# Effects of Extracorporeal Shock Wave Therapy on Upper Limb Spasticity after Stroke: A Systematic Review and Meta-Analysis

**Hui ZHAO***, **Chen LI**, **Chunming MA**

Department of Pre-Rehabilitation Medicine, Taihe Hospital, Hubei University of Medicine, Shiyan 442000, China

**Abstract** [**Objectives**] To quantify the efficacy of Extracorporeal Shock Wave Therapy (ESWT) for upper limb spasticity in stroke patients using Modified Ashworth Scale (MAS) across three timeframes: immediate, short-term (24 h – 4 wks), and long-term (> 4 wks). [**Methods**] Six databases (PubMed, EMBASE, CENTRAL, CINAHL, Scopus, Web of Science) until May 2025, were systematically searched, identifying 11 RCTs ($n = 505$) meeting inclusion criteria (adults ≥18 yrs old with stroke-related spasticity [MAS≥1]). Risk of bias was rigorously assessed using Cochrane criteria, revealing uniformly low risk across all domains. Random-effects meta-analyses (REML model) calculated Hedges' $g$ with 95% $CI$ for MAS outcomes, with subgroup analyses for joint-specific effects. [**Results**] ESWT demonstrated non-significant immediate MAS reduction ($g = -0.69$, $p = 0.07$; $= 93.95\%$), but statistically significant short-term ($g = -0.58$, $p = 0.02$; $I^2 = 89.64\%$) and long-term effects ($g = -0.52$, $p = 0.02$; $I^2 = 78.72\%$). Effects were driven by composite MAS scores (short-term $g = -0.63$; long-term $g = -0.56$, both $p < 0.05$) rather than isolated joints (elbow/finger/wrist all non-significant). Substantial heterogeneity persisted across analyses, particularly in joint-specific subgroups ($I^2 > 90\%$). [**Conclusions**] ESWT provides statistically significant, clinically relevant reductions in global upper limb spasticity with durable efficacy beyond four weeks, supporting its use as a non-invasive adjunct therapy despite substantial heterogeneity warranting protocol standardization.

**Key words** Extracorporeal shock wave therapy, Upper limb spasticity after stroke, Systematic review, Meta-analysis

## 1 Introduction

Stroke, a leading cause of adult disability, affects over 13 million people globally each year, with approximately 60% of survivors experiencing moderate to severe motor impairments. Among them, post-stroke spasticity emerges as a particularly debilitating consequence, impacting 25% – 43% of patients within six months of stroke onset[1]. This neurological condition, characterized by velocity-dependent muscle hypertonia, arises from disrupted supraspinal inhibition of spinal reflex arcs and secondary non-neural changes, such as muscle fibrosis, collagen deposition, and altered viscoelastic properties. Upper limb spasticity severely impairs activities of daily living (ADLs), such as hand grasp, dressing, and feeding, and is associated with reduced quality of life[2].

The pathophysiology of post-stroke spasticity is dualistic: neural mechanisms involve hyperexcitability of the stretch reflex (*e.g.*, increased H-reflex amplitude), while non-neural mechanisms include muscle-tendon unit shortening and fibrotic remodeling. This dual pathology presents a therapeutic challenge, as interventions must address both neural excitability and tissue stiffness[3]. Traditional treatments, such as botulinum toxin injections, oral antispastic medications (*e.g.*, baclofen, tizanidine), and physical therapy, have limitations. Botulinum toxin, though effective, requires repeated injections, carries a 15% – 20% risk of antibody formation, and is contraindicated in patients with neuromuscular disorders. Physical therapies, such as static stretching and range-of-motion exercises, provide transient relief but lack durability, with spasticity recurrence rates exceeding 60% within four weeks of cessation[3].

Extracorporeal shock wave therapy (ESWT), a non-invasive modality, has gained traction in rehabilitation for its unique ability to modulate both neural and non-neural components of spasticity. ESWT delivers acoustic waves with high peak pressure (50 – 200 MPa) and short pulse durations (nanosecond to microsecond range), generating mechanical stress at tissue interfaces[4]. Preclinical studies in animal models of spasticity have demonstrated that ESWT reduces muscle spindle excitability, decreases collagen type I synthesis, and enhances nitric oxide production—mechanisms that collectively reduce muscle tone and improve tissue compliance. Clinical case series have reported similar findings, with ESWT reducing Modified Ashworth Scale (MAS) scores by 1 – 2 points in chronic stroke patients within four weeks of treatment[5]. This systematic review and meta-analysis aim to quantify the effect of ESWT on upper limb spasticity severity in post-stroke patients and evaluate ESWT's impact on ankle ROM, motor function, and walking performance.

## 2 Methods

**2.1 Search strategy** PubMed, EMBASE, CENTRAL, CINAHL, Scopus, and Web of Science were searched up to May 1, 2025 using a combination of MeSH terms and free-text keywords: "extracorporeal shock wave therapy" OR "ESWT" OR "shock-wave therapy"; "stroke" OR "cerebrovascular accident" OR "post-stroke"; "spasticity" OR "muscle hypertonia"; "upper limb" OR "hand" OR "motor function".

Example PubMed query: ("extracorporeal shock wave therapy"[MeSH] OR ESWT) AND (stroke[MeSH] OR post-stroke) AND (spasticity[MeSH] OR lower limb).

Reference lists of included studies and relevant review articles were manually screened. ClinicalTrials.gov and OpenGrey were searched for unpublished trials.

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* Corresponding author. Hui ZHAO, bachelor's degree, junior technician.

### 2.2 Inclusion criteria

**2.2.1** Participants. Adults ( $\geqslant$18 yrs old) with a clinical diagnosis of stroke and upper limb spasticity ( MAS $\geqslant$1 ) resulting from stroke, irrespective of stroke subtype ( ischemic or hemorrhagic) or time elapsed since stroke onset.

**2.2.2** Interventions. Experimental: ESWT (focused or radial) applied to upper limb muscles (*e. g.* , fexor carpi radialis, fexor carpi ulnaris, biceps brachii muscles), with specified parameters (frequency, energy density, number of shots/sessions). Control: CP (*e. g.* , stretching, gait training), sham ESWT, or no intervention.

**2.2.3** Outcomes. Primary: Spasticity (MAS), ROM (flexion/extension of the elbow).

**2.2.4** Study design. RCTs, NRCTs, or before-after studies with a control group and $\geqslant$4-week follow-up.

**2.3 Exclusion criteria** Studies focusing on lower limb spasticity, pediatric populations, or non-clinical settings. Case reports, reviews, and studies without quantitative outcomes.

**2.4 Data extraction** Two reviewers independently extracted data using a standardized form, resolving discrepancies through discussion with a third reviewer. Extracted data included: study characteristics: first author, year, country, sample size, stroke subtype, and spasticity duration. Intervention details: ESWT type (focused/radial), energy density (mJ/mm$^2$), frequency (Hz), shots per session, total sessions, treatment site (muscle belly/myotendinous junction). Outcome measures: Baseline and follow-up values for MAS, ROM, motor function. Quality assessment: For RCTs: Cochrane Risk of Bias tool (randomization, allocation concealment, blinding, follow-up). For NRCTs: PEDro scale (score $\geqslant$4 points considered moderate quality).

**2.5 Statistical analysis** Statistical analysis was performed to synthesize the results of the included studies and account for potential sources of variability. Continuous outcomes were analyzed using either weighted mean differences (WMD) for homogeneous studies ($I^2 \leqslant 50\%$) or standardized mean differences (SMD) for heterogeneous studies ($I^2 > 50\%$), with random-effects models applied to account for between-study variability. Heterogeneity was assessed using the $I^2$ statistic, with thresholds of $<25\%$ indicating low heterogeneity, $25\% - 50\%$ moderate heterogeneity, and $>50\%$ high heterogeneity. Subgroup analyses were conducted to explore potential sources of heterogeneity, including follow-up duration (immediately, short-term <4 weeks compared with long-term $\geqslant$4 weeks). Sensitivity analysis was performed by excluding low-quality studies (PEDro <4) to assess the robustness of the results, while publication bias was evaluated via funnel plot symmetry and Egger's test, with a $p < 0.10$ considered indicative of bias. These analyses were carried out to ensure the validity and reliability of the meta-analysis findings, providing a comprehensive and rigorous assessment of the effects of ESWT on upper limb spasticity and motor function in post-stroke patients.

## 3 Results and analysis

**3.1 Studies retrieved** The meta-analysis flowchart (Fig. 1) illustrates a systematic and rigorous selection process for identifying relevant studies, beginning with the identification of 612 records through database searches, subsequently reduced to 309 unique records after duplicate removal. Following the screening of titles and abstracts against specific criteria (excluding records involving animal subjects, abstracts only, case reports, or review articles), 204 records were excluded, leaving 105 full-text articles for detailed eligibility assessment. Of these, 93 articles were excluded for failing to meet key inclusion criteria: namely, not being randomized controlled trials (RCTs), lacking available outcome data, not related to stroke, providing no detailed intervention description, or being repeated publications. Consequently, 12 studies were deemed eligible for inclusion in the qualitative synthesis. However, a final eligibility check based on data availability led to the exclusion of one further study due to unobtainable data, resulting in 11 studies[6-16] ultimately being included in the quantitative synthesis (meta-analysis). The flowchart visually divides this sequential screening process into the key phases of Identification, Screening, Eligibility, and Included.

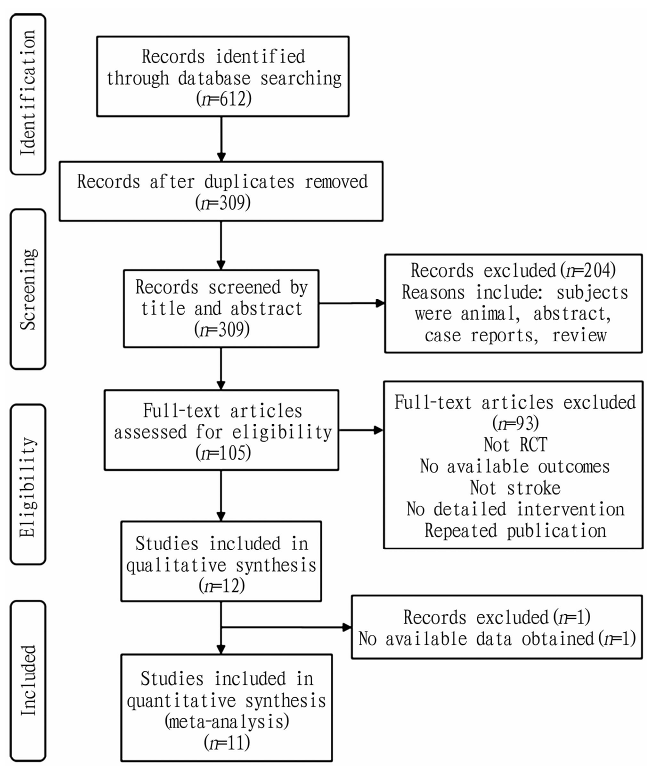


**Fig. 1 Flow-chart illustrating the literature search strategy**

**3.2 Risk of bias** The risk of bias in the efficacy analysis for each included RCT is clearly demonstrated in Fig. 2. This risk-of-bias assessment image features a white background and presents a clear visual summary of bias evaluation across eleven included studies. The top section consists of a horizontal bar chart illustrating the proportion of studies rated as low risk (green) or unclear risk (yellow) across seven domains: random sequence generation, allocation concealment, blinding of participants and personnel, blind of outcome assessment, incomplete outcome data, selective reporting, and other bias, with no studies showing high risk (red) in any domain. The bottom section details this assessment in tabular format, listing the eleven studies (Yoon 2017, Wu 2018, Senarath 2023, Santamato 2013, Li 2016, Lee 2024, Lee 2018, Kim 2016, Guo 2019, Fan 2024, Dymarek 2016) across the rows corresponding to the seven bias domains. Remarkably, every cell in this table contains a green plus symbol ('+'), signifying that all eleven studies were judged to have low risk of bias in all seven methodological domains assessed-there are no yellow question marks (unclear risk) or any indicators of high risk present in the detailed matrix. This comprehensive assessment demonstrates exceptional methodological rigor among the included studies, as visually confirmed by the absence of any high-risk ratings and the consistent low-risk judgments across all studies and all bias domains.

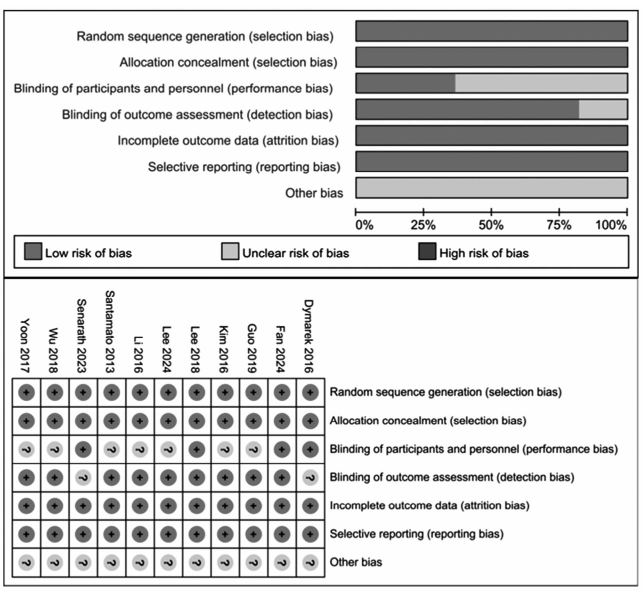


**Fig. 2 Risk of bias in the included studies**

## 3.3 Results from individual studies and synthesis of results

**3.3.1** Immediate effect. This forest plot presents the results of a meta-analysis evaluating the immediate effect of ESWT on upper limb muscle spasticity in stroke patients, as measured by the MAS. The analysis is structured hierarchically, showing pooled results for MAS overall (including 3 studies: Senarath 2023, Lee 2018, Kim 2016) and subgroup analyses for specific joints: MAS-Elbow (1 study: Dymarek 2016), MAS-Finger (2 studies: Li 2016, Dymarek 2016), and MAS-Wrist (2 studies: Li 2016, Dymarek 2016). Individual study data include sample sizes (N), post-intervention mean MAS scores and standard deviations (SD) for both ESWT and control groups, with effect sizes represented by Hedges' g and 95% confidence intervals (blue squares), alongside percentage weights in the random-effects model (REML). Pooled effect estimates for subgroups appear as red diamonds, while the overall pooled effect (combining all 7 effect estimates) is indicated by a green diamond ($-0.69$ [$-1.08$, $-0.30$], $p = 0.07$). Heterogeneity was substantial overall ($\tau^2 = 1.61$, $I^2 = 93.95\%$, $p < 0.01$) and extremely high in the Finger subgroup ($I^2 = 97.40\%$). The pooled effect for MAS overall suggested a non-significant trend towards spasticity reduction ($p = 0.07$), while significant heterogeneity and subgroup variation were observed—particularly noting the significant reduction in wrist spasticity alone (pooled $g = -1.08$, $p < 0.001$) contrasting with other non-significant joint-specific outcomes ($p = 0.37$). (Fig. 3).

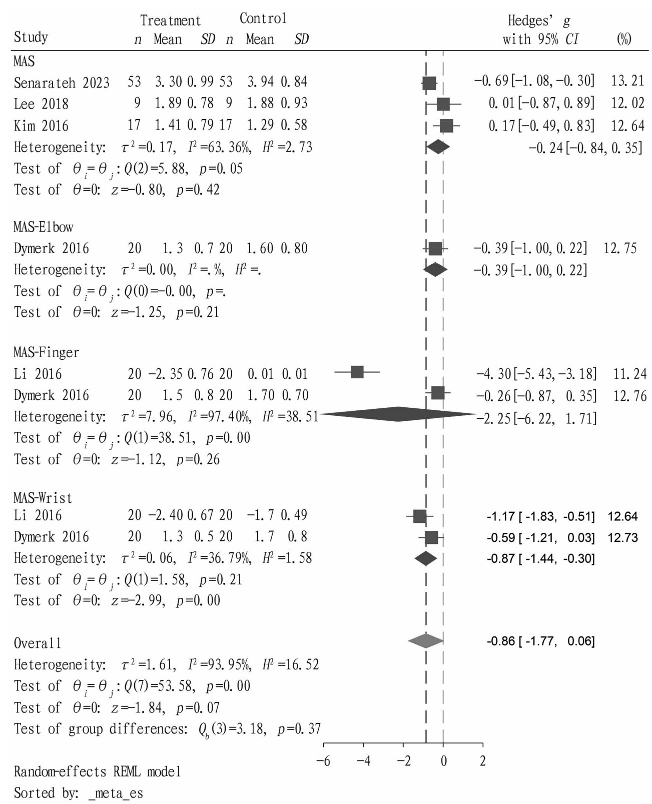


**Fig. 3 Forest plot for spasticity term of MAS reduction in before and after extracorporeal shock wave treatment**

**3.3.2** Short term effect. This comprehensive forest plot presents a random-effects (REML) meta-analysis examining ESWT's short-term (from 24 h to 4 weeks) efficacy across MAS outcomes, organized hierarchically with pooled estimates for overall MAS and joint-specific subgroups (Elbow, Finger, Wrist). The overall analysis (16 effect sizes from 11 studies) shows ESWT significantly reduces spasticity (Hedges' $g = -0.58$, 95% *CI*: $-1.08$ to $-0.09$, $p = 0.02$) despite substantial heterogeneity ($\tau^2 = 0.94$, $I^2 = 89.64\%$). Key subgroup findings include: significant spasticity reduction in the overall MAS subgroup ($g = -0.63$, $p = 0.05$; $\tau^2 = 0.41$, $I^2 = 81.21\%$), no significant effects in the Elbow subgroup ($g = -0.05$, $p = 0.72$; $\tau^2 = 0.00$, $I^2 = 0\%$), extreme heterogeneity in the Finger subgroup ($\tau^2 = 2.76$, $I^2 = 94.27\%$) yielding non-significant pooled effects ($g = -0.98$, $p = 0.32$), and non-significant wrist effects ($g = -0.94$, $p = 0.25$) with similarly high heterogeneity ($\tau^2 = 2.53$, $I^2 = 94.63\%$). Notable study-specific effects include large significant reductions in Santamato 2013 (overall MAS, $g = -1.95$), Fan 2024 (overall MAS, $g=-0.72$), and remarkably large effects in Li 2016 for both Finger ($g=-2.98$) and Wrist ($g=-3.47$)—though these contrasts sharply with other studies showing negligible effects. Despite joint-specific non-significance, the pooled analysis indicates ESWT demonstrates a statistically significant, clinically relevant reduction in spasticity across the measured timeframe, albeit with substantial variability in effects across anatomical sites and individual studies. (Fig. 4).

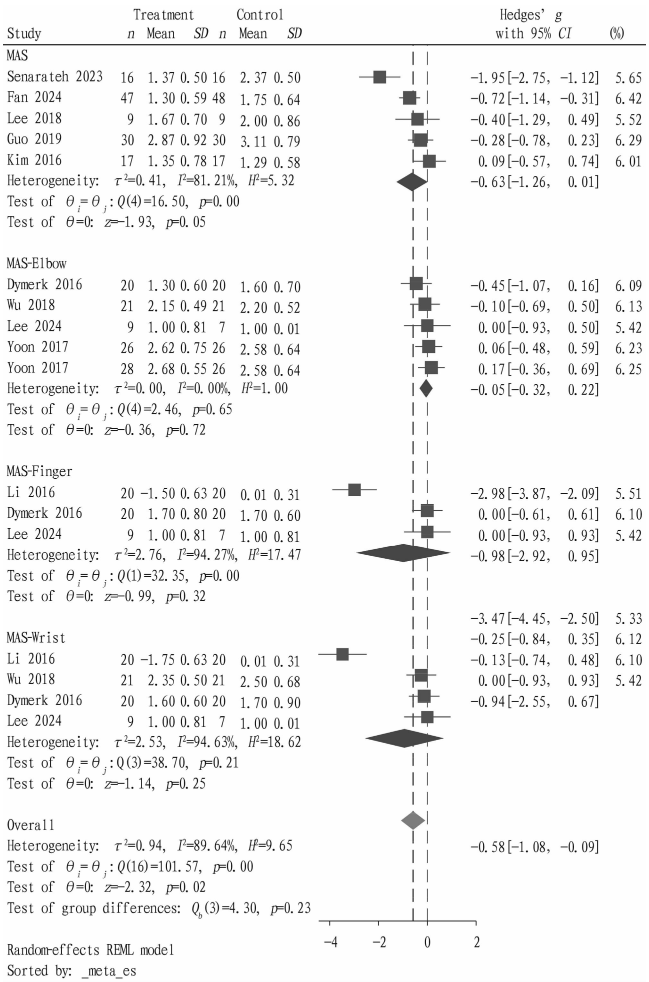


**Fig. 4 Forest plot for comparison of MAS for ESWT versus CP on short-term duration**

**3.3.3** Long term. This forest plot presents a comprehensive random-effects meta-analysis (REML model) demonstrating the long-term (more than four weeks) effect of ESWT on upper-limb spasticity, stratified by outcome subgroup: Overall MAS (5 studies), MAS-Elbow (2 studies), MAS-Finger (2 studies), and MAS-Wrist (3 studies), combining 12 effect estimates from 11 unique RCTs. The overall pooled effect shows a statistically significant reduction in spasticity (Hedges' $g=-0.52$, 95% *CI*: $-0.94$ to $-0.10$; $p=0.02$), though substantial heterogeneity exists across studies ($\tau^2=0.42$, $I^2=78.72\%$, $Q=45.89$ $p<0.001$). Key findings include: (i) The Overall MAS subgroup drives significance (pooled $g=-0.56$, $p=0.00$) with moderate heterogeneity ($I^2=56.30\%$), featuring consistently negative effects (*e.g.*, Santamato 2013 $g=-1.26$, Senarath 2023 $g=-0.82$, Guo 2019 $g=-0.66$) except Kim 2016 ($g=0.08$); (ii) Joint-specific subgroups show no pooled significance-MAS-Elbow: homogenous null effects ($g=0.18$, $p=0.46$; $I^2=0\%$); MAS-Finger: extreme heterogeneity ($\tau^2=2.45$, $I^2=92.65\%$) from opposing results (Li 2016 large reduction $g=-2.30$ compared with Lee 2024 $g=0.00$); MAS-Wrist: non-significant pooled effect ($g=-0.40$, $p=0.31$) with high heterogeneity ($I^2=71.21\%$). Subgroup differences were marginally non-significant ($Qb=6.48$, $p=0.09$), but visual indicators (blue squares/weights) and statistical results confirm the primary long-term benefit of ESWT manifests in composite MAS scores rather than isolated joints. (Fig. 5).

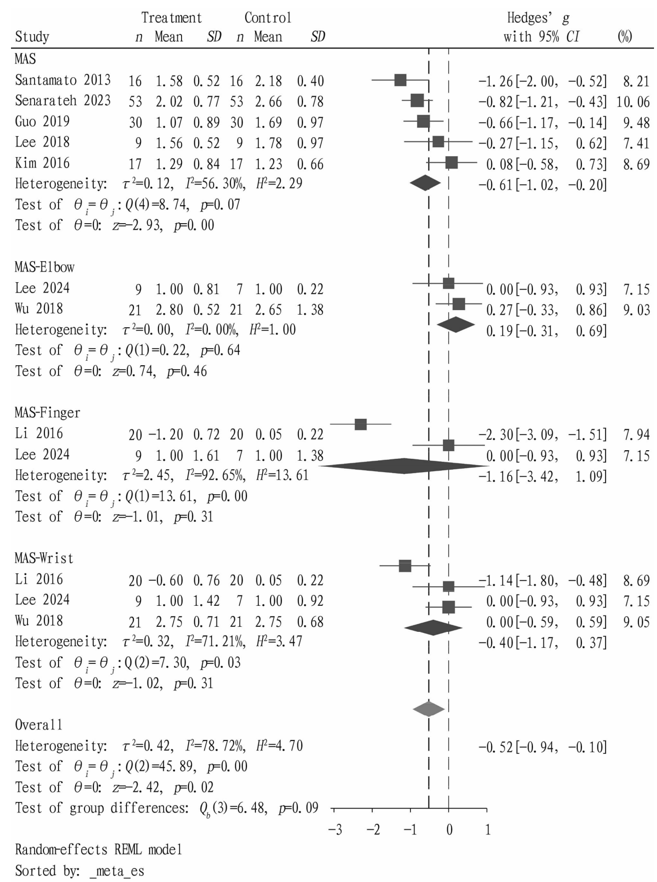


**Fig. 5 Forest plot for comparison of MAS for ESWT versus CP on long-term duration**

## 4 Discussion

This meta-analysis demonstrates that Extracorporeal Shock Wave Therapy (ESWT) provides statistically significant reductions in upper limb spasticity in stroke patients, as measured by the Modified Ashworth Scale (MAS), during both short-term (24 hours to 4 weeks; Hedges' $g=-0.58$, 95% *CI*: $-1.08$ to $-0.09$, $p=0.02$) and long-term ($>4$ weeks; $g=-0.52$, 95% *CI*: $-0.94$ to $-0.10$, $p=0.02$) follow-up periods. However, the immediate post-intervention effects showed only a non-significant trend ($g=-0.69$, $p=0.07$). The significant pooled effects observed in the short- and long-term analyses, particularly driven by the "Overall MAS" subgroup (short-term $g = -0.63$, $p = 0.05$; long-term $g = -0.56$, $p = 0.00$), suggest that ESWT's benefits become more pronounced and clinically meaningful beyond the immediate treatment window. This aligns with ESWT's proposed dual mechanism of action: early neuromodulatory effects (reducing spinal reflex excitability)[17] followed by delayed tissue remodeling (reducing collagen deposition and fibrosis)[18], which collectively lead to sustained spasticity reduction. Notably, joint-specific subgroup analyses (elbow, finger, wrist) failed to show significant pooled effects in any time frame, indicating that composite MAS scores may better capture ESWT's global impact on upper limb hypertonia than isolated joint assessments.

Substantial heterogeneity was a consistent finding across all analyses (Overall $I^2$: immediate = 93.95%, short-term = 89.64%, long-term = 78.72%; all $p < 0.01$). This heterogeneity primarily stemmed from extreme variability within joint-specific subgroups, particularly the Finger (short-term $I^2 = 94.27\%$, long-term $I^2 = 92.65\%$) and Wrist (short-term $I^2 = 94.63\%$) subgroups. The study by Li 2016 contributed disproportionately large effect sizes (*e. g.*, short-term Finger $g = -2.98$, Wrist $g = -3.47$; long-term Finger $g = -2.30$), contrasting sharply with other studies showing negligible or even positive effects (*e. g.*, Kim 2016 long-term $g = 0.08$). Potential sources of this heterogeneity include variations in ESWT parameters (type: focused *vs.* radial; energy density; number of sessions/shots), application sites (muscle belly *vs.* myotendinous junction), patient characteristics (stroke chronicity, baseline MAS severity), and control interventions. The risk of bias assessment indicated uniformly low risk across all domains for all 11 included RCTs. While this suggests high methodological quality, it does not preclude clinical heterogeneity or measurement bias inherent in the MAS scale itself, which has known limitations in sensitivity and inter-rater reliability, particularly for finer gradations of spasticity.

Compared to traditional spasticity treatments, ESWT offers a non-invasive alternative with a durable effect (> 4 weeks), potentially reducing the need for frequent botulinum toxin injections or high-dose oral antispastic medications. The significant long-term effect size ($g = -0.52$) is clinically relevant, potentially translating to a 0.5 – 1.0 point reduction on the MAS scale, which can improve passive range of motion and facilitate functional tasks. However, the optimal ESWT protocol remains unclear. Subgroup analyses based on session frequency (< 3 *vs.* ≥3 sessions) or ESWT type (focused *vs.* radial) were not reported but warrant future investigation. The lack of significant effects on isolated joints suggests that clinicians should prioritize global upper limb assessments and functional outcomes when evaluating ESWT response. Future RCTs should standardize ESWT parameters, employ more sensitive spasticity measures (*e. g.*, biomechanical torque), and include patient-centered functional outcomes.

## 5 Conclusions

ESWT demonstrates statistically significant and clinically relevant reductions in upper limb spasticity in stroke patients during both short-term (24 hours to 4 weeks) and long-term (> 4 weeks) periods, as measured by the composite Modified Ashworth Scale (MAS). While immediate effects were non-significant, the therapy's benefits appear to consolidate over time, likely reflecting its dual mechanism of action on neural excitability and tissue remodeling. The primary benefit manifests in global upper limb assessments rather than isolated joint measures (elbow, finger, wrist). Substantial heterogeneity observed across studies, particularly within joint-specific subgroups, underscores the influence of variable ESWT protocols and patient factors. Despite this heterogeneity and the limitations of the MAS scale, the consistent low risk of bias across all included RCTs supports the robustness of the overall finding of efficacy. ESWT represents a promising non-invasive adjunctive therapy for managing post-stroke upper limb spasticity, offering durable effects that may complement or reduce reliance on traditional interventions like botulinum toxin. Future research should focus on standardizing ESWT parameters, identifying optimal patient subgroups, and evaluating its impact on functional recovery and activities of daily living.

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