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Review Article

The Impact of Neuromuscular Stimulation on the Rehabilitation Outcomes of Patients Following Joint Replacement Surgery: A Systematic Review and Meta-Analysis

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Abstract

Background: We aimed to comprehensively evaluate the impact of neuromuscular electrical stimulation (NMES) on rehabilitation outcomes in patients following joint replacement surgery.

Methods: The systematic review and meta-analysis performed a computerized search of six databases—PubMed, Wiley Library, EMBASE, Web of Science, Cochrane Central, and PEDro—from 2009-2024, for relevant randomized controlled trials (RCTs). Two independent reviewers screened the literature, extracted data, and assessed the risk of bias according to predefined criteria. The primary outcome measures included range of Motion (ROM), pain scores, muscle strength, and functional recovery scores.

Results: Ten RCTs involving 549 participants were included in the analysis, all of which met the inclusion criteria and had a moderate to low risk of bias. NMES significantly reduced pain scores in patients following joint replacement surgery (Standardized mean differences, with high heterogeneity ($I^2 = 82\%$). NMES had no significant effect on flexion range of motion ($I^2 = 33\%$) and a limited impact on extension range of motion (P=0.04). NMES positively affected quadriceps strength ($I^2 = 95\%$). For the Timed Up and Go (TUG) test, NMES had a small positive effect ($P < 0.01$), but after standardizing TUG test scores based on baseline levels, NMES had a significant positive effect ($P < 0.01$). NMES had a significant positive effect on the stairs climb test ($P < 0.01$) and on function score ($P = 0.01$).

Conclusion: NMES is an effective adjunctive therapy for improving joint range of motion, reducing pain, and enhancing functional recovery after joint replacement surgery, but further high-quality RCTs are needed to confirm these findings.

Keywords: Transcutaneous electric nerve stimulation; Joint replacement; Rehabilitation; Meta-analysis

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Introduction

With the increasing trend of global population aging, the demand for joint replacement surgery continues to rise. Joint replacement surgery has become one of the effective treatments for end-stage joint diseases, significantly alleviating pain and improving patients' quality of life (1). However, the postoperative rehabilitation process is crucial for restoring patients' joint function. The goals of postoperative rehabilitation not only include pain relief but also the restoration of joint range of motion, enhancement of muscle strength, and improvement of daily living activities (2).

Neuromuscular electrical stimulation (NMES), as a physical therapy technique, has been widely applied to accelerate the postoperative rehabilitation process. NMES as a physical therapy technique, has been widely applied to accelerate the postoperative rehabilitation process. NMES works by sending weak electrical pulses to the muscles to induce contractions, which can improve circulation, reduce pain, and mitigate muscle atrophy, thereby helping patients recover joint function more quickly (3-6). In recent years, NMES has gained considerable attention and widespread application in various clinical settings, including postoperative rehabilitation following joint replacement surgeries.

In one study, the application of neuromuscular electrical stimulation combined with trunk functional training in the postoperative rehabilitation of patients with femoral neck fractures showed that this approach could enhance hip joint function, balance, and improve daily living abilities. In the rehabilitation following knee joint replacement surgery, biofeedback-assisted electrical stimulation devices are also widely used, helping patients recover function through three treatment modes (7, 8). Moreover, NMES has also found applications in the rehabilitation of shoulder and ankle replacements, helping to mitigate muscle atrophy and improve circulation (9). Electrical stimulation techniques have unique advantages and applications in various types of joint replacement surgeries.

Despite its widespread use, the effectiveness of NMES in postoperative rehabilitation remains a topic of debate. Studies have reported mixed results regarding the clinical benefits of NMES. NMES can accelerate recovery, reduce pain, and enhance muscle strength (3-6), while others have failed to demonstrate significant clinical benefits, questioning the efficacy of NMES as a standard rehabilitation tool (9, 10). This inconsistency not only challenges the popularity of NMES as a standard means of rehabilitation, but also reflects the methodological differences and diversity of application protocols in the current literature.

To address this gap, the current study aimed to provide a more in-depth analysis by including new data from recently published RCTs. By expanding the scope of NMES application to different joint replacement surgeries and systematically evaluating a broader range of clinical outcomes, this study seeks to clarify the role of NMES in postoperative rehabilitation. This approach not only addresses previous methodological differences but also aims to offer stronger evidence to support clinical practice, making it a valuable contribution to the ongoing discussion about NMES efficacy in rehabilitation.

Methods

Search Strategy

Computerized searches were conducted in six databases: PubMed, Wiley Library, EMBASE, Web of Science, Cochrane Central, and PEDro. The search period covered from the inception of each database until August 2024. A combination of subject headings and free-text terms related to "neuromuscular electrical stimulation" and "joint replacement" along with their synonyms were used, tailored to the features of each database. Additionally, we traced the reference lists of included studies to supplement the search for relevant literature. The complete search strategy is provided in Supplementary Table 1.

Inclusion and Exclusion Criteria

Inclusion criteria: Study type: randomized controlled clinical trials. Participants: patients who underwent joint replacement surgery. Intervention: NMES group received NMES treatment plus conventional rehabilitation. Control group: received only conventional rehabilitation (RR).

Exclusion criteria: Animal studies. Conference proceedings, academic reports, or review articles. Studies without full-text availability, lacking required data, or combined with other rehabilitation therapies.

Literature Screening and Data Extraction

Two reviewers independently screened the titles and abstracts of studies for inclusion. Each study was evaluated using a checklist based on eligibility criteria. Studies not meeting the criteria were excluded. Disagreements regarding trial eligibility were resolved by a third reviewer, who assisted in the decision-making process for inclusion or exclusion. For studies lacking sufficient information to assess eligibility, we contacted the authors via email for clarification. Studies with insufficient information, even after contacting the authors, were excluded.

The following data were extracted from the studies: methodological design, number of participants, control group, intervention protocol, frequency, intensity, and duration of stimulation, as well as outcome measures. The primary outcomes extracted included pain scores, quadriceps strength, range of motion, and timed up-and-go tests. In cases of inconsistent data, a third reviewer reanalyzed the data.

Risk of Bias Assessment

The same two reviewers used the Cochrane Risk of Bias tool to assess the risk of bias in the studies. The assessment covered random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessors, completeness of outcome data, selective reporting, and other sources of bias. Discrepancies in the assessment were resolved by discussion with a third reviewer until consensus was reached.

Statistical Methods

Meta-analysis was conducted using R Studio software. Continuous variable data were analyzed using standardized mean differences (SMD) as the effect measure, with 95% confidence intervals (95% CI). Heterogeneity was assessed using the I^2 statistic. If there was no significant heterogeneity ($P>0.1$, $I^2<50\%$), a fixed-effect model was used; otherwise, a random-effects model was employed. Statistical significance was set at $P<0.05$.

Ethics Statement

The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). As this study involves the summary and analysis of other studies, it does not involve medical ethics approval or patient-informed consent.

Results

Literature Search Results and Basic Characteristics

Through domestic and international database searches, a total of 592 relevant articles were identified. Based on the inclusion and exclusion criteria, 10 articles (7, 9-17) were ultimately included, encompassing 549 patients. All studies were randomized controlled clinical trials. The literature screening flowchart is shown in Fig. 1, and the basic characteristics of the included studies are presented in Table 1.

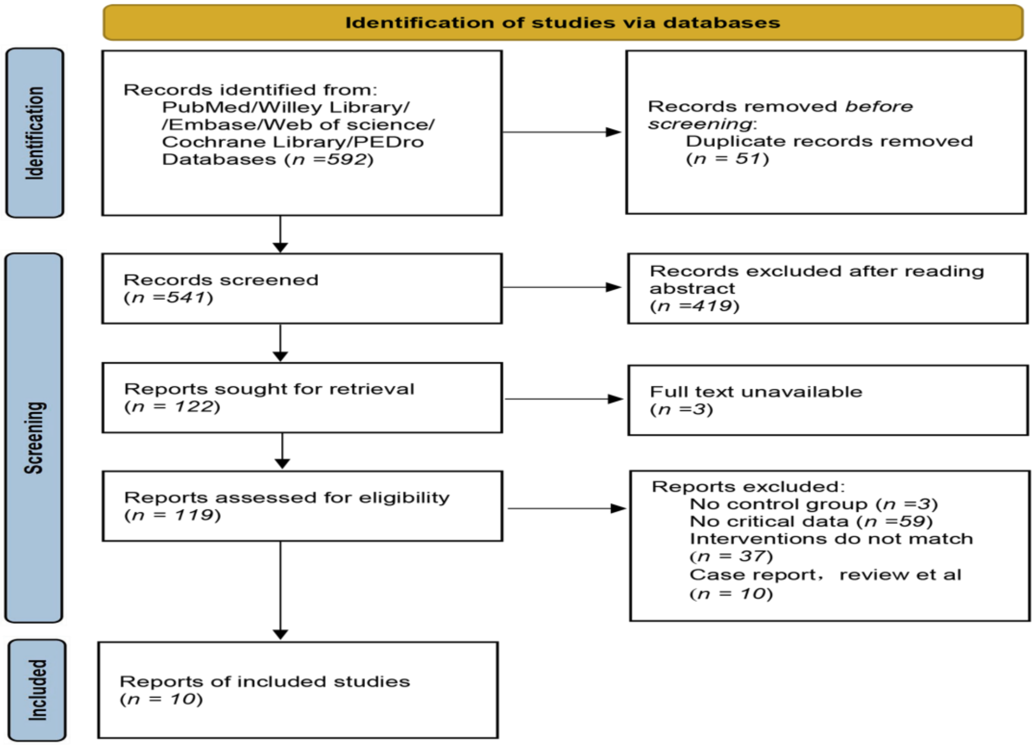

Fig. 1: Study inclusion flow chart

Table 1: Includes the basic characteristics of personnel

Included literature	Year	Sample size	Age (year)		Body mass index (kg/m2)		Gender (male/female)	
		Experimental /Control	Experimental group	Control group	Experimental group	Control group	Experimental group	Control group
Cheuy, V. A.(11)	2023	10/9	68±4	65±6	26.8±4.6	25.8±3.6	6/4	3/6
Delanois, R.(12)	2019	26/26	67.31 (55 to 82)	62.65 (43 to 85)	32.95 (25 to 51)	33.57 (25 to 60)	7/19	5/21
Klika, A. K.(7)	2022	44/22	64±6.2	65±7.6	-	-	17/27	5/17
Lee, Jae-Hoo(9)	2023	33/43	74.0±4.4	73.7±6.8	24.6 ± 2.5	24.0 ± 2.7	15/18	16/27
Levine, M. (13)	2013	35/35	Average 68.1	Average 65.1	Average 30.6	Average 31.9	7/25	13/21
Şavkin, R.(14)	2021	20/20	64.1±5.06	64.25 ± 5.52	32.03 ± 4.25	31.85 ± 5.74	18/2	19/1
Stevens-Lapsley, J. E.(15)	2012	35/31	66.2±9.1	64.8±7.7	27.1± 4.9	31.2± 4.2	15/20	15/16
Zhao, Y. (16)	2022	30/30	53.1 ± 5.7	53.4 ± 5.5	23.8 ± 3.7	22.3 ± 3.2	12/18	9/21
Yoshida, Y. (10)	2017	22/22	75.9±4.7	72.5±6.2	24.6±2.9	25.8±3.3	4/18	2/20
Dabadghav, R. (17)	2019	28/28	60.82±5.69	60.82±5.69	-	-	12/16	12/16

Risk of Bias Assessment of Included Studies

All 10 included studies were randomized controlled clinical trials. Due to the unique nature of NMES treatment, it is easy for both patients and researchers to become aware of the intervention allocation. Only two studies reported the use of single-blinding (Fig. 2).

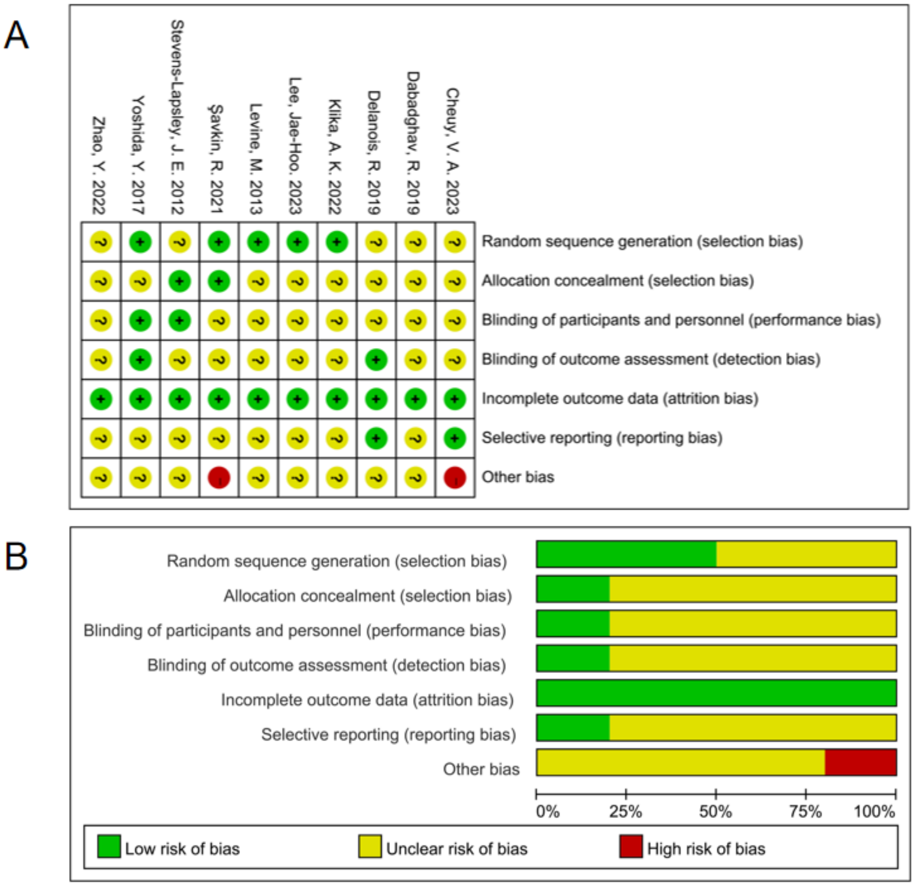

Fig. 2: Risk of Bias Assessment of Included Studies
A: Risk of bias summary; B: Risk of bias graph

Pain Scores

NMES significantly reduced pain scores in patients following joint replacement surgery (SMD = -0.40, 95% CI [-0.62; -0.19]), but with high heterogeneity (I^2 = 82%). Specifically, among seven studies (7, 9, 10, 12, 15-17), Klika et al.'s study showed a significant decrease in pain scores (SMD = -0.40, 95% CI [-0.62; -0.19]), and Lee et al.'s study also demonstrated a similar effect (SMD = -0.45, 95% CI [-0.97; 0.07]). Other studies showed varying effect sizes, but the overall trend was consistent. Sensitivity analysis indicated that this effect was robust. Subgroup analysis revealed that the degree of improvement in pain scores varied depending on the duration of intervention (Fig. 3). In the short-term intervention group, NMES had a more pronounced effect on reducing pain scores (SMD= -0.47, 95% CI [-0.74; -0.20]), whereas the effect was smaller in the long-term intervention group (SMD= -0.28, 95% CI [-0.64; 0.08]). However, the difference between the two groups was not statistically significant (χ^2=0.70, df=1, P=0.40).

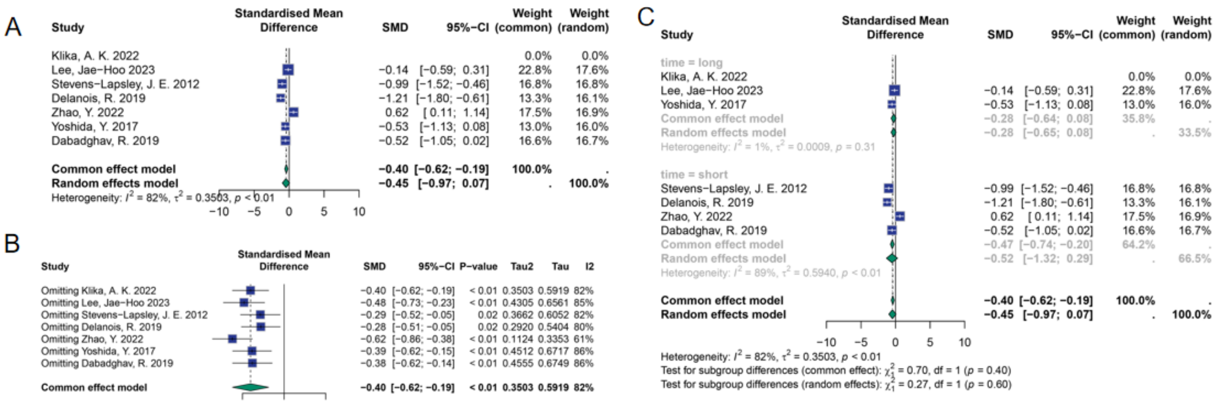

Fig. 3: Analysis of pain score
A: pain score meta; B: Sensitivity analysis of pain score; C: Subgroup analysis of pain score

Range of Motion

NMES did not have a significant effect on flexion range of motion (SMD = 0.07, 95% CI [-0.15; 0.29]) with low heterogeneity (I^2=33%). Neuromuscular electrical stimulation (NMES) had a limited impact on extension range of motion (standardized mean difference [SMD] = -0.14, 95% CI [-0.38; 0.11]), with some heterogeneity (I^2 = 59%, τ^2 = 0.1104, *P*=0.04) (Fig. 4AB).

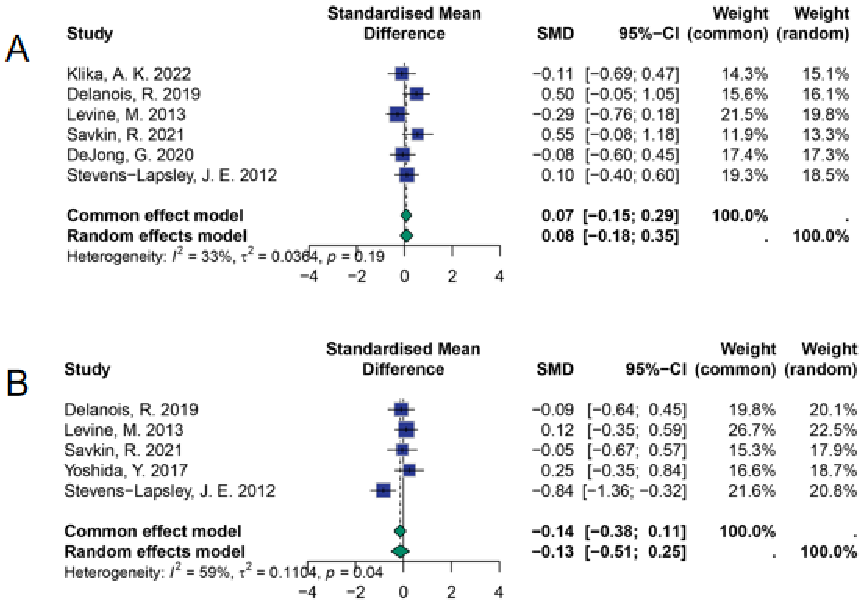

Fig. 4: Analysis of ROM:
A: FROM meta; B: EROM meta

Muscle Strength

NMES had a positive impact on quadriceps strength (SMD = 0.45, 95% CI [0.11; 0.79]), but there was also high heterogeneity (I^2=95%). Sensitivity analysis showed that after removing individual studies, the enhancement effect on quadriceps strength remained significant, although heterogeneity increased. For example, after excluding the study by Klika et al. (7), the enhancement effect on quadriceps strength slightly decreased (SMD=0.39, 95% CI [-0.02; 0.80]), with heterogeneity increasing to 96%. Subgroup analysis indicated that the degree of improvement in quadriceps strength varied depending on whether standardization was applied. In the subgroup where standardization was applied, the effect of NMES was more pronounced (SMD = 0.86, 95% CI [0.33; 1.39]), whereas in the subgroup without standardization, the effect was smaller (SMD = 0.16, 95% CI [-0.29; 0.60]), but the difference between the two subgroups was not statistically significant (χ^2 = 3.94, df = 1, *P*=0.05) (Fig. 5ABC).

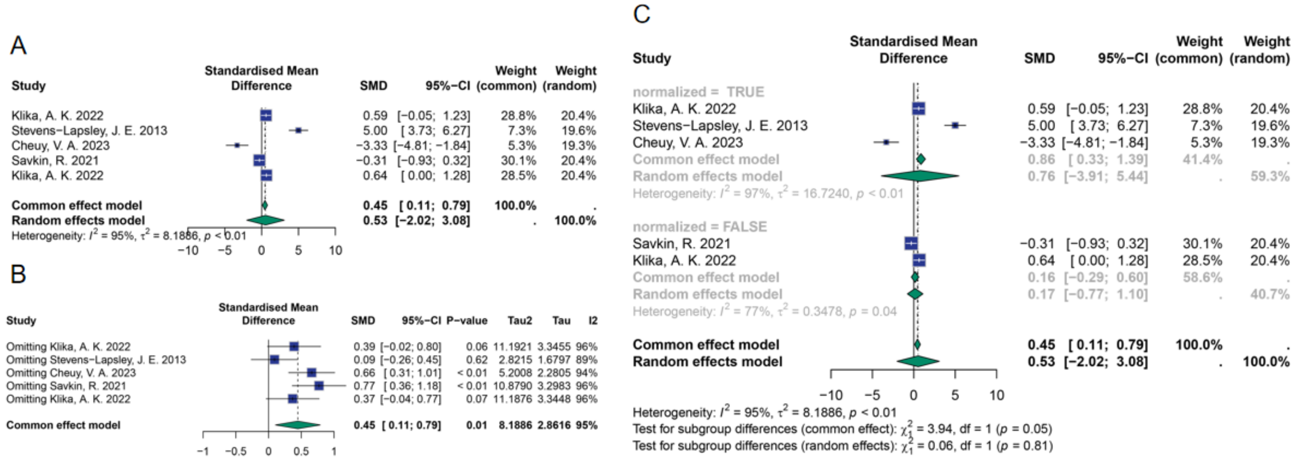

Fig. 5: Analysis of quadriceps strength
A: Quadriceps strength meta; B: Sensitivity analysis for quadriceps strength; C: Subgroup analysis of quadriceps strength

Function Tests

NMES had no significant effect on the Timed Up and Go (TUG) test (SMD = -0.90, 95% CI [-2.44; 0.64]) with high heterogeneity (I^2=95%, τ^2 = 1.7547, *P*<0.01). After standardizing TUG test scores based on baseline levels, NMES also had no significant effect on TUG performance (SMD = -1.68, 95% CI [-3.02; 6.38]), and the results showed high heterogeneity (I^2 = 99%, τ^2 =11.3546, *P*<0.01). There was a significant difference between the groups under the common effect model (χ^2 = 22.67, df = 1, *P*<0.01), but not under the random effects model (χ^2 = 1.04, df=1, *P*=0.31) (Fig. 6A).

NMES had a significant positive effect on the stairs climb test (SMD = 0.71, 95% CI [0.32; 1.11]), but there was high heterogeneity (I^2=97%, τ^2=6.8182, *P*<0.01) (Fig. 6B).

Based on scoring, NMES had a significant positive effect on the function score (SMD=0.63, 95% CI [0.28; 0.97]) (Fig. 6C), but there was moderate heterogeneity (I^2=81%, τ^2 = 0.2595, *P*=0.0). For the Knee score, NMES had a minimal impact (SMD=0.10, 95% CI [-0.23; 0.44]), and no heterogeneity was observed (I^2 =0%, τ^2 =0, *P*=0.32) (Fig. 6D).

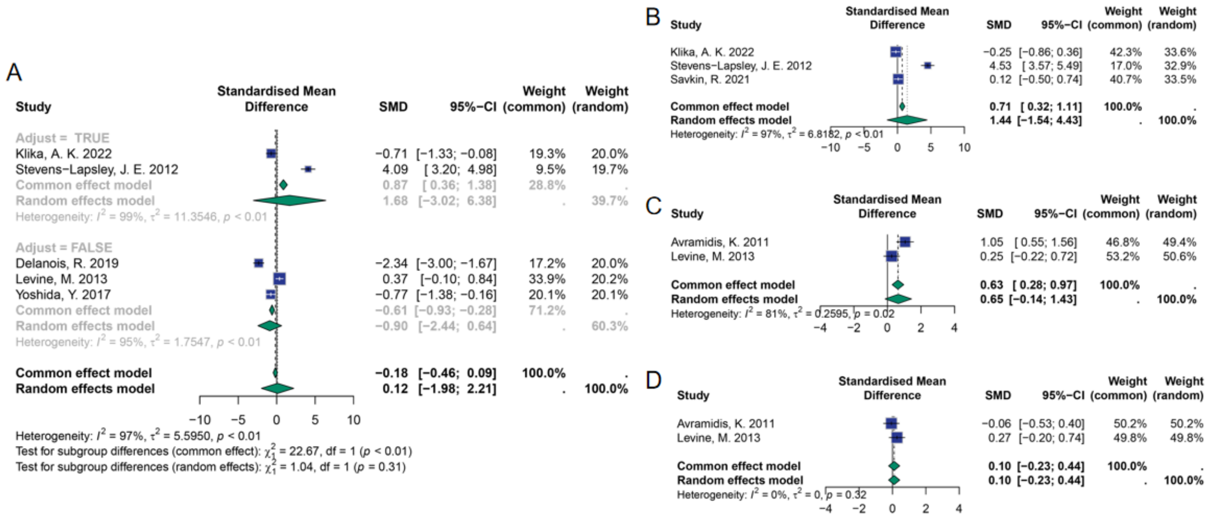

Fig. 6: Analysis of function test
A: Subgroup Analysis for the Timed Up and Go (TUG) Test Meta-Analysis; B. Meta-Analysis for the Stairs Climb Test (SCT); C: FS meta; D: KS meta

Discussion

Joint replacement surgery is a widely used procedure for treating severe joint damage from conditions like osteoarthritis and rheumatoid arthritis (18). While this surgery significantly improves patients' quality of life, effective postoperative rehabilitation is crucial for restoring joint function. Among the various rehabilitation methods NMES has been increasingly used as an adjunct therapy. NMES promotes muscle contraction by stimulating muscle fibers, improving circulation, and reducing muscle atrophy, which are all key to enhancing muscle strength and joint mobility after surgery (19).

In this study, 10 RCT studies were included in a meta-analysis through multiple database searches to evaluate the effect of NMES on rehabilitation after joint replacement. Patients receiving NMES reported significantly less pain than those in the control group, which is consistent with the findings of previous studies (20). Pain is one of the common complications after joint replacement, which seriously affects patients' quality of life and rehabilitation process. Pain management is an important aspect of postoperative rehabilitation (21). However, the application effect of NMES may be affected by many factors. First of all, there are significant differences in the time point, frequency and duration of NMES application in different studies. For example, some studies have employed shorter intervention cycles or lower frequency of stimulation (7, 14), which may not be sufficient to trigger a significant physiological response, while others have observed better pain relief with long-term, high frequency stimulation. In addition, the early and late postoperative pain mechanisms are different, and the mechanism of action of NMES in different stages of rehabilitation may also be different. Early application of NMES may provide pain relief primarily by reducing inflammation and improving blood circulation, while in later stages, NMES may achieve pain management more by enhancing muscle function and reducing muscle stiffness. These factors account for the differences in results between studies.

In terms of muscle strength enhancement, the effect of NMES was significantly influenced by the preoperative muscle status of the patient. In patients with pre-existing muscle weakness, NMES was found to significantly enhance muscle strength by increasing muscle fiber activation. This is in line with the findings of Klika and Stevens, which demonstrated a clear improvement in muscle function following NMES treatment

(7, 15). However, for patients with good preoperative muscle strength, the additional effect of NMES may be relatively limited. In addition, the recovery of muscle strength is also closely related to postoperative rehabilitation exercises. If patients fail to actively participate in rehabilitation training after surgery, the muscle strengthening effect of NMES may be limited. In addition, differences in physiological responses to NMES stimuli between individuals may also contribute to the diversity of outcomes.

With respect to ROM, the role of NMES was limited in both flexion and extension movements. After joint replacement, the ROM recovery of patients not only depends on the functional recovery of postoperative muscles, but also is affected by the structural changes of the joint itself and the postoperative rehabilitation exercise. In some studies, NMES may fail to significantly improve ROM, in part because the intervention intensity or regimen of NMES is insufficient to counteract the fibrosis and tissue adhesion that develops after joint surgery (17, 22). In addition, the recovery of ROM is also closely related to the patient's compliance and rehabilitation exercise. Those with poor adherence may not be able to maximize the benefits of treatment with NMES, leading to inconsistent study results.

In terms of functional recovery, the effect of NMES may be closely related to the overall rehabilitation plan of the patient. Postoperative rehabilitation usually involves a variety of treatments, such as physical therapy, exercise therapy and medication. As an adjunctive therapy, the effect of NMES may be synergistic or interfered with by other treatments. For example, in some studies, NMES were used in patients who were already participating in more intense rehabilitation exercises, which may have masked the independent effect of NMES (23). Conversely, NMES may show more significant functional improvements in some low-intensity rehabilitation programs. The effectiveness of NMES largely depends on how it is integrated into the overall rehabilitation program.

In contrast to the previous systematic review, which focused on the impact of NMES after total knee arthroplasty, our study offers a more in-depth analysis by evaluating the differences in NMES effectiveness across various postoperative stages (early and late stages) (20). Our study provides a more comprehensive assessment by including additional outcomes such as functional recovery scores, which were not fully explored in previous work.

This study has certain limitations. First, the limited number of included studies may impact the stability and generalizability of the results, potentially reducing the robustness of the conclusions. Second, although the risk of bias assessment indicates that most studies are of high quality, the presence of some studies with a risk of bias could introduce variability into the findings. Moreover, the diversity of the included studies increases the likelihood of uncontrolled confounding factors, which may influence the observed outcomes. To address these limitations, future research should aim to include a larger sample of studies to enhance result reliability, implement stricter criteria to minimize bias, and consider advanced statistical methods or stratified analyses to control for potential confounding factors.

Conclusion

NMES, as an adjunctive rehabilitation tool, has a significant positive effect on the rehabilitation outcomes of patients following joint replacement surgery. It can effectively improve joint range of motion, reduce pain, and promote functional recovery. However, given the limitations of the included studies and the heterogeneity across studies, more high-quality research is needed to further validate these findings and explore optimized NMES application protocols.

Journalism Ethics considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

Funding

Not applicable.

Conflicts of Interest

There are no competing interests for any author.

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