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ORIGINAL ARTICLE

Effect of electrical acupoint stimulation and electroacupuncture on pain and function in knee osteoarthritis: A systematic review and meta-analysis with hypotheses for analgesic rehabilitation of osteoporotic fractures

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ABSTRACT

Objectives: In this review, we evaluate the effects of electroacupuncture (EA) and transcutaneous electrical nerve stimulation (TENS) on pain and function in knee osteoarthritis (KOA) and discuss whether this evidence can inform analgesic rehabilitation research in osteoporotic fractures.

Materials and methods: PubMed, Embase, Cochrane CENTRAL, Web of Science, and CNKI were searched from inception to January 2025 for randomized-controlled trials in KOA. Trials comparing EA or TENS with sham procedures, manual acupuncture, no-treatment controls, or pharmacological therapy were included. Continuous pain, function, and WOMAC-related outcomes were synthesized as standardized mean differences (SMDs) using Hedges' g, whereas categorical responder or effective-rate outcomes were analyzed separately as risk ratios (RRs). For multi-arm trials sharing the same intervention or comparator group, the shared group was split across relevant comparisons to preserve statistical independence.

Results: Eight studies contributed 10 continuous comparisons and one categorical responder comparison. After correction for shared groups in multi-arm trials, electrical acupoint stimulation showed a significant benefit for continuous pain and function-related outcomes (SMD = 0.45, 95% confidence interval [CI]: 0.31-0.58; $p < 0.0001$), with no statistical heterogeneity ($I^2 = 0.0\%$). The 95% prediction interval was 0.29 to 0.61. Pain outcomes showed a pooled SMD of 0.53 (95% CI: 0.35-0.71), and function-related continuous outcomes showed a pooled SMD of 0.34 (95% CI: 0.13-0.55). The categorical responder comparison was not merged with the SMD model and favored EA (RR = 1.32, 95% CI: 1.07-1.63). Sensitivity analysis excluding studies had high risk in key bias domains remained significant (SMD = 0.44, 95% CI: 0.28-0.59).

Conclusion: Electrical acupoint stimulation, particularly EA, significantly improves pain and function in KOA. These findings support its role in KOA management and provide preliminary translational support for future electroacupuncture-based analgesic rehabilitation studies in osteoporotic fractures.

Keywords: Electroacupuncture, knee osteoarthritis, meta-analysis, pain, transcutaneous electrical nerve stimulation.

Knee osteoarthritis (KOA) is the most prevalent form of degenerative joint disease worldwide, affecting an estimated 365 million individuals globally in 2020, and its prevalence has roughly doubled since the mid-20th century.[1] The disease is characterized by progressive cartilage degradation, subchondral bone remodeling, synovial inflammation, and osteophyte formation, leading to chronic pain, joint stiffness, and functional impairment that significantly compromise patients' quality of life.[2] Given the aging global population and rising obesity rates, the socioeconomic burden of KOA is expected to increase substantially over the coming decades.[3] Knee osteoarthritis frequently coexists with osteoporotic fragility fractures in elderly populations, forming a mutually aggravating clinical cycle. Patients with

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hip or vertebral osteoporotic fractures often carry preexisting symptomatic KOA; persistent knee pain restricts early postoperative mobilization, gait training and adherence to rehabilitation exercises, which further worsens joint stiffness and lower limb dysfunction, ultimately delaying functional recovery after fracture surgery.

Current clinical guidelines recommend a multimodal approach to KOA management, combining non-pharmacological interventions such as exercise, weight management, and patient education with pharmacological agents including non-steroidal anti-inflammatory drugs (NSAIDs), acetaminophen, and intra-articular injections.[4] However, the long-term use of NSAIDs is limited by well-documented gastrointestinal, cardiovascular, and renal adverse effects, and opioid analgesics carry substantial risks of dependence and misuse.[5] Consequently, there is growing clinical interest in complementary and alternative therapies that offer analgesic efficacy with favorable safety profiles. This clinical demand is particularly prominent in elderly osteoporotic fracture survivors complicated with KOA, who are more susceptible to adverse reactions of oral analgesics due to advanced age and multiple underlying diseases.

Electroacupuncture (EA), a modified form of traditional acupuncture in which electrical current is delivered through acupuncture needles, has emerged as a promising non-pharmacological intervention for chronic musculoskeletal pain conditions in recent years.[6] The proposed mechanisms of EA include activation of endogenous opioid systems, modulation of descending inhibitory pain pathways, reduction of local inflammatory mediators, and regulation of neural oscillatory activity in pain processing networks.[7] Transcutaneous electrical nerve stimulation (TENS), which delivers electrical impulses via surface electrodes without needle insertion, represents a related but less invasive modality that shares some mechanistic pathways with EA. Both modalities are classified as forms of electrical acupoint stimulation and are increasingly used in clinical practice for KOA symptom management. Several systematic reviews and meta-analyses have examined the efficacy of acupuncture for KOA, with controversial conclusions. A recent comprehensive systematic review by Li et al.[8] reported that acupuncture might provide clinically important pain relief compared to sham acupuncture, with EA showing a potentially greater effect than manual acupuncture. Li et al.[9] specifically evaluated EA versus analgesics and reported significant improvements in Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) stiffness and function scores.

On the other hand, existing meta-analyses only evaluated EA or TENS separately, and the combined efficacy of these two electrical acupoint stimulation modalities remains poorly characterized.[8,9] Furthermore, no previous pooled evidence has summarized the analgesic and functional benefits of electrical acupoint stimulation to provide translational evidence for analgesic rehabilitation in patients with osteoporotic fractures combined with KOA. In this review, we sought to determine whether electrical acupoint stimulation could reduce pain and improve physical function in patients with KOA, and to compare the therapeutic effects of EA and TENS. In this review, we sought to synthesize the available evidence on the effects of electrical acupoint stimulation on pain and physical function in patients with KOA, compare the therapeutic effects of EA and TENS, and determine whether the pooled efficacy data could provide a preliminary rationale for future clinical trials investigating analgesic rehabilitation after osteoporotic fragility fractures. We, therefore, address the above research gaps to comprehensively clarify the clinical efficacy of electrical acupoint stimulation for KOA, and further provide preliminary translational support for subsequent clinical trials exploring its application in osteoporotic fracture analgesic rehabilitation.

MATERIALS AND METHODS

This systematic review and meta-analysis was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines.[10] The review protocol was prospectively registered on the International Platform of Registered Systematic Review and Meta-analysis Protocols (INPLASY). As this study was conducted as a systematic review and meta-analysis of previously published and publicly available data and no new data were collected from human participants and no identifiable individual-level information was accessed, ethical approval and informed consent were not required.

Eligibility criteria

Studies were eligible for inclusion if they met all of the following criteria, which were established *a priori* according to the Population, Intervention, Comparator, Outcomes, and Study Design (PICOS) framework. The population comprised adult

patients (≥ 18 years) with a clinical or radiographic diagnosis of primary KOA based on recognized diagnostic criteria such as the American College of Rheumatology (ACR) criteria or Kellgren-Lawrence radiographic grading. The intervention of interest was electrical acupoint stimulation delivered as either EA, defined as the application of pulsed electrical current through filiform acupuncture needles inserted at acupuncture points, or TENS applied at acupuncture points or dermatomes corresponding to the knee joint. The comparator could be *(i)* sham acupuncture or sham TENS, *(ii)* manual acupuncture without electrical stimulation, *(iii)* no-treatment or waitlist control, or *(iv)* pharmacological therapy such as NSAIDs. The primary outcomes were pain intensity measured by validated instruments such as the Visual Analog Scale (VAS), Numerical Rating Scale (NRS), or WOMAC pain subscale, and physical function assessed by the WOMAC function subscale, Lequesne index, or equivalent validated tools. Only randomized-controlled trials (RCTs) published as full-text articles in peer-reviewed journals were included, without language restriction.

Studies were excluded if they met any of the following conditions: *(i)* the intervention combined EA or TENS with other concomitant therapies in a manner that precluded isolation of the electrical stimulation effect; *(ii)* the study population included patients with secondary osteoarthritis due to trauma, inflammatory arthritis, or post-surgical conditions; *(iii)* the study was a crossover design without adequate washout period data; *(iv)* the publication was a conference abstract, case report, narrative review, or editorial without original quantitative data; or *(v)* insufficient numerical data were available for effect size calculation even after contacting the authors.

Information sources and search strategy

A comprehensive electronic search was performed across five databases: PubMed/MEDLINE, Embase, the Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, and China National Knowledge Infrastructure (CNKI), covering database inception through January 31st, 2025. The PubMed strategy combined Medical Subject Headings (MeSH) terms and free-text keywords as follows: (("Electroacupuncture"[Mesh] OR electroacupuncture OR electro-acupuncture OR EA OR "transcutaneous electrical nerve stimulation" OR TENS OR "electrical acupoint stimulation" OR "percutaneous electrical nerve stimulation") AND ("Osteoarthritis, Knee"[Mesh] OR "knee osteoarthritis" OR "knee OA" OR gonarthrosis OR "degenerative knee joint disease") AND (randomized controlled trial[Publication Type] OR randomized OR randomised OR trial)). The Embase strategy used equivalent Emtree and free-text terms: ('electroacupuncture'/exp OR electroacupuncture:ti,ab OR 'transcutaneous electrical nerve stimulation'/exp OR TENS:ti,ab) AND ('knee osteoarthritis'/exp OR 'knee osteoarthritis':ti,ab OR gonarthrosis:ti,ab) AND ('randomized controlled trial'/exp OR random*:ti,ab). For CENTRAL and Web of Science, the search was adapted as: (electroacupuncture OR electro-acupuncture OR TENS OR "electrical acupoint stimulation") AND (knee osteoarthritis OR knee OA OR gonarthrosis) AND (randomized controlled trial OR clinical trial). For CNKI, the following Chinese search was used: ((电针 OR 经皮神经电刺激 OR 经穴电刺激) AND (膝骨关节炎 OR 膝 osteoarthritis) AND (随机对照试验 OR 随机 OR 临床试验)). Reference lists of included studies and relevant reviews were also hand-searched to identify additional eligible trials.

Study selection

Study selection followed a two-stage process conducted independently by two reviewers. In the first stage, titles and abstracts of all retrieved records were screened against the eligibility criteria, and clearly irrelevant records were excluded. In the second stage, full-text articles of potentially eligible studies were retrieved and evaluated in detail for compliance with all inclusion and exclusion criteria. Any disagreements between reviewers at either stage were resolved through discussion, and a third reviewer was consulted when consensus could not be reached. The inter-rater agreement was quantified using Cohen's kappa statistic. The entire study selection process was documented in the PRISMA flow diagram.

Data extraction

Data were extracted independently by two reviewers using a pre-piloted standardized extraction form. The following variables were recorded for each included study: *(i)* bibliographic details including first author, publication year, and country; *(ii)* study design, sample size, and randomization method; *(iii)* participant characteristics including age, sex distribution, disease severity, and diagnostic criteria; *(iv)* intervention details including stimulation modality (EA or TENS), acupuncture point selection, stimulation parameters (frequency, intensity, waveform), session duration, treatment frequency, and total treatment course; *(v)* comparator details

including type of control, sham procedure description, and co-interventions if applicable; *(vi)* outcome measures and assessment time points; and *(vii)* means, standard deviations (SDs), and sample sizes for continuous outcomes and event counts with total sample sizes for categorical responder or effective-rate outcomes. Outcomes were classified before quantitative synthesis as continuous pain outcomes, function-related continuous outcomes including WOMAC or composite functional scales, or categorical responder outcomes. Categorical outcomes were not transformed into standardized mean differences (SMDs) and were analyzed separately. For multi-arm studies, shared groups were handled according to the structure of the trial: when more than one eligible intervention arm was compared with the same control group, the shared control sample size was divided evenly across relevant comparisons; when one intervention arm was compared with more than one control group, the shared intervention sample size was divided evenly across comparisons. This approach preserved the independence assumption and prevented repeated counting of participants in the pooled inverse-variance model. Where standard deviations were not directly reported, they were derived from standard errors, confidence intervals (CIs), or interquartile ranges using established conversion formulas. For studies reporting only graphical data, digital plot extraction tools were used to estimate numerical values. Data extraction discrepancies were resolved by cross-referencing the source publication.

Risk-of-bias assessment

A modified Cochrane risk-of-bias framework adapted for acupuncture and device-based RCTs was used instead of the generic RoB 2 tool. This adaptation was required to address methodological specificities of acupuncture not fully captured by RoB 2, including standardization of treatment protocols and feasibility of blinding. All core RoB 2 domains were retained, with three acupuncture-specific domains added. Nine domains were evaluated: random sequence generation, allocation concealment, participant blinding, assessor blinding, completeness of outcome data, selective outcome reporting, baseline comparability, use of a standardized treatment protocol, and appropriateness of statistical analyses. Each domain was judged as low risk, some concerns, or high risk according to the information reported in the original article. Disagreements were resolved by discussion. No composite numeric quality score was calculated; instead, the results are presented as a study-level traffic-light plot and a domain-level summary bar chart.

Statistical analysis

All meta-analytic computations were performed using the meta package (version 7.0) in R version 4.3 software (R Foundation for Statistical Computing, Vienna, Austria). The primary effect measure for continuous outcomes was the SMD calculated as Hedges' g, which incorporates a correction for small-sample bias. Continuous pain, function, and WOMAC-related scales were entered into the SMD model only when the endpoint was measured on a continuous scale. Categorical responder or effective-rate outcomes were not combined with continuous outcomes; they were analyzed separately using risk ratios (RRs) with 95% CI. A random-effects inverse-variance model with the restricted maximum likelihood (REML) estimator for between-study variance was used throughout. The pooled SMD and its 95% CI were reported, along with a 95% prediction interval to characterize the expected range of effects in future studies.

Between-study heterogeneity was quantified using the I^2 statistic, where values of 25%, 50%, and 75% were interpreted as low, moderate, and substantial heterogeneity, respectively, complemented by the τ^2 estimate and Cochran's Q test. Three pre-specified subgroup or domain analyses were conducted: *(i)* by stimulation modality (EA versus TENS), *(ii)* by comparator type (sham, manual acupuncture, no-treatment control, or pharmacological comparator), and *(iii)* by continuous outcome domain (pain versus function-related outcomes, including WOMAC or composite functional scales). Subgroup differences were tested using the chi-squared statistic with the mixed-effects model. The categorical responder comparison was described separately and was not entered into the SMD subgroup models.

Sensitivity analysis was performed using the leave-one-out method, sequentially removing each continuous comparison and recalculating the pooled estimate to evaluate its stability. Since the risk-of-bias assessment showed higher concern in the older Ng et al.'s[11] study and the Plaster et al.'s[12] study, a sensitivity model excluding studies judged to have high risk in key bias domains was also conducted. A Baujat plot was generated to identify comparisons contributing

disproportionately to both heterogeneity and influence on the overall result. Publication bias was assessed visually using a contour-enhanced funnel plot. The Egger's regression test was not performed, as the unit required for this test is the number of independent studies rather than the number of study arms, and the present evidence base contained only eight independent RCTs. A two-sided p value of < 0.05 was considered statistically significant.

RESULTS

Study selection

The initial electronic database search yielded a total of 256 records: 68 from PubMed, 77 from Embase, 55 from Cochrane CENTRAL, and 55 from Web of Science. After removing 89 duplicate records and four other reasons, 163 unique records remained for title and abstract screening. Of these, 112 records were excluded, as they did not meet the eligibility criteria, leaving 51 full-text articles for detailed assessment. Excluding six articles that were not retrieved, 45 articles remain for assessment of eligibility. During full-text screening, 37 articles were further excluded for the following reasons: 14 were not RCTs, 10 applied combined interventions confounded with other physical therapies, eight were not accessible data, or five were duplicate population. Finally, eight studies contributing 11 eligible comparisons met all inclusion criteria. Ten continuous comparisons were included in the SMD-based quantitative synthesis, and one categorical responder comparison was analyzed separately as an RR. The study selection process is illustrated in Figure 1.

Study characteristics

The characteristics of the eight included studies and their 11 eligible comparisons are summarized in Table I.[11-18] The studies were published between 2003 and 2025 and were conducted in China, the United Kingdom, the United States, and Germany. Before analytical adjustment for shared groups, the eligible trial arms comprised 624 treatment assignments and 592 comparator assignments. For the SMD model, shared groups in Ng et al.,[11] Lv et al.,[14] and Sun et al.[18] were split across eligible comparisons, and the adjusted denominators used for

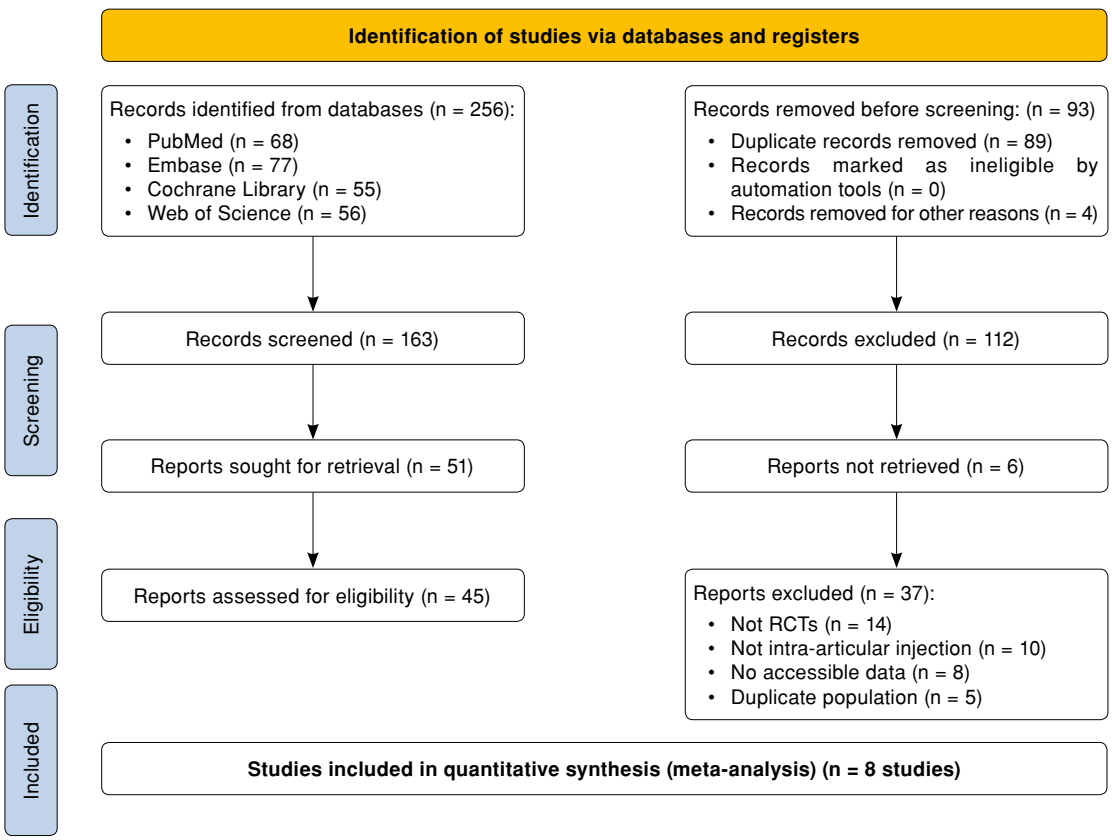


FIGURE 1. PRISMA study flowchart.

TABLE I

Characteristics of studies included in the quantitative synthesis

Study/arm	Year	Modality	Comparator	Outcome domain	Adjusted n (treat)	Adjusted n (Ctrl)	Effect measure	95% CI
Ng et al.[11]	2003	EA	Control	Pain	8	4.0	SMD 1.01	[–0.27; 2.29]
Ng et al.[11]	2003	TENS	Control	Pain	8	4.0	SMD 0.76	[–0.49; 2.01]
Plaster et al.[12]	2014	EA	Manual acu	Function-related	20	20	SMD 0.49	[–0.14; 1.12]
Palmer et al.[13]	2014	TENS	Control	Function-related	112	112	SMD 0.31	[0.05; 0.58]
Lv et al.[14]	2019	EA	Sham	Pain	100	50.5	SMD 0.82	[0.47; 1.17]
Lv et al.[14]	2019	EA	Sham	Pain	100	50.5	SMD 0.35	[0.01; 0.69]
Wang et al.[15]	2020	EA	Sham	Function	15	15	SMD 0.65	[–0.09; 1.39]
Wang et al.[16]	2020	EA	Manual acu	WOMAC	30	30	SMD 0.19	[–0.32; 0.69]
Tu et al.[17]	2021	EA	Sham	Responder/effective rate	151	146	RR 1.32	[1.07; 1.63]
Sun et al.[18]	2025	EA	Sham	Pain	40.0	80	SMD 0.43	[0.05; 0.81]

CI, confidence interval; EA, electroacupuncture; SMD, standardized mean difference; TENS, transcutaneous electrical nerve stimulation; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index; RR, risk ratio. Continuous outcomes were pooled as SMDs, whereas the responder/effective-rate outcome was analyzed separately as an RR. Adjusted sample sizes reflect shared-group splitting for multi-arm trials and were used only for variance estimation in the meta-analysis.

pooling are shown in Table I. Eight continuous comparisons evaluated EA and two evaluated TENS; one categorical responder comparison was analyzed separately. Comparators included sham acupuncture, no-treatment controls, manual acupuncture, and celecoxib. Pain was the primary continuous outcome in six comparisons, function-related or WOMAC/composite continuous outcomes were reported in four comparisons, and responder rate was reported in one comparison. Treatment durations ranged from four to eight weeks, with stimulation frequencies between 2 and 100 Hz.

Risk-of-bias assessment

The risk-of-bias results are presented in Figure 2 (study-level traffic-light plot) and Figure 3 (domain-level summary bar chart). Standardized treatment protocols were judged as low risk in all eight studies. Random sequence generation, baseline comparability, completeness of outcome data, selective reporting, and appropriateness of statistical analyses were assessed as low risk in most studies, with only occasional judgments of some concerns. Allocation concealment showed greater uncertainty, with approximately half of the studies judged as some concerns, as the concealment procedures were insufficiently described. The domains with the greatest methodological concerns were participant blinding and assessor blinding. Participant blinding was judged as high risk in three studies using no-treatment or inadequately blinded control procedures, whereas assessor blinding was frequently rated as some concerns and was judged as high risk in one study. The Ng et al.'s[11] study was considered more vulnerable to bias due to its extremely small sample size and limited blinding information, and the Plaster et al.'s[12] study was considered higher risk mainly due to incomplete blinding and uncertainty in allocation concealment. Overall, the pattern suggests usually acceptable methodological quality, but blinding-related limitations remain the main source of potential bias.

Overall meta-analysis

The forest plot of the overall continuous-outcome meta-analysis is shown in Figure 4. Ten continuous comparisons from eight studies were pooled after correcting shared groups in multi-arm trials and excluding the categorical responder endpoint from the SMD model. The pooled SMD (Hedges' g) was 0.45 (95% CI: 0.31-0.58, $p < 0.0001$), indicating a statistically significant

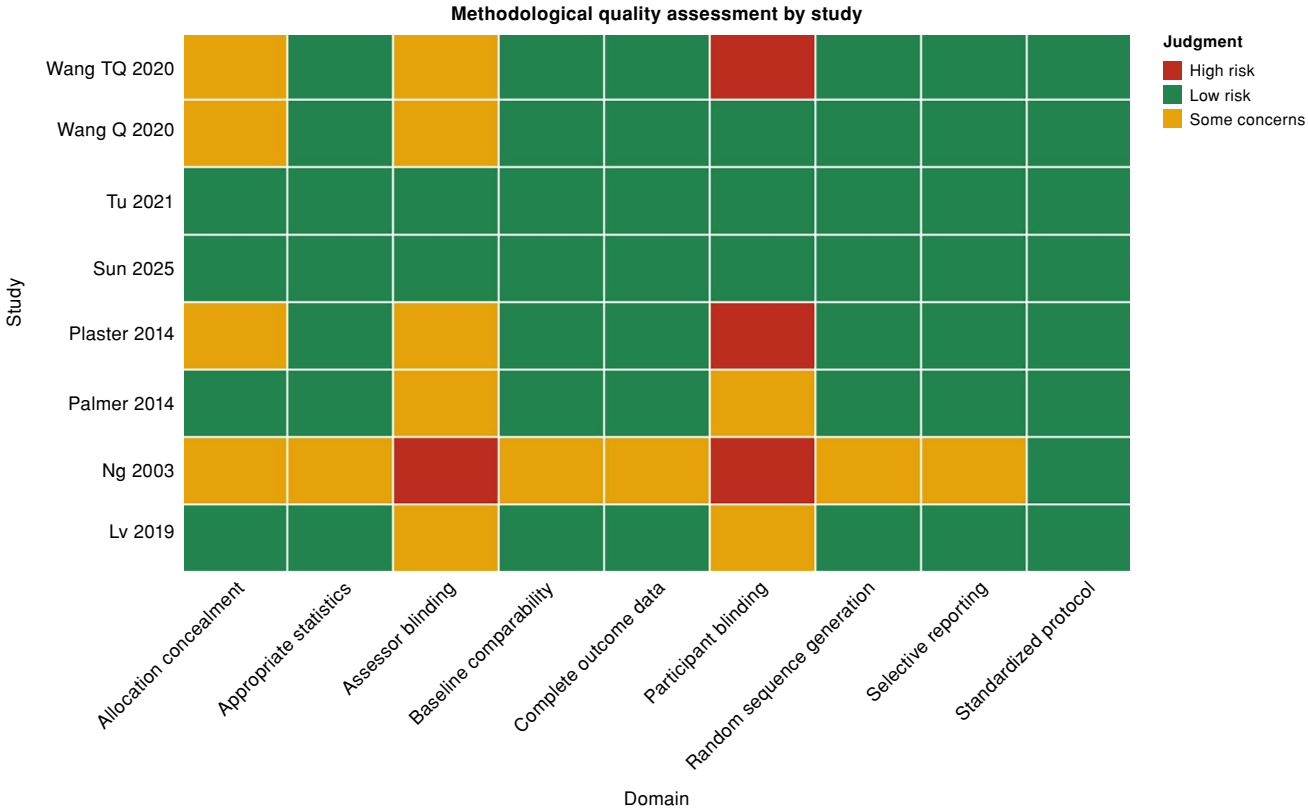


FIGURE 2. Methodological quality assessment by individual study (traffic-light plot).

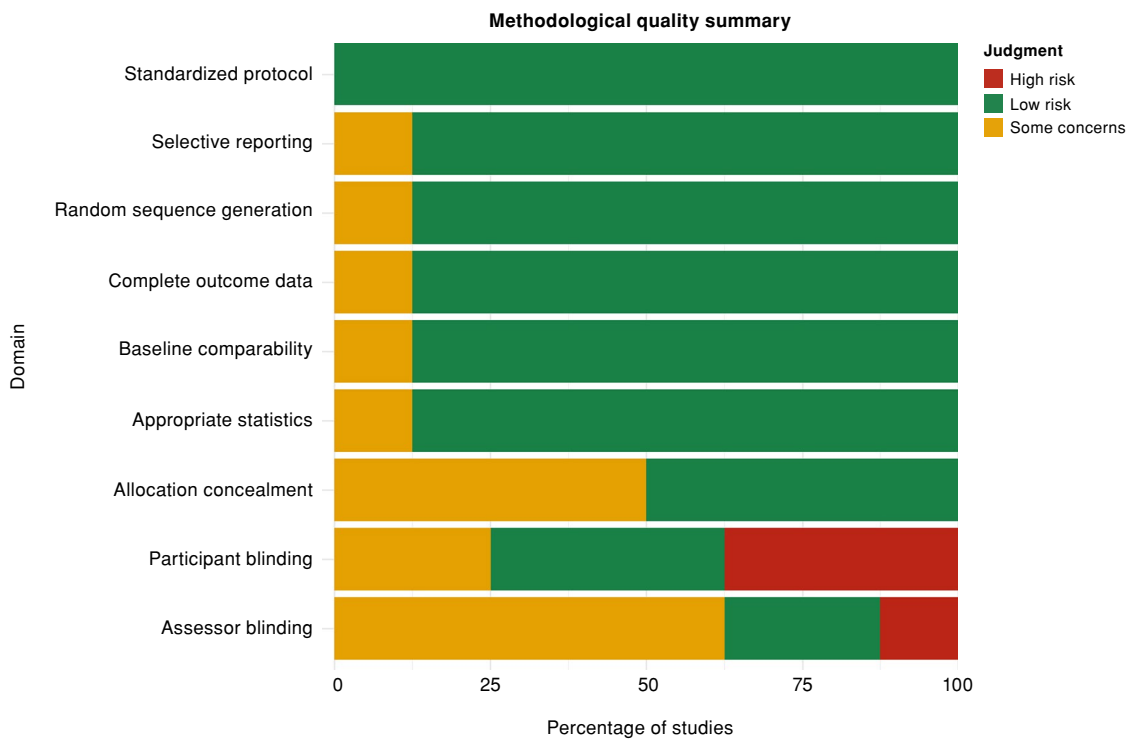


FIGURE 3. Summary of methodological quality across all included studies.

moderate beneficial effect of electrical acupoint stimulation on continuous pain and function-related outcomes in KOA. The 95% prediction interval ranged from 0.29 to 0.61, suggesting that the expected effect in a future comparable trial would remain favorable. Heterogeneity was not observed (I^2 = 0.0%, τ^2 = 0.0000, Q = 7.98, p = 0.536). In the outcome-domain analysis, pain outcomes showed a pooled SMD of 0.53 (95% CI: 0.35-0.71), whereas function-related continuous outcomes, including WOMAC or composite functional scales, showed a pooled SMD of 0.34 (95% CI: 0.13-0.55). The between-domain test was not statistically significant (χ^2 = 1.86, df = 1, p = 0.173). The categorical responder comparison from Tu 2021 was analyzed separately and favored EA over sham acupuncture (94/151 versus 69/146 responders; RR = 1.32, 95% CI: 1.07-1.63).

Subgroup analysis by stimulation modality

Subgroup analysis by stimulation modality is presented in Figure 5. The EA subgroup comprised eight continuous comparisons and yielded a pooled SMD of 0.49 (95% CI: 0.33-0.65), which was statistically significant with no observed heterogeneity (I^2 = 0.0%). The TENS subgroup included two continuous comparisons and produced a pooled SMD of 0.33 (95% CI: 0.07-0.59), although this estimate should be interpreted cautiously, as it was based on only two comparisons and was heavily influenced by the larger Palmer et al.'s[13] pragmatic trial. The test for subgroup differences was not significant (χ^2 = 1.14, df = 1, p = 0.286), indicating no statistically detectable difference between EA and TENS at the current level of evidence.

Subgroup analysis by comparator type

Figure 6 shows the subgroup analysis stratified by comparator type. The sham acupuncture subgroup included four continuous comparisons and produced a pooled SMD of 0.55 (95% CI: 0.31-0.78), with low heterogeneity (I^2 = 25.8%). The no-treatment control subgroup included three continuous comparisons and yielded a pooled SMD of 0.36 (95% CI: 0.10-0.61, I^2 = 0.0%). The manual acupuncture subgroup included two continuous comparisons and showed a pooled SMD of 0.31 (95% CI: −0.09 to 0.70, I^2 = 0.0%). The celecoxib comparator subgroup included only one study, yielding an SMD of 0.44 (95% CI: 0.06-0.82), which is presented descriptively due to limited data. The test for subgroup differences was not significant (χ^2 = 1.89, df = 3, p = 0.596), indicating that the beneficial effect of electrical stimulation was usually consistent across comparator categories.

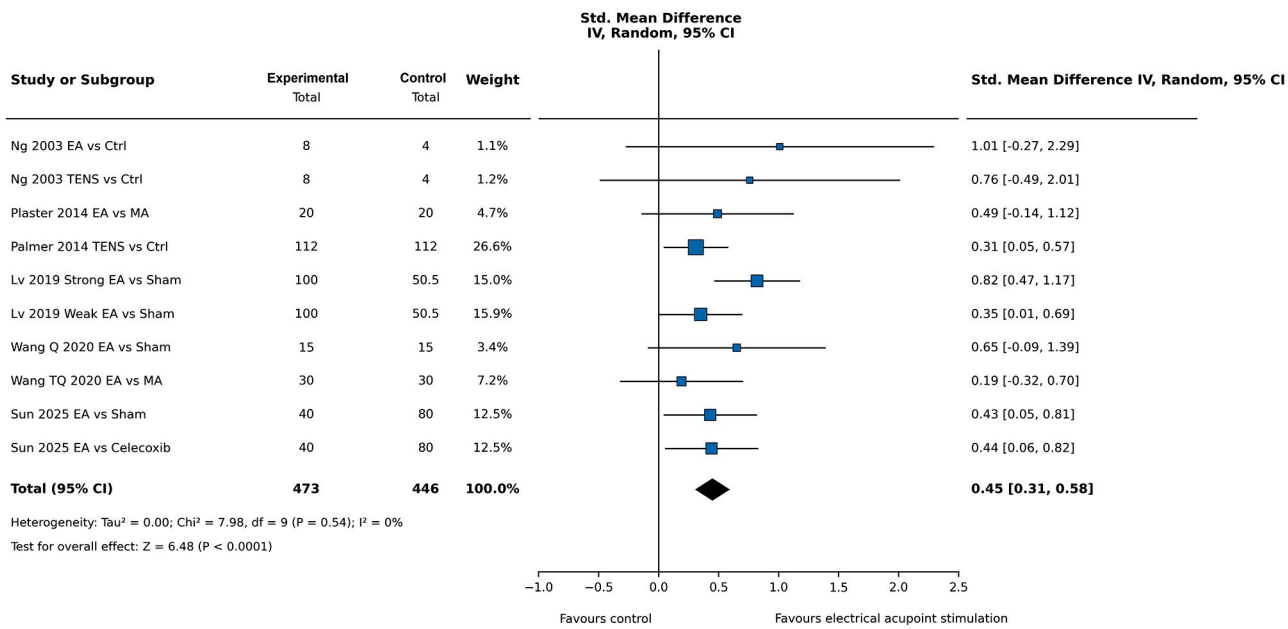


FIGURE 4. Forest plot of the continuous-outcome meta-analysis after multi-arm shared-group correction (random-effects model, Hedges' g).
Std, standard; CI, confidence interval; EA, electroacupuncture; Ctrl, control; MA, manual acupuncture.

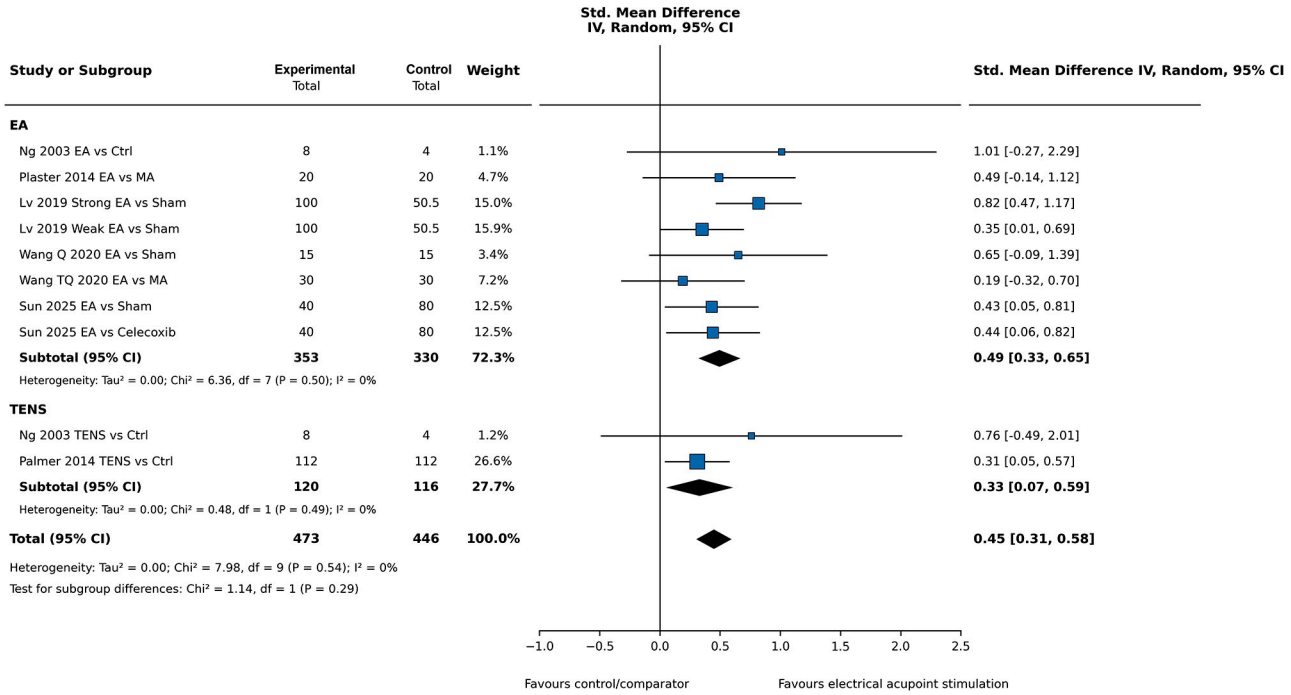


FIGURE 5. Leave-one-out sensitivity analysis of the continuous-outcome model.
Std, standard; CI, confidence interval; EA, electroacupuncture; Ctrl, control; MA, manual acupuncture.

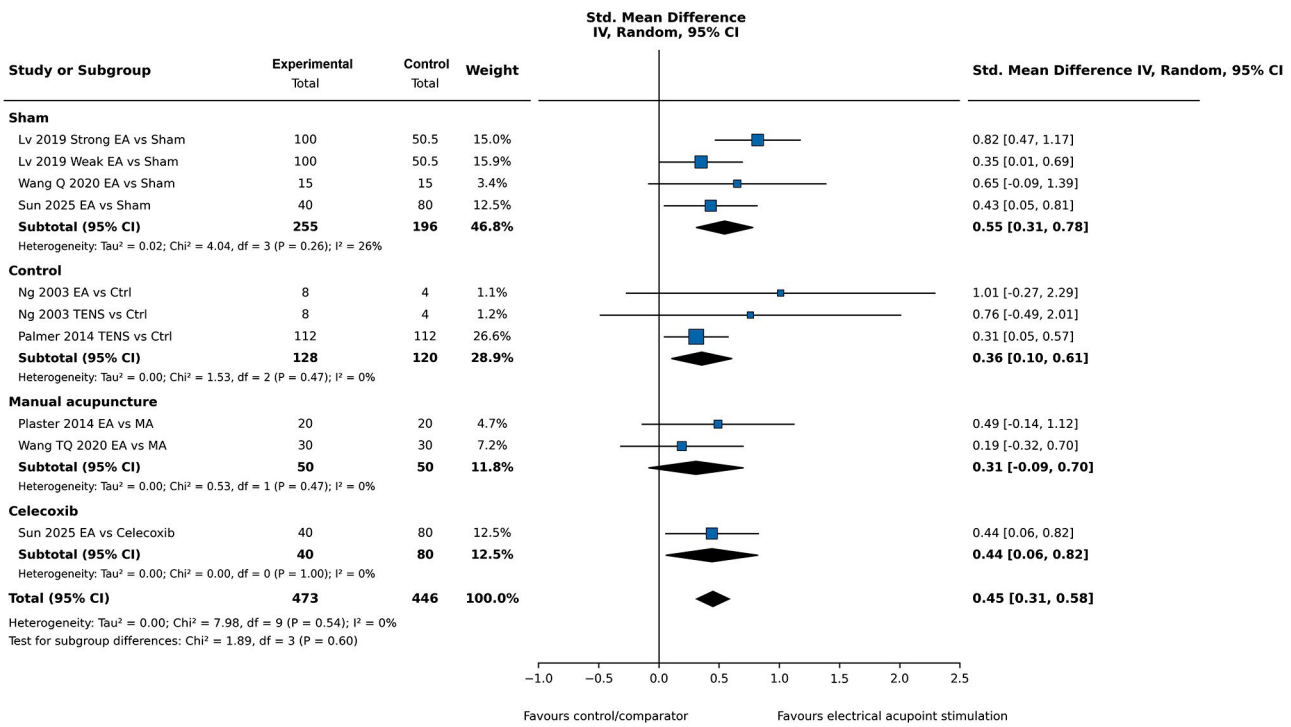


FIGURE 6. Subgroup analysis by comparator type using continuous outcomes only.
Std, standard; CI, confidence interval; EA, electroacupuncture; Ctrl, control; MA, manual acupuncture; The celecoxib subgroup is based on a single study and presented descriptively only.

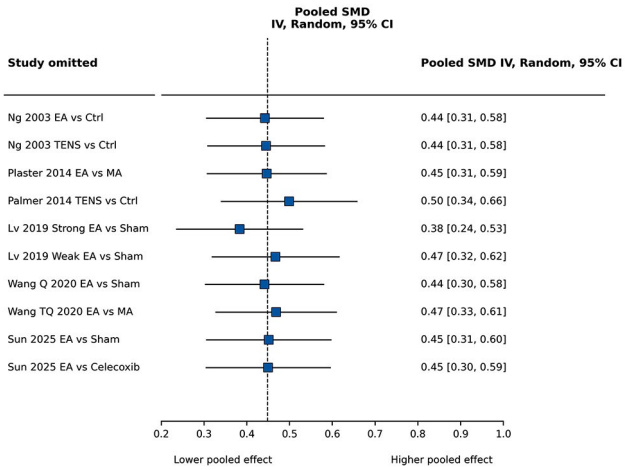


FIGURE 7. Leave-one-out sensitivity analysis of the continuous-outcome model.
SMD, standardized mean difference; CI, confidence interval; EA, electroacupuncture; Ctrl, control; MA, manual acupuncture.

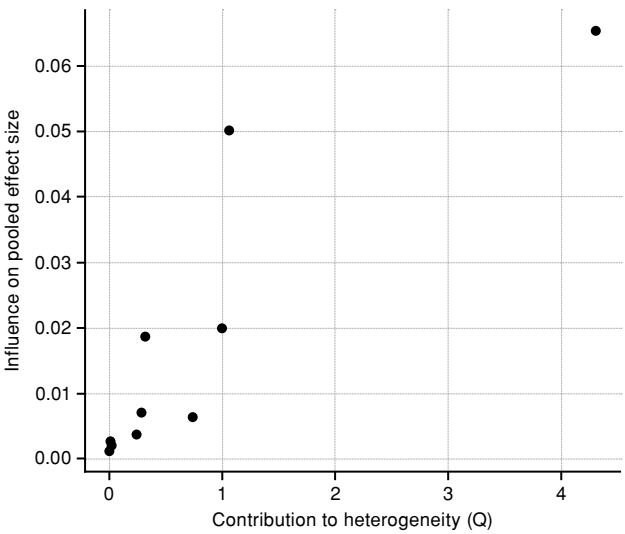


FIGURE 8. Baujat plot identifying influential continuous comparisons.

Sensitivity analysis

The leave-one-out sensitivity analysis is displayed in Figure 7. Sequential omission of each continuous comparison did not reverse the direction or statistical significance of the pooled estimate. Recalculated SMDs ranged from 0.38 (when omitting Lv et al.[14] Strong EA *vs*. Sham, which was the comparison with the largest individual effect size) to 0.50 (when omitting Palmer et al.[13] TENS *vs*. Control). All iterations maintained statistical significance. The I^2 values remained between 0.0% and 13.7%, confirming that no single

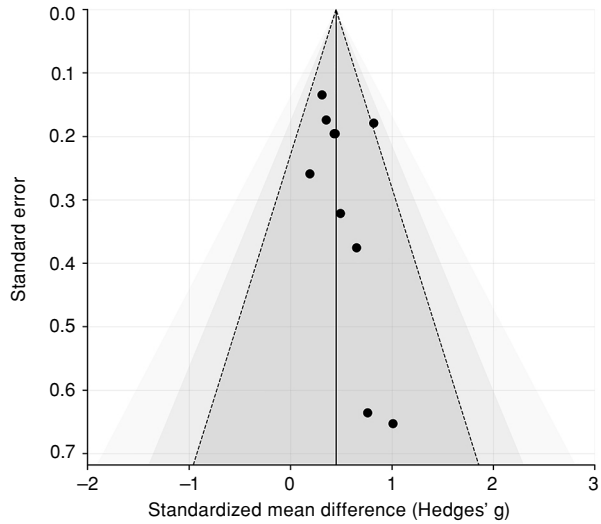


FIGURE 9. Contour-enhanced funnel plot for the continuous-outcome model.

continuous comparison was a dominant source of heterogeneity. The sensitivity model excluding the higher-risk Ng et al.[11] and Plaster et al.'s[12] studies included seven continuous comparisons and remained statistically significant (SMD = 0.44, 95% CI: 0.28-0.59, I^2 = 13.7%). The Baujat plot (Figure 8) identified the Lv et al.[14] Strong EA *vs*. Sham comparison as the most influential single comparison, consistent with its relatively large effect size (SMD = 0.82) and substantial sample size.

Publication bias

The contour-enhanced funnel plot is presented in Figure 9. Visual inspection revealed a usually symmetric distribution of continuous study estimates around the pooled effect, with most points falling within the expected contour regions. A slight preponderance of smaller studies with positive effects was observed in the lower right quadrant, but this pattern was not sufficient to indicate definite small-study effects. Egger's regression test was not performed, as the present review included only eight independent RCTs, and multi-arm comparisons sharing participants do not constitute independent studies for regression-based funnel plot testing. Therefore, the funnel plot was interpreted descriptively, and publication bias conclusions remain cautious.

DISCUSSION

In this meta-analysis, we provide novel insights into electrical acupoint stimulation for KOA, offering

incremental value beyond previous reviews. Unlike prior meta-analyses that evaluated EA or TENS separately, this study is the first to synthesize evidence for both modalities as a unified intervention, with rigorous adjustment for multi-arm trials and systematic subgroup analysis by comparator type. The findings confirm that electrical acupoint stimulation significantly improves pain and function in KOA with consistent effects across analyses, supporting its clinical utility for KOA management. While these results form a preliminary evidence base, inferences for osteoporotic fracture rehabilitation remain exploratory and hypothesis-generating.

The magnitude of the observed continuous effect corresponds to a moderate clinical benefit according to Cohen's conventional benchmarks. The domain-specific analysis showed a larger effect for pain outcomes than for function-related continuous outcomes, although the between-domain difference was not statistically significant. To contextualize this finding, a recent network meta-analysis by Li et al.[8] reported that acupuncture reduced pain compared with sham acupuncture with an SMD of approximately –0.74,[8] while Bannuru et al.[4] in their Osteoarthritis Research Society International (OARSI) guidelines systematic review found that topical NSAIDs produced SMDs in the range of 0.3-0.5 for pain relief compared with placebo.[4] Thus, the effect size observed for electrical acupoint stimulation in the present analysis is comparable to the analgesic benefit of some commonly recommended pharmacological interventions, while avoiding the systemic adverse effects associated with oral medications.

The subgroup analysis by stimulation modality did not reveal a statistically significant difference between EA and TENS, although the TENS subgroup remains underpowered, as it contained only two continuous comparisons. The slightly larger point estimate for EA is consistent with findings from the Bayesian network meta-analysis by Shi et al.,[19] who reported that EA might provide greater pain control than TENS for KOA. The mechanistic rationale for this difference lies in the depth of stimulation: EA delivers electrical current directly to deep tissue via inserted needles, potentially activating both A-delta and C fibers more effectively than surface-applied TENS electrodes.[20] Nevertheless, the non-significant subgroup test precludes definitive conclusions about modality superiority at this time, and future head-to-head trials with adequate sample sizes are warranted.

The consistency of effect across comparator types is particularly noteworthy. The non-significant test for subgroup differences by comparator indicates that electrical acupoint stimulation demonstrates benefit regardless of whether the comparison group receives sham acupuncture, manual acupuncture, no treatment, or pharmacological therapy. The largest and most clinically informative subgroup was the sham comparator (SMD = 0.55), which controls for placebo and contextual effects, providing the strongest evidence that the observed benefit is attributable to the specific physiological effects of electrical stimulation rather than non-specific factors. Yuan et al.[21] similarly found that high-intensity EA was superior to low-intensity EA for KOA, further supporting a dose-response relationship that argues against a purely placebo-mediated mechanism.

The low statistical heterogeneity is notable, given clear differences across studies in participant characteristics, stimulation parameters, comparators, and outcome measures. A key methodological factor is the handling of multi-arm trials: splitting shared control groups across comparisons, while preserving statistical independence, may artificially reduce apparent heterogeneity and inflate consistency. Despite this, the strict inclusion of only electrical acupoint stimulation modalities, consistent trial design features, and uniformly positive effect directions likely contributed to the low between-study variance. This finding supports a consistent beneficial effect of electrical stimulation for KOA, although the potential impact of multi-arm adjustment on heterogeneity estimates should be acknowledged as a limitation. The leave-one-out sensitivity analysis, high-risk-study sensitivity model, and Baujat plot confirmed that the pooled estimate remained statistically significant after accounting for influential or methodologically weaker evidence. The study by Lv et al.,[14] which contributed the largest individual effect size, was identified as the most influential comparison, consistent with its investigation of high-intensity EA parameters that may produce enhanced analgesic effects through more vigorous activation of endogenous opioid pathways.[14]

The risk-of-bias assessment indicates that the included trials were usually methodologically acceptable at the domain level, although blinding-related issues remain important. Standardized treatment protocols were consistently

rated as low risk, and most studies were also judged as low risk for random sequence generation, baseline comparability, completeness of outcome data, selective reporting, and statistical analysis. Although the overall risk-of-bias was acceptable at the domain level, the identified shortcomings in allocation concealment, participant blinding, and assessor blinding warrant careful interpretation. The primary endpoints of this meta-analysis are entirely subjective patient-reported outcomes: pain scales (VAS, NRS) and functional assessments (WOMAC, Lequesne index) rely on self-evaluation rather than objective biomarkers or performance-based measures. In non-pharmacological interventions such as acupuncture, inadequate blinding of participants and outcome assessors can amplify placebo responses and reporting bias, which may inflate the observed pooled effect size. The sensitivity analysis excluding trials with higher bias risk attenuated the estimate only marginally (SMD = 0.45 to 0.44), yet we cannot rule out that the true effect in clinical practice may be more modest than reported here. Future trials should prioritize rigorous double-dummy blinding designs and incorporate objective functional performance outcomes (e.g., gait speed, timed up-and-go test) to mitigate these biases.

These findings may have hypothesis-generating implications for osteoporotic fracture rehabilitation in older adults. Fragility fracture patients commonly have preexisting KOA, with up to 66% of fragility hip fracture patients presenting symptomatic knee OA in clinical cohorts.[22] Both conditions share key risk factors including advanced age, frailty, and impaired lower-limb physical function, forming a clinically meaningful bidirectional interaction where one disorder exacerbates functional limitations caused by the other.[23] Persistent KOA pain can hinder early mobilization, gait training, and postoperative exercise adherence after fracture surgery, while fracture-related immobilization may exacerbate knee dysfunction. As such, effective KOA pain control could facilitate postoperative rehabilitation, although this remains speculative. The present meta-analysis, focused solely on KOA, provides foundational mechanistic and efficacy data on electrical acupoint stimulation, particularly EA. These observations are exploratory and cannot confirm benefits in fracture populations, but they generate hypotheses to guide future trials evaluating EA for postoperative analgesia and rehabilitation in osteoporotic fractures.

Nonetheless, several limitations of this review should be acknowledged. First, the total number of included independent studies was modest (eight RCTs), which limits the statistical power for subgroup analyses and precludes reliable regression-based assessment of publication bias. Second, the TENS subgroup was represented by only two continuous comparisons, making it difficult to draw firm conclusions about this modality specifically. Third, the included studies varied in their specific continuous outcome measures, including VAS, WOMAC subscales, and composite function scales; therefore, pain and function-related continuous outcomes were analyzed as SMDs and also examined by outcome domain. The categorical responder endpoint was analyzed separately as an RR and was not pooled with the SMD model, which improves statistical validity but leaves only one categorical comparison for that outcome type. Fourth, treatment protocols varied in terms of acupoint selection, stimulation parameters, session frequency, and total treatment duration, which may introduce some degree of clinical heterogeneity not captured by statistical heterogeneity measures. Fifth, the data from some smaller or older studies required conservative imputation of standard deviations from reported standard errors or graphical estimates, which could introduce minor imprecision. Chen et al.[24] found similar data extraction challenges in their review of EA efficacy for KOA and emphasized the importance of standardized reporting in future acupuncture trials. Sixth, the modified risk-of-bias tool, rather than standard RoB 2, was used to accommodate acupuncture-specific methodological features. This adaptation limits cross-study comparability but likely improved sensitivity to bias in non-pharmacological interventions, with no observed impact on the stability of the overall effect estimate.

From a clinical perspective, the present findings support the recommendation that EA should be considered as a viable adjunctive or alternative therapy for KOA patients, particularly those who are intolerant of or inadequately responsive to conventional pharmacological therapy. The favorable safety profile of acupuncture, with adverse events typically limited to mild and transient local reactions such as bruising or soreness, further supports its clinical adoption. The National Institute for Health and Care Excellence (NICE) has recommended EA as a research priority for KOA, and the evidence synthesized in this meta-analysis aligns with the

growing body of literature supporting its routine clinical application. Future research priorities should include multi-center, large-scale, sham-controlled trials with standardized EA protocols, longer follow-up periods to assess durability of effects, and cost-effectiveness analyses to inform healthcare policy decisions.

In conclusion, this meta-analysis shows that electrical acupoint stimulation, particularly EA, provides consistent moderate relief for KOA pain and functional impairment, with benefits remaining stable across different control groups. It offers a safe adjunct or alternative for patients who respond poorly to or cannot tolerate conventional pharmacotherapy. While these findings support integrating EA into routine KOA management, any extension to osteoporotic fracture rehabilitation remains hypothesis-generating and requires dedicated clinical validation. Future adequately powered trials are needed to clarify the comparative efficacy of EA versus TENS and optimize long-term stimulation protocols.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

1. Long H, Liu Q, Yin H, Wang K, Diao N, Zhang Y, et al. Prevalence trends of site-specific osteoarthritis from 1990 to 2019: Findings from the Global Burden of Disease Study 2019. Arthritis Rheumatol 2022;74:1172-83. doi: 10.1002/art.42089.
2. Katz JN, Arant KR, Loeser RF. Diagnosis and treatment of hip and knee osteoarthritis: A review. JAMA 2021;325:568-78. doi: 10.1001/jama.2020.22171.
3. Chen F, Su W, Bedenbaugh AV, Oruc A. Health care resource utilization and burden of disease in a U.S. Medicare population with a principal diagnosis of osteoarthritis of the knee. J Med Econ 2020;23:1151-8. doi: 10.1080/13696998.2020.1801453.
4. Bannuru RR, Osani MC, Vaysbrot EE, Arden NK, Bennell K, Bierma-Zeinstra SMA, et al. OARSI guidelines for the non-surgical management of knee, hip, and polyarticular osteoarthritis. Osteoarthritis Cartilage 2019;27:1578-89. doi: 10.1016/j.joca.2019.06.011.
5. Silverman S, Rice JB, White AG, Beck CG, Robinson RL, Fernan C, et al. Clinical and economic burden of prescribing tramadol and other opioids for patients with osteoarthritis in a commercially insured population in the United States. Pain 2022;163:75-82. doi: 10.1097/j.pain.0000000000002300.
6. Zhang R, Lao L, Ren K, Berman BM. Mechanisms of acupuncture-electroacupuncture on persistent pain. Anesthesiology 2014;120:482-503. doi: 10.1097/ALN.0000000000000101.
7. Wu R, Ma H, Hu J, Wang D, Wang F, Yu X, et al. Electroacupuncture stimulation to modulate neural oscillations in promoting neurological rehabilitation. Brain Res 2024;1822:148642. doi: 10.1016/j.brainres.2023.148642.
8. Li Y, Yu J, Liu Y, Zhu L, Zhang Y, Jin M, et al. Investigating the efficacy of acupoint acupuncture combined with rehabilitation training in knee osteoarthritis treatment: A prospective comparative study informed by systematic acupoint analysis. Jt Dis Relat Surg 2026;37:614-25. doi: 10.52312/jdrs.2026.2205.
9. Li P, Zhang Y, Li F, Cai F, Xiao B, Yang H. The efficacy of electroacupuncture in the treatment of knee osteoarthritis: A systematic review and meta-analysis. Adv Biol (Weinh) 2023;7:e2200304. doi: 10.1002/adbi.202200304.
10. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71.
11. Ng MM, Leung MC, Poon DM. The effects of electro-acupuncture and transcutaneous electrical nerve stimulation on patients with painful osteoarthritic knees: A randomized controlled trial with follow-up evaluation. J Altern Complement Med 2003;9:641-9. doi: 10.1089/107555303322524490.
12. Plaster R, Vieira WB, Alencar FA, Nakano EY, Liebano RE. Immediate effects of electroacupuncture and manual acupuncture on pain, mobility and muscle strength in patients with knee osteoarthritis: A randomised controlled trial. Acupunct Med 2014;32:236-41. doi: 10.1136/acupmed-2013-010489.
13. Palmer S, Domaille M, Cramp F, Walsh N, Pollock J, Kirwan J, et al. Transcutaneous electrical nerve stimulation as an adjunct to education and exercise for knee osteoarthritis: A randomized controlled trial. Arthritis Care Res (Hoboken) 2014;66:387-94. doi: 10.1002/acr.22147.
14. Lv ZT, Shen LL, Zhu B, Zhang ZQ, Ma CY, Huang GF, et al. Effects of intensity of electroacupuncture on chronic pain in patients with knee osteoarthritis: A randomized controlled trial. Arthritis Res Ther 2019;21:120. doi: 10.1186/s13075-019-1899-6.

15. Wang Q, Lv H, Sun ZT, Tu JF, Feng YW, Wang TQ, et al. Effect of Electroacupuncture versus Sham Electroacupuncture in Patients with Knee Osteoarthritis: A Pilot Randomized Controlled Trial. Evid Based Complement Alternat Med 2020;2020:1686952. doi: 10.1155/2020/1686952.
16. Wang TQ, Li YT, Wang LQ, Shi GX, Tu JF, Yang JW, et al. Electroacupuncture versus manual acupuncture for knee osteoarthritis: A randomized controlled pilot trial. Acupunct Med 2020;38:291-300. doi: 10.1177/0964528419900781.
17. Tu JF, Yang JW, Shi GX, Yu ZS, Li JL, Lin LL, et al. Efficacy of intensive acupuncture versus sham acupuncture in knee osteoarthritis: A randomized controlled trial. Arthritis Rheumatol 2021;73:448-58. doi: 10.1002/art.41584.
18. Sun J, Liang Y, Luo KT, Shao XM, Tu MQ, Wu XT, et al. Efficacy of different acupuncture techniques for pain and dysfunction in patients with knee osteoarthritis: A randomized controlled trial. Pain Ther 2025;14:737-51. doi: 10.1007/s40122-025-00713-x.
19. Shi X, Yu W, Zhang W, Wang T, Battulga O, Wang L, et al. A comparison of the effects of electroacupuncture versus transcutaneous electrical nerve stimulation for pain control in knee osteoarthritis: A Bayesian network meta-analysis of randomized controlled trials. Acupunct Med 2021;39:163-74. doi: 10.1177/0964528420921193.
20. Goldman N, Chen M, Fujita T, Xu Q, Peng W, Liu W, et al. Adenosine A1 receptors mediate local anti-nociceptive effects of acupuncture. Nat Neurosci 2010;13:883-8. doi: 10.1038/nn.2562.
21. Yuan SG, Chen J, Chen MX, Zheng NS, Zhang ZW, Wang HJ, et al. High-intensity electroacupuncture is superior to low-intensity electroacupuncture for knee osteoarthritis: A meta-analysis of randomized controlled trials. Acupunct Med 2024;42:303-10. doi: 10.1177/09645284241298718.
22. Mekariya K, Vanitcharoenkul E, Chotiyarnwong P, Adulkasem N, Unnanuntana A. High prevalence of symptomatic knee osteoarthritis among patients who have fragility hip fractures. J Arthroplasty 2025;40:2179-85.e1. doi: 10.1016/j.arth.2025.01.016.
23. Veronese N, Smith L, Zigoura E, Barbagallo M, Dominguez LJ, Barone A, et al. Multidimensional prognostic index and the risk of fractures: An 8-year longitudinal cohort study in the Osteoarthritis Initiative. Arch Osteoporos 2021;17:5. doi: 10.1007/s11657-021-01015-3.
24. Chen N, Wang J, Mucelli A, Zhang X, Wang C. Electroacupuncture is beneficial for knee osteoarthritis: The evidence from meta-analysis of randomized controlled trials. Am J Chin Med 2017;45:965-85. doi: 10.1142/S0192415X17500513.