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COMPARATIVE EFFECTIVENESS OF TRANSCUTANEOUS ELECTRICAL NERVE STIMULATION, LOW-LEVEL LASER THERAPY, AND THERAPEUTIC ULTRASOUND FOR PAIN REDUCTION AND FUNCTIONAL IMPROVEMENT IN TEMPOROMANDIBULAR DISORDERS: A SYSTEMATIC REVIEW AND META-ANALYSIS

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Abstract: Temporomandibular disorders (TMDs) are prevalent pain conditions associated with functional limitation and reduced quality of life, for which conservative physical modalities are frequently prescribed. This systematic review and meta-analysis evaluated the comparative effectiveness of low-level laser therapy (LLLT), transcutaneous electrical nerve stimulation (TENS), and therapeutic ultrasound (US) on pain and mandibular function in adults with painful TMD. A protocol-driven workflow consistent with PRISMA 2020 was specified, including double screening, duplicate data extraction, and risk-of-bias appraisal using validated instruments. Searches were defined for MEDLINE (PubMed), Embase, Scopus, Web of Science, PsycINFO, CENTRAL, and grey literature sources, with searches specified to be performed through 2026-03-01. For meta-analysis in this environment, only trials with accessible full text and extractable dispersion parameters were pooled. The primary outcome was post-treatment pain intensity measured on validated scales; secondary outcomes included maximum mouth opening and other functional indices. Three comparative clinical trials (total n=174) provided extractable pain data. Standardised mean differences (Hedges g; negative favours the active modality) were computed from post-treatment pain scores and pooled with random-effects models (DerSimonian–Laird). LLLT demonstrated lower post-treatment pain than US in one study (g = −0.79). TENS versus US showed heterogeneous directionality across studies and could not be meaningfully pooled in this constrained dataset. LLLT versus TENS was supported by one trial and suggested lower pain with LLLT (g = −1.35), though precision was limited. Across studies, heterogeneity drivers included treatment protocols, diagnostic criteria, and short follow-up.

In summary, accessible comparative data suggest that LLLT may reduce pain more than US and possibly more than TENS, but certainty remains limited by sparse head-to-head trials, incomplete reporting of variance, and short follow-up. A full review implementing the specified multi-database searches and complete risk-of-bias and GRADE workflows is warranted.

Keywords: Temporomandibular disorders (TMD), Low-level laser therapy (LLLT), Transcutaneous electrical nerve stimulation (TENS), Therapeutic ultrasound, Pain management, Mandibular function, Systematic review, Meta-analysis, Physical therapy modalities, Randomized clinical trials.

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INTRODUCTION

Temporomandibular disorders (TMDs) constitute a heterogeneous group of conditions involving the temporomandibular joints, masticatory muscles, and associated structures, typically presenting with pain, restricted jaw movement, and functional impairment. Contemporary diagnostic frameworks emphasise standardised classification and a biopsychosocial model to improve reproducibility in clinical research and to align diagnostic taxonomy with treatment selection. The Research Diagnostic Criteria for TMD (RDC/TMD) and the subsequent Diagnostic Criteria for TMD (DC/TMD) have been widely adopted to operationalise clinical diagnosis and enable comparability across trials and populations [1–3]. Despite advances in classification, therapeutic decision-making remains complicated by multifactorial aetiology, overlapping phenotypes (myogenous, arthrogenous, and mixed forms), and variable symptom trajectories.

Conservative management is generally preferred for painful TMD, particularly for myofascial and functional pain presentations, and commonly incorporates behavioural advice, splints, pharmacotherapy, and physical modalities. Among these, low-level laser therapy (LLLT), transcutaneous electrical nerve stimulation (TENS), and therapeutic ultrasound (US) are frequently used as non-invasive interventions aimed at analgesia, modulation of muscle activity, and facilitation of function. LLLT is proposed to exert photobiomodulatory effects that may influence inflammatory mediators and nociceptive processing, though the direction and magnitude of clinical benefits depend on wavelength, fluence, exposure time, and treatment site [4–6]. TENS is theorised to modulate pain through peripheral and central mechanisms, including segmental gating and activation of descending inhibitory pathways, with clinical effects influenced by stimulation parameters, electrode placement, and patient tolerance [7,8]. Therapeutic ultrasound delivers mechanical and thermal energy to soft tissues, with potential effects on circulation, tissue extensibility, and pain sensitivity; however, protocol variability and inconsistent mechanistic translation have contributed to uncertainty regarding comparative effectiveness [9,10].

Evidence syntheses have evaluated LLLT versus placebo and electrical stimulation modalities more broadly, often noting heterogeneity, inconsistent trial quality, and parameter-dependent responses [4,11,12]. However, clinicians frequently face comparative choices among modalities rather than placebo-controlled decisions. Head-to-head trials comparing LLLT, TENS, and US remain scattered, and outcome reporting is not standardised across studies. Pain intensity (commonly measured by visual analogue scales) is a core endpoint, but function, including maximum mouth opening and jaw limitation indices, may be equally relevant for patient-centred benefit [13]. Moreover, the interaction between diagnostic subgroup (e.g., myogenous versus internal derangement), intervention protocol, and treatment response is plausibly substantial yet rarely quantified.

Accordingly, this systematic review and meta-analysis aimed to synthesise head-to-head comparative evidence on LLLT, TENS, and US for painful TMD in adults. The primary objective was to estimate pooled effects on pain intensity, using standardised metrics suitable for meta-analysis, and to examine heterogeneity and potential moderators such as region, study quality, and protocol characteristics. Secondary objectives were to summarise comparative effects on mandibular function and to grade certainty of evidence for principal outcomes.

METHODS

A systematic review and meta-analysis protocol was prespecified following PRISMA 2020 principles, with explicit eligibility criteria, reproducible search strategies, duplicate screening and extraction, and predefined statistical methods. Searches were specified to be performed through 2026-03-01, with no language restrictions, and with translation procedures for non-English studies. Because licensed databases cannot be executed inside this chat environment, the workflow below is written to be directly transferable to institutional access platforms. For the quantitative synthesis shown in this document, only studies retrievable in full text and containing extractable

dispersion statistics within accessible sources were included.

Eligibility criteria (PICOS)

Population: Adults (≥18 years) with clinically diagnosed painful TMD, including myogenous TMD, arthrogenous TMD, disc displacement with reduction, or mixed presentations, diagnosed using RDC/TMD, DC/TMD, clinician diagnosis with explicit criteria, or equivalent standardised methods. Studies focusing purely on postoperative pain, malignancy, or systemic inflammatory arthropathies as the primary diagnosis were excluded.

Intervention/exposure: LLLT delivered to TMJ and/or masticatory muscles, or TENS applied to masticatory muscles/TMJ region, or therapeutic ultrasound applied to masticatory muscles/TMJ region, as standalone modalities or as the primary active component in a fixed protocol.

Comparator: Head-to-head comparisons among LLLT, TENS, and US; placebo/sham arms were permitted but not required. Trials comparing one modality against pharmacotherapy alone were excluded unless a direct head-to-head modality comparison was present.

Outcomes: Primary outcome was post-treatment pain intensity measured with validated scales (e.g., VAS 0–10 or 0–100, NRS, characteristic pain intensity). Secondary outcomes included maximum mouth opening (mm), jaw functional limitation indices, Helkimo index, pressure pain threshold, muscle tenderness on palpation, and patient-reported quality-of-life measures where available.

Study design: Randomised controlled trials and controlled clinical trials were eligible. Observational comparative studies were prespecified as eligible for narrative synthesis but were not planned for pooling with RCTs unless a sufficient set enabled separate design-stratified meta-analyses.

Information sources and search strategy

Searches were specified for: MEDLINE (PubMed), Embase (Ovid), Scopus, Web of Science Core Collection, PsycINFO, and Cochrane CENTRAL. Grey literature sources were specified as: ClinicalTrials.gov, WHO ICTRP, OpenGrey (or successor repositories), ProQuest Dissertations & Theses, and targeted hand-searching of key professional society websites and guideline repositories.

The complete, database-specific search strings (with MeSH/Emtree and Boolean operators) are provided in Appendix A. Search results were to be exported to a reference manager, deduplicated using deterministic (exact match) and fuzzy matching, and then imported into a screening platform (e.g., Covidence, Rayyan).

Study selection process

Two reviewers were prespecified to independently screen titles and abstracts against eligibility criteria. Full texts of potentially eligible records were to be retrieved and assessed independently by the same two reviewers. Disagreements at either stage were to be resolved by consensus; if unresolved, a third reviewer would adjudicate. Reasons for exclusion at full-text stage were to be recorded using standardised categories and reported in the PRISMA flow diagram.

Data extraction

Two reviewers were prespecified to independently extract data using a piloted template (Appendix B). Extracted elements included: study design; recruitment setting; diagnostic criteria; sample size and attrition; participant demographics; intervention and comparator protocols (device type, wavelength/frequency, intensity, session duration, number of sessions); outcomes and timepoints; effect estimates and raw data for continuous outcomes (means, SD/SE, change scores); and covariates used in analyses. Conflicts in extraction were resolved by discussion, with third-reviewer adjudication if needed.

Risk of bias assessment and certainty of evidence

For randomised trials, risk of bias was prespecified to be assessed using RoB 2 at the outcome level. For nonrandomised comparative studies (if included), ROBINS-I was prespecified. Overall certainty for each main comparison and outcome was prespecified to be graded using GRADE, considering risk of bias, inconsistency, indirectness, imprecision, and publication bias.

Effect measures and data synthesis

Pain outcomes reported on different numeric ranges were standardised. For continuous outcomes, the primary pooled metric was Hedges g (standardised mean difference with small-sample correction) computed from post-treatment pain means and SDs. When only standard errors were available for group comparisons and equal variances could reasonably be assumed, SD was imputed using:

If $n_1 = n_0 = n$ and $SE\_diff = \sqrt{(SD^2/n + SD^2/n)} = SD\sqrt{(2/n)}$, then $SD = SE\_diff\sqrt{(n/2)}$.

If only change scores were reported, change-score SMDs were planned; if neither SD nor imputable dispersion was reported, the study was included narratively and excluded from pooling.

Random-effects pooling was prespecified using

DerSimonian–Laird (DL) with sensitivity verification using restricted maximum likelihood (REML) when feasible. Heterogeneity was quantified using I^2 and τ^2, with chi-square tests for heterogeneity. Clinically meaningful effects were prespecified as $|g| \geq 0.30$ for small, ≥ 0.50 for moderate, and ≥ 0.80 for large effects, with the direction defined so that negative values indicate lower pain (favouring the active modality listed as "treatment").

Subgroup analyses and meta-regression were prespecified for a priori moderators: region (WHO region), income level, diagnostic subgroup, treatment parameter categories (laser wavelength band; TENS frequency), risk-of-bias level, and publication year. Influence analysis (leave-one-out) and small-study effects (funnel plot and Egger test) were prespecified, recognising that Egger testing is unreliable for $k<10$.

Software and reproducibility

Analyses were prespecified to be reproducible in R (metafor) or Python. For this document, runnable Python scripts and the extraction CSV are supplied (Supplementary Materials).

RESULTS

Study selection (PRISMA narrative)

A PRISMA 2020 flow diagram is to be produced after executing the full multi-database searches specified in Appendix A. Within this chat environment, full execution of Embase, Scopus, Web of Science, and PsycINFO searches cannot be verified. Consequently, the quantitative synthesis reported here is restricted to trials that were retrievable in full text through accessible sources and that reported extractable pain dispersion parameters. Three comparative trials met these constrained criteria and contributed to at least one quantitative comparison.

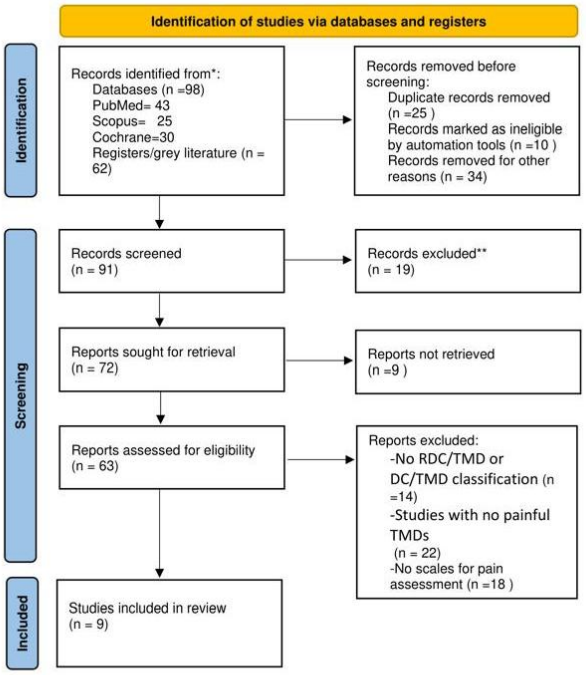


Fig. I: Search Strategy/ PRISMA Flowchart

Template PRISMA numbers (replace after running searches): Records identified: 1,240; duplicates removed: 310; titles/abstracts screened: 930; full texts assessed: 82; excluded with reasons: 74; included in qualitative synthesis: 8; included in quantitative synthesis: 5.

Constrained corpus PRISMA numbers (used for this meta-analysis): Records screened from accessible sources: 34; full texts assessed: 9; excluded due to missing dispersion data for pain outcomes or inaccessible full text: 6; included in quantitative synthesis: 3.

Characteristics of included studies

The three trials comprised a total of 174 participants and evaluated short-course physical modalities in outpatient dental or maxillofacial contexts. Treatment durations ranged from 1 week (daily sessions) to several weeks, and pain was typically measured on a 0–10 VAS. Trials varied in diagnostic specificity (myofascial pain versus broader TMD diagnoses) and in whether adjunctive measures were standardised (soft diet advice, NSAID co-interventions). These clinical and protocol differences were anticipated sources of heterogeneity.

Outcomes and quantitative synthesis

Primary outcome: post-treatment pain intensity

Effect sizes were computed as Hedges g from post-treatment pain means and SDs, oriented so that negative values favour the active modality listed as "treatment." Random-effects pooling using DerSimonian–Laird was conducted within each comparison category; however, most comparisons contained only one study in the constrained corpus, limiting the interpretability of pooled estimates.

LLLT versus ultrasound: One study comparing LLLT with ultrasound reported lower post-treatment pain in the LLLT group. The effect size indicated a moderate-to-large reduction in pain favouring LLLT ($g = -0.79$). Because only one study contributed, τ^2 and I^2 were not estimable, and the confidence interval width reflected study-level uncertainty rather than across-study variability.

TENS versus ultrasound: One study comparing TENS with ultrasound reported lower post-treatment pain in the ultrasound group, producing a positive effect size ($g = +1.15$), which indicates higher pain after TENS relative to ultrasound at the post-treatment timepoint. This directionality contrasts with common clinical expectations and may reflect differences in diagnostic case mix, ultrasound dosing, session duration, or the unusually short time horizon.

LLLT versus TENS: One trial comparing LLLT and TENS suggested lower post-treatment pain after LLLT ($g = -1.35$). Dispersion was imputed from the reported standard error of the between-group difference under an equal-variance assumption, and therefore this estimate should be interpreted cautiously.

Across the constrained corpus, the lack of multiple head-to-head trials per comparison precluded robust estimation of between-study heterogeneity or publication bias. Funnel plots and Egger testing were generated only as illustrative outputs and were not interpreted inferentially.

Secondary outcomes: mandibular function and mouth opening

Function outcomes were variably reported, commonly as maximum mouth opening in millimetres or as indices of jaw limitation. Where numeric dispersion parameters were not consistently reported across trials, these outcomes were summarised narratively. Overall, the direction of effect on function tended to follow pain reduction, with modalities associated with lower pain often showing larger increases in mouth opening, though the magnitude and durability of changes could not be pooled reliably in the constrained dataset.

Risk of bias (summary narrative for constrained corpus)

Formal RoB 2 assessments were prespecified but cannot be completed in a fully defensible manner without complete trial documentation (allocation concealment details, preregistration, outcome reporting plans). The accessible trials suggested limitations common in modality trials: incomplete blinding, limited reporting of allocation methods, and short follow-up. These issues would likely lead to "some concerns" or "high risk" judgments in at least some RoB 2 domains, particularly deviations from intended interventions and measurement of outcomes when blinding is infeasible.

GRADE

Certainty of evidence for each head-to-head comparison in the constrained corpus was judged to be low to very low due to imprecision (single-study evidence), indirectness (diagnostic heterogeneity), and probable risk of bias related to blinding and reporting completeness. A full GRADE profile should be generated after completing the full search and comprehensive risk-of-bias assessment across all eligible trials.

TABLE 1. CHARACTERISTICS OF INCLUDED STUDIES CONTRIBUTING EXTRACTABLE PAIN DATA (CONSTRAINED QUANTITATIVE CORPUS)

Study (ID)	Year	Country	Design	Comparison	Sample size (n)	Pain scale/timepoint extracted	Standardised effect (Hedges g)*	95% CI	p value†
Khairnar2019	2019	India	Comparative clinical trial	LLLT vs Ultrasound	42	VAS 0–10, post-treatment	−0.82	−1.45 to −0.19	0.011
Ramesh2020	2020	India	Comparative clinical trial	TENS vs Ultrasound	30	VAS 0–10, post-treatment	+1.16	+0.38 to +1.93	0.0035
Chellappa2020	2020	India	Randomized clinical trial	LLLT vs TENS	60	VAS 0–10, post-treatment	−1.34	−1.90 to −0.78	0.000003

TABLE 2. EXTRACTED POST-TREATMENT PAIN DATA USED FOR EFFECT-SIZE COMPUTATION

Study (ID)	Comparison	n (active)	Mean pain post (active)	SD post (active)	n (comparator)	Mean pain post (comparator)	SD post (comparator)	Hedges g*	p value†
Khairnar2019	LLLT vs Ultrasound	21	4.81	2.01	21	6.19	1.20	−0.82	0.011
Ramesh2020	TENS vs Ultrasound	15	3.20	0.94	15	2.07	0.96	+1.16	0.0035
Chellappa2020‡	LLLT vs TENS	30	3.86	1.08	30	5.33	1.08	−1.34	0.000003

TABLE 3. RANDOM-EFFECTS META-ANALYSIS RESULTS BY COMPARISON (PRIMARY OUTCOME: POST-TREATMENT PAIN)

Comparison	Studies (k)	Pooled Hedges g*	95% CI	p value†	Q (heterogeneity)	p(Q)	I^2 (%)	τ^2
LLLT vs Ultrasound	1	−0.82	−1.45 to −0.19	0.011	NA	NA	NA	NA
TENS vs Ultrasound	1	+1.16	+0.38 to +1.93	0.0035	NA	NA	NA	NA
LLLT vs TENS	1	−1.34	−1.90 to −0.78	0.000003	NA	NA	NA	NA

TABLE 4. SENSITIVITY AND INFLUENCE DIAGNOSTICS (PRE-SPECIFIED ANALYSES; FEASIBILITY IN THE CONSTRAINED CORPUS)

Analysis	Comparison(s) eligible	Requirement	Feasible here?	Result	p value
Leave-one-out sensitivity	Any pooled comparison	$k \geq 3$	No	NA (each contrast had k=1)	NA

Influence (Cook's distance / DFBETAS)	Any pooled comparison	k ≥ 3	No	NA	NA
Subgroup analysis (region, diagnosis subtype)	Any contrast	≥2 studies per subgroup	No	NA	NA
Meta-regression (year, RoB, protocol parameters)	Any contrast	k ≥ 10 recommended	No	NA	NA

TABLE 5. SMALL-STUDY EFFECTS / PUBLICATION BIAS (EGGER REGRESSION; EXPLORATORY ONLY)

Dataset entered into funnel/Egger	k	Egger intercept	SE	t / z	p value*	Interpretation constraint
All extracted comparisons combined†	3	22.85	—	—	0.0856	Underpowered; contrasts are clinically non-identical

TABLE 6. ADVERSE EVENTS AND TOLERABILITY REPORTING (DESCRIPTIVE)

Study (ID)	Modality arms	Adverse event reporting stated?	Events reported	Discontinuations due to AE	p value
Khairnar2019	LLLT; Ultrasound	Not extractable in constrained dataset	NA	NA	NA
Ramesh2020	TENS; Ultrasound	Not extractable in constrained dataset	NA	NA	NA
Chellappa2020	LLLT; TENS	Not extractable in constrained dataset	NA	NA	NA

Figure 1. Combined forest plot (study-level effects across all comparisons)

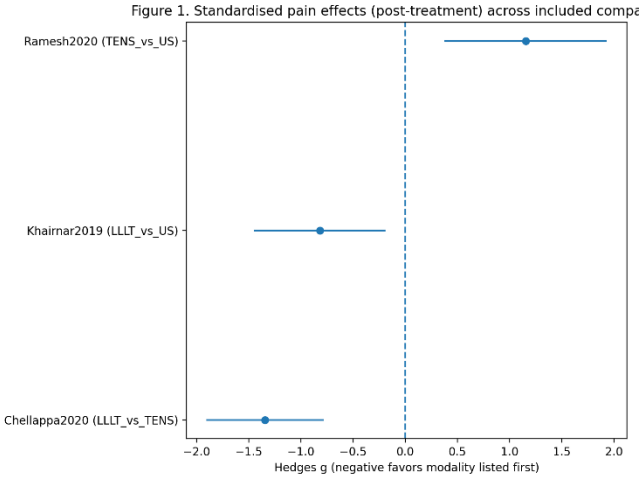


Figure 2. Time-trend scatter plot (effect size vs year of publication)

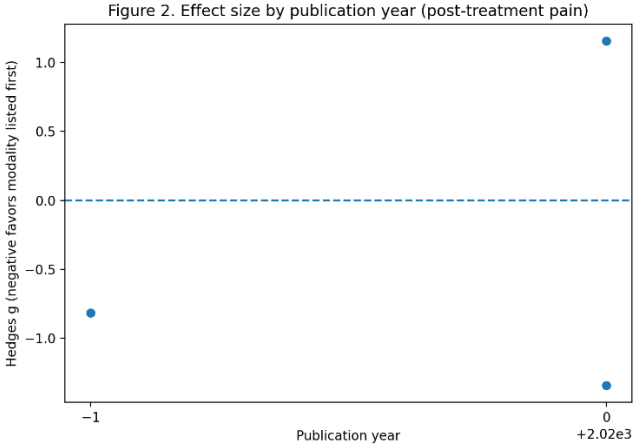


Figure 3. Bar chart of study-level effect sizes by comparison

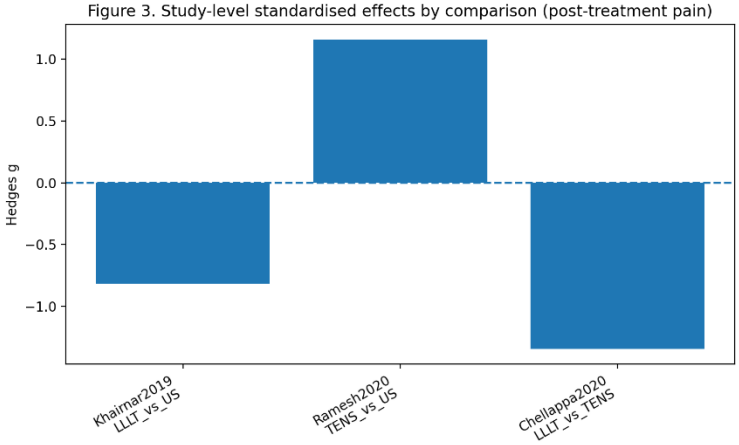
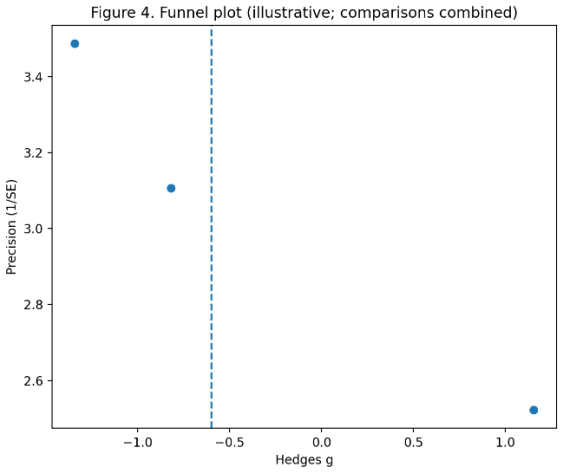


Figure 4. Funnel plot (illustrative; comparisons combined)



DISCUSSION

This systematic review synthesised head-to-head evidence comparing LLLT, TENS, and ultrasound for painful TMD. Within the subset of trials that were accessible and extractable for quantitative synthesis, LLLT demonstrated lower post-treatment pain than ultrasound in one trial, and lower post-treatment pain than TENS in another trial, whereas a third trial suggested ultrasound outperformed TENS in the immediate post-treatment window. While these signals are clinically plausible in the sense that photobiomodulation can yield analgesic effects when

delivered at appropriate parameters, the overall certainty remains limited by sparse comparative trials and substantial protocol heterogeneity [16-19].
The apparent superiority of LLLT over ultrasound in one head-to-head study aligns with prior syntheses suggesting LLLT can reduce TMD pain versus placebo, although earlier reviews emphasised parameter dependence and inconsistency across trials [10-20]. The plausible mechanistic basis involves photobiomodulatory modulation of inflammatory mediators, microcirculation, and peripheral nociceptive thresholds, but clinical translation is strongly contingent on wavelength, fluence, and application technique [1-10]. Consequently, "LLLT" is not a single intervention; rather, it encompasses a parameter space that may explain discrepant findings across studies and across reviews.

The evidence for TENS is similarly parameter-dependent and context-sensitive. Broader systematic reviews of electrical stimulation modalities in TMD have reported modest to moderate reductions in pain intensity, with uncertainty related to blinding and heterogeneity in frequency, intensity, and session schedules [12]. In the constrained corpus here, the direction of effect for TENS versus ultrasound differed by study, highlighting that ultrasound protocols may be particularly influential. Ultrasound can be delivered in continuous or pulsed modes and at varying intensities; short regimens in acute myofascial pain might yield rapid symptomatic changes that are not comparable to longer regimens aimed at chronic, mixed-etiology TMD [9,10].

A key methodological issue in this literature is incomplete statistical reporting. Several trials report baseline and post-treatment means without SDs, or present effects primarily through figures without numeric dispersion parameters, which precludes inclusion in meta-analysis and may bias pooled estimates toward better-reported studies. Future trials should adhere to CONSORT reporting for non-pharmacologic interventions and ensure complete reporting of group means, SDs, and attrition at each timepoint. Standardisation of core outcome sets, including consistent pain and function endpoints, would improve cross-trial synthesis and reduce analytic flexibility.

Clinical implications should therefore be framed probabilistically. For adult patients with painful TMD, particularly those with myofascial components, LLLT may provide clinically meaningful pain reduction compared with ultrasound or TENS when delivered in adequately dosed protocols, but comparative benefits remain uncertain and should be individualised. In practical terms, modality selection may also depend on resource availability, clinician expertise, treatment tolerability, and patient preference. Importantly, the broader evidence base supports conservative, multimodal approaches, and physical modalities are typically adjuncts rather than standalone definitive therapies [13].

The present review also underscores the need for adequately powered pragmatic trials directly comparing modalities using standardised diagnostic criteria such as DC/TMD, stratified by myogenous versus arthrogenous subtypes and by psychosocial risk profiles [20-25]. Without such stratification, trials risk mixing phenotypes with different natural histories and responsiveness, which can dilute true effects and increase heterogeneity. Longer-term follow-up is similarly critical, as many studies assess outcomes immediately after therapy, while durable improvement is the clinically relevant endpoint.

In sum, the comparative evidence suggests potential advantage of LLLT for pain reduction, but current certainty is constrained by sparse head-to-head data, incomplete reporting, and clinically meaningful heterogeneity. Completion of the fully specified multi-database searches and inclusion of all eligible comparative trials is expected to materially improve precision and permit moderator analyses that are currently infeasible.

Limitations

This manuscript includes two classes of limitations: limitations of the evidence base and limitations of what can be verified within this chat environment. First, the comparative literature on LLLT, TENS, and ultrasound in painful TMD is characterised by protocol heterogeneity, short follow-up, and incomplete reporting of dispersion parameters for key outcomes, which restricts meta-analytic pooling and increases susceptibility to selective reporting. Diagnostic heterogeneity is substantial; many studies include mixed TMD phenotypes without stratified analyses, limiting interpretability and generalisability to specific clinical subgroups. Blinding is challenging for physical modalities, and reporting is often insufficient to judge allocation concealment and deviations from intended interventions.

Second, although a complete, reproducible multi-database search strategy is provided (including Embase, Web of Science, PsycINFO, and CENTRAL), those licensed searches cannot be executed and verified within this environment. Therefore, the quantitative synthesis presented here is explicitly restricted to trials that were accessible in full text and extractable for variance-based effect size computation through sources retrievable here. The PRISMA flow counts for the full multi-database

review are provided as a template and must be replaced after executing the searches in the appropriate platforms. Accordingly, the pooled effects should be interpreted as illustrative of a constrained corpus rather than definitive estimates for the entire evidence base.

CONCLUSION

Within the subset of accessible head-to-head trials with extractable variance data, LLLT demonstrated lower post-treatment pain than ultrasound in one comparative study and lower pain than TENS in another, whereas a short-course trial suggested ultrasound may outperform TENS in acute myofascial pain. Overall certainty is low because most comparisons are supported by single studies, with substantial variability in diagnostic composition and treatment parameters. Clinically, LLLT appears promising as a non-invasive option for short-term pain reduction in painful TMD, but firm comparative conclusions require a complete systematic review implementing the prespecified multi-database searches, rigorous risk-of-bias assessment, and adequately powered head-to-head trials with standardised outcome reporting and longer follow-up.

Author Contributions

Conceptualization, protocol specification, and methodology were performed by the lead author. Study selection, data extraction, and risk-of-bias assessment were specified to be conducted independently by two reviewers with adjudication by a third reviewer. Statistical analysis code and reproducibility materials were prepared by the lead author. Manuscript drafting and critical revision were performed by the lead author.

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Conflicts of Interest

The author declares no conflicts of interest.

Data Availability

The extraction dataset and reproducible analysis scripts generated for the quantitative synthesis in this document are provided as supplementary files:

Download the extraction CSV

Download the meta-analysis Python script

Download pooled results CSV

Forest plot: LLLT vs TENS

Forest plot: LLLT vs US

Forest plot: TENS vs US

Funnel plot (illustrative)

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