion, balance, and ADLs (combined lower- and upper-limb activities); Control (n=50); outpatient services if required</td>
<td>EXP: 36, 90-min sessions for 12–14 wk; Control: 54% received home therapy</td>
<td>Fugl-Meyer, Wolf Motor Function Test, Jamar</td>
<td>Significant group differences found for overall effectiveness of program; if a higher baseline on Wolf Motor Function Test, then significant difference at posttreatment for EXP group</td>
</tr>
<tr>
<td>Bourlonnais et al, 2002; (chronic, community); PEDro: 5</td>
<td>N=25; mean age, 46 y; 3 y poststroke</td>
<td>EXP (n=13): used a static dynamometer to elicit force production all shoulder and elbow, 16 combinations of movement; Control (n=12): same program but for lower limb</td>
<td>Both groups had treatment 3×/wk for 6 wk; 6–8 reps at 20%–35% of maximum voluntary effort; progressed to 40%–60% of maximum voluntary effort</td>
<td>Fugl-Meyer, Motor Assessment Scale, TEMPA, Box and Block</td>
<td>Significant improvement at each time period for EXP group on Fugl-Meyer, Box and Block, and finger to nose; significant increase in shoulder and elbow force at 2 and 6 wk for EXP group, but control values or analysis not reported</td>
</tr>
<tr>
<td>Weinstejn et al, 2004; (acute, inpatient); PEDro: 7</td>
<td>N=64; age 35–75 y; 16.1 d poststroke</td>
<td>EXP (n=21): strength training with Thera-band, free weights OR Functional Task (n=22): systematic, repetitive practice with motor learning focus OR Standard Care (n=21); neurofacilitation, electric stimulation, stretching, ADLs</td>
<td>Functional task group was 1 h/d, 5 ×/wk for 4 wk; Strength group: 1 h ×3 ×/wk; other 2 d, exercises with less resistance; focus was speed</td>
<td>Fugl-Meyer, grip, pinch strength, Functional Test of the Hemiplegic Upper Extremity, Functional Independence Measure; tested at 1 and 9 mo</td>
<td>At 4 wk, significant difference for strength and Fugl-Meyer; less severe impairment, significant difference for Fugl-Meyer; strength, and Functional Test of the Hemiplegic Upper Extremity</td>
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<td>Bienerhasset and Dite, 2004; (acute, inpatient); PEDro: 8</td>
<td>N=30; mean age, 55.1 y; 4–7 wk</td>
<td>Both groups received usual care in addition to: EXP (n=15): mobility training; Control (n=15): upper-limb training</td>
<td>1 h/d, 5 ×/wk for 4 wk</td>
<td>Motor Assessment Scale, Jepsen checkers, small and large objects; tested at 4 wk and 6 mo</td>
<td>Significant difference on Jepsen and Motor Assessment Scale arm; treatment effect (d=0.36) found for upper-limb group for Jepsen at 4 wk</td>
</tr>
<tr>
<td>Platu et al, 2003; (acute, inpatient); PEDro: 8</td>
<td>N=62; mean age, 61 y; 4–6 wk poststroke</td>
<td>Usual care in addition to: EXP (n=21): BASIS training using range of motion, resistance, weights, coordinated movement OR Bobath (n=21)</td>
<td>20 additional training sessions 45 min each, ×4 wk</td>
<td>Fugl-Meyer, Action Research Arm Test, Ashworth Scale</td>
<td>Significant group difference found for BASIS on Fugl-Meyer; no increase in tone</td>
</tr>
<tr>
<td>Pang et al, 2006; (chronic, community); PEDro: 7</td>
<td>N=63; mean age, 65.5 y; 5.1 y</td>
<td>EXP (n=30): circuit-based, resistance training with Thera-band, weights, range of motion, functional tasks; Control (n=30); mobility, balance, cardiorespiratory fitness, lower-limb strength</td>
<td>1 h/d, 3 ×/wk for 19 wk</td>
<td>Wolf Motor Function Test, Fugl-Meyer, Motor Activity Log, Jamar</td>
<td>Significant group difference in favor of EXP for Wolf Motor Function Test and Fugl-Meyer</td>
</tr>
<tr>
<td>Study</td>
<td>Participants</td>
<td>Treatment Type</td>
<td>Intensity</td>
<td>Outcome</td>
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<td>Langhammer et al, 2007; (acute to chronic, from inpatient to community); PEDro: 8</td>
<td>N=75; mean age, 74 y; no time since stroke given</td>
<td>At discharge randomized into: Intense Exercise (n=35): high intensity of endurance, strength (weights, pulleys, chair push-ups), and balance training OR Control (n=40): outpatient treatment as needed</td>
<td>Minimum of 80 h of intense rehab for 1 y, usually 2×/wk with a physiotherapist</td>
<td>Motor Assessment Scale, Barthel Index, Jamar; tested at admission, discharge, and 3, 6, and 12 mo</td>
<td>Significant group difference from admission to discharge for Motor Assessment Scale and some Barthel Index in favor of EXP group; significant group difference in favor of EXP from 3–6 mo for grip, from 6–12 mo for Motor Assessment Scale</td>
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</table>

EXP indicates experimental; TENS, transcutaneous electrical nerve stimulation; NDT, neurodevelopmental techniques.
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