NeuroRegulation

Application of Transcutaneous Electrical Nerve Stimulation (TENS) in Stroke Rehabilitation: An Umbrella Review

Sahand Eslami[1,2], Fateme Tahmasbi[1,3], Sanam Mohammadzadeh[1,4], Sarvin Sanaie[5], Salar Ghaderi[1,4], and Alireza Rahimi Mamaghani[6]

[1]Research Center for Evidence-based Medicine, Iranian EBM Centre: A JBI Centre of Excellence, Faculty of Medicine, Tabriz University of Medical Sciences, Tabriz, Iran
[2]Immunology Research Center, Tabriz University of Medical Sciences, Tabriz, Iran
[3]Social Determinants of Health Research Center, Health Management and Safety Promotion Research Institute, Tabriz University of Medical Sciences, Tabriz, Iran
[4]Tabriz University of Medical Sciences, Tabriz, Iran
[5]Research Center for Integrative Medicine in Aging, Aging Research Institute, Tabriz University of Medical Sciences, Tabriz, Iran
[6]Clinical Research Development Unit of Tabriz Valiasr Hospital, University of Medical Sciences, Tabriz, Iran

Abstract

Background. Given that stroke is one of the most important causes of long-term disability, it is essential to adopt efficient rehabilitation techniques to maximize functional recovery. Transcutaneous electrical nerve stimulation (TENS) has become a viable treatment option for stroke recovery in recent years. **Method**. A systematic search was conducted in several databases and complemented by manual searches of reference lists. Study selection criteria included systematic reviews, with or without meta-analyses, that assessed the effects of TENS on poststroke rehabilitation. The quality of the studies was assessed using the JBI assessment tool. **Results**. According to 34 systematic reviews, TENS is applied in several settings in poststroke rehabilitation, including motor dysfunction, urinary and fecal dysfunction, spasticity, and pain management, and has shown promising results in these areas. However, the absence of standardized guidelines makes it challenging to determine the optimal TENS parameters for specific poststroke rehabilitation goals. **Conclusion**. The application of TENS in poststroke rehabilitation has shown potential benefits. While these potential benefits are promising, it is important to note that the effectiveness of TENS may vary among individuals, and further research is needed to understand its optimal application and long-term effects.

Keywords: transcutaneous electric nerve stimulation (TENS); stroke; rehabilitation; systematic review

Citation: Eslami, S., Tahmasbi, F., Mohammadzadeh, S., Sanaie, S., Ghaderi, S., & Mamaghani, A. R. (2024). Application of transcutaneous electrical nerve stimulation (TENS) in stroke rehabilitation: An umbrella review. *NeuroRegulation, 11*(3), 304–325. https://doi.org/10.15540/nr.11.3.304

***Address correspondence to**: Dr. Alireza Rahimi Mamaghani, Valiasr Hospital, Tabriz, Iran, 5157935818. Email: rahimi.as@gmail.com

Edited by:
Rex L. Cannon, PhD, Currents, Knoxville, Tennessee, USA

Reviewed by:
Rex L. Cannon, PhD, Currents, Knoxville, Tennessee, USA
Michael Keane, PhD, Actualise Psychological Services, Dublin, Ireland

Introduction

Stroke is one of the primary causes of permanent disability and impairment all over the world (Katan & Luft, 2018). In recent years, due to the declining stroke mortality rate, along with population growth and aging, there has been an increase in the number of people living with the consequences of this condition (Donkor, 2018). Hence, rehabilitation plays a crucial role in the recovery and overall outcomes of stroke patients (Hatem et al., 2016).

One noninvasive method that has gained popularity is transcutaneous electrical nerve stimulation (TENS), which involves the application of electrical currents through the skin to stimulate peripheral nerves. Though its most prevalent usage is for pain management, TENS is increasingly being employed in rehabilitation for various purposes (Tahmasbi, Ghaderpanah, et al., 2023). For instance, several studies have suggested its beneficial effect on enhancing fecal or urinary function (Tahmasbi, Hosseini, et al., 2023; Tahmasbi, Mosaddeghi-Heris, et al., 2023; Tahmasbi et al., 2024).

In poststroke settings, the application of TENS has gained attention as a potential approach for rehabilitative purposes, offering noninvasive electrical stimulation to modulate neural pathways and promote recovery (In et al., 2021). For instance, stroke survivors often experience chronic pain, muscle stiffness, and discomfort. Different studies have suggested that TENS can help alleviate pain by stimulating the nerves and blocking pain signals to the brain (Li et al., 2023; Zhou et al., 2018). In addition, TENS has shown beneficial effects on regaining functional abilities, including muscle strength and balance, in stroke survivors (Cho et al., 2013; Jung et al., 2017).

However, the existing body of evidence on the effects of TENS in stroke rehabilitation is scattered across various systematic reviews (SR[s]) and meta-analyses (MA[s]), making it challenging to derive conclusive findings. An umbrella review, which systematically evaluates and synthesizes the findings of multiple SRs, can provide a comprehensive overview of the available evidence and offer valuable insights into the effectiveness of an intervention (Beheshti et al., 2023). Hence, this study aims to assess the current evidence on the use of TENS for stroke rehabilitation, providing a consolidated analysis of the existing SRs in this field.

Method

Registration and Ethics of Approval Statement

Upon registration of the study protocol with PROSPERO, an international prospective register of systematic reviews, a SR was carried out (reference number: CRD42023449886). The Preferred Reporting Items for Systematic Reviews (PRISMA) criteria have been followed in the presentation of the study's results (Page et al., 2021). The Ethical Committee of Tabriz University of Medical Sciences approved the current study (Code: IR.TBZMED.REC.1402.706). The protocol of the current study was registered in the Research Center for Evidence-based Medicine, Iranian EBM Centre: A JBI Centre of Excellence, Faculty of Medicine, Tabriz University of Medical Sciences (Code: 72647).

Review Question

The following research question was developed prior to designing the search strategy: "What evidence is available through the current SRs on the effects of TENS for the rehabilitation of stroke?"

Searching the Literature

As shown in Table 1, we created the search strategy in accordance with PICOS recommendations:

- P – population (stroke survivors aged ≥18 years),
- I – intervention (TENS),
- C – comparison (conventional rehabilitation, sham control, etc.),
- O – outcome (valid and reliable outcomes related to poststroke rehabilitation), and
- S – study design (SR, with and without MA).

Table 1
Different Key Terms Used in Designing the Search Strategy

Population	Intervention	Study design
Stroke	Transcutaneous electrical nerve stimulation	Systematic review
Cerebrovascular accident	Transcutaneous electrostimulation	Meta-analysis
Cerebrovascular apoplexy	Transcutaneous neuromodulation	
Brain Vascular accident	Transcutaneous nerve stimulation	
Brain infarction	Electrostimulation	
CVA	Electrical stimulation	
	Neuromodulation	
	TENS	

Note. The *OR* Boolean operator was used between the terms in each column, while *AND* was used to combine the columns.

From the beginning to August 1, 2023, a search of the literature was conducted in English through the following electronic bibliographic databases: MEDLINE (via PubMed), Scopus, Web of Science, Cochrane Library, and PEDro. Two independent reviewers conducted the search (S. E., F. T.). The full search strategies are available in the Appendix. To find research that might not have been found by the database search, the reference lists of all pertinent publications were also manually searched. For additional research, the search results were imported into the EndNote X20 citation management software, and duplicates were automatically removed.

Study Selection and Eligibility Criteria

SRs, with or without MAs, on interventional or observational human populations that assessed the effects of TENS (via different protocols) on poststroke rehabilitation were included. We excluded studies with at least one of the following criteria: studies other than SR, not reporting the effects of the desired intervention, and the absence of English available full text. Moreover, we excluded articles that did not report quantitative data.

All titles and abstracts found by the literature search were separately examined by two reviewers (S. E., F. T.). They next collected the full texts of all potentially relevant research and assessed each one's eligibility. Reviewers discussed differences of opinion in this respect and, if necessary, sought resolution from a third reviewer (S. M.).

Data Extraction

In pairs, reviewers (S. E., F. T.) extracted data independently from the included SRs. Discussions or, if required, a third reviewer adjudication were used to settle disagreements (S. M.). They gathered data on the bibliography, quality assessment, interventions, outcomes, adverse events, and overall findings using a pretested data extraction form.

Quality Assessment

Two impartial reviewers assessed the quality of all the included SRs using the JBI assessment tool (S. E., A. R. M.). Eleven items on this checklist help direct the evaluation of SRs (Aromataris et al., 2015). If there were 0–1, 2–3, or more than 3 no/unclear responses, the SRs were classified as high, moderate, or low quality, accordingly. Differences of opinion were settled by discussion and, when needed, by referring to the third reviewer (S. G.).

Results

Study Selection

The literature searches led to the identification of 853 citations. However, after screening the title and abstract, 55 full-text published articles were selected for full assessment. Out of these, 21 were excluded and 34 studies were finalized for review. Figure 1 shows the flow diagram of the selection process for this umbrella review.

Overall Characteristics of the studies

All of the included studies were SRs, 18 out of 34 also conducted MA, and 3 out of 34 applied network MA (Ahmed et al., 2022; Fang et al., 2023; Xue et al., 2022). SRs were published from 2001 (Price & Pandyan, 2001) to 2023 (Fang et al., 2023; Perpetuini et al., 2023; Wang et al., 2023) and originated from all over the world. Different variations of TENS protocols and techniques were applied across studies, including transcutaneous vagal nerve stimulation (tVNS), which delivers electrical impulses to the auricular branch of the vagus nerve through the skin on the outer ear (Ahmed et al., 2022; Ramos-Castaneda et al., 2022; Wang et al., 2023; Xie et al., 2021; Yan et al., 2022; Zhao et al., 2022), and transcutaneous tibial nerve stimulation (tTNS), which involves the application of electrical stimulation to the tibial branch of the sciatic nerve through the skin on the lower limb (Ali et al., 2022; Gross et al., 2016). Regarding the safety profile, none of the studies reported any major events. Mild skin irritation (Mills & Dossa, 2016; Xie et al., 2021; Yan et al., 2022; Zhao et al., 2022), nausea and vomiting (Xie et al., 2021; Yan et al., 2022), and mild pain were reported by SRs (Xie et al., 2021; Yan et al., 2022). Table 2 provides a summary of the included studies. The results of the TENS application on different poststroke conditions are reported categorically in the following paragraphs.

TENS and Motor Rehabilitation

The majority of the included SRs (21/34) investigated the application of TENS for poststroke motor rehabilitation. Some of the earlier studies, like Pomerory et al. (2006) and Robbins et al. (2006) reported that not enough evidence is available to demonstrate TENS's usefulness in helping stroke patients recover their motor skills. However, in more recent publications, the evidence for the efficacy of TENS has grown substantially, which will be addressed in the following paragraphs.

Ahmed et al. (2022) reviewed different electric neurostimulation techniques, including tVNS. According to their results, tVNS effectively improves upper limb motor function. The efficacy of tVNS for motor rehabilitation was further confirmed by Ramos-Castaneda et al. (2022), Wang et al. (2023), Xie et al. (2021), Xue et al. (2022), Yan et al. (2022), and Zhao et al. (2022).

Figure 1. *PRISMA 2020 Flow Diagram for New Systematic Reviews Which Included Searches of Databases, Registers, and Other Sources*.

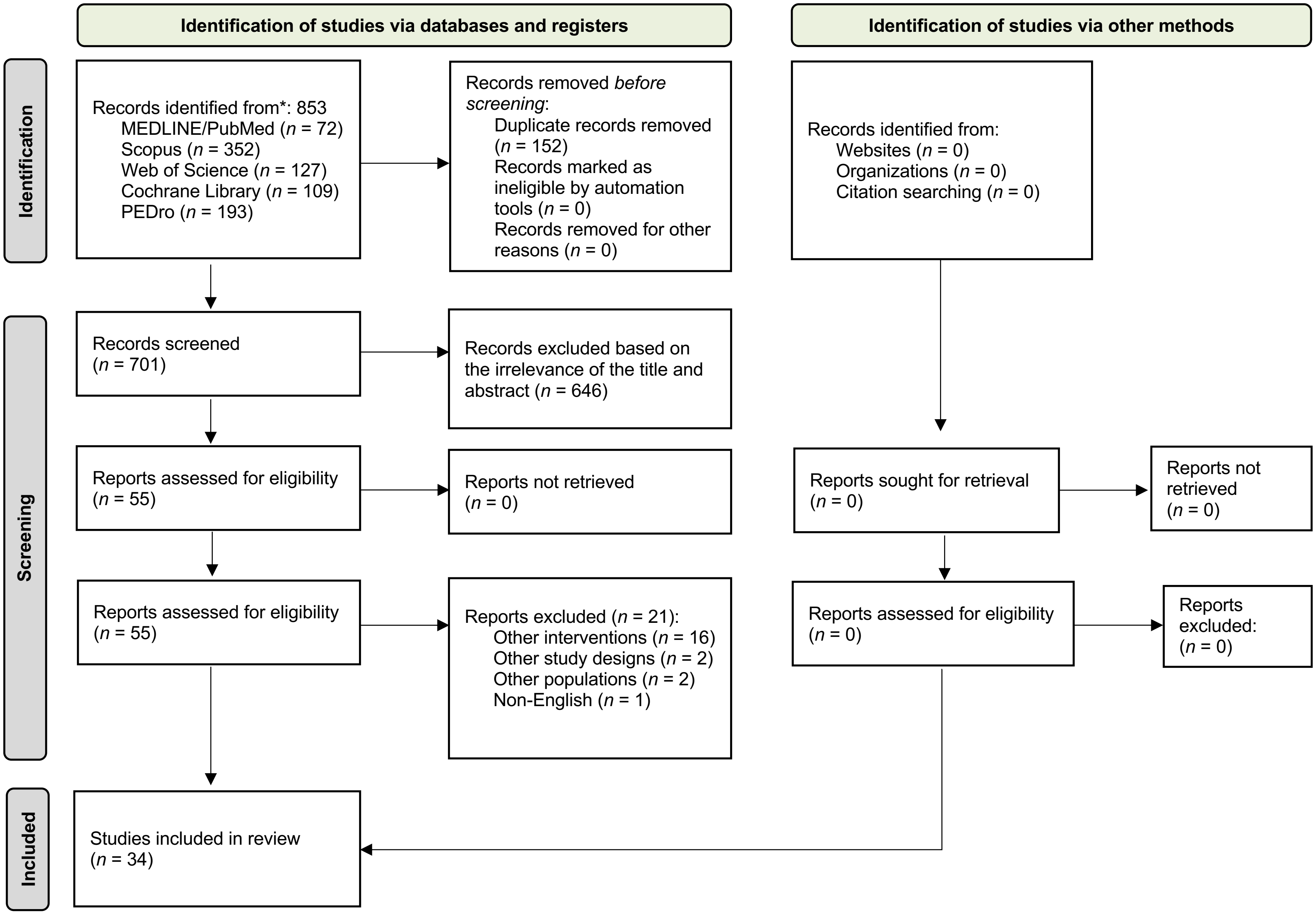

Table 2
General and Methodological Characteristics of Included SRs

Author, Year	Origin	Design	Journal	Searched Databases	Type of Intervention	Included Studies	Quality Appraisal	Grade	AE	Overall Results
Motor Function										
Ahmed et al., 2022	Turkey	SR + network MA	Neuromodulation: Technology at the Neural Interface	PubMed, WoS, Cochrane, and Google Scholar	Electrical neurostimulation, including tVNS	Total: 38 RCTs, tVNS: 2	The Cochrane RoB assessment tool	No	-	Analysis showed that tVNS is the most effective treatment for enhancing upper limb motor function and performance in daily living activities.
Fang et al., 2023	China	SR + network MA	PLoS ONE	CNKI, VIP Database for Chinese Technical Periodicals, WAN FANG Database, Chinese biomedical literature service system (SinoMed), PubMed, WoS, Embase, and Cochrane Library	Electrical stimulation including TENS and TEAS	Total: 33 trials, TENS: 6, TEAS: 4	The Cochrane RoB assessment tool	Yes	-	Compared to traditional TENS, TEAS in conjunction with acupuncture locations shown a higher potential for therapy.
Grant et al., 2018	Australia	SR + MA	Topics in Stroke Rehabilitation	MEDLINE, CINAHL, Embase, PEDro and OTseeker	Somatosensory stimulation	Total: 15 RCTs, TENS: 4	PEDro scale	Yes	-	Low-quality evidence from four trials suggested that sensory electrical stimulation, including TENS, did not significantly improve upper limb activity compared to placebo. Additionally, moderate-quality evidence from three trials showed that sensory electrical stimulation did not lead to significant improvements in motor impairment.
Laufer & Elboim-Gabyzon, 2011	Israel	SR	Neurorehabilitation and Neural Repair	PubMed, EMBASE, CINHAL, ISI Science Citation Index, Cochrane library, Cochrane Stroke Group Trials Register, Hooked on Evidence, and the PEDro database	TENS	Total: 15 clinical trials	PEDro scale	No	None	When combined with active training, TENS may help improve certain elements of motor recovery after a stroke.

Table 2
General and Methodological Characteristics of Included SRs

Author, Year	Origin	Design	Journal	Searched Databases	Type of Intervention	Included Studies	Quality Appraisal	Grade	AE	Overall Results
I.-H. Lin et al., 2019	Taiwan	SR	Archives of Physical Medicine and Rehabilitation	PubMed	Rehabilitative treatments including TENS	Total: 178, TENS: 2	PEDro scale	No	-	There was insufficient data to prove that experimental therapies were better than traditional rehabilitation.
Perpetuini et al., 2023	Italy	SR	Bioengineering	PubMed/MEDLINE, WoS, and Scopus	Electrosuit, using TENS	12 RCTs	None	No	-	Improvements in motor function and a decrease in spasticity have been observed to be positively correlated with the length and dose of the garment therapy.
Pomeroy et al., 2006	United Kingdom	SR	Cochrane Library	Cochrane Stroke Group Trials Register, CENTRAL, MEDLINE, EMBASE, CINAHL, AMED - Allied and Complementary Medicine Database, PEDro, REHABDATA and the ISI Science Citation Index	ES, including TENS	Total: 24 RCTs, TENS: 3	The Cochrane RoB assessment tool	No	-	At present, there are insufficient robust data to inform clinical use of electrostimulation for neuromuscular retraining.
Ramos-Castaneda et al., 2022	Colombia	SR + MA	Frontiers in Neurology	MEDLINE, CENTRAL, EBSCO and LILACS	VNS	Total: 8, TENS: 4	The Cochrane RoB assessment tool	No	None	VNS, combined with physical rehabilitation, improves upper limb motor function in stroke patients.
Sharififar et al., 2018	USA	SR + MA	Annals of Physical and Rehabilitation Medicine	MEDLINE via PubMed and the Cochrane Central Register of Controlled Trials	ES: TENS or peripheral electromyography triggered sensory stimulation, or acupuncture producing sensory effects without motor recruitment, in conjunction with routine rehabilitation	Total: 11, TENS: 3	PEDro scale	No	-	Electrical sensory input can contribute to routine rehabilitation to improve early poststroke lower-extremity impairment and late motor function, with no change in spasticity. Prolonged periods of sensory stimulation such as TENS combined with activity can have beneficial effects on impairment and function after stroke.

Table 2
General and Methodological Characteristics of Included SRs

Author, Year	Origin	Design	Journal	Searched Databases	Type of Intervention	Included Studies	Quality Appraisal	Grade	AE	Overall Results
Wang et al., 2023	China	SR + MA	Frontiers in Neurology	PubMed, Wanfang, Scopus, China Science and Technology Journal Database, EmbaseWoS, China Biology Medicine Disc, Cochrane Library, and China National Knowledge Infrastructure	VNS (taVNS, invasive VNS)	Total: 10, taVNS: 6	The Cochrane RoB assessment tool	Yes	There was no significant difference between the experimental and control groups in the incidence of AEs or serous AEs.	VNS is an effective and safe treatment for upper extremity motor dysfunction after a stroke.
Xie et al., 2021	China	SR + MA	Medicine	PUBMED, MEDLINE, EMBASE, Cochrane Library, WoS, CNKI, and Wan Fang Database	VNS (tVNS and invasive)	Total: 6 tVNS: 3	The Cochrane RoB assessment tool	No	In 3 tVNS trials, one reported skin redness, one mild nausea and vomiting; mild pain in the left ear and the last, no AE.	VNS resulted in improvement of motor function in patients after ischemic stroke, especially in the sub-chronic stage. Moreover, compared with implanted VNS, transcutaneous VNS exhibited greater efficacy in poststroke patients. Based on this meta-analysis, VNS could be a feasible and safe therapy for upper limb motor impairment.
Xue et al., 2022	China	SR + network MA	Journal of Clinical Medicine	MEDLINE, Embase, Cochrane Library and ClinicalTrials.gov	Different neurostimulation techniques, including TENS	Total: 88 RCTs, TENS: 8 tVNS: 1	The Cochrane RoB assessment tool	Yes	Almost none	Significant efficacy for improving the upper limb function after stroke with minimum AEs.
Yan et al., 2022	China	SR	Neuropsychiatric Disease and Treatment	PubMed, Embase, Cochrane Library, CNKI, Wanfang Database, and China Science and Technology Journal Database (VIP)	tVNS	4	The Cochrane RoB assessment tool	No	Two studies reported AE. One patient had redness of the skin at the electrode contact point; 28 one patient had mild nausea and vomiting, and one patient had pain in the left ear.	tVNS combined with rehabilitation training showed some improvement in upper limb motor dysfunction in poststroke patients.

Table 2
General and Methodological Characteristics of Included SRs

Author, Year	Origin	Design	Journal	Searched Databases	Type of Intervention	Included Studies	Quality Appraisal	Grade	AE	Overall Results
Zhao et al., 2022	China	SR + MA	International Journal of Rehabilitation Research	MEDLINE, WoS,Embase, CENTRAL and PEDro	VNS (transcutaneous and invasive)	Total: 5 tVNS: 2	PEDro scale	No	One study regarding tVNS did not report AEs, while one study reported that one patient in the tVNS group developed skin redness at the point of contact of the auricular skin with electrodes.	When used in conjunction with therapy, VNS can help stroke patients regain function in their upper limbs.
Aries et al., 2022	United Kingdom	SR	Brain Sciences	AgeLine, AMED, CINAHL PLUS, EMBASE, EMCARE MEDLINE, PEDro, PsycARTICLES, PsycINFO, SPORTDiscus and WoS, CENTRAL	Various types of somatosensory stimulation including TENS	Total: 16 RCTs, TENS: 6	The Cochrane RoB assessment tool	No	-	This study does not provide a comprehensive conclusion regarding the effects of TENS; however, it concludes that sensory stimulation might benefit the rehabilitation of stroke patients based on heterogeneous studies.
S. Lin et al., 2018	China	SR + MA	Journal of Rehabilitation Medicine	PubMed, Embase, WoS, EBSCO, and Cochrane Library	TENS	7 RCTs	The Jadad Scale	No	-	TENS had no effect on dynamic balance but is linked to a considerable reduction in spasticity, an increase in walking speed, and static balance.
Robbins et al., 2006	Canada	SR + MA	Archives of Physical Medicine and Rehabilitation	Medline, EMBASE, CINHAL, and PubMed	Functional and Transcutaneous electric stimulation	Total: 21, TENS: 3	Downs and Black checklist	No	-	Insufficient data was available to draw firm conclusions about TENS's efficacy.
Shankaranarayana et al., 2021	India	SR	Gait & Posture	MEDLINE, CINAHL, Cochrane Library, ProQuest, and Citation Indexes, WoS and Scopus	Gait training interventions	Total: 12, TENS: 1	PEDro scale	No	None	According to one trial, no significant difference between TENS and task-based program.

Table 2
General and Methodological Characteristics of Included SRs

Author, Year	Origin	Design	Journal	Searched Databases	Type of Intervention	Included Studies	Quality Appraisal	Grade	AE	Overall Results
Kwong et al., 2018	China	SR + MA	Clinical Rehabilitation	CINAHL, ClinicalTrials.gov, the Cochrane Central Register of Controlled Trials, EMBASE, MEDLINE, PEDro, PubMed and WoS	TENS	Total: 11	PEDro scale	No	None	For stroke survivors, TENS is useful in improving walking ability and decreasing plantar flexor spasticity.
Mijic et al., 2022	Germany	SR	Frontiers in Neurology	Pubmed/MEDLINE, Scopus, ScienceDirect, WoS/Clarivate, Cochrane Library, PEDro, and ClinicalTrials.gov	Peripheral electrical stimulation including TENS	Total: 10, TENS: 3	ROBINS-I for observational studies, NIH tool for pre-post studies without a control group	Yes	-	The shift in the amplitude and latency of somatosensory evoked potentials may suggest that PES have a predictive influence on sensory reconfiguration.
Urinary/Fecal Dysfunction										
Bapir et al., 2022	Unclear	SR + MA	The Archives of Italian Urology and Andrology	PubMed, EMBASE	Different treatments for neurogenic bladder with different etiologies, including TENS for stroke	Total: 62 RCTs, TENS/stroke: 4	The Cochrane RoB assessment tool	Yes	-	TENS reduced symptom scores, increased urodynamic results (maximum cystometry volume, flow rate, and pressure of the detrusor at the end of the filling phase), and improved voiding diary metrics (daily micturition, nocturia, urgent urination, and urge UI).
Cruz et al., 2022	Australia	SR + MA	International journal of stroke	MEDLINE, EMBASE, CINAHL, PEDro, and CENTRAL	Non-implanted electrical stimulation, including TENS	Total: 10 trials, TENS: 5, electroacupuncture: 5	PEDro scale	No	-	Combining research indicates that frequent and early electrical stimulation therapy is likely more beneficial than fake or no therapy at all.
Gross et al., 2016	Switzerland	SR + MA	European Urology	Embase, Medline, CENTRAL, and Health Technology Assessment Database	TENS (including TTNS)	Total: 22 (2 RCTs, 14 prospective cohorts, five retrospective case series, one case report); Stroke: mentioned in four studies	The Cochrane RoB assessment tool for RCTs, self-defined criteria for non-RCTs	No	One patient did not tolerate stimulation and stimulation had to be stopped. No other AEs were reported.	The excellent AE profile and good effects on bladder diary and urodynamic measures suggest that TENS may be a safe and effective treatment for NLUTD.

Table 2
General and Methodological Characteristics of Included SRs

Author, Year	Origin	Design	Journal	Searched Databases	Type of Intervention	Included Studies	Quality Appraisal	Grade	AE	Overall Results
Ali et al., 2022	Nigeria	SR + MA	Therapeutic Advances in Chronic Disease	Cochrane library, EMBASE, MEDLINE, PEDro, Scopus, and WoS	Intravaginal electrical stimulation, TENS, neuromuscular electrical stimulation, TTNS, pelvic floor muscle training, and behavioral therapy	Total: 14, TENS/Stroke: 2	PEDro scale	Yes	-	According to meta-analyses, electrical stimulation can help stroke and multiple sclerosis patients with their urgency symptoms.
Thomas et al., 2019	United Kingdom	SR + MA	Cochrane Library	Cochrane Incontinence and Cochrane Stroke Specialized Registers, which contain trials identified CENTRAL, MEDLINE, MEDLINE In-Process, MEDLINE Epub Ahead of Print, CINAHL, ClinicalTrials.gov, WHO ICTRP	Different rehabilitative approaches, including TENS and TTNS	Total: 20 trials, TENS: 3 TTNS: 2	The Cochrane RoB assessment tool	Yes	TTNS-related side effects, such as slight skin irritation and ankle cramps in 1 trial	Physical treatment with TENS may reduce the mean frequency of incontinent episodes during a 24-hr period, based on two trials reporting three comparisons. ability.
Spasticity										
Fernández-Tenorio et al., 2019	Spain	SR	Neurología	PubMed, PEDro, and Cochrane databases	TENS	Total: 10, Stroke: 6	PEDro scale	No	None	Because TENS has no AEs, is inexpensive, and is simple to use, it is suggested as a possible therapy for spasticity.
Garcia & Vargas, 2019	Brazil	SR	Journal of Musculoskeletal and Neuronal Interactions	Scopus, PubMed, BVS, Google Scholar and BASE databases	Somatosensory electrical stimulation including TENS	Total: 10 TENS/Stroke: 7	None	No	-	Mostly positive effects from application of TENS were reported for improving spasticity and reflex responses.
Mahmood et al., 2019	India	SR + MA	Archives of Physical Medicine and Rehabilitation	PubMed, PEDro, CINAHL, WoS, CENTRAL, and EMBASE	TENS	15; 10 RCTs and 5 non-RCTs	The Cochrane RoB assessment tool	No	None	Compared to placebo TENS, TENS in conjunction with other physical therapy treatments was more successful in decreasing lower limb spasticity.

Table 2
General and Methodological Characteristics of Included SRs

Author, Year	Origin	Design	Journal	Searched Databases	Type of Intervention	Included Studies	Quality Appraisal	Grade	AE	Overall Results
Marcolino et al., 2020	Brazil	SR + MA	Disability and Rehabilitation	MEDLINE, Cochrane Library, EMBASE and Physiotherapy Evidence Database	TENS alone or as additional therapy	10 RCTs	The Cochrane RoB assessment tool	No	None	TENS can provide additional reduction in chronic poststroke spasticity, mainly as additional therapy to physical interventions.
Mills & Dossa, 2016	Canada	SR	American Journal of Physical Medicine & Rehabilitation	MEDLINE, EMBASE, and Cochrane Central Register of Controlled Trials.	TENS	Total: 14 RCTs, Stroke: 7	PEDro scale	No	Transient mild skin irritation with erythema that resolved spontaneously.	Better responses in outcome measures were seen when TENS was used in combination with active vs. as a single therapeutic modality.
Pain										
Chen et al., 2016	Taiwan	SR	The Journal of Physical Therapy Science	Academic Search Premier; CINAHL Plus with full text Medline Proquest; Medline Ovid SP; ProQuest Health and Medical Complete; Pubmed; Science Direct online; Scopus; The Cochrane Library; and WoS	Non-invasive physical modalities including TENS	Total: 16, TENS: 1	Evidence Classification Scheme for Therapeutic Interventions	No	-	One study found that when 15 patients were given high-frequency (traditional) and low-frequency (acupuncture-like) TENS treatments, one-third of them had a brief increase in pain.
de Sire et al., 2022	Italy	SR + MA	Annals of Physical and Rehabilitation Medicine	PubMed, Scopus, and WoS	Different rehabilitative techniques including TENS	Total: 12, TENS: 1	PEDro scale, The Cochrane RoB assessment tool	No	-	For patients with hemiplegic shoulder pain, adding segmental neuromyotherapy to conventional treatment improves arm function overall and relieves pain.
Price & Pandyan, 2001	United Kingdom	SR	Clinical Rehabilitation	Cochrane Stroke Review Group trials register and undertake further searches of Medline, Embase and CINAHL	ES, including TENS	Total: 4, TENS: 3	Self-defined checklist	No	None	There seem to be advantages for passive humeral lateral rotation, although the data from RCTs so far neither supports nor contradicts the idea that ES around the shoulder following a stroke affects ratings of pain.

Table 2
General and Methodological Characteristics of Included SRs

Author, Year	Origin	Design	Journal	Searched Databases	Type of Intervention	Included Studies	Quality Appraisal	Grade	AE	Overall Results
Other Condition(s)										
Lisa et al., 2013	Belgium	SR	NeuroRehabilitation	PubMed, WoS, and PEDro	Different rehabilitative techniques including TENS	Total: 15 RCTs, TENS: 1	9-item Delphi list	No	-	TENS is an effective method for reducing unilateral neglect syndrome.

AE = Adverse Event; CENTRAL = Cochrane Central Register of Controlled Trials; CINAHL = Cumulative Index to Nursing & Allied Health Literature; CNKI = China National Knowledge Infrastructure; ES = Electrostimulation; MA = Meta-analysis; NIH = National Institutes of Health; PEDro = Physiotherapy Evidence Database; RCT = Randomized controlled trial; RoB = Risk of bias; SR = Systematic review; taVNS = Transcutaneous auricular vagus nerve stimulation; TEAS = Transcutaneous electrical acupoint stimulation; TENS = Transcutaneous electrical nerve stimulation; TTNS = Transcutaneous tibial nerve stimulation; tVNS = Transcutaneous vagus nerve stimulation; VNS = Vagus nerve stimulation; WoS = Web of Science

The goal of Grant et al.'s (2018) study was to ascertain if somatosensory stimulation might improve upper limb motor performance following a stroke. According to their included trials, an overall improvement following TENS was reported. For instance, in one of their included trials, patients were told to wear a wristwatch-like device called a ReliefBand, which uses surface electrodes to give biphasic square-wave electrical stimulation at a frequency of 31 Hz for 2 hr per day, right before motor training (dos Santos-Fontes et al., 2013).

Further, the I.-H. Lin et al. (2019) study suggested that while electrical stimulation was found to be effective in enhancing motor recovery poststroke, its superiority over conventional rehabilitation was not supported by strong evidence.

The Fang et al. (2023) study investigated and compared five commonly used electrical stimulation techniques for treating stroke patients with lower limb impairment through a network meta-analysis. According to their results, transcutaneous electrical acupuncture stimulation (TEAS), which delivers electrical impulses to certain acupuncture points, showed more therapeutic promise compared to traditional TENS (Fang et al., 2023).

The application of TENS in combination with other rehabilitative methods was also investigated. According to Sharififar et al. (2018) SR, electrical sensory inputs, such as TENS, combined with routine therapy can improve lower-extremity impairment in the early poststroke period and motor function in the long term. However, it did not have a significant impact on spasticity. Further, according to Laufer and Elboim-Gabyzon's (2011) research, TENS sensory stimulation can help improve certain parts of motor recovery after a stroke, especially when combined with active training.

Most recently, Perpetuini et al. (2023) conducted a SR of the effectiveness of the Exopulse Mollii Suit (EMS), a wearable device that delivers electrical stimulation transcutaneously, in neurological disorders like stroke. Their results showed that this device can improve motor functions and reduce spasticity. The duration and dose of the treatment, which are dependent on the patient's health and the objectives of the treatment, have been linked to these effects. Patients also reported a feeling of well-being in the afflicted limb during the electrical stimulation (Perpetuini et al., 2023).

The purpose of Aries et al.'s (2022) SR was to assess how well somatosensory stimulation of the feet and lower limbs can improve walking and balance following a stroke. The interventions included in the review involved different sensory stimulation, such as customized insoles, taping, and electrical stimulation, among others. TENS was investigated through six studies, all of which reported positive effects.

S. Lin et al. (2018) reported improved walking speed, static balance, and reductions in spasticity following TENS supplementation. However, the dynamic balance was unaffected by the treatment.

In Shankaranarayana et al. (2021), only one of the included studies contributed to the effects of TENS on poststroke gait. In this trial, three groups of participants were recruited to test TENS and a task-based program which concentrated on motor learning that occurs upon the completion of meaningful tasks like bodyweight support treadmill training. Group 1 was the only group to get task-based instruction. In addition to task-based training, Groups 2 and 3 had TENS for 30 and 60 min, respectively. The findings demonstrated that there was no discernible difference in each group's performances from one another (Shankaranarayana et al., 2021).

TENS increased walking capacity measured by gait speed or the Timed Up and Go Test, according to Kwong et al. (2018) SR. Additionally, TENS helped stroke survivors with their paretic plantar flexor spasticity. The duration of TENS sessions had an impact on its effectiveness. Research with 60-min sessions demonstrated an increase in walking capacity, but trials with shorter sessions (20 or 30 min) did not demonstrate a statistically significant benefit (Kwong et al., 2018).

Lastly, Mijic et al. (2022) examined the role of peripheral electrical stimulation (PES), including TENS, in poststroke patients. The review showed that there is insufficient data to support the use of somatosensory evoked potentials as a predictor to gauge a stroke patient's likelihood of rehabilitation. The research did, however, find a relationship between alterations in the components of somatosensory evoked potentials and various measures of sensory and motor function. There is a favorable connection and association between evaluations of motor function and PES that induce a voluntary contraction for a certain activity or task. This implies that alterations in the amplitude and latency of somatosensory evoked potentials may indicate a predictive influence of PES on sensory reconfiguration (Mijic et al., 2022).

TENS and Urinary/Fecal Dysfunction

Five SRs investigated the use of TENS for poststroke urinary dysfunction (Ali et al., 2022; Bapir et al., 2022; Cruz et al., 2022; Gross et al., 2016; Thomas et al., 2019) and one for fecal dysfunction (Cruz et al., 2022). In Bapir et al. (2022) SR, when it comes to reducing the frequency of nocturia episodes in patients with overactive bladder (OAB) symptoms linked to neurological illnesses, such as stroke, TENS was found to be more effective compared to its sham-control. Cruz et al. (2022) SR reported that TENS significantly improves urinary continence when started within 3 months of a stroke. However, when TENS was initiated more than 3 months after stroke, the effect size was medium. This indicates that the timing of TENS treatment may influence its effectiveness in reducing urinary dysfunction in stroke patients (Cruz et al., 2022). The effect of nonimplanted electrical stimulation on poststroke fecal incontinence was the subject of only one of their included studies, which found that the TENS group's improvement was noticeably higher than that of the controls (Cruz et al., 2022).

Further, the effectiveness and safety of TENS for treating neurogenic lower urinary tract dysfunction (NLUTD) in patients with underlying neurological illnesses, such as stroke, multiple sclerosis, and spinal cord injury, were examined in Gross et al. (2016) SR. The results of the review indicate that both acute and chronic TENS show promise in improving various aspects of NLUTD (Gross et al., 2016).

According to Ali et al.'s (2022) MA, electrical stimulation—including TENS—significantly reduces urge urine incontinence brought on by stroke.

A Cochrane review by Thomas et al. (2019) included two trials on the subject. In one of them, transcutaneous posterior tibial nerve stimulation (TPTNS) showed minimal or no impact on the number of participants who were continent after treatment or the number of incontinent episodes. In the other study, there was evidence of improvement in the group receiving TPTNS after 26 weeks.

TENS and Spasticity

Five SRs focused on the application of TENS in management of poststroke spasticity (Fernández-Tenorio et al., 2019; Garcia & Vargas, 2019; Mahmood et al., 2019; Marcolino et al., 2020; Mills & Dossa, 2016), and one SR mentioned spasticity as a secondary outcome. The results of the review suggest that because of its affordability, simplicity of use, and lack of side effects, TENS is regarded as an effective therapy for spasticity (Fernández-Tenorio et al., 2019). In the Garcia and Vargas (2019) SR, inconsistent results were reported by included trials; some suggesting an improvement in spasticity even after one session while there were reports of lack of efficacy.

TENS was more successful in decreasing lower limb spasticity when it was administered in conjunction with other physical therapy than when it was administered as sham stimulation, according to Mahmood et al. (2019) SR. Moreover, compared to other physical therapy therapies alone, TENS applied in addition to other treatments was more successful in lowering spasticity (Mahmood et al., 2019).

The findings of Marcolino et al. (2020) research showed that TENS, either used alone or as an additional therapy, is effective in reducing poststroke spasticity compared to placebo TENS. Their analysis showed statistically significant improvements in spasticity, particularly in the lower limbs.

Lastly, in the study by Kwong et al. (2018), as mentioned in the previous section, TENS was effective in reducing paretic plantar flexor spasticity in stroke survivors.

TENS and Pain

Three SRs investigated the effects of the TENS application on poststroke pain; including shoulder pain (de Sire et al., 2022; Price & Pandyan, 2001) and central pain (Chen et al., 2016).

In Chen et al. (2016) SR, only one study was found that examined the use of TENS as a noninvasive modality intervention for central poststroke pain (CPSP).

Price and Pandyan (2001) study focused on the efficacy of various forms of surface electrical stimulation in the prevention and treatment of shoulder pain after stroke, which found insufficient evidence to draw any conclusions.

A variety of rehabilitation techniques were studied in de Sire et al. (2022) SR, but only one trial looked at the effectiveness of TENS in addition to traditional therapy as opposed to conventional rehabilitation alone. In this trial, the study group was given 12 intramuscular and subcutaneous injections of 5 mL of 1% lidocaine solution into the tight band and trigger sites, close to the affected spinal region (paraspinal block), in addition to 20 min of local heat application and TENS to deltoid and supraspinatus muscles (40 Hz, 11 mA) and 10 min of passive stretching of the affected shoulder three times per week for 4 weeks. Over the course of the 4-week treatment period, the intervention group outperformed the control group, which received the hospital's standard treatment regimen, in shoulder pain outcome measures (Ratmansky et al., 2012).

TENS and Other Condition(s)

In a SR by Lisa et al. (2013) TENS was mentioned as one of the treatment modalities that can reduce the symptoms of unilateral neglect in poststroke patients. This SR suggested that TENS, along with other interventions such as optokinetic stimulation, somatosensory electrostimulation, mirror therapy, and virtual reality training, can be effective in alleviating the symptoms of unilateral neglect (Lisa et al., 2013).

Risk of Bias Assessment

Based on the JBI quality evaluation checklist, 8 out of 34 studies were rated as high quality, 14 as moderate, and 12 as low quality. The included SRs' strongest domains were addressing the research question (33/34), adequate sources and resources of data (32/34), using proper method of quality assessment (31/34), and proper inclusion criteria (30/34). There were major concerns in domains of publication bias and providing guidance for policy and practice. The result of the assessment of risk of bias is presented in Table 3. For every individual outcome, we created "traffic light" charts of the domain-level evaluations.

Table 3
The Quality of the Included Systematic Reviews, Based on the JBI Checklist

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Overall Quality
Ahmed et al., 2022	✅	✅	⚠️	✅	✅	⚠️	✅	✅	✅	✅	✅	Moderate
Ali et al., 2022	✅	✅	✅	✅	✅	✅	✅	✅	✅	✅	❌	High
Aries et al., 2022	✅	✅	❌	✅	✅	✅	✅	✅	❌	❌	❌	Low
Bapir et al., 2022	✅	✅	⚠️	✅	✅	✅	✅	✅	✅	❌	❌	Moderate
Chen et al., 2016	✅	❌	⚠️	✅	✅	⚠️	⚠️	❌	❌	❌	❌	Low
Cruz et al., 2022	✅	✅	✅	✅	✅	✅	✅	✅	❌	❌	✅	Moderate
de Sire et al., 2022	❌	✅	✅	✅	✅	✅	✅	✅	⚠️	✅	❌	Moderate
Fernández-Tenorio et al., 2019	✅	✅	⚠️	✅	✅	⚠️	⚠️	❌	❌	❌	✅	Low
Fang et al., 2023	✅	✅	✅	✅	✅	✅	✅	✅	✅	⚠️	⚠️	Moderate
Garcia & Vargas, 2019	✅	⚠️	✅	❌	❌	⚠️	❌	❌	❌	⚠️	❌	Low
Grant et al., 2018	✅	✅	✅	✅	✅	✅	✅	✅	❌	❌	❌	Moderate
Gross et al., 2016	✅	✅	⚠️	✅	❌	⚠️	✅	✅	❌	✅	✅	Low
Kwong et al., 2018	✅	✅	✅	✅	✅	✅	⚠️	✅	✅	✅	✅	High
Laufer & Elboim-Gabyzon, 2011	✅	✅	⚠️	✅	✅	✅	✅	✅	❌	✅	❌	Moderate
I.-H. Lin et al., 2019	✅	✅	⚠️	❌	✅	✅	⚠️	✅	❌	✅	❌	Low
S. Lin et al., 2018	✅	❌	❌	✅	✅	❌	❌	✅	NA	❌	❌	Low
Lisa et al., 2013	✅	✅	✅	✅	✅	❌	❌	✅	❌	✅	✅	Moderate
Mahmood et al., 2019	✅	✅	❌	✅	✅	❌	✅	✅	❌	✅	✅	Moderate
Marcolino et al., 2020	✅	✅	✅	✅	✅	✅	✅	✅	❌	✅	❌	Moderate
Mijic et al., 2022	✅	✅	⚠️	✅	✅	⚠️	❌	✅	✅	❌	❌	Low
Mills & Dossa, 2016	✅	✅	⚠️	✅	✅	✅	✅	✅	❌	❌	✅	Moderate
Perpetuini et al., 2023	✅	✅	⚠️	✅	❌	❌	❌	✅	❌	❌	✅	Low
Pomeroy et al., 2006	✅	✅	✅	✅	✅	✅	✅	✅	❌	✅	✅	High

Table 3
The Quality of the Included Systematic Reviews, Based on the JBI Checklist

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Overall Quality
Price & Pandyan, 2001	✅	✅	⚠️	✅	✅	✅	✅	✅	NA	✅	✅	High
Ramos-Castaneda et al., 2022	✅	✅	⚠️	✅	✅	⚠️	✅	✅	NA	❌	✅	Moderate
Robbins et al., 2006	✅	✅	⚠️	✅	✅	✅	✅	❌	❌	❌	✅	Low
Shankaranara et al., 2021	✅	✅	✅	✅	✅	⚠️	✅	❌	❌	❌	✅	Low
Sharififar et al., 2018	✅	✅	⚠️	✅	✅	✅	✅	✅	❌	❌	✅	Moderate
Thomas et al., 2019	✅	✅	✅	✅	✅	✅	✅	✅	✅	✅	✅	High
Wang et al., 2023	✅	✅	⚠️	✅	✅	✅	✅	✅	✅	✅	✅	High
Xie et al., 2021	✅	✅	⚠️	✅	✅	✅	✅	✅	NA	❌	✅	Moderate
Xue et al., 2022	✅	❌	❌	✅	✅	⚠️	⚠️	✅	✅	✅	❌	Low
Yan et al., 2022	✅	✅	✅	✅	✅	✅	✅	✅	NA	❌	✅	High
Zhao et al., 2022	✅	✅	✅	✅	✅	✅	✅	✅	NA	❌	✅	High

✅ = Yes; ⚠️ = Unclear; ❌ = No; NA = Not Applicable.
Q1 = Is the review question clearly and explicitly stated?; Q2 = Were the inclusion criteria appropriate for the review question?; Q3 = Was the search strategy appropriate?; Q4 = Were the sources and resources used to search for studies adequate?; Q5 = Were the criteria for appraising studies appropriate?; Q6 = Was critical appraisal conducted by two or more reviewers independently?; Q7 = Were there methods to minimize errors in data extraction?; Q8 = Were the methods used to combine studies appropriate?; Q9 = Was the likelihood of publication bias assessed?; Q10 = Were recommendations for policy and/or practice supported by the reported data?; Q11 = Were the specific directives for new research appropriate?

Discussion

TENS is a noninvasive peripheral nerve stimulation technique that involves the application of low-intensity electrical currents to the peripheral nerves through electrodes placed on the skin (Teoli et al., 2024). This technique has garnered significant attention in the field of stroke rehabilitation, mainly due to its potential to enhance motor and sensory recovery. The precise mechanisms by which TENS can be beneficial to stroke recovery are still unclear, even though there is an increasing number of published research in this area. Currently, several theoretical concepts are proposed in this regard. First, researchers have proposed that TENS can trigger the gate control hypothesis of pain modulation by stimulating peripheral nerves and activating A-beta fibers, which are large-diameter sensory fibers (Johnson, 2007). Second, TENS can provide sensory stimulation to the affected area, promoting neuroplasticity and cortical reorganization, hence, helping restore sensory input to the brain and facilitate the reorganization of neural networks (Bao et al., 2020). In addition, by activating weakened or paralyzed muscles, TENS may help prevent muscle atrophy and promote muscle strengthening (In et al., 2021). Neurochemical changes have also been attributed to TENS; as it has been suggested to modulate the release of various neurotransmitters such as endorphins, serotonin, and norepinephrine (Sluka & Walsh, 2003). These neurochemical changes may contribute to pain relief, mood enhancement, and modulation of neuronal excitability, which could have positive effects on stroke rehabilitation outcomes. Moreover, a recent in vitro study has suggested that by inhibiting neuronal oxidative stress and pyroptosis, TENS can enhance brain ischemic injury (Tan et al., 2023).

According to the results of our study, TENS offers several advantages as an intervention in stroke rehabilitation which are addressed thoroughly in the previous section. Further, it is noninvasive, and electrodes are placed on specific areas of the body, allowing for targeted stimulation without the need for incisions or implants. This noninvasive nature makes TENS a safe and well-tolerated option for individuals recovering from stroke.

However, it is worth noting that the quality of the evidence varied across the included SRs. While some reviews reported robust evidence supporting the efficacy of TENS in stroke rehabilitation, others highlighted the need for higher quality studies and larger sample sizes to draw definitive conclusions. Standardization of outcome measures and protocols for TENS application would also contribute to better comparability and generalizability of the findings across studies.

Furthermore, even though there appears to be a lot of available data in favor of TENS usage in poststroke rehabilitation, the overall body of research is still relatively limited. Many studies have small sample sizes and varying methodologies. Some patients may experience significant pain reduction or improvements in motor function, while others may not respond as favorably. Factors such as the location and severity of the stroke, the presence of other medical conditions, and individual differences in pain perception or motor recovery potential can influence the response to TENS. Also, the absence of standardized guidelines and the uncertainty of its long-term effects make it challenging to determine the optimal TENS parameters for specific poststroke rehabilitation goals. The gaps in the current scientific literature identified in the current study can inspire and guide future research to build upon existing knowledge and address important unanswered questions.

Lastly, it should be considered that while TENS may be helpful in stroke recovery, it is crucial to take each patient's unique circumstances into account, including stroke severity, lesion location, and comorbidities, when determining the suitability and optimal parameters for TENS application. Personalized approaches to TENS intervention, tailored to individual patient needs, may yield better outcomes and the current literature is unable to provide sufficient data in this regard.

Strengths and Limitations

This study has several strengths and limitations that need to be noted. First, the findings were presented following the PRISMA guidelines, which provide a standardized framework to enhance credibility and transparency. Further, the study employed a comprehensive search strategy that adhered to the PICOs guidelines in multiple electronic bibliographic databases, in addition to the manual search. With no time restrictions in the search, included studies were published from 2001 to 2023, spanning over 2 decades. This extended study period enhances the likelihood of encompassing studies conducted at different time points, thereby contributing to a more comprehensive understanding of the topic.

This study was also subject to some limitations. First and foremost, some limitations are directly the results of an umbrella design. For instance, the quality of the umbrella review is dependent on the quality of the included systematic reviews. If the SRs themselves are of low quality or have methodological limitations, it can affect the overall reliability and validity of the umbrella review. Therefore, it is crucial to critically appraise the included SRs and consider their methodological rigor. In addition, depending on the selection criteria used in the umbrella review, there may be overlapping primary studies across the included systematic reviews. If the same primary studies are included in multiple SRs, it can potentially inflate the significance of those studies and result in an overestimation of the effect sizes or impacts of certain interventions or exposures.

Apart from the methodology, some limitations are associated with the target intervention. For instance, the included studies applied different variations of TENS protocols and techniques. This heterogeneity in TENS application makes it challenging to draw consistent conclusions or make direct comparisons between studies. In the context of urinary dysfunction, TENS was found to have a larger effect on improving urinary continence when initiated within 3 months after stroke compared to when initiated more than 3 months later. This indicates that the timing of TENS application may be an important factor to consider, but further research is needed to establish optimal timing and its impact on outcomes. Some areas, such as the effects of TENS on poststroke pain and balance/gait, had a limited number of included studies (three and four studies, respectively). These limitations highlight the need for more robust research in these areas to draw more definitive conclusions.

Conclusion

The results of this study point to a generally favorable trend in TENS's application for several facets of poststroke rehabilitation, including motor recovery, balance, urinary and fecal function, pain management, and spasticity. Nevertheless, the low to moderate quality SRs supports this conclusion. Future research should explore this intervention further through well-designed clinical trials to establish their optimal protocols, long-term effects, and treatment plans that are tailored to individual needs.

Author Acknowledgements

The author would like to acknowledge the support of the Research Center for Evidence-based Medicine, Iranian EBM Centre: A JBI Centre of Excellence, Faculty of Medicine, Tabriz University of Medical Sciences. Also, we would like to thank the Clinical Research Development Unit of Tabriz Valiasr Hospital, Tabriz University of Medical Sciences, Tabriz, Iran for their assistance in this research.

Author Disclosure

The authors declared no potential conflicts of interest concerning the research, authorship, and/or publication of this article. The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was supported by the Deputy for Research of Tabriz University of Medical Sciences. The data that support the findings of this study is retrieved from previously published materials and available from the corresponding author upon reasonable request.

References

Ahmed, I., Yeldan, I., & Mustafaoglu, R. (2022). The adjunct of electric neurostimulation to rehabilitation approaches in upper limb stroke rehabilitation: A systematic review with network meta-analysis of randomized controlled trials. *Neuromodulation: Technology at the Neural Interface, 25*(8), 1197–1214. https://doi.org/10.1016/j.neurom.2022.01.005

Ali, M. U., Fong, K. N.-K., Kannan, P., Bello, U. M., & Kranz, G. (2022). Effects of nonsurgical, minimally or noninvasive therapies for urinary incontinence due to neurogenic bladder: A systematic review and meta-analysis. *Therapeutic Advances in Chronic Disease, 13*. https://doi.org/10.1177/20406223211063059

Aries, A. M., Downing, P., Sim, J., & Hunter, S. M. (2022). Effectiveness of somatosensory stimulation for the lower limb and foot to improve balance and gait after stroke: A systematic review. *Brain Sciences, 12*(8), Article 1102. https://doi.org/10.3390/brainsci12081102

Aromataris, E., Fernandez, R., Godfrey, C., Holly, C., Kahlil, H., & Tungpunkom P. (2015). Summarizing systematic reviews: Methodological development, conduct and reporting of an umbrella review approach. *International Journal of Evidence-Based Healthcare, 13*(3), 132–140. https://doi.org/10.1097/xeb.0000000000000055

Bao, S.-C., Khan, A., Song, R., & Kai-Yu Tong, R. (2020). Rewiring the lesioned brain: Electrical stimulation for post-stroke motor restoration. *Journal of Stroke, 22*(1), 47–63. https://doi.org/10.5853/jos.2019.03027

Bapir, R., Bhatti, K. H., Eliwa, A., García-Perdomo, H. A., Gherabi, N., Hennessey, D., Magri, V., Mourmouris, P., Ouattara, A., Perletti, G., Philipraj, J., Stamatiou, K., Trinchieri, A., & Buchholz, N. (2022). Efficacy of overactive neurogenic bladder treatment: A systematic review of randomized controlled trials. *Archivio Italiano di Urologia e Andrologia, 94*(4), 492–506. https://doi.org/10.4081/aiua.2022.4.492

Beheshti, R., Shahbazi, A., Tahmasbi, F., Naseri, A., & Vahdati, S. S. (2023). Comparison of interventions in in anterior vs. posterior circulation stroke: An umbrella review. *Journal of the Neurological Sciences, 455*, Article 122272. https://doi.org/10.1016/j.jns.2023.122272

Chen, C.-C., Chuang, Y.-F., Huang, A. C.-W., Chen, C.-K., & Chang, Y.-J. (2016). The antalgic effects of non-invasive physical modalities on central post-stroke pain: A systematic review. *Journal of Physical Therapy Science, 28*(4), 1368–1373. https://doi.org/10.1589/jpts.28.1368

Cho, H.-Y., In, T. S., Cho, K. H., & Song, C. H. (2013). A single trial of transcutaneous electrical nerve stimulation (TENS) improves spasticity and balance in patients with chronic stroke. *The Tohoku Journal of Experimental Medicine, 229*(3), 187–193. https://doi.org/10.1620/tjem.229.187

Cruz, E., Miller, C., Zhang, W., Rogers, K., Lee, H.-J., Wells, Y., Cloud, G. C., & Lannin, N. A. (2022). Does non-implanted electrical stimulation reduce post-stroke urinary or fecal incontinence? A systematic review with meta-analysis. *International Journal of Stroke, 17*(4), 378–388. https://doi.org/10.1177/17474930211006301

de Sire, A., Moggio, L., Demeco, A., Fortunato, F., Spanò, R., Aiello, V., Marotta, N., & Ammendolia, A. (2022). Efficacy of rehabilitative techniques in reducing hemiplegic shoulder pain in stroke: Systematic review and meta-analysis. *Annals of Physical and Rehabilitation Medicine, 65*(5), Article 101602. https://doi.org/10.1016/j.rehab.2021.101602

Donkor, E. S. (2018). Stroke in the 21st Century: A snapshot of the burden, epidemiology, and quality of life. *Stroke Research and Treatment, 2018*(1), Article 3238165. https://doi.org/10.1155/2018/3238165

dos Santos-Fontes, R. L., Ferreiro de Andrade, K. N., Sterr, A., & Conforto, A. B. (2013). Home-based nerve stimulation to enhance effects of motor training in patients in the chronic phase after stroke: A proof-of-principle study. *Neurorehabilitation and Neural Repair, 27*(6), 483–490. https://doi.org/10.1177/1545968313478488

Fang, Y., Li, J., Liu, S., Wang, Y., Li, J., Yang, D., & Wang, Q. (2023). Optimization of electrical stimulation for the treatment of lower limb dysfunction after stroke: A systematic review and Bayesian network meta-analysis of randomized controlled trials. *PLoS ONE, 18*(5), Article e0285523. https://doi.org/10.1371/journal.pone.0285523

Fernández-Tenorio, E., Serrano-Muñoz, D., Avendaño-Coy, J., & Gómez-Soriano, J. (2019). Transcutaneous electrical nerve stimulation for spasticity: A systematic review. *Neurología (English Edition), 34*(7), 451–460. https://doi.org/10.1016/j.nrl.2016.06.009

Garcia, M. A. C., & Vargas, C. D. (2019). Is somatosensory electrical stimulation effective in relieving spasticity? A systematic review. *Journal of Musculoskeletal & Neuronal Interactions, 19*(3), 317–325.

Grant, V. M., Gibson, A., & Shields, N. (2018). Somatosensory stimulation to improve hand and upper limb function after stroke—A systematic review with meta-analyses. *Topics in Stroke Rehabilitation, 25*(2), 150–160. https://doi.org/10.1080/10749357.2017.1389054

Gross, T., Schneider, M. P., Bachmann, L. M., Blok, B. F., Groen, J., 't Hoen, L. A., Castro-Diaz, D., Padilla Fernández, B., Del Popolo, G., Musco, S., Hamid, R., Ecclestone, H., Karsenty, G., Phé, V., Pannek, J., & Kessler, T. M. (2016). Transcutaneous electrical nerve stimulation for treating neurogenic lower urinary tract dysfunction: A systematic review. *European Urology, 69*(6), 1102–1111. https://doi.org/10.1016/j.eururo.2016.01.010

Hatem, S. M., Saussez, G., Della Faille, M., Prist, V., Zhang, X., Dispa, D., & Bleyenheuft, Y. (2016). Rehabilitation of motor function after stroke: A multiple systematic review focused on techniques to stimulate upper extremity recovery. *Frontiers in Human Neuroscience, 10*, Article 442. https://doi.org/10.3389/fnhum.2016.00442

In, T.-S., Jung, J.-H., Jung, K.-S., & Cho, H.-Y. (2021). Effectiveness of transcutaneous electrical nerve stimulation with taping for stroke rehabilitation. *BioMed Research International, 2021*(1), Article 9912094. https://doi.org/10.1155/2021/9912094

Johnson, M. (2007). Transcutaneous electrical nerve stimulation: Mechanisms, clinical application and evidence. *Reviews in Pain, 1*(1), 7–11. https://doi.org/10.1177/204946370700100103

Jung, K.-S., In, T.-S., & Cho, H.-Y. (2017). Effects of sit-to-stand training combined with transcutaneous electrical stimulation on spasticity, muscle strength and balance ability in patients with stroke: A randomized controlled study. *Gait & Posture, 54*, 183–187. https://doi.org/10.1016/j.gaitpost.2017.03.007

Katan, M., & Luft, A. (2018). Global burden of stroke. *Seminars in Neurology, 38*(2), 208–211. https://doi.org/10.1055/s-0038-1649503

Kwong, P. W. H., Ng, G. Y. F., Chung, R. C. K., & Ng, S. S. M. (2018). Transcutaneous electrical nerve stimulation improves walking capacity and reduces spasticity in stroke survivors: A systematic review and meta-analysis. *Clinical rehabilitation, 32*(9), 1203–1219. https://doi.org/10.1177/0269215517745349

Laufer, Y., & Elboim-Gabyzon, M. (2011). Does sensory transcutaneous electrical stimulation enhance motor recovery following a stroke? A systematic review. *Neurorehabilitation and Neural Repair, 25*(9), 799–809. https://doi.org/10.1177/1545968310397205

Li, Y., Yan, Z.-P., Zhang, N.-N., Ni, J., & Wang, Z.-Y. (2023). Investigation into the effectiveness of combining transcranial direct current stimulation and transcutaneous electrical nerve stimulation as treatment options for poststroke shoulder pain by utilizing functional near-infrared spectroscopy. *Therapeutics and Clinical Risk Management, 19*, 875–887. https://doi.org/10.2147/tcrm.s431816

Lin, I.-H., Tsai, H.-T., Wang, C.-Y., Hsu, C.-Y., Liou, T.-H., & Lin, Y.-N. (2019). Effectiveness and superiority of rehabilitative treatments in enhancing motor recovery within 6 months poststroke: A systemic review. *Archives of Physical Medicine and Rehabilitation, 100*(2), 366–378. https://doi.org/10.1016/j.apmr.2018.09.123

Lin, S., Sun, Q., Wang, H., & Xie, G. (2018). Influence of transcutaneous electrical nerve stimulation on spasticity, balance, and walking speed in stroke patients: A systematic review and meta-analysis. *Journal of Rehabilitation Medicine, 50*(1), 3–7. https://doi.org/10.2340/16501977-2266

Lisa, L. P., Jughters, A., & Kerckhofs, E. (2013). The effectiveness of different treatment modalities for the rehabilitation of unilateral neglect in stroke patients: A systematic review. *NeuroRehabilitation, 33*(4), 611–620. https://doi.org/10.3233/nre-130986

Mahmood, A., Veluswamy, S. K., Hombali, A., Mullick, A., N, M., & Solomon, J. M. (2019). Effect of transcutaneous electrical nerve stimulation on spasticity in adults with stroke: A systematic review and meta-analysis. *Archives of Physical Medicine and Rehabilitation, 100*(4), 751–768. https://doi.org/10.1016/j.apmr.2018.10.016

Marcolino, M. A. Z., Hauck, M., Stein, C., Schardong, J., Pagnussat, A. S., & Plentz, R. D. M. (2020). Effects of transcutaneous electrical nerve stimulation alone or as additional therapy on chronic post-stroke spasticity: Systematic review and meta-analysis of randomized controlled trials. *Disability and Rehabilitation, 42*(5), 623–635. https://doi.org/10.1080/09638288.2018.1503736

Mijic, M., Jung, A., Schoser, B., & Young, P. (2022). Use of peripheral electrical stimulation on healthy individual and patients after stroke and its effects on the somatosensory evoked potentials. A systematic review. *Frontiers in Neurology, 13*, Article 1036891. https://doi.org/10.3389/fneur.2022.1036891

Mills, P. B., & Dossa, F. (2016). Transcutaneous electrical nerve stimulation for management of limb spasticity: A systematic review. *American Journal of Physical Medicine & Rehabilitation, 95*(4), 309–318. https://doi.org/10.1097/phm.0000000000000437

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*(n71). https://doi.org/10.1136/bmj.n71

Perpetuini, D., Russo, E. F., Cardone, D., Palmieri, R., De Giacomo, A., Pellegrino, R., Merla, A., Calabrò, R. S., & Filoni, S. (2023). Use and effectiveness of electrosuit in neurological disorders: A systematic review with clinical implications. *Bioengineering (Basel), 10*(6), Article 680. https://doi.org/10.3390/bioengineering10060680

Pomeroy, V. M., King, L., Pollock, A., Baily-Hallam, A., & Langhorne, P. (2006). Electrostimulation for promoting recovery of movement or functional ability after stroke. *Cochrane Database Systematic Reviews, 2006*(2), Article CD003241. https://doi.org/10.1002/14651858.CD003241.pub2

Price, C. I., & Pandyan, A. D. (2001). Electrical stimulation for preventing and treating post-stroke shoulder pain: A systematic Cochrane review. *Clinical Rehabilitation, 15*(1), 5–19. https://doi.org/10.1191/026921501670667822

Ramos-Castaneda, J. A., Barreto-Cortes, C. F., Losada-Floriano, D., Sanabria-Barrera, S. M., Silva-Sieger, F. A., & Garcia, R. G. (2022). Efficacy and safety of vagus nerve stimulation on upper limb motor recovery after stroke. A systematic review and meta-analysis. *Frontiers in Neurology, 13*, Article 889953. https://doi.org/10.3389/fneur.2022.889953

Ratmansky, M., Defrin, R., & Soroker, N. (2012). A randomized controlled study of segmental neuromyotherapy for post-stroke hemiplegic shoulder pain. *Journal of Rehabilitation Medicine, 44*(10), 830–836. https://doi.org/10.2340/16501977-1021

Robbins, S. M., Houghton, P. E., Woodbury, M. G., & Brown, J. L. (2006). The therapeutic effect of functional and transcutaneous electric stimulation on improving gait speed in stroke patients: A meta-analysis. *Archives of Physical Medicine and Rehabilitation, 87*(6), 853–859. https://doi.org/10.1016/j.apmr.2006.02.026

Shankaranarayana, A. M., Gururaj, S., Natarajan, M., Balasubramanian, C. K., & Solomon, J. M. (2021). Gait training interventions for patients with stroke in India: A systematic review. *Gait & Posture, 83*, 132–140. https://doi.org/10.1016/j.gaitpost.2020.10.012

Sharififar, S., Shuster, J. J., & Bishop, M. D. (2018). Adding electrical stimulation during standard rehabilitation after stroke to improve motor function. A systematic review and meta-analysis. *Annals of Physical and Rehabilitation Medicine, 61*(5), 339–344. https://doi.org/10.1016/j.rehab.2018.06.005

Sluka, K. A., & Walsh, D. (2003). Transcutaneous electrical nerve stimulation: Basic science mechanisms and clinical effectiveness. *The Journal of Pain, 4*(3), 109–121. https://doi.org/10.1054/jpai.2003.434

Tahmasbi, F., Ghaderpanah, R., Sadrian, S., Heris, R. M., & Salehi-Pourmehr, H. (2023). Effects of transcutaneous electrical nerve stimulation (TENS) on chronic pain in older adults: A systematic review and meta-analysis. *Current Physical Medicine and Rehabilitation Reports, 11*(2), 242–253. https://doi.org/10.1007/s40141-023-00397-4

Tahmasbi, F., Hosseini, S., Hajebrahimi, S., Heris, R. M., & Salehi-Pourmehr, H. (2023). Efficacy of tibial nerve stimulation in neurogenic lower urinary tract dysfunction among patients with multiple sclerosis: A systematic review

and meta-analysis. *Urology Research and Practice, 49*(2), 100. https://doi.org/10.5152/tud.2023.22241
Tahmasbi, F., Mosaddeghi-Heris, R., Soleimanzadeh, F., Ghaderpanah, R., Sadrian, S., Hajebrahimi, S., & Salehi-Pourmehr, H. (2023). Effects of posterior tibial nerve stimulation on fecal incontinence: An umbrella review. *Neuromodulation: Technology at the Neural Interface, 27*(2), 229–242. https://doi.org/10.1016/j.neurom.2023.06.004
Tahmasbi, F., Salehi-Pourmehr, H., Naseri, A., Ghaderi, S., Javadi-Farid, F., Hajebrahimi, S., Sedigh, O., & Soleimanzadeh, F. (2024). Effects of posterior tibial nerve stimulation (PTNS) on lower urinary tract dysfunction: An umbrella review. *Neurourology and Urodynamics, 43*(2), 494–515. https://doi.org/10.1002/nau.25343
Tan, Z., Dong, F., Wu, L., Feng, Y., Zhang, M., & Zhang, F. (2023). Transcutaneous electrical nerve stimulation (TENS) alleviates brain ischemic injury by regulating neuronal oxidative stress, pyroptosis, and mitophagy. *Mediators of Inflammation, 2023*(1), Article 5677865. https://doi.org /10.1155/2023/5677865
Teoli, D., Dua, A., & An, J. (2024). Transcutaneous electrical nerve stimulation. In *StatPearls*. StatsPearls Publishing.
Thomas, L. H., Coupe, J., Cross, L. D., Tan, A. L., & Watkins, C. L. (2019). Interventions for treating urinary incontinence after stroke in adults. *Cochrane Database of Systematic Reviews, 2*(2), Article CD004462. https://doi.org/10.1002 /14651858.CD004462.pub4
Wang, X., Ding, Q., Li, T., Li, W., Yin, J., Li, Y., Li, Y., & Zhuang, W. (2023). Application of vagus nerve stimulation on the rehabilitation of upper limb dysfunction after stroke: A systematic review and meta-analysis. *Frontiers in Neurology, 14*, Article 1189034. https://doi.org/10.3389 /fneur.2023.1189034
Xie, Y.-L., Wang, S., Wu, Q., & Chen, X. (2021). Vagus nerve stimulation for upper limb motor impairment after ischemic stroke: A meta-analysis. *Medicine (Baltimore), 100*(46), Article e27871. https://doi.org/10.1097 /md.0000000000027871
Xue, T., Yan, Z., Meng, J., Wang, W., Chen, S., Wu, X., Gu, F., Tao, X., Wu, W., Chen, Z., Bai, Y., Wang, Z., & Zhang, J. (2022). Efficacy of neurostimulations for upper extremity function recovery after stroke: A systematic review and network meta-analysis. *Journal of Clinical Medicine, 11*(20), Article 6162. https://doi.org/10.3390 /jcm11206162
Yan, L., Qian, Y., & Li, H. (2022). Transcutaneous vagus nerve stimulation combined with rehabilitation training in the intervention of upper limb movement disorders after stroke: A systematic review. *Neuropsychiatric Disease and Treatment, 18*, 2095–2106. https://doi.org/10.2147/ndt.S376399
Zhao, K., Yang, J., Huang, J., Zhao, Z., & Qu, Y. (2022). Effect of vagus nerve stimulation paired with rehabilitation for upper limb function improvement after stroke: A systematic review and meta-analysis of randomized controlled trials. *International Journal of Rehabilitation Research, 45*(2), 99–108. https://doi.org/10.1097/mrr.0000000000000509
Zhou, M., Li, F., Lu, W., Wu, J., & Pei, S. (2018). Efficiency of neuromuscular electrical stimulation and transcutaneous nerve stimulation on hemiplegic shoulder pain: A randomized controlled trial. *Archives of Physical Medicine and Rehabilitation, 99*(9), 1730–1739. https://doi.org/10.1016 /j.apmr.2018.04.020

Received: January 31, 2024
Accepted: May 6, 2024
Published: September 30, 2024

Appendix

Search Strategies

PubMed

Search: ((((((((((((("Transcutaneous Electric Nerve Stimulation"[Mesh]) OR (Transcutaneous Electric Nerve Stimulation[Title/Abstract])) OR (Transcutaneous Electrical Nerve Stimulation[Title/Abstract])) OR (Transcutaneous Nerve Stimulation[Title/Abstract])) OR (Transcutaneous Electric Stimulation[Title/Abstract])) OR (TENS[Title/Abstract])) OR (electrostimulation[Title/Abstract])) OR (neuromodulation[Title/Abstract])) OR (transdermal electric nerve stimulation[Title/Abstract])) OR (transdermal electrical nerve stimulation[Title/Abstract])) OR (transdermal nerve stimulation[Title/Abstract])) OR (transdermal electric stimulation[Title/Abstract])) OR (Transcutaneous Neuromodulation Therapy[Title/Abstract])) OR (Nerve Stimulation, Transcutaneous[Title/Abstract])) AND ((((((((((((("Stroke"[Mesh] OR "Embolic Stroke"[Mesh] OR "Hemorrhagic Stroke"[Mesh] OR "Thrombotic Stroke"[Mesh] OR "Ischemic Stroke"[Mesh] OR "Stroke, Lacunar"[Mesh] OR "Brain Stem Infarctions"[Mesh] OR "Infarction, Middle Cerebral Artery"[Mesh] OR "Infarction, Anterior Cerebral Artery"[Mesh] OR "Anterior spinal artery stroke" [Supplementary Concept]) OR (stroke[Title/Abstract])) OR (embolic stroke[Title/Abstract])) OR (hemorrhagic stroke[Title/Abstract])) OR (thrombotic stroke[Title/Abstract])) OR (ischemic stroke[Title/Abstract])) OR (lacunar stroke[Title/Abstract])) OR (brain ischemia[Title/Abstract])) OR (brain infarction[Title/Abstract])) OR (brain attack[Title/Abstract])) OR (Cerebrovascular accident[Title/Abstract])) OR (CVA[Title/Abstract])) OR (intracerebral hemorrhage[Title/Abstract])) OR (((("Ischemic Attack, Transient"[Mesh]) OR (Ischemic Attack, Transient[Title/Abstract])) OR (Transient Ischemic Attack[Title/Abstract])) OR (Transient Ischemic Stroke[Title/Abstract]))) Filters: Meta-Analysis, Systematic Review

Web of Science (WoS)

Transcutaneous electric nerve stimulation OR Transcutaneous electrical nerve stimulation OR Transcutaneous nerve stimulation OR Transcutaneous electric stimulation OR transdermal electric nerve stimulation OR transdermal electrical nerve stimulation OR transdermal nerve stimulation OR transdermal electric stimulation OR neuromodulation OR electrostimulation OR TENS (Topic) and Stroke OR cerebrovascular accident OR CVA OR ischemic stroke OR brain stroke OR cerebral stroke OR hemorrhagic stroke OR brain attack OR transient ischemic stroke OR TIA OR brain infarction OR cerebral infarction OR cerebrovascular infarction OR intracranial stroke OR intracranial hemorrhage (Topic) and systematic review OR meta-analysis OR review systematic OR metaanalysis OR meta analysis OR comprehensive review (All Fields)

COCHRANE

Search Name: STROKE + UMBRELLA
Date Run: 01/08/2023 05:46:20
Comment:

ID Search Hits

#1 systematic review OR meta-analysis OR review systematic OR metaanalysis OR meta analysis OR comprehensive review 69196

#2 Transcutaneous electric nerve stimulation OR Transcutaneous electrical nerve stimulation OR Transcutaneous nerve stimulation OR Transcutaneous electric stimulation OR transdermal electric nerve stimulation OR transdermal electrical nerve stimulation OR transdermal nerve stimulation OR transdermal electric stimulation OR neuromodulation OR electrostimulation OR TENS 10864

#3 Stroke OR cerebrovascular accident OR CVA OR ischemic stroke OR brain stroke OR cerebral stroke OR hemorrhagic stroke OR brain attack OR transient ischemic stroke OR TIA OR brain infarction OR cerebral infarction OR cerebrovascular infarction OR intracranial stroke OR intracranial hemorrhage 91257

#4 #1 AND #2 AND #3 152

Scopus
(TITLE-ABS-KEY ("Transcutaneous electric nerve stimulation" OR "Transcutaneous electrical nerve stimulation" OR "Transcutaneous nerve stimulation" OR "Transcutaneous electric stimulation" OR "transdermal electric nerve stimulation" OR "transdermal electrical nerve stimulation" OR "transdermal nerve stimulation" OR "transdermal electric stimulation" OR neuromodulation OR electrostimulation OR tens) AND TITLE-ABS-KEY (stroke OR "cerebrovascular accident" OR cva OR "ischemic stroke" OR "brain stroke" OR "cerebral stroke" OR "hemorrhagic stroke" OR "brain attack" OR "transient ischemic stroke" OR tia OR "brain infarction" OR "cerebral infarction" OR "cerebrovascular infarction" OR "intracranial stroke" OR "intracranial hemorrhage") AND TITLE-ABS-KEY ("systematic review" OR "meta-analysis" OR "review systematic" OR metaanalysis OR "meta analysis" OR "comprehensive review"))