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Evaluating the Impact of Transcutaneous Electrical Nerve Stimulation on Patients Undergoing Inguinal Hernia Surgery: A Meta-Analysis of Randomized Controlled Trials

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Abstract: *Objective:* A comprehensive meta-analysis based on the latest randomized controlled trials (RCTs) was conducted to investigate the effects of transcutaneous electrical nerve stimulation (TENS) on patients undergoing treatment after inguinal hernia surgery. *Methods:* A detailed search of Embase, PubMed, Web of Science, and the Cochrane Library was performed for RCTs investigating the use of TENS during inguinal hernia surgery up to September 28, 2021. The Cochrane tool was applied to assess the risk of bias in the included studies. *Results:* Seven eligible RCTs with a total of 379 cases were included. The meta-analysis showed a mean difference (MD) in VAS of -1.61 [95% CI: -2.20 – -1.02, $P < 0.00001$] at 2 hours post-operation, VAS MD = -1.33 at 4 hours post-operation [95% CI: -2.84 – -0.18, $P = 0.09$], VAS MD = -2.36 at 8 hours post-operation [95% CI: -4.04 – -0.69, $P = 0.006$], and VAS MD = -1.75 at 24 hours post-operation [95% CI: -2.64 – -0.85, $P = 0.0001$]. The cortisol level MD at 24 hours post-operation was -52.56 [95% CI: -168.8 – -63.76, $P = 0.38$]. *Conclusion:* TENS significantly reduces postoperative pain following inguinal hernia surgery and promotes patient recovery. TENS is recommended for patients undergoing inguinal hernia surgery. However, further high-quality studies are needed to confirm additional effects.

Keywords: Inguinal hernia surgery; Pain; Meta-analysis; Transcutaneous electrical nerve stimulation

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1. Introduction

Inguinal hernia is a common condition, with a lifetime incidence ranging from 27% to 43% in men and 3% to 6% in women. Surgical intervention is the only definitive treatment. It is estimated that over 200 million inguinal hernia repair surgeries are performed worldwide annually [1,2]. Postoperative pain is a major concern, with approximately 80% of patients experiencing acute pain and 86% reporting varying degrees of discomfort [3]. Conventional postoperative analgesics, primarily opioids and nonsteroidal anti-inflammatory drugs, are widely used but often cause adverse effects, including nausea, vomiting, dizziness, and reduced bowel motility [4].

Transcutaneous electrical nerve stimulation (TENS) offers a drug-free approach to pain management [5]. Since its development in the 1960s, TENS has been used for various painful conditions, demonstrating versatility in pain relief [6]. According to the American Physical Therapy Association (APTA), TENS operates by delivering electrical currents to the skin, which activate A-beta sensory fibers that block pain signals at the spinal cord level [7,8]. Additionally, TENS promotes the release of endogenous opioids, reducing pain perception [9]. The method is cost-effective, well-tolerated, and easy to use [10].

Several clinical trials have evaluated the use of TENS as an adjunctive therapy for pain relief following inguinal hernia surgery [8,11-16]. This meta-analysis aims to provide a quantitative summary of current findings on TENS's effectiveness in managing postoperative pain, based on recent randomized clinical trial (RCT) data. While various reviews and meta-analyses have explored TENS as an adjunct analgesic in cases such as post-total knee arthroplasty and chronic lower back pain, no review has specifically examined its efficacy in the context of inguinal hernia surgery [17,18].

2. Methods

2.1. Literature search and selection criteria

An extensive search was conducted in Embase, PubMed, Web of Science, and the Cochrane Library, covering all publications from inception until September 2022. The search terms used were "Transcutaneous Electric Nerve Stimulation" or "TENS," along with "Hernia Inguinal." There were no language restrictions. Additional eligible studies were identified by reviewing reference lists and related literature. This process was iteratively performed until no further articles could be identified. For more information on the search process, see **Table 1**. This study employed a double-check screening method. Two independent researchers selected the studies to be included. If there was a dispute regarding the eligibility of a study, it was negotiated and discussed. In cases where the dispute could not be resolved through negotiation and discussion, an impartial third party was involved to make the final decision.

Inclusion criteria:

(1) Study group: Individuals with an inguinal hernia.

(2) Treatment: TENS.

(3) Control group: Negative control (sham, placebo, or medication only).

(4) Studies were excluded if they did not provide exact data on pain. Letters, abstracts, editorials, and case reports were also excluded. Studies involving chronic pain, defined as pain persisting for over 12 weeks, were not considered.

(5) Outcome measure: Visual Analogue Pain Scale (VAS).

(6) Study and experimental design: Randomized controlled trial.

The following data were extracted from the included RCTs: first author, sample size, baseline characteristics of patients, TENS intervention, control, study design, VAS scores at 2, 4, 8, and 24 hours postoperatively, and 24-hour postoperative cortisol content. If additional data were needed, the authors were contacted.

The primary outcome was VAS ratings at 2, 4, 8, and 24 hours postoperatively. The secondary outcome was the 24-hour postoperative cortisol levels.

Table 1. Search strategy

#1	"Hernia, Inguinal"[MeSH]
#2	"hernias inguinal"[Title/Abstract] OR "inguinal hernias"[Title/Abstract] OR "inguinal hernia"[Title/Abstract] OR "inguinal hernia indirect"[Title/Abstract] OR "hernia indirect inguinal"[Title/Abstract] OR "hernias indirect inguinal"[Title/Abstract] OR "indirect inguinal hernia"[Title/Abstract] OR "indirect inguinal hernias"[Title/Abstract] OR "inguinal hernias indirect"[Title/Abstract] OR "inguinal hernia direct"[Title/Abstract] OR "direct inguinal hernia"[Title/Abstract] OR "direct inguinal hernias"[Title/Abstract] OR "hernia direct inguinal"[Title/Abstract] OR "hernias direct inguinal"[Title/Abstract] OR "inguinal hernias direct"[Title/Abstract]
#3	#1 OR #2
#4	"Transcutaneous Electric Nerve Stimulation"[MeSH]
#5	"electric stimulation transcutaneous"[Title/Abstract] OR "stimulation transcutaneous electric"[Title/Abstract] OR "transcutaneous electric stimulation"[Title/Abstract] OR "percutaneous electric nerve stimulation"[Title/Abstract] OR "electrical stimulation transcutaneous"[Title/Abstract] OR "transcutaneous electrical stimulation"[Title/Abstract] OR "transdermal electrostimulation"[Title/Abstract] OR (("electrostimulated"[All Fields] OR "electrostimulating"[All Fields] OR "Electrostimulation"[All Fields] OR "electrostimulations"[All Fields] OR "electrostimulator"[All Fields] OR "electrostimulators"[All Fields]) AND "Transdermal"[Title/Abstract]) OR "percutaneous electrical nerve stimulation"[Title/Abstract] OR "transcutaneous electrical nerve stimulation"[Title/Abstract] OR "transcutaneous nerve stimulation"[Title/Abstract] OR "nerve stimulation transcutaneous"[Title/Abstract] OR "stimulation transcutaneous nerve"[Title/Abstract] OR "TENS"[Title/Abstract] OR "percutaneous neuromodulation therapy"[Title/Abstract] OR (("neuromodulate"[All Fields] OR "neuromodulating"[All Fields] OR "Neuromodulation"[All Fields] OR "Neuromodulations"[All Fields] OR "neuromodulative"[All Fields] OR "neurotransmitter agents"[Pharmacological Action] OR "neurotransmitter agents"[MeSH Terms] OR ("neurotransmitter"[All Fields] AND "agents"[All Fields]) OR "neurotransmitter agents"[All Fields] OR "neuromodulator"[All Fields] OR "neuromodulators"[All Fields]) AND "therapy percutaneous"[Title/Abstract]) OR "percutaneous neuromodulation therapies"[Title/Abstract] OR (("therapeutics"[MeSH Terms] OR "therapeutics"[All Fields] OR "Therapies"[All Fields] OR "Therapy"[MeSH Subheading] OR "Therapy"[All Fields] OR "therapy s"[All Fields] OR "therapys"[All Fields]) AND "percutaneous neuromodulation"[Title/Abstract]) OR "percutaneous electrical neuromodulation"[Title/Abstract] OR (("electricity"[MeSH Terms] OR "electricity"[All Fields] OR "Electric"[All Fields] OR "Electrical"[All Fields] OR "electrically"[All Fields] OR "electrics"[All Fields]) AND "neuromodulation percutaneous"[Title/Abstract]) OR (("electricity"[MeSH Terms] OR "electricity"[All Fields] OR "Electric"[All Fields] OR "Electrical"[All Fields] OR "electrically"[All Fields] OR "electrics"[All Fields]) AND ("neuromodulate"[All Fields] OR "neuromodulating"[All Fields] OR "Neuromodulation"[All Fields] OR "Neuromodulations"[All Fields] OR "neuromodulative"[All Fields] OR "neurotransmitter agents"[Pharmacological Action] OR "neurotransmitter agents"[MeSH Terms] OR ("neurotransmitter"[All Fields] AND "agents"[All Fields]) OR "neurotransmitter agents"[All Fields] OR "neuromodulator"[All Fields] OR "neuromodulators"[All Fields])) AND "Percutaneous"[Title/Abstract]) OR (("neuromodulate"[All Fields] OR "neuromodulating"[All Fields] OR "Neuromodulation"[All Fields] OR "Neuromodulations"[All Fields] OR "neuromodulative"[All Fields] OR "neurotransmitter agents"[Pharmacological Action] OR "neurotransmitter agents"[MeSH Terms] OR ("neurotransmitter"[All Fields] AND "agents"[All Fields]) OR "neurotransmitter agents"[All Fields] OR "neuromodulator"[All Fields] OR "neuromodulators"[All Fields]) AND "percutaneous electrical"[Title/Abstract]) OR (("neuromodulate"[All Fields] OR "neuromodulating"[All Fields] OR "Neuromodulation"[All Fields] OR "Neuromodulations"[All Fields] OR "neuromodulative"[All Fields] OR "neurotransmitter agents"[Pharmacological Action] OR "neurotransmitter agents"[MeSH Terms] OR ("neurotransmitter"[All Fields] AND "agents"[All Fields]) OR "neurotransmitter agents"[All Fields] OR "neuromodulator"[All Fields] OR "neuromodulators"[All Fields]) AND "percutaneous electrical"[Title/Abstract]) OR (("Percutaneous"[All Fields] OR "percutaneously"[All Fields] OR "percutanous"[All Fields]) AND ("electricity"[MeSH Terms] OR "electricity"[All Fields] OR "Electric"[All Fields] OR "Electrical"[All Fields] OR "electrically"[All Fields] OR "electrics"[All Fields])) AND "Neuromodulations"[Title/Abstract]) OR "analgesic cutaneous electrostimulation"[Title/Abstract] OR (("Cutaneous"[All Fields] OR "cutaneously"[All Fields] OR "cutanous"[All Fields]) AND ("electrostimulated"[All Fields] OR "electrostimulating"[All Fields] OR "Electrostimulation"[All Fields] OR "electrostimulations"[All Fields] OR "electrostimulator"[All Fields] OR "electrostimulators"[All Fields])) AND "Analgesic"[Title/Abstract]) OR (("electrostimulated"[All Fields] OR "electrostimulating"[All Fields] OR "Electrostimulation"[All Fields] OR "electrostimulations"[All Fields] OR "electrostimulator"[All Fields] OR "electrostimulators"[All Fields]) AND "analgesic cutaneous"[Title/Abstract]) OR "Electroanalgesia"[Title/Abstract]
#6	#4 OR #5
#7	randomized controlled trials[Publication Type]
#8	#3 AND #6 AND #7

2.2. Quality evaluation

The methodological quality of each RCT was assessed using the Cochrane Risk of Bias Tool (ROB-II). This tool evaluates seven key domains, including random sequence generation (to assess selection bias), allocation concealment, blinding of participants and personnel (for performance bias), and blinding of outcome assessors (to detect potential detection bias). It also examines the management of incomplete data (attrition bias), selective outcome reporting (reporting bias), and other potential sources of bias. Each domain was classified as representing either an unknown risk, low risk, or high risk.

2.3. Statistical analysis

Continuous outcomes, such as VAS scores and cortisol levels measured 24 hours postoperatively, were analyzed using means, standard deviations (SD), and 95% confidence intervals (95% CI) to estimate overall effects. Meta-analyses were performed using random-effects models with DerSimonian and Laird weights to adjust for study-to-study variability. Heterogeneity was assessed using the Cochran Q test ($P < 0.1$ for significance) and quantified by the I^2 statistic, which measures the percentage of total variation attributed to between-study differences, with values above 50% suggesting significant heterogeneity. Sensitivity analyses were performed by excluding individual studies one at a time to assess their impact on the overall findings. Funnel plots were used to visually inspect for small-study bias, with symmetry indicating minimal bias. The threshold for statistical significance was set at $P < 0.05$ for two-tailed tests, and all analyses were conducted using Review Manager version 5.3, developed by The Cochrane Collaboration.

3. Results

3.1. Study characteristics and quality assessment

Figure 1 illustrates the selection workflow and identification process in detail. Seven RCTs were included in this meta-analysis, and their baseline characteristics are summarized in **Table 2**. The studies, conducted between 2010 and 2021, had sample sizes ranging from 16 to 40 participants, totaling 379 individuals. Follow-up periods ranged from the immediate postoperative phase to 14 days post-surgery. Of the seven RCTs, three reported VAS scores at 2 hours post-surgery [8,12,17], four at 4 hours post-surgery [8,12-14], three at 8 hours post-surgery [8,12,13], and five provided VAS scores at 24 hours post-surgery [8,11,12,15,16]. Additionally, two studies reported cortisol levels at 24 hours post-surgery [11,16]. The Cochrane ROB-II was used to assess the quality of these studies, all of which were rated as high quality. **Figure 2** illustrates the bias risk graph, while **Figure 3** provides a summary of this assessment.

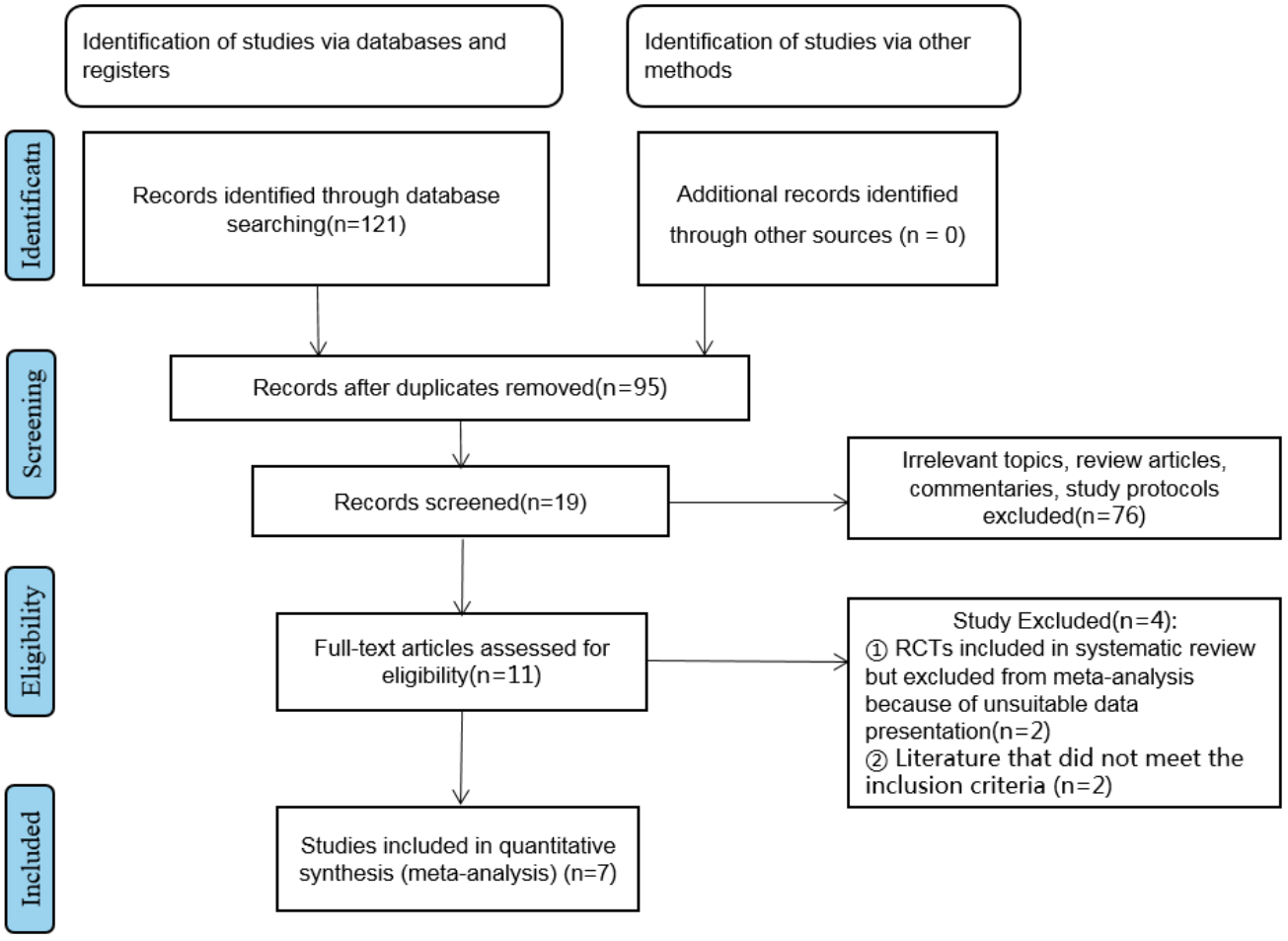


Figure 1. Flow chart of literature screening

Table 2. Characteristics of the studies included in the meta-analysis

Author (years)	TENS group				Control group				TENS method	Comparative items
	Patient (*n*)	Age (mean ± SD, years)	Male (*n*)	BMI (kg/m², mean ± SD)	Patient (*n*)	Age (mean ± SD, years)	Male (*n*)	BMI (kg/m², mean ± SD)		
Emel Yılmaz, PhD (2018)	26	44.96 ± 14.48	24	25.36 ± 2.52 kg/m²	26	50.04 ± 15.04	25	24.97 ± 2.45 kg/m²	Intervention group patients received TENS postoperatively 5 times for 30 minutes each.	VAS score at 2, 4, 8, and 24 hours after the operation
Mohammed Taher AHMED (2010)	30	36.06 ± 8.18	N/A	25.39 ± 3.2 kg/m²	30	34.3 ± 6.18	N/A	25.47 ± 2.87 kg/m²	TENS treatments were applied for 30 minutes, twice daily for 5 consecutive days using 2 electrodes placed parallel to the incision.	% change in pain intensity at 1, 2, 3, 4, and 5 days after the operation
Marcio Dias (2010)	17	43.1 ± 10	N/A	N/A	16	47.0 ± 14	N/A	N/A	The starting frequency was 3 Hz in continuous mode for 5 min, which was then increased in steps of 5, 10, 20, 50, 100, and 160 Hz and finally up to 240 Hz after 30 min.	Comparison of VAS scores 1–14 days after the operation
Josimari M. DeSantana (2008)	20	48.5 ± 48.3	N/A	25.7 ± 3.578 kg/m²	20	42.2 ± 78.26	NA	27.5 ± 1.342 kg/m²	TENS (100 Hz, solid but comfortable sensory intensity) was applied for 30 minutes through 4 electrodes placed around the incision twice.	Comparison of NRS scores at 2, 4, 8, and 24 hours after the operation
Mateusz Szmit (2021)	24	54.6 ± 15.8	21	N/A	24	57.8 ± 15.6	20	N/A	The TENS group received mixed frequency stimulation (alternating at 2 and 100 Hz every 3 s) in continuous mode for 30 min at intervals of 2 h.	Comparison of 24 h VAS score and 24 h cortisol level after operation
Mohammad Eidy (2016)	33	34.15 ± 7.34	N/A	23.11 ± 1.74 kg/m²	33	33.3 ± 7.06	NA	22.3 ± 1.76 kg/m²	That was set at 0–18 milliamps after the relevant dis-posable electrodes were placed on the incision site for the intervention group. The frequency and wavelength of each channel were increased until the patient felt tingling.	Comparison of VAS scores at 2, 4, 6, and 12 hours after the operation
Audrius Parseliunas (2020)	40	61.77 ± 10.84	NA	26.75 ± 3.78 kg/m²	40	61.08 ± 12.51	NA	26.10 ± 2.99 kg/m²	The TENS device was set to a constant stimulation frequency of 100 Hz and a pulse duration of 200 μs. In the placebo TENS group, the intensity was set at 0–0.5 mA.	A comparison of patients' VAS scores one, two, three, and four days after surgery

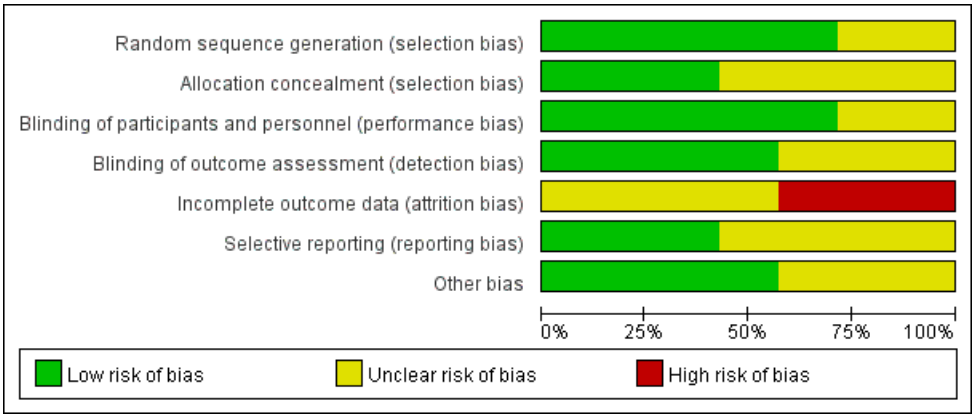


Figure 2. Bias risk graph

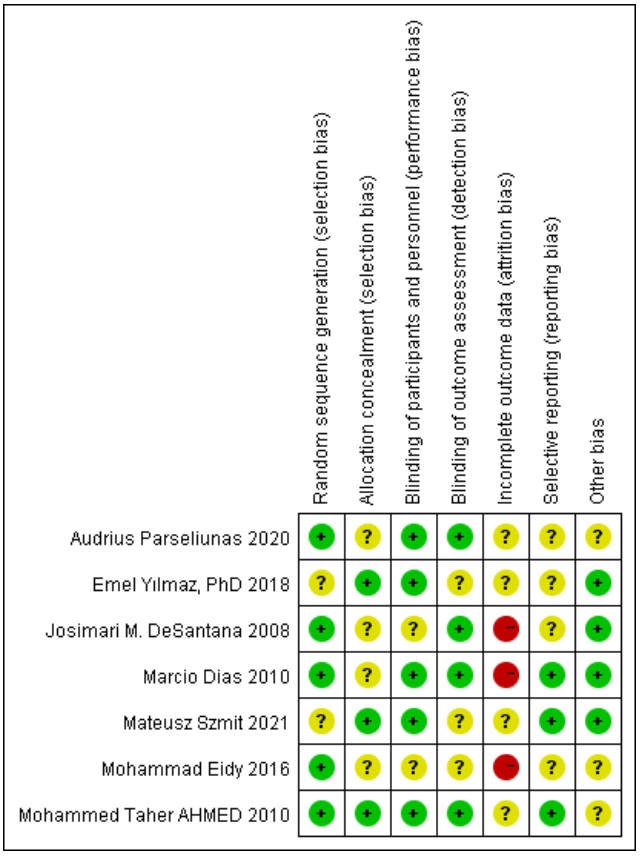


Figure 3. Summary of bias risk

3.2. Primary outcome: postoperative VAS scores

At 2 hours post-surgery, VAS scores were analyzed using a random-effects model. Combined data from three RCTs showed that TENS significantly reduced VAS scores compared to controls (standardized mean difference = -1.61; 95% CI = -2.20 to -1.02; $P < 0.00001$), with no significant variability between studies ($I^2 = 0\%$, heterogeneity P = 0.86). See **Figure 4A** for the forest plot of VAS scores at 2 hours post-surgery.

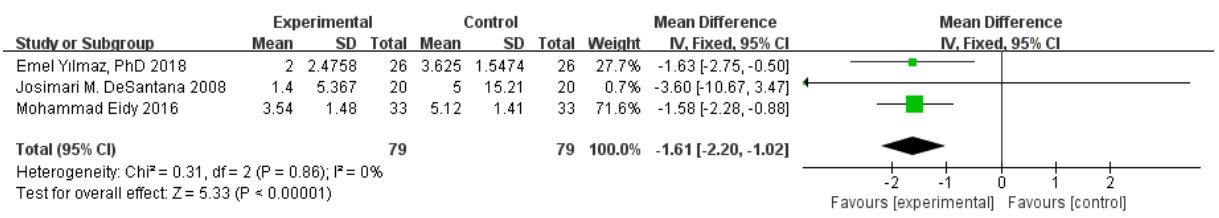
At 4 hours post-surgery, the analysis again used a random-effects model. Data from four RCTs indicated

that TENS intervention did not significantly reduce VAS scores compared to controls (standardized mean difference = -1.33; 95% CI = -2.84 to -0.18; *P* = 0.09). Significant heterogeneity was observed (I^2 = 74%, heterogeneity *P* = 0.01). See **Figure 4B** for the forest plot of VAS scores at 4 hours post-surgery.

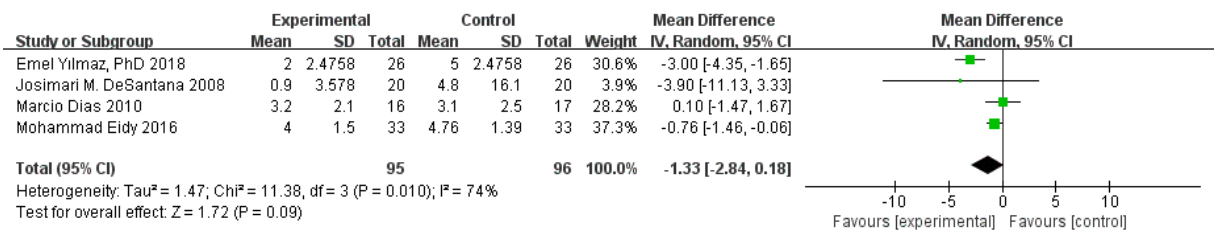
VAS scores at 8 hours post-surgery were assessed using a random-effects model. Aggregated results from three RCTs showed that TENS significantly reduced VAS scores compared to controls (standardized mean difference = -2.36; 95% CI = -4.04 to -0.69; *P* = 0.006). Moderate heterogeneity was noted (I^2 = 68%, heterogeneity *P* = 0.04). See **Figure 4C** for the forest plot of VAS scores at 8 hours post-surgery.

For VAS scores at 24 hours post-surgery, the random-effects model demonstrated a substantial reduction in pain levels with TENS compared to the control group (standardized mean difference = -1.75; 95% CI = -2.64 to -0.85; *P* = 0.0001) based on data from five RCTs. Significant heterogeneity was present (I^2 = 90%, heterogeneity *P* < 0.00001). See **Figure 4D** for the forest plot of VAS scores at 24 hours post-surgery.

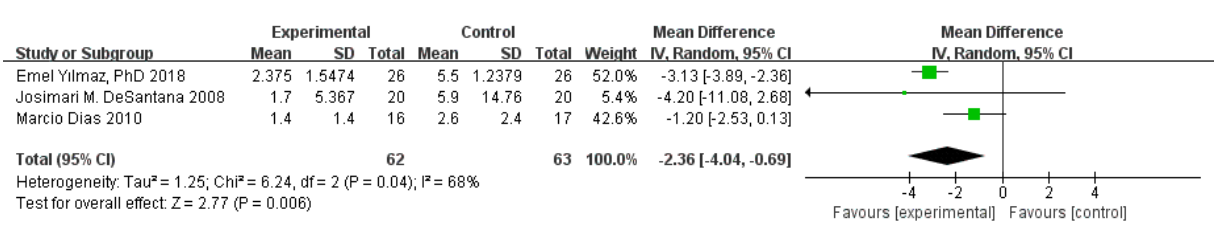
(A)



(B)



(C)



(D)

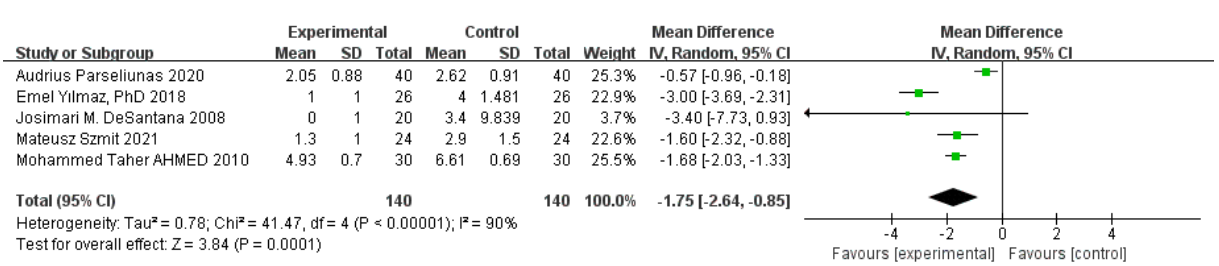


Figure 4. Forest plot of VAS scores at **(A)** 2 hours, **(B)** 4 hours, **(C)** 8 hours, and **(D)** 24 hours post-surgery

3.3. Secondary outcome: cortisol levels at 24 hours postoperatively

Cortisol levels at 24 hours post-surgery were evaluated using a random-effects model. Data from two RCTs showed no significant correlation between TENS and reduced cortisol levels compared to the control group (standardized mean difference = -52.56; 95% CI = -168.8 to 63.76; $P = 0.38$). Significant heterogeneity was detected ($I^2 = 91\%$, heterogeneity $P = 0.02$). See **Figure 5** for the forest plot of cortisol levels at 24 hours post-surgery.

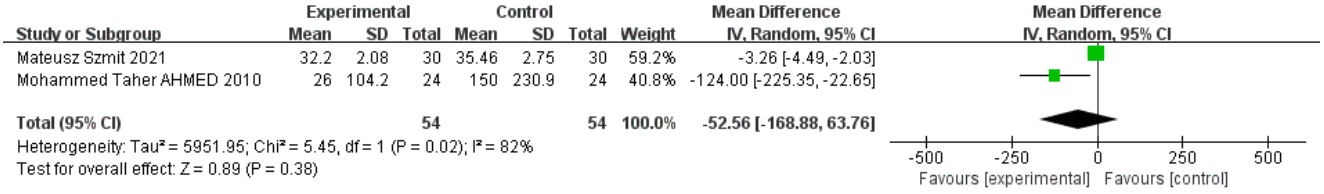


Figure 5. Forest plot of cortisol levels at 24 hours post-surgery

3.4. Funnel plots for VAS scores and cortisol levels

Figure 6 shows the funnel plot of VAS scores at 2 hours, 4 hours, 8 hours, and 24 hours post-surgery, while **Figure 7** shows the funnel plot of cortisol levels at 24 hours post-surgery.

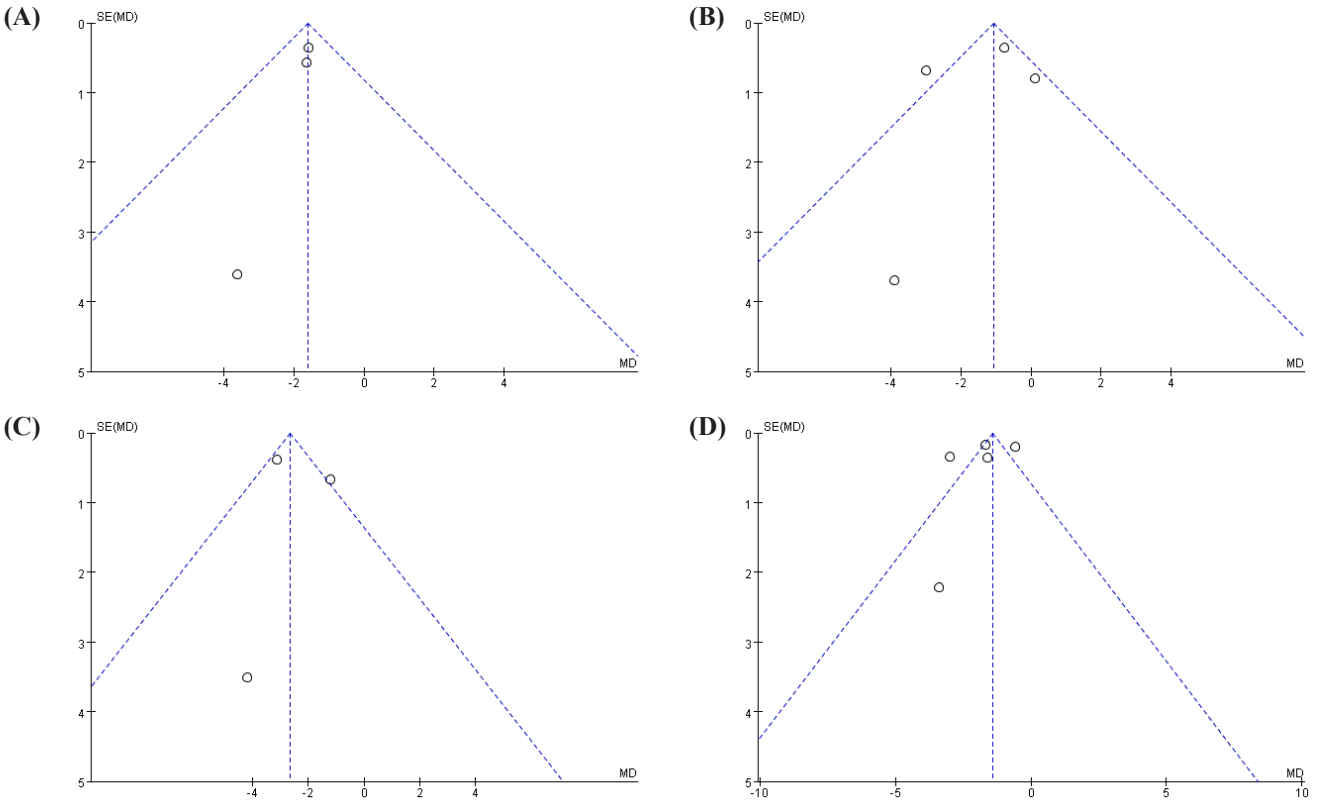


Figure 6. Funnel plot of VAS scores at **(A)** 2 hours, **(B)** 4 hours, **(C)** 8 hours, and **(D)** 24 hours post-surgery

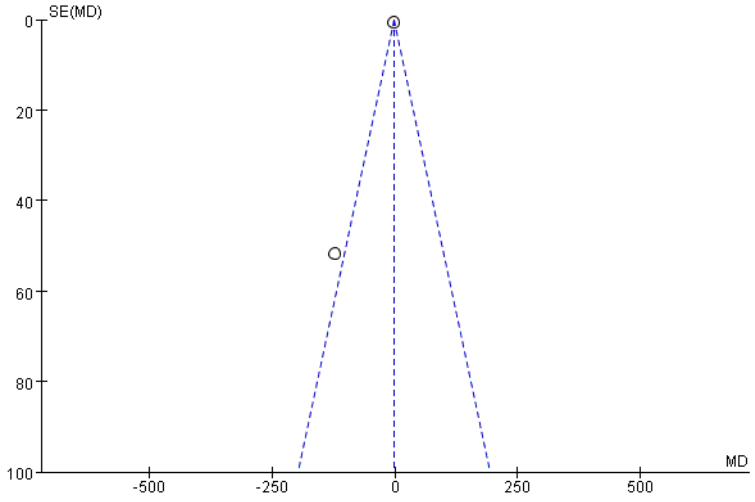


Figure 7. Funnel plot of cortisol levels at 24 hours post-surgery

4. Discussion

This meta-analysis revealed that TENS interventions resulted in lower VAS scores at 2, 8, and 24 hours following surgery compared to control interventions, while no significant effect was observed on VAS scores at 4 hours post-surgery. Furthermore, TENS intervention was not associated with a reduction in cortisol levels within 24 hours post-surgery. While TENS effectively alleviates pain following inguinal hernia surgery, particularly in the early postoperative phase, its impact on pain appears negligible during longer-term follow-up. This outcome may be attributed to the consistently low pain intensity observed during the follow-up period. Additionally, low-intensity TENS may not substantially affect patients' functional recovery or postoperative quality of life. Notably, this study is the first meta-analysis to assess the efficacy of TENS in managing postoperative pain for inguinal hernia patients.

Supporting evidence from Maeda Y and Sluka KA indicates that TENS effectively reduces postoperative pain, likely by activating opioid and GABAA receptors, thereby reducing input to the central spinothalamic tract [19,20]. However, this meta-analysis found that TENS did not significantly reduce VAS scores at the 4-hour postoperative mark. This lack of effect may be explained by findings from the American Society of Anesthesiologists, which indicate that the effects of epidural or local anesthesia typically diminish after approximately 4 hours, leading to increased pain levels [21]. According to research by Fabrizio Benedetti, TENS is less effective for managing severe pain [22]. Additionally, the study found that TENS intervention did not significantly reduce cortisol levels within 24 hours post-surgery, which aligns with findings from Javier Mata's research, suggesting that cortisol release results from HPA axis activation, which TENS does not appear to influence [23].

Two additional studies included in this review found that patients treated with TENS required less analgesic medication—such as dipyrone, diclofenac, and paracetamol—compared to those receiving placebo TENS, with this effect being particularly notable during the first three days post-surgery. However, due to inconsistencies in the types of analgesic drugs used and the timing of statistical analyses, a meta-analysis could not be conducted. Nonetheless, TENS appears to effectively reduce the amount and frequency of postoperative

analgesic drug use.

This meta-analysis has several limitations that warrant consideration. First, it includes only seven randomized controlled trials, each with relatively small sample sizes, which could lead to an overestimation of treatment benefits. Additionally, considerable variability existed in the intensity, application duration, methods, and device manufacturers of TENS across the studies, potentially affecting the pooled outcomes. The impact of ethnic diversity on TENS effectiveness also remains uncertain. Finally, the inclusion of unpublished data may introduce bias into the overall findings.

5. Conclusion

In conclusion, TENS shows promise as a non-pharmacological intervention for reducing postoperative pain in inguinal hernia surgery. However, further high-quality randomized controlled trials with larger sample sizes are essential to confirm its effectiveness and explore its potential impacts on a broader scale.

Author contributions

Conceptualization: Huiping Li
Formal analysis: Junfeng Li
Investigation: Junfeng Li
Writing – original draft: Junfeng Li
Writing – review & editing: all authors
Visualization: Lunwu Wei
Supervision: Xinghao Zhao

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Disclosure statement

The authors declare no conflict of interest.

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