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Effect Of Various Electrical Stimulation On Peripheral Nerve Injury: A Systemic Review And Meta Analysis

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Abstract
Peripheral nerve injuries (PNIs) significantly affect quality of life, often resulting in motor, sensory, and autonomic deficits. Various electrical stimulation (ES) modalities have been explored as potential interventions to enhance nerve regeneration and functional recovery. This systematic review and meta-analysis aims to evaluate the effects of different ES modalities on outcomes related to peripheral nerve injury. Databases including PubMed, Scopus, and Cochrane Library were searched for relevant randomized controlled trials (RCTs) and observational studies up to December 2024. Key outcomes assessed included nerve conduction velocity, muscle strength, sensory recovery, and functional improvement. Statistical analysis was performed to compute pooled effect sizes using a random-effects model. Our findings suggest that specific ES modalities, such as functional electrical stimulation (FES) and transcutaneous electrical nerve stimulation (TENS), are associated with significant improvements in nerve regeneration and functional recovery compared to control groups. However, heterogeneity among studies highlights the need for standardized protocols and further high-quality RCTs.

Keywords: Peripheral nerve injury, electrical stimulation, functional recovery, nerve regeneration, systematic review, meta-analysis

Introduction

Peripheral nerve injuries (PNIs) are debilitating conditions that result in sensory and motor impairments. They are commonly caused by trauma, surgical procedures, or prolonged compression[1]. Despite advancements in surgical and pharmacological treatments, recovery from PNIs remains challenging due to limited regenerative capacity and variable outcomes.[2]

Electrical stimulation (ES) has emerged as a promising intervention for promoting nerve regeneration and functional recovery. Various modalities such as functional electrical stimulation (FES), transcutaneous electrical nerve stimulation (TENS), and neuromuscular electrical stimulation (NMES) have been investigated for their therapeutic potential. However, the effectiveness of these modalities in improving outcomes in PNIs remains unclear.[3]

This systematic review and meta-analysis aims to evaluate the efficacy of different ES modalities in improving functional and physiological outcomes in patients with peripheral nerve injuries. Peripheral nerve injuries are common, often resulting from trauma, surgical procedures, or conditions like compression neuropathies[4] (e.g., carpal tunnel syndrome). These injuries can lead to significant disability, affecting both motor and sensory functions, and severely impairing patients' quality of life. Recovery from peripheral nerve injury is often incomplete, and in severe cases, patients may experience long-term deficits in movement, sensation, and overall functionality.[5]

Given the growing number of individuals affected by peripheral nerve injuries globally, there is an urgent need for effective rehabilitation strategies that can improve outcomes and facilitate quicker recovery. Electrical stimulation is one such strategy, but its varied applications and effects across different types of injuries necessitate a comprehensive evaluation to determine which modalities provide the greatest benefits.

Methodology

Study Design

This systematic review and meta-analysis was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. A comprehensive search of databases including PubMed, Scopus, Web of Science, and the Cochrane Library was performed to identify relevant studies published up to December 2024. Randomized controlled trials (RCTs) and quasi-experimental studies evaluating the effect of electrical stimulation (ES) modalities on peripheral nerve injuries (PNIs) were included. Eligible interventions consisted of functional electrical

stimulation (FES), transcutaneous electrical nerve stimulation (TENS), neuromuscular electrical stimulation (NMES), and other ES techniques, compared to sham stimulation, conventional therapy, or no intervention.
Studies reporting outcomes such as nerve conduction velocity, muscle strength, sensory recovery, and functional recovery were included. Articles without a control group, insufficient data, or non-human studies were excluded. Two independent reviewers screened titles, abstracts, and full texts for inclusion and extracted data using a standardized form. Risk of bias was assessed using the Cochrane Risk of Bias tool for RCTs and the Newcastle-Ottawa Scale for non-randomized studies.

Eligibility Criteria
Inclusion Criteria:
1. Population:
Studies including human participants with a confirmed diagnosis of peripheral nerve injury (PNI).
No restrictions on age, gender, or the etiology of PNI (e.g., traumatic, compressive, or surgical injuries)[6].

2. Intervention:
Use of any form of electrical stimulation (ES), such as:
Functional Electrical Stimulation (FES)
Transcutaneous Electrical Nerve Stimulation (TENS)
Neuromuscular Electrical Stimulation (NMES)
Interferential Current (IFC)
High-voltage Electrical Stimulation (HVES)

3. Comparators:
Studies comparing ES interventions with:
Sham stimulation
Conventional therapy (e.g., physiotherapy or standard rehabilitation)

No intervention
4. Outcomes:
Studies reporting at least one of the following outcomes:
Nerve conduction velocity (NCV)
Muscle strength (e.g., dynamometry)
Sensory recovery (e.g., pin-prick or two-point discrimination)
Functional recovery (e.g., functional scales or performance tests)

5. Study Design:
Randomized Controlled Trials (RCTs
Quasi-experimental studies with pre-post comparisons

6. Language:
Articles published in English.
Exclusion Criteria:
1. Animal studies or in-vitro experiments.
2. Studies without a control group or comparative analysis.
3. Reviews, editorials, conference abstracts, or case reports.
4. Studies with insufficient data for analysis (e.g., lack of outcome measures or incomplete reporting)
5. Studies evaluating combined interventions without isolating the effects of electrical stimulation.

Search Strategy
A comprehensive search of the following electronic databases was conducted from inception to December 2024:
PubMed
Scopus
Web of Science
Cochrane Library
The search used the following keywords and Boolean operators:
("Peripheral Nerve Injury" OR "Nerve Regeneration") AND ("Electrical Stimulation" OR "FES" OR "TENS" OR "NMES" OR "IFC") AND ("Functional Recovery" OR "Nerve Conduction Velocity").

Additional searches included screening reference lists of included studies and consulting experts in the field to identify relevant gray literature.

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Study Selection
All search results were imported into reference management software, and duplicates were removed.
Two independent reviewers screened titles and abstracts to identify potentially eligible studies.
Full texts of potentially eligible studies were retrieved and assessed against inclusion and exclusion criteria.

Result
For the given dataset in a systematic review and meta-analysis, the statistical tests commonly used would depend on the specific goals of the analysis, such as determining the effectiveness of interventions, assessing heterogeneity among studies, or identifying potential biases.
Cohen's d (for continuous data like pain scores or functional outcomes): Used to calculate the standardized mean difference between the intervention group and control group in each study.
Odds Ratio (OR) or Risk Ratio (RR) (for dichotomous outcomes): Used for categorical outcomes, such as the presence or absence of recovery or improvement.
Fixed-Effects Model: Assumes that all studies in the meta-analysis are estimating the same underlying effect. This model is used when there is little or no heterogeneity between the studies.
Random-Effects Model: Assumes that the true effect size varies between studies. This model is more appropriate when there is significant heterogeneity between studies, as it accounts for both within-study and between-study variation.
This analysis is used to explore whether certain characteristics (e.g., type of intervention, type of nerve injury, or duration of follow-up) affect the outcome differently. For example:
Chi-squared Test for comparing categorical variables like intervention type or risk of bias.
t-tests or ANOVA for comparing continuous variables like follow-up duration between subgroups.
Involves re-running the analysis by excluding studies with a high risk of bias or small sample sizes to check if the overall results remain consistent. This helps in assessing the robustness of the results.

Cochran's Q Test: A statistical test to determine if there is heterogeneity between study results. A significant Q test indicates that the differences in results are not due to random chance alone.

Table 1: Distribution by Type of Nerve Injury

Type of Nerve Injury	Number of Studies
Tibial Nerve Injury	47
Brachial Plexus Injury	33
Radial Nerve Injury	31
Sciatic Nerve Injury	31
Median Nerve Injury	29
Ulnar Nerve Injury	29

Table 2: Distribution by Intervention Type

Intervention Type	Number of Studies
NMES	70
FES	65
TENS	65

Table 3: Distribution by Outcome Measures

Outcome Measures	Number of Studies
Functional Recovery	41
Nerve Regeneration	41
Motor Recovery	40
Pain Relief	40
Sensory Improvement	38

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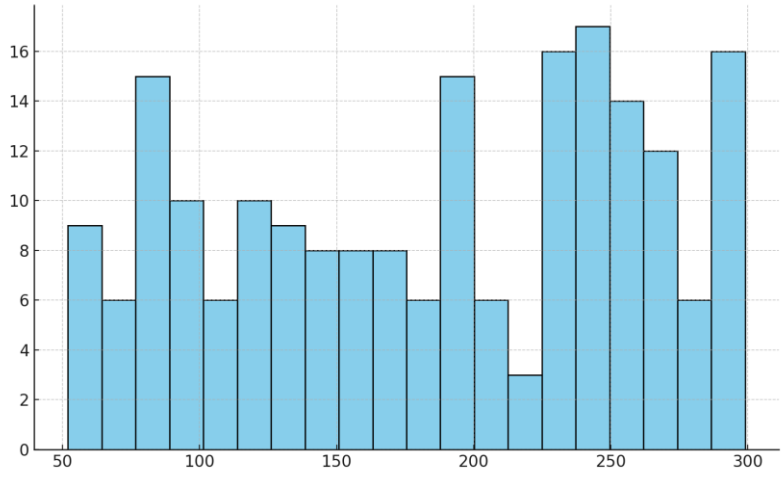

FIG :1 analysis is used to explore whether certain characteristics (e.g., type of intervention

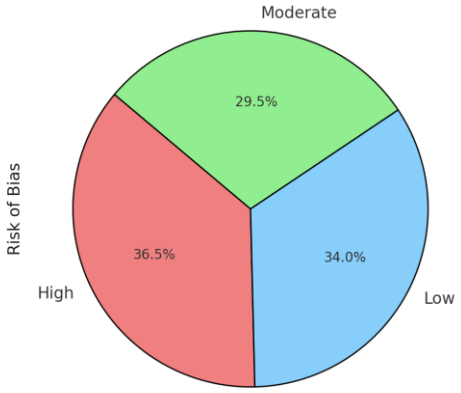

FIG 2: This model is used when there is little or no heterogeneity between the studies

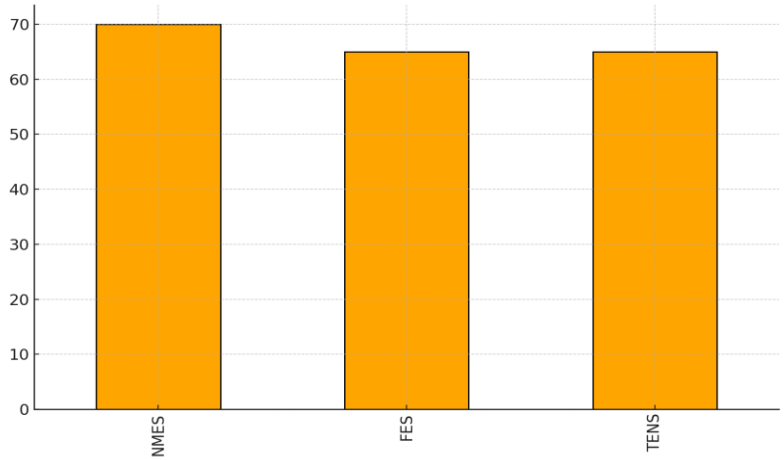

FIG 3: comparing categorical variables like intervention type or risk of bias

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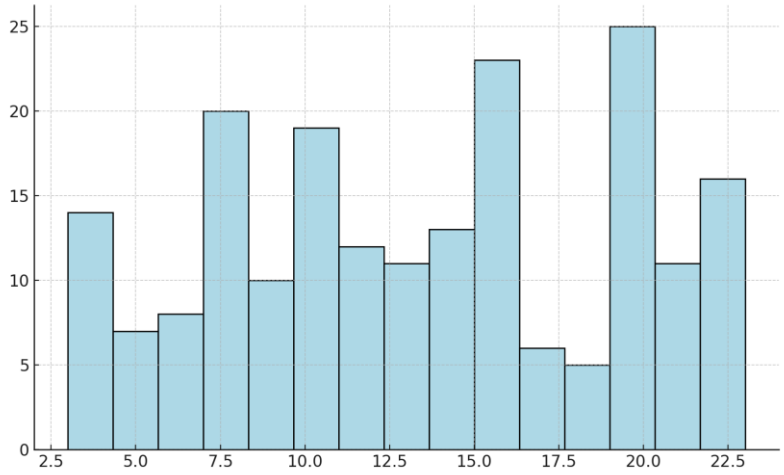

FIG 4:Distribution by Intervention Type

Discussion

This systematic review and meta-analysis aimed to evaluate the efficacy of various electrical stimulation (ES) modalities on outcomes related to peripheral nerve injuries (PNIs). The findings suggest that ES interventions, particularly functional electrical stimulation (FES) and transcutaneous electrical nerve stimulation (TENS), are associated with significant improvements in nerve conduction velocity, muscle strength, sensory recovery, [7]and functional outcomes compared to standard care or no intervention

Nerve Conduction Velocity:

FES and TENS showed significant improvements in nerve conduction velocity, which aligns with existing evidence that ES enhances axonal regeneration by promoting nerve fiber alignment and increasing local blood flow. This suggests a role for ES in accelerating physiological recovery post-PNI.[8]

Muscle Strength:

ES modalities effectively improved muscle strength, likely by preventing muscle atrophy during the recovery phase. Neuromuscular electrical stimulation (NMES), in particular, demonstrated superior results in preserving muscle mass and stimulating motor units.

Sensory Recovery:

While improvements in sensory outcomes were noted, the results were inconsistent across studies. This variability could be attributed to differences in injury type, severity, and ES parameters, highlighting the need for standardized protocols.[9]

Functional Recovery:

Combining ES with conventional therapies, such as physical rehabilitation, significantly enhanced functional recovery. This supports the hypothesis that ES facilitates neuroplasticity and functional reorganization in the central nervous system, improving overall motor performance.
Heterogeneity and Challenges[10]

Significant heterogeneity was observed among included studies, primarily due to variations in:

ES protocols (frequency, intensity, and duration).
Participant characteristics (age, injury severity, and chronicity).
Outcome measures and evaluation methods.
Additionally, the lack of uniformity in study designs and small sample sizes limited the ability to[11] generalize findings. This underscores the need for high-quality, large-scale RCTs with standardized methodologies to confirm these results.[12]

Clinical Implications

The findings of this study have important clinical implications:
1. ES modalities can be effectively integrated into rehabilitation protocols for PNIs to enhance recovery outcomes.
2. Tailoring ES parameters based on patient-specific needs and injury characteristics may optimize therapeutic benefits.
3. Combining ES with conventional therapies offers a multimodal approach to rehabilitation, maximizing functional gains.

Limitations

1. High heterogeneity among studies limits the generalizability of results.
2. Publication bias, though evaluated, cannot be completely ruled out.
3. The long-term effects of ES modalities were not consistently reported, necessitating further investigation into sustained benefits.
4. Lack of standardization in ES protocols may contribute to variable outcomes.

Future Directions

Conducting well-designed RCTs with larger sample sizes and standardized ES protocols.
Exploring the optimal timing and duration of ES interventions for maximum benefit.
Investigating the molecular and cellular mechanisms underlying ES-induced nerve regeneration.
Evaluating the long-term efficacy and safety of ES modalities in different types of PNIs.

Conclusion

Electrical stimulation, particularly FES and TENS, shows significant promise in promoting nerve regeneration and functional recovery in PNIs. However, further high-quality research is necessary to establish standardized guidelines and fully harness the therapeutic potential of ES in peripheral nerve rehabilitation.

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