Journal of Health Physiotherapy and Orthopaedics

Research Article

Comparative effectiveness of repetitive transcranial magnetic stimulation and transcranial direct current stimulation on post-stroke spasticity: a narrative review

Reenu Devi*, Supreet Bindra, Pankaj preet Singh, Harshdeep kaur

Sri Guru Granth Sahib World University, Fatehgarh Sahib, Punjab, India

Corresponding author: Reenu Devi, ✉ devireenu491@gmail.com, **Orcid Id**: https://orcid.org/0009-0003-3991-1207

Received - 12-06-2026**, Revised** - 15-07-2026, **Accepted** - 20-08-2026 **(DD-MM-YYYY)**

Refer this article

Reenu Devi, Supreet Bindra, Pankaj Preet Singh, Harshdeep Kaur, Comparative effectiveness of repetitive transcranial magnetic stimulation and transcranial direct current stimulation on post-stroke spasticity: a narrative review, Journal of Health Physiotherapy and Orthopaedics. July-August 2026, V 3 - I 4, Pages - 15 – 18. Doi: https://doi.org/10.55522/jhpo.V3I4.0095.

ABSTRACT

In recent years, non-invasive brain stimulation techniques such as Repetitive Transcranial Magnetic Stimulation (rTMS) and Transcranial Direct Current Stimulation (tDCS) have emerged as promising interventions for improving stroke related comorbidities, particularly post-stroke spasticity. However, direct comparisons between these two modalities are limited, which makes clinical decision-making unclear. Therefore, this study aimed to compare the effectiveness of rTMS and tDCS in the management of post-stroke spasticity. The databases used were Google Scholar, MEDLINE, PubMed, and ResearchGate for studies published in the English language between years 2010-2025. A total of 21 studies were included in this review based on the selection criteria. We found that both interventions are effective in reducing spasticity, more importantly when supplemented by conventional physiotherapy and rehabilitation methods. Relative comparison suggested that rTMS showed slightly greater clinical improvement in spasticity. In conclusion, both rTMS and tDCS are effective treatments for post-stroke spasticity, However, rTMS may offer a more reliable reduction in spasticity than tDCS, although further well-designed comparative research is required to determine the feasibility, optimal practice and long-term outcomes.

Keywords: Stroke, Spasticity, Repetitive transcranial magnetic stimulation (rTMS), Transcranial direct current stimulation (tDCS).

INTRODUCTION

Stroke is a major leading cause of long-term neurological disability worldwide and contributes significantly to mortality and functional dependence [1]. It is defined as rapid onset of clinical signs of focal or global disturbance of cerebral function lasting more than 24 hours or leading to death with no apparent cause other than of vascular origin [2]. Stroke may be ischemic or hemorrhagic in nature, with ischemic stroke accounting for nearly 80% of all cases [2, 3]. Stroke survivors commonly experience motor, sensory, cognitive and language impairments that limit the activities of daily living and social participation [3].

One of the most incapacitating motor impairments is spasticity that occurs after stroke, which is characterised by a velocity-dependent increase in muscle tone associated with exaggerated tendon reflexes, resulting from upper motor neuron lesions [4,5]. It occurs in 30–80% of stroke survivors and typically develops within the first 1–3 months following stroke [6,7]. Spasticity most commonly involves flexor muscles of the upper limb and the extensor muscles of the lower limb, which can result in pain, poor mobility, abnormal posture, and a lower quality of life [8-10].

Management of post-stroke spasticity involves pharmacological intervention (e.g., botulinum toxin and oral antispastic medications), surgical procedures, and rehabilitation strategies such as stretching, splinting, electrical stimulation, task-oriented training, and physiotherapy [11-13]. More recently, non-invasive methods such as rTMS and tDCS are starting to be used as therapies, due to the ability to modulate cortical excitability and promote neuroplasticity [14,15].

In Repetitive Transcranial Magnetic Stimulation (rTMS), electromagnetic induction is used to manipulate cortical excitability, with high-frequency stimulation increasing excitability in the hemisphere it is targeting while low-frequency stimulation inhibits hyperexcitability in the contralesional hemisphere, balancing interhemispheric function [16,17]. Likewise, Transcranial Direct Current Stimulation (tDCS) uses scalp electrodes to pass a 1-2 mA electrical current through the scalp, inducing changes in neuronal membrane potentials and cortical excitability. The direction of current flow, anodal or cathodal, changes cortical excitability in the respective hemispheres to balance function [18,19].

Although both approaches have proved to be beneficial for the outcome of stroke-related spasticity and motor recovery, evidence from the direct comparison of rTMS and tDCS on post-stroke spasticity is limited, and inconsistent findings of available evidence regarding their efficacy make clinical decision-making uncertain. Therefore, the current review aimed to compare the effectiveness of rTMS and tDCS on post-stroke spasticity. [10].

MATERIAL AND METHODS

Study design

This study was conducted as a narrative review to compare the effectiveness of rTMS and tDCS on post-stroke spasticity.

Data sources and search strategy

A literature search was performed using electronic databases including PubMed, Google Scholar, ResearchGate, and MEDLINE. Keywords such as "Stroke", "Spasticity", "Repetitive Transcranial Magnetic Stimulation (rTMS)", and "Transcranial Direct Current Stimulation (tDCS)" were used.

Inclusion criteria

Articles published between 2010 to 2025 were included.

Studies including subjects with chronic and subacute stroke were included.

Studies involving adult subjects aged 18 years and above were included.

Both male and female subjects were included.

Articles published in English were included.

Full-text published articles were included.

Exclusion criteria

Studies not involving rTMS or tDCS interventions were excluded.

Unpublished articles were excluded.

Articles available only as abstracts were excluded.

RESULTS

A total of 21 studies were included in this review, based on selection criteria. The characteristics of the included studies are summarized in Tables 1, 2 and 3. Based on the selection criteria, a total of 11 studies have reported the effectiveness of rTMS on post-stroke spasticity, while 9 studies have reported the effectiveness of tDCS on post-stroke spasticity, and 1 study directly compared the effectiveness of rTMS and tDCS [11].

Table 1: Studies showing effectiveness of rTMS on post-stroke spasticity

Author/ Year	Title of the study	Study Design	Intervention	Outcome Measures	Results
Kakuda *et al*. [20] (2011)	Antispastic effect of low-frequency rTMS applied with occupational therapy in post-stroke patients with upper limb hemiparesis.	Prospective clinical study	22 sessions of low-frequency rTMS + occupational therapy over 15 days	MAS, FMA, WMFT	Significant reduction in finger and wrist spasticity; significant improvement in motor function.
Etoh *et al*. [21] (2013)	Effects of repetitive transcranial magnetic stimulation on repetitive facilitation exercises of the hemiplegic hand in chronic stroke patients.	Randomized double-blind crossover study	1-Hz rTMS + repetitive facilitation exercises for 2 weeks	FMA, ARAT, STEF, MAS, F-wave	Improved motor function; no significant change in spasticity.
Galvão *et al*. [22] (2014)	Efficacy of Coupling Repetitive Transcranial Magnetic Stimulation and Physical Therapy to Reduce Upper-Limb Spasticity in Patients with Stroke.	Randomized sham-controlled trial	10 sessions of 1 Hz rTMS + physical therapy vs sham + physical therapy	MAS, FMA, FIM, QoL	Significant reduction in spasticity; 90% achieved ≥1-point MAS improvement.
Naghdi *et al*. [23] (2014)	The effects of low-frequency repetitive transcranial magnetic stimulation on lower extremity spasticity and motor neuron excitability in patients after stroke.	Pilot study	1 Hz rTMS for 5 days	MMAS, Hmax/Mmax ratio, FMA, TUG	Significant reduction in lower-limb spasticity and improved motor function.
Rastgoo *et al*. [24] (2016)	Effects of repetitive transcranial magnetic stimulation on lower extremity spasticity and motor function in stroke patients.	Randomized crossover trial	Active vs sham rTMS for 5 sessions	MMAS, H-reflex, LE-FMA, TUG	Active rTMS significantly reduced spasticity and improved motor recovery.
Özkeskin *et al*. [25] (2017)	The Effects of Navigated Repetitive Transcranial Magnetic Stimulation and Brunnstrom Movement Therapy on Upper Extremity Proprioceptive Sense and Spasticity in Stroke Patients.	Double-blind randomized trial	rTMS + Brunnstrom Movement Therapy	BRS, Proprioception Tests, MAS	Improved motor function and proprioception; no significant spasticity change.
Aşkın *et al*. [26] (2017)	Effects of low-frequency rTMS on upper extremity motor recovery and functional outcomes in chronic stroke patients.	Randomized controlled trial	Low-frequency rTMS + physical therapy for 4 weeks	FMA, BBT, MAS, FIM, MMSE, BRS, FAS	Improved motor recovery, cognition, and reduced spasticity.
Chervyakov *et al*. [27] (2018)	Effects of navigated repetitive transcranial magnetic stimulation in stroke	Randomized sham-controlled trial	Low-frequency, high-frequency, or combined rTMS + rehabilitation	FM, MAS, BI	Significant improvement in motor function, spasticity, and functional independence.

Kuzu *et al.* [28] (2021)	The effect of sham-controlled continuous theta burst stimulation and low-frequency repetitive transcranial magnetic stimulation on upper extremity spasticity and functional recovery in chronic ischemic stroke patients	Randomized sham-controlled trial	Real rTMS or cTBS + physical therapy	MAS, FMA, FIM, MAL	Improved motor function and ADL; limited improvement in spasticity.
Mahmoud *et al.* [29] (2023)	Testing spasticity mechanisms in chronic stroke before and after intervention with contralesional motor cortex 1 Hz rTMS and physiotherapy	Clinical interventional study	Contralesional 1-Hz rTMS + physiotherapy	FMA-UE, WMFT, MAS, MAL, VAS	Significant reduction in spasticity and improvement in motor function.
Shaik,[30] (2025)	Effect of Repetitive Transcranial Magnetic Stimulation on Spasticity in Stroke patients	Randomized controlled trial	rTMS + physiotherapy vs physiotherapy alone	MAS, H-reflex parameters	Greater reduction in spasticity and spinal motor neuron excitability.

* MAS: Modified Ashworth Scale, FMA: Fugl-Meyer Assessment, WMFT: Wolf Motor Function Test, ARAT: Action Research Arm Test, STEF: Simple Test for Evaluating Hand Function, F-wave: F-wave Response, FIM: Functional Independence Measure, QoL: Quality of Life, MMAS: Modified Modified Ashworth Scale, Hmax/Mmax Ratio: Hoffman Reflex to Maximum Muscle Response Ratio, TUG: Timed Up and Go Test, LE-FMA: Lower Extremity Fugl-Meyer Assessment, BRS: Brunnstrom Recovery Stages, BBT: Box and Block Test, MMSE: Mini-Mental State Examination, FAS: Functional Ambulation Scale, FM: Fugl-Meyer Motor Assessment, BI: Barthel Index, MAL: Motor Activity Log, VAS: Visual Analogue Scale.

Table 2: Studies showing effectiveness of tDCS on post-stroke spasticity

Author/ Year	Title of the Study	Study Design	Intervention	Outcome Measures	Results
Bradnam *et al.* [31] (2011)	Contralesional Hemisphere Control of the Proximal Paretic Upper Limb following Stroke.	Cross-over experimental study	Cathodal tDCS (1 mA, 20 min) vs sham stimulation	FMA, ARAT, MAS, SR	Severity-dependent effects; improved proximal control in mild cases.
Wu *et al.* [32] (2013)	Effects on Decreasing Upper-Limb Poststroke Muscle Tone Using Transcranial Direct Current Stimulation.	Randomized sham-controlled trial	Cathodal tDCS + conventional treatment for 4 weeks	MAS, FMA, BI	Significant reduction in spasticity and improved motor and functional outcomes.
Ochi *et al.* [33] (2013)	Effects of anodal and cathodal transcranial direct current stimulation combined with robotic therapy on severely affected arms in chronic stroke patients.	Double-blind crossover study	Anodal/cathodal tDCS + robotic arm training	FMUL, MAS, MAL	Both protocols improved motor function; cathodal stimulation better reduced finger spasticity.
Lee and Chun, [34] (2014)	Combination Transcranial Direct Current Stimulation and Virtual Reality Therapy for Upper Extremity Training in Patients with Subacute Stroke.	Pilot randomized controlled trial	Cathodal tDCS, VR, or combined tDCS + VR	MAS, MMT, MFT, FMS, BBT, K-MBI	Combination therapy produced greater upper-limb recovery.
Viana *et al*. [35] (2014)	Effects of the addition of transcranial direct current stimulation to virtual reality therapy after stroke.	Double-blind randomized controlled trial	tDCS + virtual reality therapy vs sham	FMA-UL, WMFT, MAS, Grip Strength, QoL	Significant improvement in both groups; only wrist spasticity improved significantly with tDCS.
Del Felice *et al.* [36] (2016)	Contralesional Cathodal versus Dual Transcranial Direct Current Stimulation for Decreasing Upper Limb Spasticity in Chronic Stroke Individuals.	Double-blind crossover study	Cathodal tDCS vs dual tDCS	MAS, MRC, ARAT, Postural Scales, H-reflex	Both improved spasticity and function; cathodal tDCS showed superior effects.
Koh *et al.* [37] (2017)	Effects of Transcranial direct current stimulation with sensory modulation on stroke motor rehabilitation.	Double-blind randomized controlled trial	tDCS + sensory modulation vs sham	FMA-UE, MAS, ARAT, BI	Non-significant trends toward motor improvement; limited effect on spasticity.
Halakoo *et al.* [38] (2020)	Does anodal transcranial direct current stimulation of the damaged primary motor cortex affect wrist flexor muscle spasticity and also activity of the wrist flexor and extensor muscles in patients with stroke?	Double-blind sham-controlled RCT	Anodal tDCS + FES vs sham + FES vs FES	MAS, EMG (FCR, ECR)	Significant reduction in wrist spasticity and improved muscle activity.
Molero-Chamizo *et al.* [15] 2021	Bilateral Motor Cortex tDCS Effects on Post-Stroke Pain and Spasticity.	Double-blind crossover pilot study	Anodal tDCS vs sham stimulation	MAS, AVAS	Significant pain reduction; limited effect on spasticity.

*SR: Stretch Reflex, FMUL: Fugl-Meyer Upper Limb Assessment, MMT: Manual Muscle Testing, MFT: Manual Function Test, FMS: Functional Movement Scale, K-MBI: Korean Modified Barthel Index, FMA-UL: Fugl-Meyer Assessment-Upper Limb, Grip Strength: Hand Grip Strength, MRC: Medical Research Council Scale, Postural Scales: Postural Assessment Scales, FMA-UE: Fugl-Meyer Assessment-Upper Extremity, FES: Functional Electrical Stimulation, EMG: Electromyography, FCR: Flexor Carpi Radialis, ECR: Extensor Carpi Radialis, AVAS: Adapted Visual Analogue Scale.

Table 3: The comparative effectiveness of rTMS and tDCS on post-stroke spasticity

Author (Year)	Title of the Study	Study Design	Intervention	Outcome Measures	Results
Miu *et al.* [39] 2020	Comparison of Repetitive Transcranial Magnetic Stimulation and Transcranial Direct Current Stimulation on Upper Limb Recovery Among Patients With Recent Stroke.	Single-blind RCT	rTMS or tDCS followed by rehabilitation for 2 weeks	MAS, MBI, Handgrip Strength, FMA, NHPT	Both groups improved significantly; rTMS showed slightly greater but non-significant improvement in spasticity and hand function.

* MBI: Modified Barthel Index, NHPT: Nine-Hole Peg Test.

DISCUSSION

Our results have been reported as per the study objectives.

The effects of rTMS on reducing post-stroke spasticity have been well studied, with most studies showing significant effects. Most of the studies showed that rTMS could ameliorate post-stroke spasticity along with improved motor function and outcomes. Reductions in spasticity of the upper limbs and increased motor function were found, as well as reductions in lower limb spasticity and improved motor function. The results suggest that rTMS may be able to modulate abnormal muscle tone along with promoting motor relearning post-stroke.

This may be explained by the interhemispheric inhibition theory: by suppressing cortical hyperexcitability of the non-affected hemisphere, the balance of the bilateral neural network between hemispheres could be reset, increasing excitability of the motor cortex of the affected side, enhancing activation of the corticospinal pathway, promoting voluntary motor control and also reducing excitability of spinal motor neurons and exaggerated stretch reflex activity of spastic limbs [27]. In addition, applying rehabilitation interventions along with rTMS can lead to better cortical reorganisation, neuroplasticity, motor relearning, and improvement of function [23,24,27]. However, there were some studies without significant reduction in spasticity. Motor function improved, but spasticity did not significantly decrease in the study. Motor relearning and increased proprioception were demonstrated; muscle tone was not affected. Similarly, improved motor function and activities of daily living but spasticity showed only slight changes. This indicates that improvement in motor function was not associated with changes in muscle tone.

Differences among study outcomes could be due to differences in stimulation protocol, course of treatment, rehabilitation methods, sample sizes, and time after stroke. Chronic changes following stroke might cause degeneration and modification of reflex pathways of the spinal cord, making rTMS less effective in modulating the tone of spastic limbs [21,25,28]. Generally, rTMS might be an available and promising adjunct therapy for post-stroke spasticity.

Conversely, tDCS intervention for post-stroke spasticity has demonstrated variable but generally beneficial outcomes across studies. Significant reductions in spasticity were observed, and there was a greater reduction of spasticity with cathodal stimulation, indicating that inhibitory stimulation of the non-affected hemisphere could be beneficial for control of pathological muscle tone. Sustained effect of tDCS on wrist spasticity showed significantly greater improvements in wrist spasticity in the tDCS group than in the control group.

Some studies found a dose- or severity-dependent effect of tDCS, reported better outcomes in less impaired patients than those with greater neurological impairment. The findings suggest that the response to tDCS for spasticity is influenced by the severity of stroke-related disability.

The mechanism through which tDCS decreases post-stroke spasticity may be related to changes in corticospinal excitability, balance between hemispheres and suppression of overactivity in the non-affected hemisphere. These effects may result in improved normalization of corticospinal and spinal reflex function and therefore reduce abnormal muscle tone. Furthermore, the use of tDCS in conjunction with rehabilitation may increase cortical plasticity and reorganize the cerebral cortex, leading to improved modulation of the activity in muscles [31,33,36,38].

However, not all the reviewed studies resulted in significant decreases in spasticity. Limited changes were observed; highly variable responses were found only one participant achieving clinically meaningful improvements in spasticity. Inconsistent results among studies might be attributed to a number of factors such as patient characteristics, including severity and chronicity of stroke, as well as tDCS parameters, such as electrode montage, stimulation intensity and duration, and inter-individual differences in responses to neuromodulation. These factors might impact the effect of tDCS on corticospinal excitability and on the neural processes related to spasticity [15,37]. Overall, the evidence reviewed supports the use of tDCS to reduce post-stroke spasticity, particularly when integrated with rehabilitation, but its efficacy seems dependent on patient selection and treatment parameters.

Most research studying rTMS and tDCS coupled these two interventions with additional rehabilitation training, including conventional physiotherapy, occupational therapy, robot-assisted arm training, virtual reality therapy, Brunnstrom Movement Therapy, and upper-limb exercises, which bolstered their effects on post-stroke spasticity. Positive results were commonly seen in studies using low-frequency rTMS (1Hz, 20-30 min/session for 5 days to 4 weeks) and cathodal tDCS (1-2 mA, 10-20 min/session for 5 days to 5 weeks). MAS, MMAS, and H-reflex parameters were most frequently documented as improved, indicating reduced tone and excitability of the spinal motor neuron.

To more directly compare the effectiveness of these two neuromodulation methods, Miu et al. [39] applied low-frequency rTMS (1 Hz at 90% motor threshold for 20 minutes) or cathodal tDCS (1.5 mA for 20 minutes) to the non-lesioned motor cortex. Following neuromodulation, the patients underwent upper-limb rehabilitation for 60 minutes three times per week for 2 weeks. While both methods showed significant improvements in motor function and spasticity, there was no statistically significant difference between the groups. However, the rTMS group demonstrated slightly greater improvements in spasticity and finer hand function than the tDCS group. rTMS may be more effective because it has more targeted cortical modulation and less inter-individual variability. Furthermore, subject-specific variables such as brain-derived neurotrophic factor (BDNF) genotype,[40] sulcal depth, and skull thickness may affect the response to tDCS but appear to have less of an effect on the response to rTMS. Consequently, rTMS may be a more reliable treatment to achieve therapeutic effects.

Limitations

Most of the studies comparing Repetitive Transcranial Magnetic Stimulation (rTMS) examined both upper-limb and lower-limb post-stroke spasticity, while the majority of Transcranial Direct Current Stimulation (tDCS) studies focused only on upper-limb spasticity; there is very little research done on the effect of tDCS on lower-limb post-stroke spasticity, thus limiting its generalizability to lower-limb function outcomes. Secondly, a lot of the studies used rTMS and tDCS in conjunction with standard treatments, such as physiotherapy and task-oriented training, so it is hard to determine the isolated effect of rTMS and tDCS on spasticity.

Future directions

Further studies are required to examine the effects of tDCS on lower limb spasticity post-stroke and long-term follow-up of rTMS and tDCS are needed.

CONCLUSION

Both rTMS and tDCS are effective interventions for reducing post-stroke spasticity. The studies have shown that rTMS is generally more consistent and reliable, whereas tDCS is also effective but with more variation in its application depending on parameters and combination with rehabilitation. Overall, no clear distinction could be seen of which technique was better than the other. Both are not a standalone technique and are more useful when applied in conjunction with existing rehabilitation protocols, and act as an adjuvant therapy. There are also a greater number of studies supports the use of rTMS in post-stroke spasticity than tDCS.

REFERENCES

1. Lavados PM, Hennis AJ, Fernandes JG, et al, 2007. Stroke epidemiology, prevention, and management strategies at a regional level: Latin America and the Caribbean. The Lancet Neurology. 6(4), Pages 362-372. Doi: 10.1016/S1474-4422(07)70003-0.
2. Markus H, 2003. Stroke Genetics. Oxford Medical Publications. Oxford University Press. Doi: https://doi.org/10.1093/brain/awh062.
3. Lance JW, 1980. The control of muscle tone, reflexes, and movement: Robert Wartenbeg Lecture. Neurology. 30(12), Pages 1303-1303. Doi: https://doi.org/10.1212/WNL.30.12.1303.
4. Bethoux F, 2015. Spasticity management after stroke. Physical Medicine and Rehabilitation Clinics. 26(4), Pages 625-639. Doi: 10.1016/j.pmr.2015.07.003.
5. Alashram AR, Padua E, Aburub A, et al, 2023. Transcranial direct current stimulation for upper extremity spasticity rehabilitation in stroke survivors: A systematic review of randomized controlled trials. PM&R. 15(2), Pages 222-234. Doi: 10.1002/pmrj.12804.
6. Kuo CL, Hu GC, 2018. Post-stroke spasticity: a review of epidemiology, pathophysiology, and treatments. International Journal of Gerontology. 12(4), Pages 280-284. Doi: https://doi.org/10.1016/j.ijge.2018.05.005.
7. Wissel J, Schelosky LD, Scott J, et al, 2010. Early development of spasticity following stroke: a prospective, observational trial. Journal of Neurology. 257(7), Pages 1067-1072. Doi: 10.1007/s00415-010-5463-1.
8. Lundström E, Smits A, Terént A, et al, 2010. Time course and determinants of spasticity during the first six months following first-ever stroke. Journal of Rehabilitation Medicine. 42(4), Pages 296-301. Doi: 10.2340/16501977-0509.
9. Harrison RA, Field TS, 2015. Post-stroke pain: identification, assessment, and therapy. Cerebrovascular Diseases. 39(3-4), Pages 190-201. Doi: 10.1159/000375397.
10. Ozcakir S, Sivrioglu K, 2007. Botulinum toxin in poststroke spasticity. Clinical medicine & research. 5(2), Pages 132-138. Doi: https://doi.org/10.3121/cmr.2007.716.
11. Kofler M, Quirbach E, Schauer R, et al, 2009. Limitations of intrathecal baclofen for spastic hemiparesis following stroke. Neurorehabilitation and Neural Repair. 23(1), Pages 26-31. Doi: 10.1177/1545968308317700.
12. Stein C, Fritsch CG, Robinson C, et al, 2015. Effects of electrical stimulation in spastic muscles after stroke: systematic review and meta-analysis of randomised controlled trials. Stroke. 46(8), Pages 2197-2205. Doi: https://doi.org/10.1161/STROKEAHA.115.009633.
13. Chen YT, Li S, DiTommaso C, et al, 2019. Possible contributions of ipsilateral pathways from the contralesional motor cortex to the voluntary contraction of the spastic elbow flexors in stroke survivors: a TMS study. American journal of physical medicine & rehabilitation. 98(7), Pages 558-565. Doi: 10.1097/PHM.0000000000001147.
14. Molero-Chamizo A, Salas Sánchez Á, Álvarez Batista B, et al, 2021. Bilateral motor cortex tDCS effects on post-stroke pain and spasticity: a three-case study. Frontiers in Pharmacology. 12, Pages 624582. Doi: 10.3389/fphar.2021.624582.

15. Nowak DA, Grefkes C, Ameli M, et al, 2009. Interhemispheric competition after stroke: brain stimulation to enhance recovery of function of the affected hand. Neurorehabilitation and neural repair. 23(7), Pages 641-656. Doi: https://doi.org/10.1177/1545968309336661.

16. Corti M, Patten C, Triggs W, 2012. Repetitive transcranial magnetic stimulation of motor cortex after stroke: a focused review. American Journal of Physical Medicine & Rehabilitation. 91(3), Pages 254-270. Doi: 10.1097/PHM.0b013e318228bf0c.

17. Nitsche MA, Paulus W, 2000. Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation. The Journal of Physiology. 527(3), Pages 633. Doi: 10.1111/j.1469-7793.2000.t01-1-00633.

18. Williams JA, Imamura M, Fregni F, 2009. Updates on the use of non-invasive brain stimulation in physical and rehabilitation medicine. Journal of Rehabilitation Medicine. 41(5), Pages 305-311. Doi: 10.2340/16501977-0356.

19. Kakuda W, Abo M, Kobayashi K, et al, 2011. Antispastic effect of low-frequency rTMS applied with occupational therapy in post-stroke patients with upper limb hemiparesis. Brain Injury. 25(5), Pages 496-502. Doi: 10.3109/02699052.2011.559610.

20. Etoh S, Noma T, Ikeda K, et al, 2013. Effects of repetitive transcranial magnetic stimulation on repetitive facilitation exercises of the hemiplegic hand in chronic stroke patients. Journal of Rehabilitation Medicine. 45(9), Pages 843-847. Doi: 10.2340/16501977-1175.

21. Galvão SC, Dos Santos RB, Dos Santos PB, et al, 2014. Efficacy of coupling repetitive transcranial magnetic stimulation and physical therapy to reduce upper-limb spasticity in patients with stroke: a randomised controlled trial. Archives of physical medicine and rehabilitation. 95(2), Pages 222-229. Doi: http://dx.doi.org/10.1016/j.apmr.2013.10.023.

22. Naghdi S, Ansari NN, Rastgoo M, et al, 2015. A pilot study on the effects of low-frequency repetitive transcranial magnetic stimulation on lower extremity spasticity and motor neuron excitability in patients after stroke. Journal of bodywork and movement therapies. 19(4), Pages 616-623. Doi: http://dx.doi.org/10.1016/j.jbmt.2014.10.001.

23. Rastgoo M, Naghdi S, Nakhostin Ansari N, et al, 2016. Effects of repetitive transcranial magnetic stimulation on lower extremity spasticity and motor function in stroke patients. Disability and Rehabilitation. 38(19), Pages 1918-1926. Doi: http://dx.doi.org/10.3109/09638288.2015.1107780.

24. Özkeskin M, Öztürk V, Çakmur R, et al, 2017. The effects of navigated repetitive transcranial magnetic stimulation and Brunnstrom movement therapy on upper extremity proprioceptive sense and spasticity in stroke patients: a double-blind randomised trial. Journal of Basic and Clinical Health Sciences. 1(2), Pages 29-35. Doi: 10.5152/jbachs.2017.110.

25. Aşkın A, Tosun A, Demirdal ÜS, 2017. Effects of low-frequency repetitive transcranial magnetic stimulation on upper extremity motor recovery and functional outcomes in chronic stroke patients: a randomised controlled trial. Somatosensory & Motor Research. 34(2), Pages 102-107. Doi: https://doi.org/10.1080/08990220.2017.1316254.

26. Chervyakov AV, Poydasheva AG, Lyukmanov RH, et al, 2018. Effects of navigated repetitive transcranial magnetic stimulation after stroke. Journal of Clinical Neurophysiology. 35(2), Pages 166-172. Doi: 10.1097/WNP.0000000000000456.

27. Kuzu Ö, Adiguzel E, Kesikburun S, et al, 2021. The effect of sham-controlled continuous theta burst stimulation and low-frequency repetitive transcranial magnetic stimulation on upper extremity spasticity and functional recovery in chronic ischemic stroke patients. Journal of Stroke and Cerebrovascular Diseases. 30(7), Pages 105795. Doi: https://doi.org/10.1016/j.jstrokecerebrovasdis.2021.105795.

28. Mahmoud W, Hultborn H, Zuluaga J, et al, 2023. Testing spasticity mechanisms in chronic stroke before and after intervention with contralesional motor cortex 1 Hz rTMS and physiotherapy. Journal of NeuroEngineering and Rehabilitation. 20(1), Pages 150. Doi: https://doi.org/10.1186/s12984-023-01275-9.

29. Shaik AR, 2025. Effect of repetitive transcranial magnetic stimulations on spasticity in stroke patients: a randomized controlled trial. Journal of Pioneering Medical Sciences. 14, Pages 449-455. Doi: https://doi.org/10.47310/jpms202514S0159.

30. Bradnam LV, Stinear CM, Barber PA, et al, 2012. Contralesional hemisphere control of the proximal paretic upper limb following stroke. Cerebral Cortex. 22(11), Pages 2662-2671. Doi: 10.1093/cercor/bhr344.

31. Wu D, Qian L, Zorowitz RD, et al, 2013. Effects on decreasing upper-limb poststroke muscle tone using transcranial direct current stimulation: a randomized sham-controlled study. Archives of physical medicine and rehabilitation. 94(1), Pages 1-8. Doi: http://dx.doi.org/10.1016/j.apmr.2012.07.022.

32. Ochi M, Saeki S, Oda T, et al, 2013. Effects of anodal and cathodal transcranial direct current stimulation combined with robotic therapy on severely affected arms in chronic stroke patients. Journal of Rehabilitation Medicine. 45(2), Pages 137-140. Doi: 10.2340/16501977-1099.

33. Lee SJ, Chun MH, 2014. Combination transcranial direct current stimulation and virtual reality therapy for upper extremity training in patients with subacute stroke. Archives of physical medicine and rehabilitation. 95(3), Pages 431-438. Doi: http://dx.doi.org/10.1016/j.apmr.2013.10.027.

34. Viana RT, Laurentino GE, Souza RJ, et al, 2014. Effects of the addition of transcranial direct current stimulation to virtual reality therapy after stroke: a pilot randomized controlled trial. NeuroRehabilitation. 34(3), Pages 437-446. Doi: 10.3233/NRE-141065.

35. Del Felice A, Daloli V, Masiero S, et al, 2016. Contralesional cathodal versus dual transcranial direct current stimulation for decreasing upper limb spasticity in chronic stroke individuals: a clinical and neurophysiological study. Journal of Stroke and Cerebrovascular Diseases. 25(12), Pages 2932-2941. Doi: 10.1016/j.jstrokecerebrovasdis.2016.08.008.

36. Koh CL, Lin JH, Jeng JS, et al, 2017. Effects of transcranial direct current stimulation with sensory modulation on stroke motor rehabilitation: a randomized controlled trial. Archives of physical medicine and rehabilitation. 98(12), Pages 2477-2484. Doi: 10.1016/j.apmr.2017.05.025.

37. Halakoo S, Ehsani F, Masoudian N, et al, 2021. Does anodal transcranial direct current stimulation of the damaged primary motor cortex affects wrist flexor muscle spasticity and also activity of the wrist flexor and extensor muscles in patients with stroke?: A Randomized Clinical Trial. Neurological

Sciences. 42(7), Pages 2763-2773. Doi: https://doi.org/10.1007/s10072-020-04858-9.

38. Miu KY, Kok C, Leung SS, et al, 2020. Comparison of repetitive transcranial magnetic stimulation and transcranial direct current stimulation on upper limb recovery among patients with recent stroke. Annals of rehabilitation medicine. 44(6), Pages 428-437. Doi: https://doi.org/10.5535/arm.20093.

39. Antal A, Chaieb L, Moliadze V, et al, 2010. Brain-derived neurotrophic factor (BDNF) gene polymorphisms shape cortical plasticity in humans. Brain stimulation. 3(4), Pages 230-237. Doi: https://doi.org/10.1016/j.brs.2009.12.003.

40. Opitz A, Paulus W, Will S, et al, 2015. Determinants of the electric field during transcranial direct current stimulation. Neuroimage. 109, Pages 140-150. Doi: 10.1016/j.neuroimage.2015.01.033.