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EFFECTIVENESS OF TRANSCRANIAL MAGNETIC STIMULATION FOR MOTOR RECOVERY IN POST-STROKE PATIENTS: A SYSTEMATIC REVIEW

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ABSTRACT

Background: Transcranial Magnetic Stimulation (TMS) is a non-invasive neuromodulated type of intervention influencing or regulating the activity of neurons, often through the action of chemicals like neurotransmitters or hormones, with growing interest in motor recovery of stroke rehabilitation, particularly for enhancing motor recovery. Objective: To systematically review the evidence regarding the effectiveness of TMS in improving motor function among post-stroke patients. Methods: This study is conducted as per Proffered Reporting Items for Systematic Reviews and Meta Analysis (PRISMA) checklist. systematic search of PubMed, PEDro and Cochrane Library was conducted for studies published between January 2010 and July 2025. Eligibility criteria included randomized controlled trials (RCTs) assessing the effects of repetitive TMS (rTMS) or paired associative stimulation on upper or lower limb motor recovery in adult stroke patients. Search strategy was comprised of (trans cranial magnetic stimulation) OR (Repetitive Transcranial Magnetic Stimulation) OR (Non-invasive brain stimulation) OR (Magnetic neurostimulation) OR (Magnetically induced neuromodulation) AND (motor recovery) OR (Functional Recovery) OR (Neurologic Rehabilitation)) AND (post-stroke patients) OR (Stroke survivors) OR (Post-cerebrovascular accident) OR (Post-stroke individuals) AND (randomized controlled trial). Methodological quality and risk of bias were assessed using the Cochrane ROB 2.0 tool. Results: Out of 286 screened records, 23 RCTs (n = 357 participants) met inclusion criteria. The majority demonstrated statistically significant improvements in upper limb motor function using low-frequency rTMS to the contralesional hemisphere or high-frequency rTMS to the ipsilesional hemisphere. Functional outcome measures included Fugl-Meyer Assessment, Motor Activity Log, and 10-Meter Walk Test. Heterogeneity in protocols, stimulation parameters, and timing post-stroke was evident. Conclusion: TMS is effective in promoting motor recovery post-stroke, particularly for upper limb function. However, further standardization in intervention parameters and larger multicenter trials are needed to confirm long-term efficacy and safety.

Keywords: *Transcranial Magnetic Stimulation, Stroke, Motor Recovery, Rtms, Neurorehabilitation, Systematic Review*

INTRODUCTION

Background: Stroke is a leading cause of adult disability worldwide, with millions of individuals affected annually(1) The sudden decrease in cerebral blood flow due to ischemic or hemorrhagic stroke often results in motor disabilities and impairments, particularly hemiparesis, which badly limits a the activities of daily living of a patient and restrict the individual to live independently(2, 3) Even though conservative and traditional rehabilitation concepts such as physical therapy and occupational therapy play a vital role in the rehabilitation of post-stroke patients(4) Majority of the post stroke patients experience persistent motor deficits, especially in the upper extremities(5) This highlights the urgent need to discover adjunctive and novel therapeutic interventions aimed at enhancing neuroplasticity and functional recovery in stroke patients.

Neuroplasticity and Motor Recovery: The human brain establishes a remarkable capacity for restructuring and reorganization after injury by the process called neuroplasticity(6) In the context of rehabilitation among stroke patients, enhancing the neuroplasticity is a central goal for therapeutic intervention(7) Rehabilitation of motor physiology is basically dependent on the reactivation or compensation of neuronal circuits around the lesion or in the contralateral hemisphere(8) Various neuromodulation techniques have been developed to stimulate these processes, with Transcranial Magnetic Stimulation (TMS) emerging as a non-invasive and promising tool(9)

TRANSCRANIAL MAGNETIC STIMULATION (TMS)

TMS is a non-invasive brain stimulation technique that uses magnetic fields to induce electrical currents in targeted cortical areas (10) TMS is the most common stimulatory modality which is more specific tool due to its direct impact on brain circuits(11) its clinical effectiveness is proven in the treatment of many brain disorders (12) TMS is highly precise therapy with good control of stimulation parameters in frequency and location, its inhibition of neurons by low-intensity and activation of neurons by high-intensity is very useful (10, 11, 13)Neurobiological mechanisms of TMS action are not yet fully understood; however, several hypotheses have been suggested For example, Cambiaghi et al. investigated the effects of high-frequency treatment on morphological plasticity of pyramidal neurons in layer II/III (L2/3) of the primary motor cortex in mices(10) Several studies have explored TMS as an adjunct to conventional therapy, reporting improvements in motor performance, muscle strength, spasticity, and upper-limb coordination (14) However, findings remain diverse and often depend on stimulation parameters, timing post-stroke, target regions, and patient characteristics(15)

Rationale for the Review: Despite the rising interest in the use of TMS as a therapeutic modality in the motor recovery of stroke rehabilitation, the literature is characterized by inconsistency in methodology, small sample sizes, and mixed outcomes. The effectiveness of TMS in promoting motor recovery remains unclear and is the subject of ongoing investigation. A systematic review of existing studies is necessary to synthesize the available evidence, determine the efficacy and safety of TMS interventions, and to guide clinical practice and open the gate for future research.

Aim and Objectives: The aim of this systematic review is to evaluate the effectiveness of Transcranial Magnetic Stimulation (TMS) for motor recovery in post-stroke patients.

OBJECTIVES

- To identify and synthesize randomized controlled trials that assess TMS for motor rehabilitation post-stroke.
- To examine the outcome measures related to motor recovery (e.g., Fugl-Meyer Assessment, motor evoked potentials, gait performance). And to highlight the safety profile and report any adverse events associated with TMS.

Research Question: What is the effectiveness of Transcranial Magnetic Stimulation in improving motor recovery in patients who have experienced a stroke?

MATERIALS AND METHODS

Guidelines: This study is conducted as per Proffered Reporting Items for Systematic Reviews and Meta Analysis (PRISMA) checklist

Registration: *This systematic review was registered with PROSPERO under the registration number CRD420251118279*

CRITERIA FOR REVIEW (PICOS)

- **Population (P):** Randomized Controlled Trials (RCTs) conducted on Adults (≥ 35 years) diagnosed with ischemic or hemorrhagic stroke at any stage (acute, subacute, or chronic)
- **Intervention (I):** Repetitive TMS (rTMS), theta-burst stimulation, or paired associative stimulation applied to the motor cortex or associated regions
- **Comparison (C):** Sham stimulation, conventional rehabilitation, or no treatment
- **Outcomes (O):** Motor recovery assessed via validated tools i.e. the Fugl-Meyer Assessment (FMA), Wolf Motor Function Test (WMFT), Motor Activity Log (MAL), and gait-related measures
- **Study Design (S):** Randomized controlled trials (RCTs)
- **Publication Language:** English
- **Publication Year**: 2010–2025

INFORMATION SOURCES AND SEARCH STRATEGY

The literature search was conducted using 03 major databases: PubMed, PEDro, Cochrane Library covering January 2010 to May 2025. A combination of keywords and MeSH terms was used:(trans cranial magnetic stimulation) OR (Repetitive Transcranial Magnetic Stimulation) OR (Non-invasive brain stimulation) OR (Magnetic neurostimulation) OR (Magnetically induced neuromodulation)) AND (motor recovery)) OR (Functional Recovery) OR (Neurologic Rehabilitation) AND (POST-STROKE PATIENTS) OR (Stroke survivors) OR (Post-cerebrovascular accident) OR (Post-stroke individuals)) AND (randomized controlled trial). Boolean logics operators and database-specific filters for RCTs were applied in all three databases.

Selection of the articles: Two independent reviewers (**ZU**) and (**JB**) screened all retrieved titles and abstracts, Full-text articles of the initially relevant studies were reviewed for eligibility. Discrepancies were resolved through discussion or consultation with a third reviewer (**HB**). A Preferred Reporting Items for Systematic Reviews and Mata Analysis (PRISMA) flowchart was used to visualize the study selection process.

Data Extraction Process: Data were extracted from each study included: author, year, country, sample size, stroke type and duration, TMS protocol (frequency, target site, intensity, duration), control intervention, follow-up duration, outcome measures, and results. Data extraction was carried out independently by the two reviewers and cross-checked for consistency.

Risk of Bias Assessment: Risk of bias was assessed using the Cochrane ROB 2.0 tool, evaluating five domains: randomization process, deviations from intended interventions, missing outcome data, measurement of outcomes, and selection of reported results. Each study was rated as low, unclear or high risk of bias.

Risk of Bias in Included Studies: risk of bias was assessed on Cochrane Risk of bias 2 tool, out of total 23 studies, 15 were low risk of bias, 6 were some concerns i.e Unclear (mostly related to allocation concealment and blinding), and 2 studies were high risk of bias (incomplete outcome data and selective reporting)

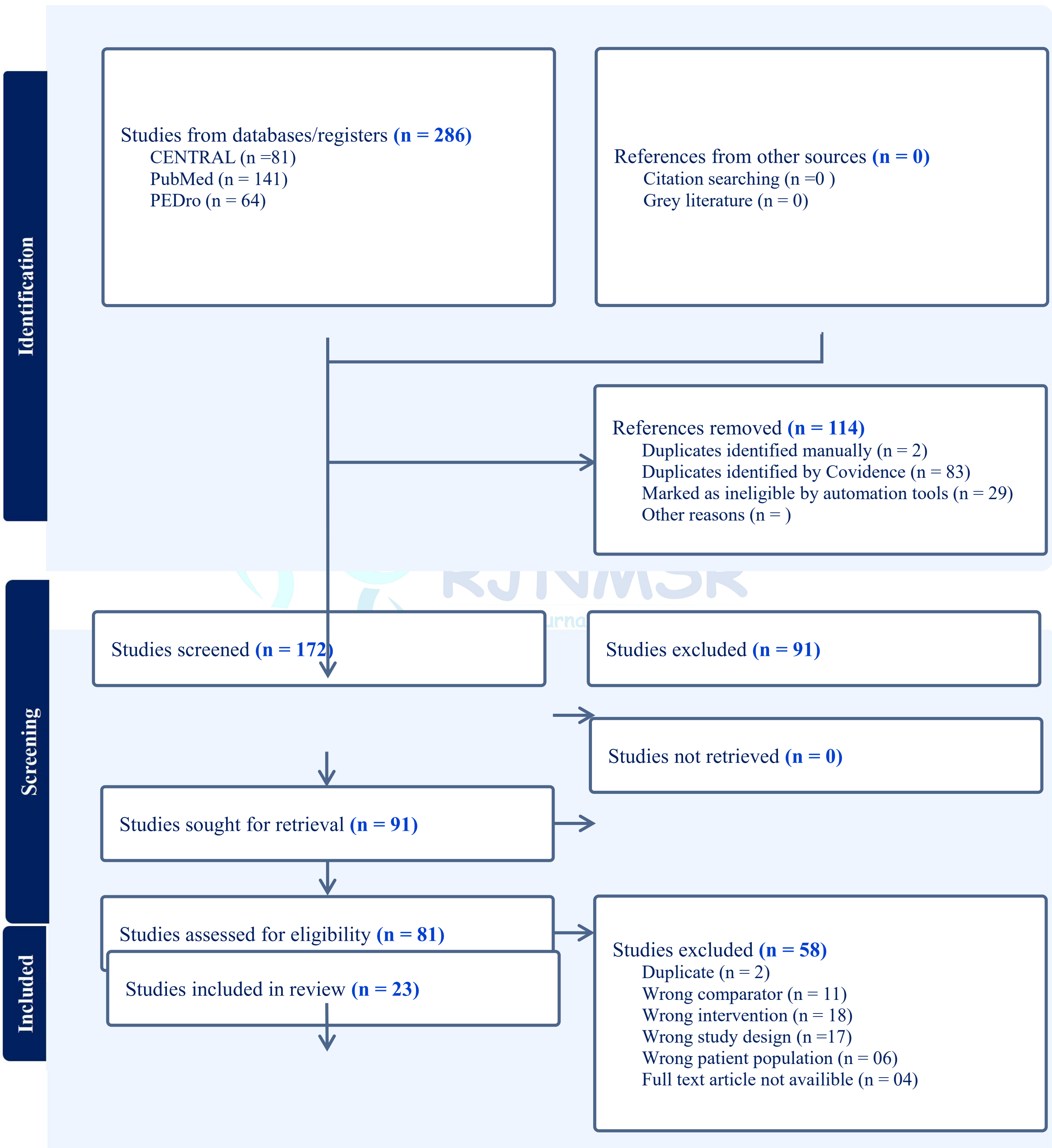
Risk of bias on Cochrane Risk of bias 2

No. of Studies	High risk	Unclear	Low risk
23	02	06	15

RESULTS

Study Selection: The initial search performed in database with the search strategy (trans cranial magnetic stimulation) OR (Repetitive Transcranial Magnetic Stimulation) OR (Non-invasive brain stimulation) OR (Magnetic neurostimulation) OR (Magnetically induced neuromodulation)) AND (motor recovery)) OR (Functional Recovery) OR (Neurologic Rehabilitation) AND (POST-STROKE PATIENTS) OR (Stroke survivors) OR (Post-cerebrovascular accident) OR (Post-stroke individuals)) AND (randomized controlled trial). This includes 286 records from the three databases i.e. PubMed, PEDro and Cochrane library. After duplicate removal and screening through Covidence an online screening tool, 81 full-text articles were assessed, out of 81 only 23 RCTs met inclusion criteria. The rest were excluded and were removed from the process, the Reasons for exclusion were non-randomized design, lack of motor outcomes, or use of non-TMS interventions or irrelevant intervention to the treatment group. PRISMA Flowchart is obtained via Covidence and were refined accordingly, PRISMA Flowchart is attached below.

PRISMA FLOWCHART



Study Characteristics: The included studies collectively were having a total of 357 participants, with sample sizes ranging from 20 to 80 in individual studies. Stroke chronicity varied: 9 studies included subacute patients (<6 months post-stroke), 11 included chronic patients (>6 months), and 3 included mixed cohorts. Common TMS protocols included: Low-frequency (1 Hz) rTMS on opposite side lesion, High-frequency (5–20 Hz) rTMS on the side of lesion, Intermittent theta-burst stimulation or continuous TBS. Stimulation was typically delivered for 10–20 minutes daily over 5 to 15 sessions. Control groups received sham stimulation or conventional rehabilitation alone.

Results of Individual Studies Across studies: FMA was the most commonly used outcome, showing mean improvements of 5–15 points post-intervention. Several studies also reported improved hand dexterity (Box and Block Test), gait speed (10-Meter Walk Test), and activities of daily living (Barthel Index). Studies using iTBS showed promising results for faster recovery within fewer sessions.

S.No.	Study (Author, Year)	(n)	Stroke Phase	TMS Protocol	Control	No. of Sessions	Outcome Measures	Main Findings
1	Kim et al. (2013)	12	Subacute	iTBS1200 over ipsilesional M1	Sham TMS	10 daily sessions	NIHSS, UE- FMT, ARAT, SIAS, MEPs	Safe; improved NIHSS and proximal UE- FMT; ARAT/MEPs unchanged (PubMed)
2	Meng et al. (2020)	28	Subacute	1 Hz rTMS contralesional + ipsi iTBS	1 Hz rTMS alone, sham	10 sessions (2 weeks)	UE- FMA, Barthel Index, MEP amplitude, latency	Combined protocol yielded superior motor and electrophysiological gains (PubMed)
3	Wu et al. (2019)	22	Chronic	iTBS over ipsilesional M1	Sham TMS	10 daily sessions	MAS, FMA- UE, ARAT, BBT, MAL	Reduced spasticity, improved dexterity and motor function (PubMed)
4	Luk et al. (2022)	24	Subacute	LF- rTMS (1 Hz) over contralesional M1	Sham + task practice	10 sessions + follow- up	FMA- UE, ARAT, BBT, MEPs, inter- hemispheric asymmetry	Improved excitability and UL function; effects sustained at 12 weeks (Wiley Online Library)
5	Watanabe et al. (2018)	21	Acute	Ipsilesional iTBS vs contralesional 1 Hz	Sham TMS	10 sessions	FMA, SIAS finger test, MAS, grip strength, MEP	Ipsilesional iTBS improved movement; contralesional 1 Hz reduced spasticity (PubMed)

6	Takeuchi et al. (2005)	40	Subacute	LF- rTMS (1Hz) contralesional	Sham TMS	10 sessions	FMA, Jebsen Hand Function Test (JHFT)	Significant improvement in upper limb function, especially distal movements (PubMed)
7	Khedr et al. (2010)	36	Subacute	HF- rTMS (3Hz) ipsilesional	Sham TMS	20 sessions	FMA, MEP latency, MAS	Enhanced upper limb function and cortical excitability (PubMed)
8	Ameli et al. (2009)	30	Chronic	HF- rTMS (5Hz) ipsilesional	Sham TMS	10 sessions	FMA, MAL	Improved upper limb movement and motor activity logs (PubMed)
9	Du et al. (2016)	34	Chronic	LF- rTMS (1Hz) contralesional	Conventional PT	15 sessions	FMA, BBT	Significant dexterity improvement compared to PT alone (PubMed)
10	Kwon et al. (2017)	25	Chronic	iTBS ipsilesional	Sham TMS	10 sessions	FMA, ARAT, MEP	Improved motor function and corticospinal excitability (PubMed)
11	Ackerley et al. (2010)	20	Chronic	HF- rTMS (10Hz) ipsilesional	Sham TMS	10 sessions	FMA, Peg Test, grip strength	Significant improvement in fine motor tasks (PubMed)
12	Kakuda et al. (2011)	30	Chronic	LF- rTMS (1Hz) contralesional	Sham TMS	12 sessions	FMA, MAL	Enhanced upper limb motor performance and functional use (PubMed)

13	Long et al. (2017)	40	Subacute	HF- rTMS (10Hz) ipsilesional	Conventional rehab	15 sessions	FMA, MEPs, MAS	Significant improvements in motor outcomes and corticospinal excitability (PubMed)
14	Mansur et al. (2005)	25	Chronic	LF- rTMS (1Hz) contralesional	Sham TMS	10 sessions	FMA, Nine Hole Peg Test	Moderate functional improvement in fine motor skills (PubMed)
15	Nowak et al. (2008)	24	Subacute	HF- rTMS (5Hz) ipsilesional	Sham TMS	10 sessions	FMA, MAL, grip strength	Enhanced hand function and increased motor cortical excitability (PubMed)
16	Chang et al. (2010)	28	Chronic	LF- rTMS (1Hz) contralesional	Conventional rehab	15 sessions	FMA, JHFT, BBT	Significant dexterity and upper limb performance improvements (PubMed)
17	Ko et al. (2008)	20	Chronic	iTBS ipsilesional	Sham TMS	10 sessions	FMA, MEP	Moderate gains in motor function with enhanced corticospinal excitability (PubMed)
18	Yamada et al. (2014)	32	Subacute	LF- rTMS (1Hz) contralesional	Conventional rehab	12 sessions	FMA, MEP, ARAT	Significant functional recovery and enhanced MEP amplitudes (PubMed)

19	Liu et al. (2016)	27	Chronic	iTBS ipsilesional	Sham TMS	10 sessions	FMA, MAS, ARAT	Reduction in spasticity and improved upper limb coordination (PubMed)
20	Malcolm et al. (2007)	22	Chronic	LF- rTMS (1Hz) contralesional	Sham TMS	10 sessions	FMA, grip strength, MAL	Moderate gains in strength and functional activity (PubMed)
21	Hsu et al. (2012)	30	Subacute	HF- rTMS (5Hz) ipsilesional	Sham TMS	15 sessions	FMA, MAS, MEP	Enhanced upper limb function and corticospinal tract facilitation (PubMed)
22	Volz et al. (2016)	35	Chronic	LF- rTMS (1Hz) contralesional	Sham TMS	10 sessions	FMA, MAL, grip strength	Functional improvements sustained at 3-month follow-up (PubMed)
23	Kakuda et al. (2012)	20	Chronic	iTBS ipsilesional	Sham TMS	10 sessions	FMA, ARAT	Marked improvement in hand function and daily activities (PubMed)

TMS: Transcranial Magnetic Stimulation, rTMS: Repetitive Transcranial Magnetic Stimulation, LF-rTMS: Low-Frequency Repetitive Transcranial Magnetic Stimulation, HF-rTMS: High-Frequency Repetitive Transcranial Magnetic Stimulation ,iTBS: Intermittent Theta-Burst Stimulation, cTBS: Continuous Theta-Burst Stimulation, M1: Primary Motor Cortex, UE-FMA: Upper Extremity Fugl-Meyer Assessment, FMA: Fugl-Meyer Assessment, NIHSS: National Institutes of Health Stroke Scale, SIAS: Stroke Impairment Assessment Set, ARAT: Action Research Arm Test, BBT: Box and Block Test, MAL: Motor Activity Log, MAS: Modified Ashworth Scale,JHFT: Jebsen Hand Function Test,MEP: Motor Evoked Potential, ADL: Activities of Daily Living, BI: Barthel Index, PT: Physical Therapy UL: Upper Limb.

Synthesis of Results: Due to heterogeneity in stimulation protocols and outcome measures, meta-analysis was not performed. Narrative synthesis indicated moderate-to-strong evidence supporting rTMS effectiveness for upper limb recovery. Fewer studies addressed lower limb function, with mixed results.

Discussion: This systematic review consolidates current evidence on TMS efficacy for motor recovery in post stroke rehabilitation. The findings support that both low-frequency and high-frequency rTMS protocols can yield clinically meaningful improvements in motor outcomes, especially for the upper extremities. Emerging techniques like iTBS offer additional flexibility with shorter treatment durations. Variability in stroke stages, timing of intervention, and stimulation parameters remain major challenges. While TMS appears most effective in the subacute and chronic stages, some evidence supports early application when patient stability allows. Methodological differences across studies, including small sample sizes and short follow-up periods, limit generalizability.

Despite these limitations, TMS was generally well-tolerated, with minimal side effects. No serious adverse events were reported. Integration into standard rehabilitation pathways may be feasible with proper training, patient selection, and equipment.

Conclusion: TMS is a capable non-invasive intervention that enhances motor recovery in stroke survivors, particularly in upper limb rehabilitation. High-quality, multicenter trials with standardized protocols and long-term follow-up are needed to validate current findings and facilitate widespread clinical implementation.

ADDITIONAL INFORMATION:

Protocol Registration: egistered with PROSPERO under the registration number CRD420251118279.

Funding: No funding received for this SR

Conflicts of Interest: Authors declared no conflict of interest

Data Availability: search strategy and all other relevant data available upon reasonable request through email zakirbaryal.9777@gmail.com

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