Review Article

JER

https://doi.org/10.12965/jer.2448428.214

Journal of Exercise Rehabilitation 2024;20(5):146-157

Effects of muscle strength exercise on muscle mass and muscle strength in patients with stroke: a systematic review and meta-analysis

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This study systematically reviews the effects of muscle strength exercises on muscle mass and strength in stroke patients by analyzing randomized controlled trials. Ten studies, involving a total of 378 stroke patients, were included in the meta-analysis. The standardized mean difference (SMD) and confidence intervals (CIs) were calculated using a random effects model. The results indicated that strength exercises had a medium effect on increasing muscle strength in stroke patients (SMD, 0.6; 95% CI, 0.47–0.72; $I^2 = 51\%$; $P < 0.05$). Specifically, strength exercises were found to be particularly effective in chronic stroke patients, showing a medium effect on muscle strength (SMD, 0.68; 95% CI, 0.55–0.81; $I^2 = 45\%$; $P < 0.05$). The study also compared the effects based on repetition maximum (RM) settings, revealing that strength increased significantly regardless of whether RM was used, with studies showing medium effects (with RM: SMD, 0.52; 95% CI, 0.4–0.64; $I^2 = 0\%$; $P < 0.05$; without RM: SMD, 0.65; 95% CI, 0.4–0.91; $I^2 = 72\%$; $P < 0.05$). The study concludes that strength exercises are beneficial for improving muscle strength in chronic stroke patients, but the use of RM to set exercise intensity is not strictly necessary.

Keywords: Stroke, Resistance exercise training, Repetition maximum, Strength exercise, Sarcopenia, Rehabilitation

INTRODUCTION

Stroke patients experience a decrease in muscle strength on the paralyzed side due to hemiparesis, leading to muscle strength asymmetry, which is closely related to functional performance (Chun et al., 2023). Recent studies on sarcopenia have been reported in these stroke patients (Kim et al., 2024). Sarcopenia is an age-related condition characterized by decreased muscle strength, skeletal muscle mass, and physical performance (Santilli et al., 2014). Reported higher prevalence of sarcopenia in acute stroke compared to chronic stroke (Su et al., 2020). The presence of sarcopenia was shown to be associated with poor functional outcomes in patients with stroke (Li et al., 2023). Stroke patients with sarcopenia demonstrated lower rates of recovery compared to those without sarcopenia, even after undergoing the same duration of rehabilitation (Park et al., 2019). Therefore, it is necessary to recognize sarcopenia in stroke patients and provide rehabilitation interventions to improve sarcopenia.

Generally, resistance training such as strength exercises are recommended for older adults with sarcopenia (Hurst et al., 2022; Yoo et al., 2018). These strength exercises are systematically performed with appropriate exercise intensity for older adults (Borde et al., 2015; de Freitas et al., 2019; Mayer et al., 2011). However, the conventional rehabilitation of stroke patients aims to improve functional outcomes, rather than muscle mass and strength (Winstein et al., 2016). Previous reviews have reported that strengthening interventions increase strength and improve activity after stroke (Ada et al., 2006). However, while these reviews reported

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Received: July 26, 2024 / Revised: August 13, 2024 / Accepted: August 18, 2024

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pISSN 2288-176X
eISSN 2288-1778

an increase in strength, they did not analyze muscle mass. Additionally, the strengthening interventions included not only exercise interventions but also other intervention methods, leading to heterogeneity among the intervention methods. Other previous reviews have reported that repetitive exercise interventions improve muscle strength in stroke patients (de Sousa et al., 2018). However, these studies have limitations as they include not only strength training but also other forms of exercise in the repetitive exercise interventions. Another previous review reported that progressive resistance exercise increases muscle strength in stroke patients (Dorsch et al., 2018). However, this study has the limitation of including only high-intensity exercises that meet the American College of Sports Medicine criteria for progressive resistance exercise. Previous reviews have not evaluated muscle mass after strength training or repetitive exercise interventions in stroke patients. Since sarcopenia involves not only muscle strength but also muscle mass, it is necessary to investigate the effects of strength training on muscle mass in stroke patients.

Therefore, the research question of this study is "What effect does strength exercise have on muscle mass and muscle strength in stroke patients?" This study aims to systematically explore previous studies on the effects of muscle strength exercises on muscle mass and strength in stroke patients and integrate these effects.

MATERIALS AND METHODS

Procedure

The systematic review and meta-analysis had its protocol registered in PROSPERO prior to commencement (CRD 42023475278). The study was conducted in accordance with the guidelines of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) 2020 checklist (Page et al., 2021).

Eligibility criteria

Inclusion criteria were based on the criteria of PICOS and are detailed as follows (1) Participants: adults diagnosed with any type of stroke regardless of duration; (2) Intervention: group receiving resistance training to all body parts alone or in combination with other treatments; (3) Comparison: usual care group without resistance training or no treatment group; (4) Outcome: outcome: primary outcome was muscle mass at any site and secondary outcome was muscle strength at any site; (5) Study: randomized controlled trials (RCTs). Exclusion criteria included (1) studies for which no full text was provided; (2) studies not written in English or Korean; (3) books, gray literature that had not been peer-reviewed; and (4) studies for which mean standard deviations for calculating effect sizes were not provided.

Search strategy and data collection

The search period was from inception to 1 November 2023. The databases used were CINAHL, Embase, PubMed, web of science, and the Cochrane library. The search terms included the keywords 'stroke' and 'strength exercise' and utilized Boolean operators (AND or OR). Examples include the following (Table 1).

The following data were collected: PICOS, title, first author, year of publication, RCTs status, number of groups, general characteristics of subjects, duration of stroke onset, in-tensity of resistance training, duration of intervention, number of interventions, outcome measures of muscle thickness and strength, and mean standard deviation values. The comparison group included all interventions except muscle strengthening. Therefore, the control groups between the included studies were not homogeneous, and to overcome this, the standardized mean differences (SMDs) were calculated and presented as a random effect model. The data were collected by two researchers, and disagreements were resolved by discussion with the coauthors.

Quality assessment

The quality of the selected studies was assessed using the physiotherapy evidence database (PEDro) scale. The PEDro scale is a

Table 1. Example search strategy

Database	Search strategy
PubMed	(("Stroke"[Mesh]) OR ("Stroke"[Title/Abstract]) OR ("Cerebrovascular Accident"[Title/Abstract]) OR ("CVA"[Title/Abstract]) OR ("Hemorrhagic Stroke"[Mesh]) OR ("Hemorrhagic Stroke"[Title/Abstract]) OR ("Subarachnoid Hemorrhagic Stroke"[Title/Abstract]) OR ("Embolic Stroke"[Mesh]) OR ("Embolic Stroke"[Title/Abstract]) OR ("Cardioembolic Stroke"[Title/Abstract]) OR ("Thrombotic Stroke"[Mesh]) OR ("Thrombotic Stroke"[Title/Abstract]) OR ("Ischemic Stroke"[Mesh]) OR ("Ischemic Stroke"[Title/Abstract]) OR ("Cryptogenic Stroke"[Title/Abstract]) OR ("Wake-up Stroke"[Title/Abstract])) AND (("Resistance Training"[Mesh]) OR ("Resistance Training"[Title/Abstract]) OR ("Strength Training"[Title/Abstract]) OR ("Weight Lifting Strengthening Program"[Title/Abstract]) OR ("Weight Lifting Exercise Program"[Title/Abstract]) OR ("Weight Bearing Strengthening Program"[Title/Abstract]) OR ("Weight Bearing Exercise Program"[Title/Abstract]) OR ("Strength Exercise"[Title/Abstract]) OR ("Resistance Exercise"[Title/Abstract]) OR ("Muscle Strengthening"[Title/Abstract]) OR ("Muscle Strengthening Exercise"[Title/Abstract]) OR ("Muscle Strengthening Training"[Title/Abstract]))

tool for reviewing physiotherapy RCTs and has been validated for validity and reliability (Maher et al., 2003). The scale was categorized as excellent with a score of 9 or more, good with 8–6, fair with 5–4, and poor with 3 or less (Cashin and McAuley, 2020). Ratings were performed by two researchers, and disagreements were resolved by discussion with a coauthor.

Statistics analysis

R studio 4.3.3 was used to analyze the data for the meta-analysis. The mean standard deviation before and after the intervention was collected in February 2024. The data collected were continuous, and because the subjects and interventions were not homogeneous, the SMD and 95% confidence intervals (CIs) were calculated using a random effects model and presented as a forest plot. The SMD was calculated using Hedges g, and the results were interpreted as a small effect size for 0.2 or less, a medium effect size for 0.5, and a large effect size for 0.8. $P < 0.05$ was considered statistically significant.

Heterogeneity among studies was assessed by I^2 statistic (Higgins et al., 2003), with <25% representing low heterogeneity, 25% to 50% representing moderate heterogeneity, and >50% representing high heterogeneity. When more than 10 studies were included in the meta-analysis, publication bias was visually analyzed using a funnel plot, and if asymmetry was confirmed, Egger regression test was additionally used. Subgroup analyses compared the effects of muscle mass and strength by stroke onset duration (acute, subacute, chronic) and with and without repetition maximum (RM) settings in strength exercise.

RESULTS

Study selection

The search resulted in 9,441 studies, and after excluding 2,558 duplicates, 6,883 studies were selected. After screening 208 studies that were likely to be relevant to the purpose of the study by checking the title and abstract, a total of 198 studies that did not meet the PICOS criteria, had no data, or could not be accessed in full text were excluded, and 10 studies were finally selected (Fig. 1).

General characteristics

A total of 426 stroke patients were included in the 10 studies (Bale and Strand, 2008; Cooke et al., 2010; da Silva et al., 2015; Ellis et al., 2018; Fernandez-Gonzalo et al., 2016; Flansbjer et al., 2008; Ivey et al., 2017; Lee et al., 2008; Marzolini et al., 2018; Yang et al., 2006). The study with the smallest number of subjects was 18 and the study with the largest was 109. The stroke onset was chronic (≥6 months) in 8 studies and acute (<3 months) in 2 studies. Intervention methods include progressive resistance training (Flansbjer et al., 2008; Lee et al., 2008), functional strength (Bale and Strand, 2008; Cooke et al., 2010), task-oriented training (da Silva et al., 2015; Yang et al., 2006), strength training (Ivey et al., 2017), flywheel resistance exercise training (Fernandez-Gonzalo et al., 2016), horizontal plane viscous resistance (Ellis et al., 2018), aerobic (Marzolini et al., 2018), etc., and strength training was done together with other training or alone. The duration ranged from 4 to 24 weeks and the number of repetitions varied from 12 to 120. Exercise intensity was set at 50%–80% of one-repetition maximum (1RM) in five studies (da Silva et al., 2015; Ellis et al., 2018; Flansbjer et al., 2008; Lee et al., 2008; Marzolini et al., 2018), and in the remaining five studies (Bale and Strand, 2008; Cooke et al., 2010; Fernandez-Gonzalo et al., 2016; Ivey et al., 2017; Yang et al., 2006) participants performed strength exercise as much as they could (Table 2).

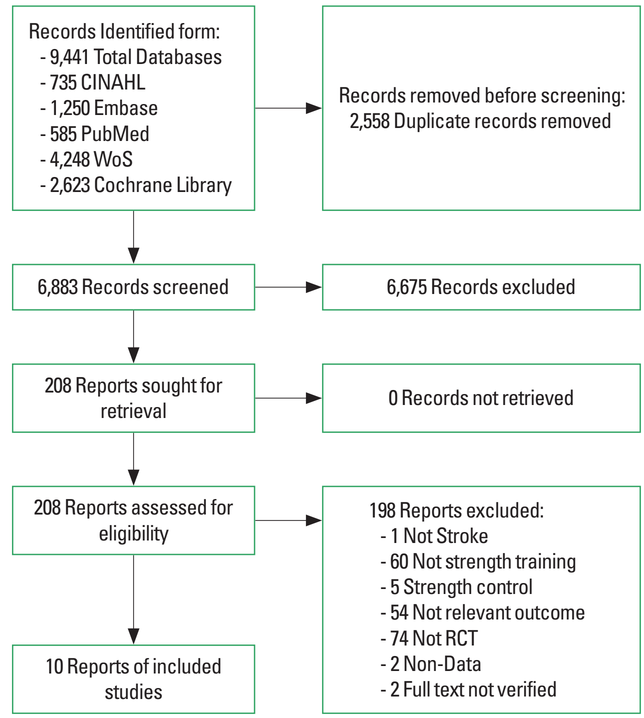

Fig. 1. Flow diagram. CINAHL, cumulative index to nursing and allied health literature; WoS, web of science; RCT, randomized controlled trials.

Study quality

The quality assessment using PEDro showed that two studies scored 9 (Cooke et al., 2010; Lee et al., 2008), three studies scored 8 (da Silva et al., 2015; Ellis et al., 2018; Flansbjer et al., 2008),

https://doi.org/10.12965/jer.2448428.214

Table 2. General characteristics

Study	Participants, M/F	Age (yr)	On set	Monitoring	Intervention			Exercise intensity	Dropouts and adverse effects	Outcomes
					EG	CG	Duration			
Yang et al., 2006	EG=16/8 CG=16/8	EG: 56.8±10.2 CG: 60.0±10.4	EG: 62.7±27.4 CG: 64.0±40.4 (mo)	No information	Task-oriented progressive RT	Did not receive any rehabilitation training	12 Times over 4 wk, 30 min per session	As much as possible	No dropout No information on adverse effects	Muscle strength (pounds) Hip/knee flexors, extensors Ankle dorsi/plantar flexors
Bale and Strand, 2008	EG=3/5 CG=4/6	EG: 60.8±13.0 CG: 64.9±8.8	EG: 49.4±22.1 CG: 32.0±18.5 (day)	No information	Functional strength group	Training-as-usual group	20 Times over 4 wk, 50 min per session	10–15 RM	No dropout No information on adverse effects	Isometric muscle strength (torque, Nm) Knee flexion, extension
Flansbjer et al., 2008	EG=9/6 CG=5/4	EG: 61.0±5.0 CG: 60.0±5.0	EG: 18.9±7.9 CG: 20.0±11.6 (mo)	No information	Progressive RT	Control	20 Times over 10 wk, 90 min per session	Maximum load 80%	Dropout: Unrelated to intervention, n=1	Dynamic and isokinetic Knee muscle strength
Lee et al., 2008	EG 1=8/4 EG 2=8/4 CG 1=6/6 CG 2=6/6	EG 1: 62.0±9.3 EG 2: 0.5±10.6 CG 1: 65.3±6.0 CG 2: 67.2±10.6	EG 1: 44.2±63.9 EG 2: 57.0±54.2 CG 1: 65.8±42.3 CG 2: 62.4±2.2 (mo)	-HR -Blood pressure	EG 1: Progressive RT EG 2: Progressive RT+cycle	CG 1: Control CG 2: Cycle	30–36 Times over 10–12 wk, 60 min per session	80% 1RM	No adverse effects Dropout: - Hip fracture due to a fall at home, n=2 - Gastrointestinal illness, n=1 - Decision to pursue exercise at home, n=1	1RM in leg (N) Power in leg (W) Endurance in leg (average number of repetitions)
Cooke et al., 2010	EG=22/14 CG 1=21/17 CG 2=22/13	EG: 71.17±10.60 CG 1: 66.37±13.70 CG 2: 67.46±11.30	EG: 33.86±16.50 CG 1: 36.76±22.41 CG 2: 32.43±21.29 (day)	No information	Functional strength training+CP	CG 1: CP CG 2: CP+CP	24 Times over 6 wk, 60 min per session	Repetitive and progressive resistive exercise	Lost to follow-up/outcome: - Unwell, n=20 - Withdrew, n=10 - Abroad, n=2 - Sectioned, n=2 - Died, n=2 - Housebound, n=2	Peak torque (Nm) Knee flexion, extension
da Silva et al., 2015	EG=3/7 CG=4/6	EG: 70.30±7.83 CG: 70.40±7.83	EG: 41.40±11.89 CG: 40.20±13.48 (mo)	No information	RT+task-oriented training	Task-oriented training	12 Times over 6 wk, 30 min per session	60% of the maximum baseline force	No dropout No information on adverse effects	Strength measure Shoulder flexors (kg) Hand grip (lb)
Ivey et al., 2017	EG=10/4 CG=11/5	EG: 57±14 CG: 55±9	EG: 5±4 CG: 6±5 (yr)	Musculoskeletal health Vital signs Blood sugar Acute illness Overall health status	Strength training	Stretch control	36 Times over 12 wk, 45 min per session	Muscle failure (10–15 repetitions)	No adverse effects 8 Lost to follow-up withdrew: unrelated medical, n=4; other, n=4	1RM

(*continued*)

Table 2. General characteristics (Continued)

Study	Participants, M/F	Age (yr)	On set	Monitoring	Intervention			Exercise intensity	Dropouts and adverse effects	Outcomes
					EG	CG	Duration			
Fernandez-Gonzalo et al., 2016	EG=11/3 CG=11/4	EG: 61.2±9.8 CG: 65.7±12.7	EG: 3.5±3.6 CG: 4.3±4.9 (yr)	No information	Flywheel resistance exercise training	Daily routines	24 Times over 12 wk, no information on min per session	4 Sets of 7 maximal repetitions, <2 min of contractile activity	Unrelated medical condition, n=3	Maximal isometric/dynamic force (N), leg Peak power (W), leg Muscle volume (cm^3): QF, RF, VL, VI, VM QF greatest CSA (cm^2) QF mean CSA (cm^2)
Ellis et al., 2018	EG=6/11 CG=1/14	EG: 59.8±15.6 CG: 56.2±12.9	EG: 10.9±6.5 CG: 11.1±6.1 (yr)	No information	Horizontal-plane viscous resistance	Control	24 Times over 8 wk, 60 min per session	Until they could reach at least 80% of the distance to the target in 8 out of 10 repetitions for three out of four sets.	No unanticipated problems or adverse effects Upper extremity fracture prior follow-up, n=1	Elbow: flexion, extension Shoulder: abduction, adduction, horizontal adduction, horizontal abduction, external rotation, internal rotation
Marzolini et al., 2018	EG=22/11 CG=22/13	EG: 65.6±13.2 CG: 61.7±10.0	EG: 9.3±5.7 CG: 14.6±15.5 (mo)	HR	RT+aerobic training	Aerobic training	120 Times over 24 wk, 20–60 min per session	70% of 1RM	No adverse effects Both had strokes unrelated to exercise, n=2 Return to work, n=1 Moved, n=1 Arthritis preprogram, n=1	Muscular strength, (kg): elbow flexion knee extension

EG, experimental group; CG, control group; RT, resistance training; CP, conventional physiotherapy; RM, repetition maximum; HR, heart rate; QF, quadriceps femoris; RF, rectus femoris; VL, vastus lateralis; VI, vastus intermedius; VM, vastus medialis; CSA, cross sectional area.

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three studies scored 7 (Bale and strand, 2008; Marzolini et al., 2018; Yang et al., 2006), one study scored 6 (Fernandez-Gonzalo et al., 2016), and one study scored 4 (Ivey et al., 2017). The quality of the studies was mostly good, with two studies rated excellent, seven good, and one fair (Table 3).

Strength

A total of 10 studies, including 195 experimental subjects and 231 control subjects, were pooled to analyze the effects of strength training in stroke patients (Fig. 2). There were five muscle strength measurement units: kg (SMD, 0.45; 95% CI, 0.22–0.69; $I^2=0\%$; $P<0.05$), N (SMD, 0.7; CI = 0.47–0.93; $I^2=0\%$; $P<0.05$), W (SMD, 0.55; 95% CI, 0.3–0.81; $I^2=0\%$; $P<0.05$), Nm (SMD, 0.21; 95% CI, 0.05–0.37; $I^2=13\%$; $P<0.05$), and lbs (SMD, 1.09; 95% CI, 0.78–1.39; $I^2=67\%$; $P<0.05$). These five units showed medium (kg, N, W, Nm) to large (lb) strength increases. When all results were combined, strength training had a medium effect on increasing muscle strength in stroke patients, with high heterogeneity (SMD, 0.6; 95% CI, 0.47–0.72; $I^2=51\%$; $P<0.05$).

Table 3. PEDro scale score

Study	1	2	3	4	5	6	7	8	9	10	11	Total
Yang et al., 2006	-	Y	N	Y	Y	N	N	Y	Y	Y	Y	7
Bale and strand, 2008	-	Y	N	Y	N	N	Y	Y	Y	Y	Y	7
Flansbjer et al., 2008	-	Y	Y	Y	Y	N	Y	Y	N	Y	Y	8
Lee et al., 2008	-	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	9
Cooke et al., 2010	-	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	9
da Silva et al., 2015	-	Y	Y	Y	Y	N	N	Y	Y	Y	Y	8
Ivey et al., 2017	-	Y	N	Y	N	N	N	N	N	Y	Y	4
Fernandez-Gonzalo et al., 2016	-	Y	N	Y	N	N	Y	Y	N	Y	Y	6
Ellis et al., 2018	-	Y	N	Y	Y	N	Y	Y	Y	Y	Y	8
Marzolini et al., 2018	-	Y	Y	Y	N	N	Y	Y	N	Y	Y	7

PEDro, physiotherapy evidence database; 1, Eligibility criteria; 2, Randomly allocated; 3, Allocation concealed; 4, Similar at baseline; 5, Blinding of subjects; 6, Blinding of therapists; 7, Blinding of assessors; 8, <15% dropouts; 9, Intention to treat analysis; 10, Between group comparison; 11, Point and variability measures.

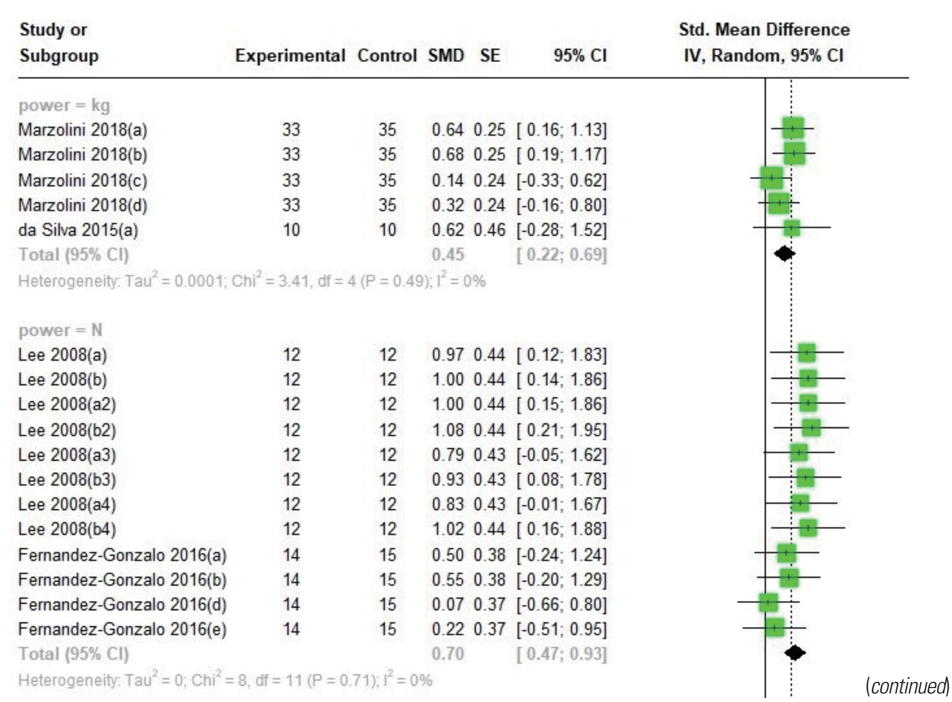

Fig. 2. Effect of strength exercise on stroke. SMD, standardized mean difference; SE, standard error; CI, confidence intervals; IV, inverse variance.

power = W					
Lee 2008(c)	12	12	0.31	0.41	[-0.50; 1.11]
Lee 2008(d)	12	12	0.75	0.42	[-0.08; 1.58]
Lee 2008(c2)	12	12	0.46	0.41	[-0.35; 1.27]
Lee 2008(d2)	12	12	0.67	0.42	[-0.15; 1.50]
Lee 2008(c3)	12	12	0.55	0.42	[-0.27; 1.36]
Lee 2008(d3)	12	12	0.75	0.42	[-0.08; 1.58]
Lee 2008(c4)	12	12	0.67	0.42	[-0.16; 1.49]
Lee 2008(d4)	12	12	0.67	0.42	[-0.16; 1.49]
Fernandez-Gonzalo 2016(c)	14	15	0.55	0.38	[-0.20; 1.29]
Fernandez-Gonzalo 2016(f)	14	15	0.28	0.37	[-0.45; 1.01]
Total (95% CI)			0.55		[0.30; 0.81]
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 1.6$, df = 9 (P = 1.00); $I^2 = 0\%$					
power = Nm					
Cooke 2010(a)	24	19	-0.10	0.31	[-0.71; 0.50]
Cooke 2010(b)	24	19	-0.14	0.31	[-0.74; 0.46]
Cooke 2010(a2)	24	18	-0.16	0.31	[-0.77; 0.46]
Cooke 2010(b2)	24	18	-0.15	0.31	[-0.77; 0.46]
Ellis 2018(a)	17	15	0.46	0.36	[-0.24; 1.17]
Ellis 2018(b)	17	15	0.40	0.36	[-0.30; 1.10]
Ellis 2018(c)	17	15	0.03	0.35	[-0.66; 0.72]
Ellis 2018(d)	17	15	0.32	0.36	[-0.38; 1.02]
Ellis 2018(e)	17	15	0.14	0.35	[-0.55; 0.84]
Ellis 2018(f)	17	15	-0.19	0.36	[-0.88; 0.51]
Ellis 2018(g)	17	15	-0.02	0.35	[-0.71; 0.68]
Ellis 2018(h)	17	15	-0.20	0.36	[-0.89; 0.50]
Flansbjer 2008(a)	15	9	1.15	0.46	[0.25; 2.05]
Flansbjer 2008(b)	15	9	1.10	0.46	[0.21; 1.99]
Flansbjer 2008(c)	15	9	1.04	0.45	[0.15; 1.92]
Flansbjer 2008(d)	15	9	1.16	0.46	[0.26; 2.06]
Flansbjer 2008(e)	15	9	0.45	0.43	[-0.39; 1.29]
Flansbjer 2008(f)	15	9	0.40	0.43	[-0.43; 1.24]
Flansbjer 2008(g)	15	9	0.38	0.43	[-0.46; 1.21]
Flansbjer 2008(h)	15	9	0.32	0.42	[-0.51; 1.16]
Bale 2008(a)	8	10	0.16	0.48	[-0.78; 1.09]
Bale 2008(b)	8	10	0.08	0.47	[-0.85; 1.01]
Bale 2008(c)	8	10	0.31	0.48	[-0.62; 1.25]
Bale 2008(d)	8	10	-0.21	0.48	[-1.14; 0.72]
Total (95% CI)			0.21		[0.05; 0.37]
Heterogeneity: $Tau^2 = 0.0112$; $Chi^2 = 26.47$, df = 23 (P = 0.28); $I^2 = 13\%$					
power = lbs					
da Silva 2015(b)	10	10	0.45	0.45	[-0.44; 1.34]
Ivey 2017(a)	14	16	2.49	0.50	[1.50; 3.47]
Ivey 2017(b)	14	15	1.80	0.45	[0.92; 2.68]
Yang 2006(a)	24	24	0.49	0.29	[-0.09; 1.06]
Yang 2006(b)	24	24	1.92	0.35	[1.22; 2.61]
Yang 2006(c)	24	24	1.18	0.31	[0.56; 1.79]
Yang 2006(d)	24	24	0.36	0.29	[-0.21; 0.93]
Yang 2006(e)	24	24	0.88	0.30	[0.28; 1.47]
Yang 2006(f)	24	24	0.68	0.30	[0.10; 1.27]
Yang 2006(g)	24	24	0.84	0.30	[0.24; 1.43]
Yang 2006(h)	24	24	1.00	0.31	[0.40; 1.60]
Yang 2006(i)	24	24	2.18	0.37	[1.45; 2.90]
Yang 2006(j)	24	24	0.86	0.30	[0.27; 1.46]
Yang 2006(k)	24	24	1.25	0.32	[0.63; 1.88]
Yang 2006(l)	24	24	0.67	0.30	[0.09; 1.26]
Total (95% CI)			1.09		[0.78; 1.39]
Heterogeneity: $Tau^2 = 0.2441$; $Chi^2 = 42.11$, df = 14 (P < 0.01); $I^2 = 67\%$					
Total (95% CI)			**0.60**		**[0.47; 0.72]**
Heterogeneity: $Tau^2 = 0.1405$; $Chi^2 = 133.33$, df = 65 (P < 0.01); $I^2 = 51\%$					
Test for subgroup differences: $Chi^2 = 30.46$, df = 4 (P < 0.01)					

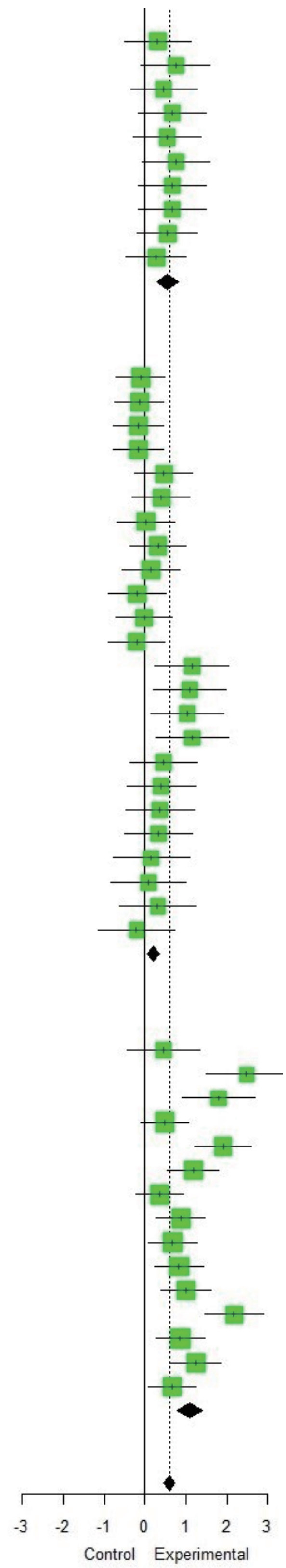

Fig. 2. Effect of strength exercise on stroke. SMD, standardized mean difference; SE, standard error; CI, confidence intervals; IV, inverse variance. (Continued)

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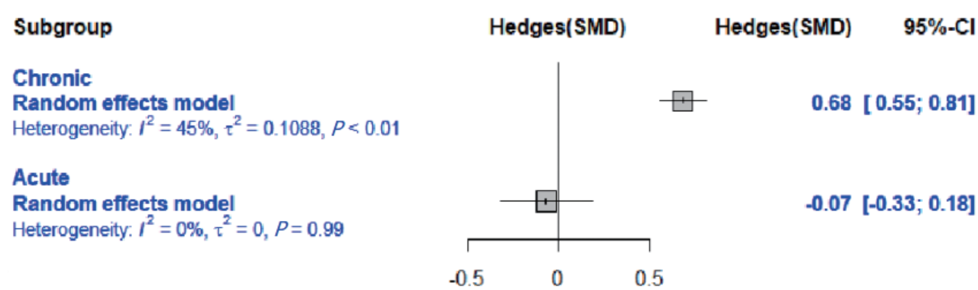

Fig. 3. Effect of strength exercise on stroke onset duration. SMD, standardized mean difference; CI, confidence intervals.

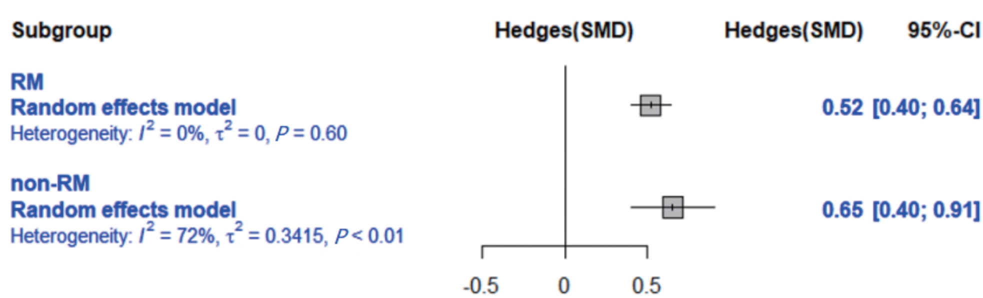

Fig. 4. Effect of strength exercise on RM setting. RM, repetition maximum; SMD, standardized mean difference; CI, confidence interval.

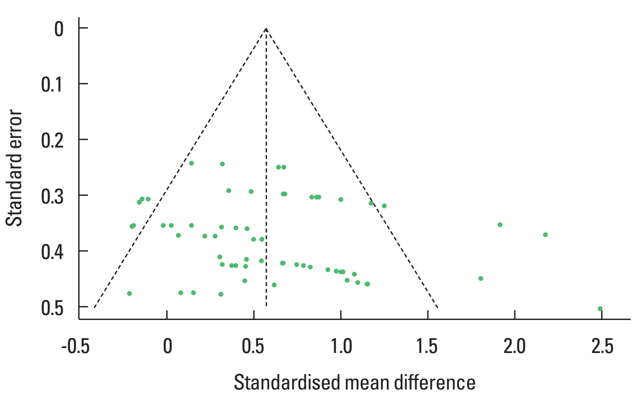

Fig. 5. Funnel plot.

Subgroup analysis

Subgroup analyses were conducted to assess the effect of strength training based on stroke onset time and RM setting (Figs. 3 and 4). The results showed that strength training had a medium effect on increasing muscle strength in chronic stroke patients according to the stroke onset duration (SMD, 0.68; 95% CI, 0.55–0.81; I^2 = 45%; P < 0.05). Regarding the effect based on the RM setting, both studies with RM (SMD, 0.52; 95% CI, 0.4–0.64; I^2 = 0%; P < 0.05) and studies without RM (SMD, 0.65; 95% CI, 0.4–0.91; I^2 = 72%; P < 0.05) showed a medium effect on increasing muscle strength.

Table 4. Egger regression test

Test	*t*	*df*	*P*-value
Egger regression test	1.8	64	0.076

df, degrees of freedom.

Publication bias

This review analyzed publication bias because there were 10 included studies. A visual analysis was performed using a funnel plot, and since it was determined that there was asymmetry, Egger's regression was additionally analyzed (Fig. 5). The results of Egger's regression analysis showed no statistically significant difference (t = 1.8; df = 64; P = 0.076). This means that there is no statistically significant relationship between the effect size and the standard error, and the funnel plot appears to be symmetrical (Table 4).

DISCUSSION

The purpose of this study was to evaluate the effect of strength training on muscle mass and strength in stroke patients. To our knowledge, this study is the first meta-analysis to examine the effectiveness not only of muscle strength but also of other muscle factors, such as muscle mass. The research question of this study was, "What effect does strength exercise have on muscle mass and muscle strength in stroke patients?"

This review selected a total of 10 studies on the effects of strength exercise on muscle mass and muscle strength in stroke patients and analyzed the effects by type. Among the 10 studies, 1 study reported the effect on muscle mass, and 10 studies reported the effect on muscle strength. Of these 10 studies, 3 studies had no dropouts, and 7 studies had one or more dropouts. The majority of these dropouts were due to health reasons. None of the studies reported any adverse effects experienced by the subjects. Only 4 out of the 10 studies mentioned the presence or absence of adverse effects, while 6 studies did not mention it.

Strength exercise significantly improved the muscle strength of stroke patients. This finding aligns with previous reports suggesting that intensive strength exercise in stroke patients is effective in improving various functional problems and that neuromuscular control can be enhanced, leading to increased muscle strength (Andersen et al., 2011; Patten et al., 2004; Perrine, 1993). Resistance-based strength exercise may be particularly effective for improving strength because it induces a higher level of neuromuscular activation than other functional exercises (Andersen et al., 2006).

Lee et al. (2010) found that after strength training was performed on stroke patients, the strength of the ankle did not improve as much as the strength of other joints. This was attributed to the fact that the ankle was trained isometrically rather than with exercises involving eccentric contraction, which improved the strength of other muscles. In contrast, Andersen et al. (2011) and Lee et al. (2008) reported that resistance exercise promoting eccentric contraction was effective in improving muscle strength in stroke patients. Eccentric contraction utilizes the maximum capacity of the muscle and creates greater tension than concentric contraction (Chaudhuri and Aruin, 2000). Therefore, providing eccentric contraction during resistance exercise for stroke patients is considered important for activating neuromuscular capacity. It appears that the studies selected in this review were also able to improve muscle strength by providing exercises that sufficiently used eccentric contraction rather than isometric contraction.

Subgroup analysis was performed to evaluate the effect of strength exercise according to stroke onset duration and type of RM setting. The analysis revealed significant improvement in muscle strength during the chronic phase, but no significant improvement in the acute phase. The acute phase corresponds to the period of neurological recovery, which is the first 3 months after the onset of the disease. During this period, as neurological recovery occurs, all other functional exercises, including strength exercise, can contribute to restoring muscle strength. Therefore, it is believed that all exercise interventions, compared to the muscle-strengthening intervention, had an effective impact on muscle strength.

In this review, most chronic cases had an average onset duration of 2 years or more, meaning the intervention was performed on patients who had already passed the period of neurological recovery. Thus, muscle-strengthening exercises, which generate repetitive muscle stimulation at higher intensities than other exercise interventions, may be helpful in restoring or maintaining muscle strength by maximizing neuromuscular activation capacity.

In the chronic stage of stroke, task-oriented therapy, including strength exercise, is effective in inducing neuromuscular adaptations that improve force generation, motor skills, and functional recovery (da Silva et al., 2015). Flansbjer et al. (2012) reported that strength exercise with progressive resistance is an effective method for improving and maintaining strength from a long-term perspective and that resistance exercise should be included in the rehabilitation program after stroke. Additionally, numerous studies have reported that voluntary neuromuscular activation capacity can be maximized through interventions that include strengthening elements in the chronic phase after stroke. Increased muscle strength can promote functional improvements and potentially improve quality of life without negative side effects such as pain (Andersen et al., 2011; Flansbjer et al., 2012; Patten et al., 2004).

Patients generally experience depression and psychological rejection of the disease and the resulting disability in the early stages of the disease (acute stage), which may cause rehabilitation exercises to be somewhat less focused (Amaricai and Poenaru, 2016; Caeiro et al., 2006). Since strength training requires the will to exert effort independently, it may be difficult to perform it intensively during the acute stage. When patients feel that their physical functions are gradually being restored through treatment and rehabilitation training, they become more hopeful and dedicate themselves to rehabilitation exercises. At this time, the focus on rehabilitation increases, and the effect of strength training can be enhanced depending on the individual's will. Therefore, strength exercise is an important component of rehabilitation programs for chronic stroke patients.

In this review, the effect of strength exercise in stroke patients according to RM settings was analyzed, and the results showed that strength significantly increased regardless of the RM setting. The most efficient way to increase muscle strength is through resistance exercise using a load greater than 70% of maximum strength (Kraemer and Ratamess, 2004). In this study, the efficacy of studies that did not use RM was slightly higher than that of studies that did use RM. In strength exercise, it is important to measure

 https://doi.org/10.12965/jer.2448428.214

1RM and maximum torque production capacity. However, in stroke patients, the ability to maintain submaximal muscle contraction may be more important for evaluating the effectiveness of exercise stimuli, and this may be even more relevant to daily life functioning (McNeil and Rice, 2007; Reuben et al., 2013). Activities of daily living are more likely to depend on submaximal maintenance than on maximal effort (Hyngstrom et al., 2014; Kuppuswamy et al., 2016; Rybar et al., 2014). In other words, for people with neurological disorders such as stroke, maximal strength can help facilitate daily functions, but the ability to repeatedly maintain submaximal muscle contraction is a more critical factor (Billinger et al., 2014; Wist et al., 2016). Therefore, even if the criteria for setting exercise intensity differ, it is believed that performing strength exercises tailored to the individual according to the specificity of the disease can help improve strength.

The studies included in this review may have caused the overall significant effect to be either underestimated or overestimated due to the presence of studies with a small number of subjects or those with high weightings. Therefore, caution is required when interpreting the results of the intervention effect. Additionally, since only literature published in Korean and English was included, studies reported in other languages were not considered. Although the types of interventions considering strength training varied somewhat, the analysis was conducted without classifying them, which presents a limitation.

In conclusion, strength training is effective in improving muscle strength in stroke patients, and it is essential for maintaining and improving muscle strength in chronic stroke patients. The use of RM to set the maximum strength standard when determining exercise intensity is not absolute. In the field of rehabilitation or exercise, it is necessary to adjust resistance intensity according to the specificity of the disease by considering the subject's maximum capacity. This study is expected to serve as the basis for future intervention research plans for muscle recovery in stroke patients and will be particularly helpful in designing research for stroke patients with chronic muscle weakness and sarcopenia. Future studies should conduct more detailed analyses of muscle-strengthening exercise interventions for stroke patients, comparing effects by age and onset period, and examining short-, mid-, and long-term outcomes.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGMENTS

The authors received no financial support for this article.

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