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REVIEW ARTICLE

Efficacy of High-intensity laser therapy in patients with temporomandibular joint disorders: A systematic review and meta-analysis

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Abstract

This study aimed to assess the effects of High-intensity laser therapy (HILT) on individuals suffering from temporomandibular joint disorders (TMDs). A search was conducted across six electronic databases for randomized controlled trials (RCTs) focusing on HILT for TMDs: PubMed, Scopus, Web of Science, ScienceDirect, EBSCOhost, Cochrane Library, the PEDro database and Google Scholar (last updated on July 18, 2024). Eligible studies were chosen by independent reviewers, and their quality was assessed with the Cochrane risk of bias tool (RoB). The main outcome was pain intensity (VAS), with secondary outcomes including mouth opening (mm), disability (JFLS-20), and quality of life (OHIP-14). A meta-analysis was conducted to assess the pooled effect by calculating mean differences (MD) for these variables (95% confidence level). The heterogeneity of the meta-analyses was explored using the I^2 statistic. Three studies met the selection criteria and were included in the meta-analysis. The main RoB was the blinding of participant and treaters. Statistically significant differences ($p < 0.05$) in favor of HILT were observed for VAS and maximum mouth opening. The pooled effect showed an MD of -14.8 mm (95% CI:-27.1,-2.5) for pain intensity and 3.7 mm (95% CI:0.9,6.5) for mouth opening, changes that were assessed as clinically important. According to GRADE, the evidence was rated as important, and the certainty was moderate due to the heterogeneity between studies. A sensitivity analysis was not performed to address heterogeneity, primarily due to the limited availability of RCTs. HILT has been found effective in short-term pain relief and improvement of jaw opening in TMDs, potentially enhancing quality of life by facilitating activities such as chewing, jaw mobility, and communication. However, further research is needed to confirm its long-term effectiveness. Combining HILT with interventions such as occlusal splints or therapeutic exercises could potentially enhance its effects, leveraging the existing evidence supporting these treatments. It is important to note that the high RoB associated with the lack of blinding of participants and treaters may influence data collection, compromising the internal validity of findings in some studies.

Keywords Lasers · Phototherapy · Pain management · Temporomandibular joints · Temporomandibular joint disorders · Systematic review

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Introduction

Temporomandibular disorders (TMDs) encompass a range of conditions that affect the masticatory muscles, the temporomandibular joint (TMJ), and their associated structures [1]. TMDs are a notable public health issue, affecting a considerable portion of the population, with estimated prevalence rates of 5 to 12% among adults and 7% among adolescents [2, 3], being a significant cause of chronic orofacial pain, distinct from dental issues [1]. Its characteristic symptoms include facial and preauricular pain, limitations in jaw mobility, and noises in the TMJ during jaw movements [1].

TMDs are divided into two primary groups [2]: those of articular origin, involving the TMJ, and those of muscular origin, affecting the orofacial muscles. Within joint TMDs, the most common manifestations include disc disorders, TMJ pain, and degenerative conditions. This aligns with studies indicating that up to 70% of TMD cases involve an abnormal disc position associated with joint osteoarthritis [3, 4].

To address TMDs as a chronic and biopsychosocial condition, a diagnostic criteria system (DC/TMD) has been developed, comprising two axes [5, 6]. Axis-I primarily concentrates on physical diagnosis, employing an algorithm to distinguish between painful conditions like myofascial pain, arthralgia, or TMJ-related headaches and non-painful conditions such as disc displacement with or without reduction, disc blockage, joint disease, or subluxation. Axis II is dedicated to evaluating psychosocial aspects and disabilities related to pain [6].

Physical therapy emerges as an effective and conservative approach in the treatment of TMDs [7, 8]. By employing interventions such as therapeutic exercises, manual therapy, and physical agents, physical therapy effectively manages symptoms and enhances orofacial function in TMD patients [8–10]. Low-level laser therapy (LLLT) is a non-invasive technique used in physical therapy in TMDs, providing pain relief and improving oral function [11–13]. LLLT operates at power levels below 0.5W without heating, and its biological effects rely on photobiomodulation, which promotes tissue healing and reduces inflammation and pain [11, 12]. The analgesic effects of LLLT primarily stem from the release of endorphins, the decrease of nociceptive conduction, and the attenuation of the inflammatory response [11, 14].

Recently, advanced technologies featuring high-intensity laser (HILT) equipment have been introduced in physical therapy to address musculoskeletal pain management [15, 17]. This technology is characterized by powers greater than 0.5W and combines the effects of photobiomodulation with thermal effects in different magnitudes, distinguishing it from LLLT [18]. Given their long wavelengths and high-power levels, HILT devices allow for enhanced penetration, quicker energy delivery, and more efficient coverage of treatment areas in less time [15, 16, 18].

Despite the established benefits of HILT in musculoskeletal pain management, there appears to be limited evidence supporting its effectiveness in treating TMDs [19–21], possibly attributed to its relatively recent introduction, in contrast to LLLT, which has clearer evidence and recommendations for TMDs [11]. Hence, the objective of this systematic review (SR) is to gather and assess the existing evidence regarding the analgesic effects of HILT in individuals with TMDs.

Methods

Design

This study adhered to the PICO approach (patient, intervention, comparison, and outcome), concentrating on TMD patients undergoing HILT treatment and comparing it to other interventions or sham HILT, with the primary outcome being the assessment of pain intensity using validated scales like the visual analog scale (VAS). Additionally, secondary outcomes, such as alterations in mandibular range of motion (particularly mouth opening) and disability levels measured using the Mandibular Functional Limitation Scale (JFLS-20), were also assessed.

SR registration

This review was conducted in accordance with the guidelines outlined in the Reporting Elements Submitted for Systematic Reviews and Meta-Analyses (PRISMA statement) [22]. It was also registered in the National Institute for Health Research (NIHR) international prospective systematic review database (PROSPERO) on March 23, 2023 (CRD42023407537) [23].

Search

An electronic search for clinical trials (RCTs) related to HILT in TMDs was performed in various databases, including PubMed, Web of Science, Scopus, EBSCOhost, Science Direct, the Evidence-Based Physiotherapy (PEDro) database, and Google Scholar updated on July 18, 2024.

The study used the following keywords for the search: "Lasers," "Laser Therapy," "Phototherapy," "High-Intensity Laser Therapy," "Class IV Laser," "Musculoskeletal Pain," "Temporomandibular Joint Disorders," "Temporomandibular Joint Dysfunction Syndrome," and "Craniomandibular Disorders". These keywords were combined using the Boolean connectors "OR" and "AND" to create the following search algorithm: *("Lasers" OR "Laser Therapy" OR "Phototherapy" OR "High-Intensity Laser Therapy" OR "Class IV laser") AND ("Musculoskeletal Pain" OR*

"Temporomandibular Joint Disorders" OR "Temporomandibular Joint Dysfunction Syndrome" OR "Craniomandibular Disorders"). To obtain the relevant results, filters for "clinical trial" and "randomized controlled trial" were applied. Appendix 1 summarizes the results of the search strategy.

The principal researcher downloaded results from each database in RIS or NBIB file formats and subsequently uploaded them to the Rayyan web platform (https://www.rayyan.ai/) [24]. Three researchers (HDB, MMV, and MAA) independently conducted the literature review, who assessed article titles and abstracts using their Rayyan accounts. The comprehensive examination included an initial review of titles and abstracts for relevance, followed by a scrutiny of full texts for selected articles. Any discrepancies in the final count were collectively addressed by the team. Data extraction addressed aspects such as participants, selection criteria, interventions, evaluations, and outcomes of interest.

Selection criteria

The review adhered to the following inclusion criteria: (a) RCTs; (b) studies involving human subjects; (c) individuals diagnosed with TMDs; (d) HILT interventions, whether administered in isolation or in conjunction with other treatments, and compared against conservative therapeutic approaches with or without sham HILT; and (e) the primary outcome measure focused on assessing pain intensity. Conversely, case studies, literature reviews, systematic reviews on HILT unrelated to this study, research involving individuals with TMDs coexisting with other musculoskeletal disorders or neurological conditions, as well as studies characterized by incomplete or inaccessible data, were excluded from consideration.

Risk of bias

Bias in the RCTs was assessed using the Cochrane Collaboration Risk of Bias (RoB) tool [25]. RCTs that exhibited two or more high RoB were classified as low-quality studies. The kappa statistic was employed to gauge the level of agreement in the assessment of the RoB between the researchers [26].

Statistical analysis

Heterogeneity among the studies was evaluated utilizing the I^2 statistic, and it was categorized into various levels based on its magnitude: negligible (0–40%), moderate (30–60%), substantial (50–90%), or significant (75–100%) [27]. The DerSimonian and Laird random effects method was employed to calculate the pooled effect using mean differences (MDs) for the results of interest, with a confidence level of 95% due to the degree of heterogeneity observed [28]. The statistical analysis was conducted using Review Manager software (RevMan 5.4).

Quality of evidence

The evaluation of evidence quality and the formulation of recommendations regarding the effectiveness of HILT in the context of TMDs were carried out using the GRADE (Grading of Recommendations, Assessment, Development, and Evaluation) approach [29]. To summarize the evidence, the GRADEpro guidelines tool was employed (available at https://www.gradepro.org).

Results

Search results

The search encompassed seven databases, yielding 1,564 articles as of the last update on July 18, 2024: PubMed (n = 86), Scopus (n = 375), Web of Science (n = 94), EBSCOhost (n = 111), Science Direct (n = 654), Cochrane Central (n = 240), and the PEDro database (n = 65). Additionally, 81 articles were identified through alternative methods, primarily a manual search on Google Scholar. After removing duplicate entries, 841 articles were singled out for further analysis. An examination of titles and abstracts led to the selection of six articles deemed suitable for inclusion. Three initial articles were excluded; one was a case report study [30], and two RCTs were focused on photobiomodulation with LLLT in the context of TMDs [31, 32]. In the alternative databases, two articles were found, but they were duplicates from the formal databases. Figure 1 outlines the search strategy through the PRISMA flowchart.

RoB Assessment

Figure 2 presents the RoB assessment conducted by the researchers (HDB, MMV, and MAA). The degree of agreement between the evaluators was quantified using a kappa coefficient, which yielded a high value of 0.91 [26]. It is observed that the random sequence generation, blinding in the measurement of results, data integrity and the possible occurrence of selective reporting presented a low RoB, at 100%. It is relevant to highlight that blinding of participants/treaters showed a higher RoB, reaching 66.6%, and hidden allocation was evaluated as unclear, also with a percentage of 66.6% [25]. These results suggest a performance bias as the main drawback [25]

Characteristics of the included RCTs

Table 1 provides a comprehensive overview of RCTs focusing on HILT for TMDs with their corresponding study groups, participant selection criteria, interventions,

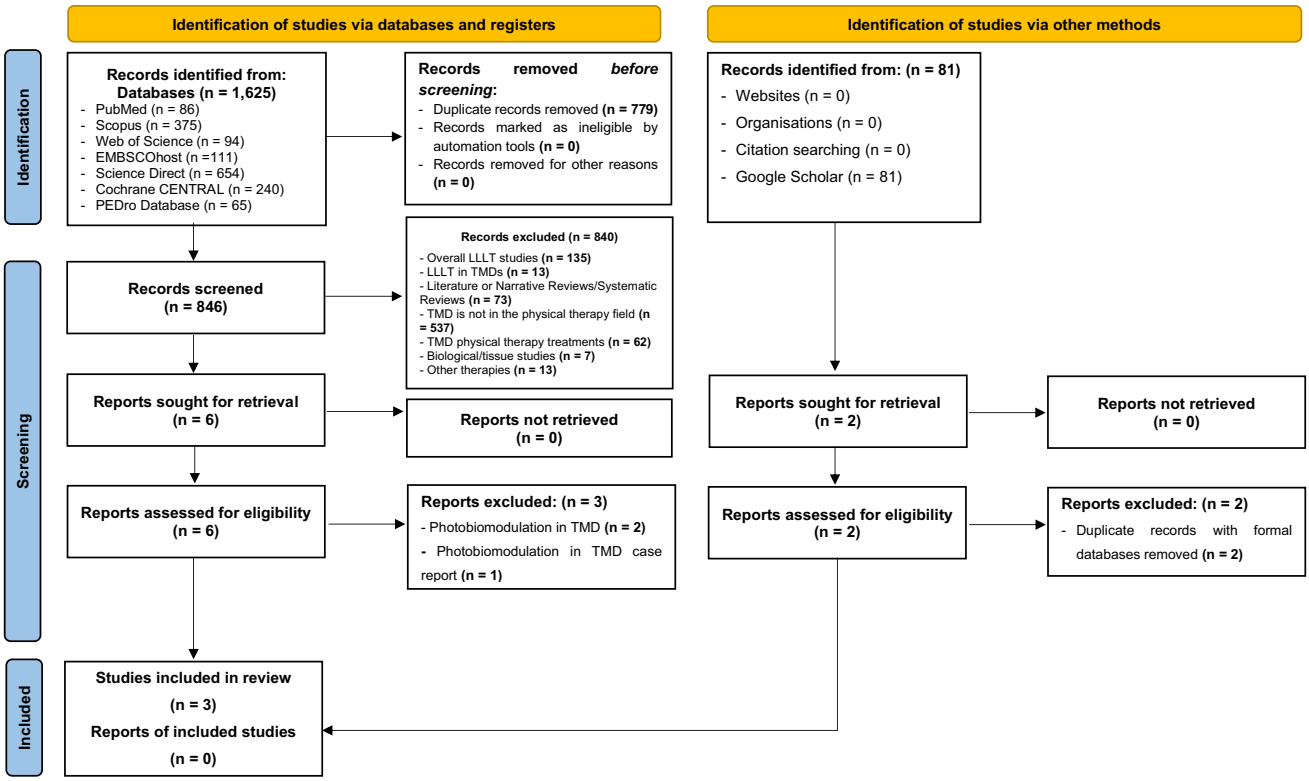

Fig. 1 PRISMA flowchart

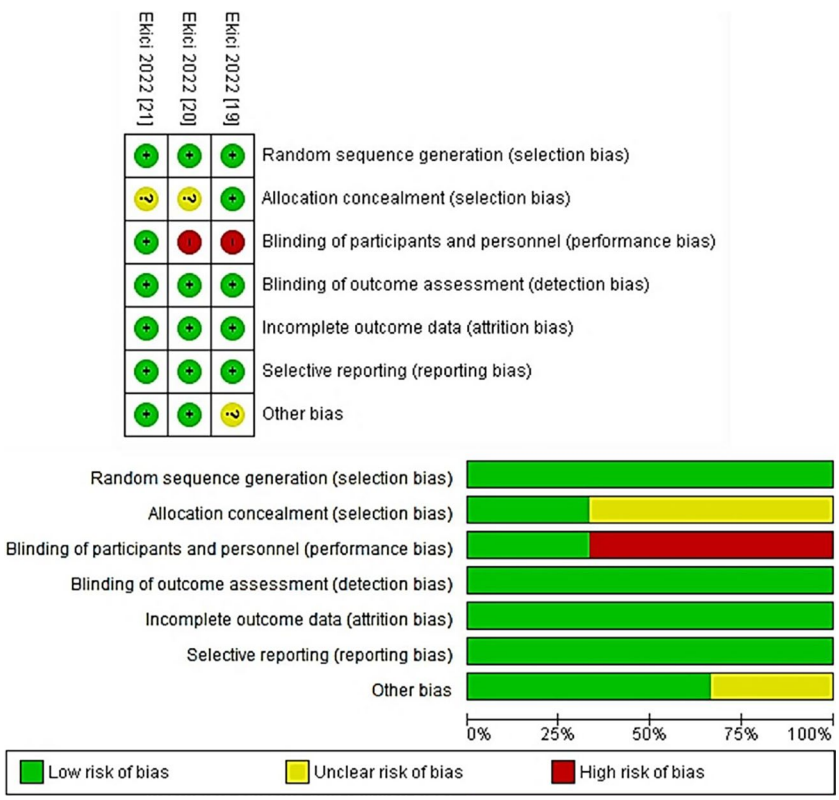

Fig. 2 Risk of Bias among the included studies

Table 1 Study characteristics comparing HILT for TMDs

	Author Year Country	Study	Participants (n) mean age (SD)	Inclusion criteria	Exclusion criteria	Interventions	Sessions	Assessment instances	Outcomes	Sources of funding
1	Ekici et al. [19] Turkey 2022	Effectiveness of high-intensity laser therapy in patients with myogenic temporomandibular joint disorder: A double-blind, placebo-controlled study	n = 67 EG = 33 (♂ = 7; ♀ = 26) 32.4 (± 12.2) CG = 34 (♂ = 4; ♀ = 30) 30.7 (± 11.8)	(1) TMJ disorder diagnosis (2) TMJ-related myofascial pain	(1) Disk displacement (2) TMJ Arthralgia (3) TMJ Osteoarthritis (4) Analgesic or antidepressant medication	EG: HILT CG: Placebo HILT Patients were instructed to avoid analgesics or NAIDs	15 sessions (3 weeks)	T0: baseline T1: after treatment (week 4) T2: follow-up (week 12)	Pain intensity (VAS) Jaw Function (VAS) Mouth open (mm) Disability (JFLS-20) QoL (OHIP-14)	The authors declare they have no financial interests
2	Ekici et al. [20] Turkey 2022	Evaluation of the efficiency of different treatment modalities in individuals with painful temporomandibular joint disc displacement with reduction: a randomised controlled clinical trial	n = 132 EG = 32 (♂ = 10; ♀ = 22) 31.5 (± 12.7) CG1 = 34 (♂ = 10; ♀ = 24) 28.6 (± 14.5) CG2 = 32 (♂ = 8; ♀ = 24) 28.8 (± 12.7) CG3 = 34 (♂ = 3; ♀ = 31) 29.5 (± 10.5)	(1) ≥ 18 years (2) TMJ pain (last 6 months) (3) DDWR (4) TMJ noise with jaw movements in the examination or reported by patients (5) MRI DDWR confirmation	(1) Asymptomatic DDWR (2) Signs of degenerative joint disease (3) DDWoR on MRI (4) History of acute trauma (5) History of use of occlusal splint (6) History of arthrocentesis (7) Rheumatic diseases (8) Pregnant (9) History PT treatment	EG: HILT CG1: occlusal splint (at night) CG2: US CG3: home EP + education Patients were instructed to avoid analgesics, NAIDs, and muscle relaxant	20 sessions (4 weeks)	T0: baseline T1: after treatment (week 4) T2: follow-up (week 12)	Pain intensity (VAS) Jaw Function (VAS) Mouth open (mm) Disability (JFLS-20) QoL (OHIP)	The authors declare they have no financial interests
3	Ekici et al. [21] Turkey 2022	Comparison of the efficiency of high-intensity laser therapy and transcutaneous electrical nerve stimulation therapy in patients with symptomatic temporomandibular joint disc displacement with reduction	n = 100 EG = 34 (♂ = 4; ♀ = 30) 33.2 (± 11.7) CG1 = 32 (♂ = 2; ♀ = 30) 32.3 (± 10.6) CG2 = 34 (♂ = 3; ♀ = 31) 31.2 (± 11.3)	(1) ≥ 18 years (2) TMJ pain (3) Unilateral DDWR (Axis I, group II) (4) MRI anterior DDWR confirmation (5) MRI biconcave disc shape confirmation	(1) Asymptomatic DDWR (2) Signs of degenerative joint disease (3) DDWoR on MRI (4) History of acute trauma (5) Neuromuscular disease (6) History of arthrocentesis (7) Rheumatic diseases (8) History PT treatment	EG: HILT + EP CG1: TENS + EP CG2: EP Patients were instructed to avoid analgesic or NAIDs	15 sessions (3 weeks)	T0: baseline T1: after treatment (week 4) T2: follow-up (week 12)	Pain intensity (VAS) Jaw Function (VAS) Mouth open (mm) Disability (JFLS-20) QoL (OHIP)	The authors declare they have no financial interests

Abbreviations: ♂- men; ♀- women; CG- control group; DDWR- disc displacement with reduction; DDWoR- disc displacement without reduction; EG- experimental group; EP- exercise program; HILT- high-intensity laser therapy; JFLS-20- Jaw Functional Limitation scale; mm- millimeters; MRI- magnetic resonance imaging; NAIDs- non-steroidal anti-inflammatory drugs; OHIP-14- Oral Health Impact Profile-14; PT- physical therapy; QoL- quality of life; ROM- range of movement; SD- standard deviation; TENS- transcutaneous electrical nerve stimulation; TMJ- temporomandibular joint; US- therapeutic ultrasound; VAS- visual analog scale

evaluations, and outcomes of interest [19–21] All the RCTs were conducted in Turkey in the year 2022. The study sample consisted of 299 participants diagnosed with TMDs, with an average age of 31.1 years (± 11.9), with 248 of them being women and 51 being men. Within this population, 101 patients underwent HILT, while the control group comprised 201 subjects who received a range of interventions. These interventions included the use of an occlusal plane [20], therapeutic ultrasound [20], transcutaneous electrical nerve stimulation (TENS) [21], and/or participation in an exercise program [20, 21]. A noteworthy aspect is the inclusion of a study that featured a control group receiving a placebo treatment for HILT [19]. Only one study included exercise as a complementary treatment alongside HILT [20].

The number of treatment sessions ranged from 15 to 20 sessions per day, spanning a duration of 3 to 4 weeks. Evaluation assessments were conducted at three time points for all RCTs: before treatment, immediately after treatment, and during a follow-up evaluation at week 12.

HILT Features

Table 2 provides a comprehensive overview of the technical specifications for the HILT equipment employed in our research. It outlines critical parameters, including wavelength, maximum power, average power, emission mode, pulse frequency, fluence, probe diameter, and treatment configuration. All studies used the high-power HIRO 3 laser device (ASA laser®). The study's treatment protocol consisted of three distinct phases. Phases 1 and 3 employed a combination of transverse and longitudinal scanning techniques over the mandibular ramus. Phase 2 employed a punctual technique to target tender points in the masseter and/or temporalis muscles. The total energy administered ranged from 1,033 to 1,060 J, averaging 500 J for phases 1 and 3, and between 30 and 60 J for phase 2. Notably, a gradual elevation in fluence is observed throughout each phase, with the average treatment spanning two to three minutes.

Relevant outcomes

Table 3 provides a summary of the key outcomes extracted from the included RCTs. Each study assessed the following parameters: pain intensity (measured using VAS), mandibular function (adapted VAS), mouth opening in millimeters, and disability, evaluated through the JFLS-20 questionnaire [19–21]. Furthermore, as part of the evaluation, we conducted a comprehensive assessment of quality of life (QoL) utilizing the Oral Health Impact Profile (OHIP-14) questionnaire [19–21].

The efficacy of the treatment was established by conducting intragroup statistical analyses for the variables of interest across the assessment instances. It is noteworthy that all studies consistently reported statistically significant changes ($p < 0.05$) in the groups that received HILT treatment, both at the conclusion of the treatment and in subsequent follow-up assessments. These changes were observed across various dimensions, including a reduction in pain (VAS), an enhancement in mandibular function measured (adapted VAS), an increase in both maximum mouth opening (MMO) and assisted maximum mouth opening (AMMO), and a decrease in disability (total score of the JFLS-20) and its three specific dimensions (chewing, vertical jaw movements, and communication-oral expression). Additionally, there was an evident improvement in the quality of life, as measured by the OHIP-14 questionnaire. These collective findings strongly support the effectiveness of HILT as a therapeutic intervention [19–21].

The positive treatment response extended beyond HILT groups, with control groups receiving ultrasound, TENS with exercises, and occlusal plane interventions also demonstrating effectiveness in measuring similar variables. However, notably, both the home exercise program and the exercise program supervised by a physical therapist did not produce statistically significant changes in patients with TMDs throughout various evaluation phases [20, 21].

Meta-analysis (MT-A)

A meta-analysis (MT-A) was conducted, encompassing all RCTs that evaluated consistent variables, including pain intensity at rest, mandibular function, MMO, AMMO, disability, and QoL. Notably, two studies featured more than one control group (occlusal splint, ultrasound, and exercise in one case; TENS and exercise in another) [20, 21], resulting in multiple comparisons within the meta-analysis. Figures 3, 4, and 5 present the meta-analysis results for the outcomes of interest.

Pain intensity (VAS). HILT is more effective than control treatments in reducing pain at the end of treatment (MD = -14.8 mm, 95% CI: -27.1,2.5; p = 0.02; EG [197], CG [200]) (Fig. 3A). However, no significant differences were observed between treatments at 12 weeks of follow-up (MD = -13.9 nm, 95% CI: -29.7,2.0; p = 0.09; EG [197], CG [200]) (Fig. 3C).

Mandibular function (adapted VAS). No significant differences were observed between HILT and controls at the end of treatment (MD = 8.1 mm, 95% CI: -6.3,22.4; p = 0.27; EG [197], CG [200])) (Fig. 3B) or for follow-up at week 12 (MD = 8.7 mm, 95% CI: -2.9,20.3; p = 0.14; EG [197], CG [200])) (Fig. 3D).

Mouth opening (mm). Statistically significant differences are observed in favor of HILT for MMO at the end of treatment (MD = 3.7 mm, 95% CI:0.9,6.5; p = 0.009; EG [197], CG [200])) (Fig. 4A), however, this advantage is not clear at 12 weeks of follow-up since no significant differences are observed between the groups (MD = -0.8 cm, 95% CI: -5.8,4.1; p = 0.75; EG [163], CG [166]) (Fig. 4C). No statistical differences were observed between the groups for the

Table 2 Characteristics of the laser parameters used in the studies

Laser features	Ekici [19]	Ekici [20]	Ekici [21]
Technique specifications			
Model	HIRO 3 devise (ASA laser®)	HIRO 3 devise (ASA laser®)	HIRO 3 devise (ASA laser®)
Wavelength	1,064 nm (Nd:YAG)	1,064 nm (Nd:YAG)	1,064 nm (Nd:YAG)
Output power (W)	3,000 W	3,000 W	3,000 W
Mean power (W)	10.5 W	10.5 W	10.5 W
Emission mode	Pulsed	Pulsed	Pulsed
Frequency	10–50 Hz	10–50 Hz	10–50 Hz
Phase duration (μs)	120–150 μs	120–150 μs	120–150 μs
Duty cycle (%)	0.1%	0.1%	0.1%
Fluency	0.36—1.78 J/cm2	0.36—1.78 J/cm2	0.36—1.78 J/cm2
Spot size	0.2 cm2	0.2 cm2	0.2 cm2
Treatment parameters			
Application	Phase 1: TMJ Phase 2: MTrPs of masseter muscle Phase 3: TMJ	Phase 1: TMJ Phase 2: MTrPs of masseter muscle Phase 3: TMJ	Phase 1: TMJ Phase 2: MTrPs of masseter and temporal muscles Phase 3: TMJ
Application angle	90° perpendicular to the skin	90° perpendicular to the skin	90° perpendicular to the skin
Treatment time (sec)	Phase 1: 30 s per side Phase 2: 30 s per side (6 s/point) Phase 3: 60 s per side	Phase 1: 30 s per side Phase 2: 30 s per side (6 s/point) Phase 3: 60 s per side	Phase 1: 30 s Phase 2: 60 s (6 s/point) Phase 3: 60 s
Frequency (Hz)	Phase 1: 20, 18 and 15 Hz (divided for every 10 s) Phase 2: 15, 15, 14 and 16 Hz Phase 3: 20, 18 and 15 Hz (divided for every 20 s)	Phase 1: 20, 18 and 15 Hz (divided for every 10 s) Phase 2: 15, 15, 14 and 16 Hz Phase 3: 20, 18 and 15 Hz (divided for every 20 s)	Phase 1: 20, 18 and 15 Hz (divided for every 10 s) Phase 2: 16 Hz Phase 3: 20, 18 and 15 Hz (divided for every 20 s)
Fluency (J/cm2)	Phase 1: 0.36, 0.41 and 0.51 J/cm2 Phase 2: 0.36, 0.51, 0.51 and 0.61 J/cm2 Phase 3: 0.36, 0.41 and 0.51 J/cm2	Phase 1: 0.36, 0.41 and 0.51 J/cm2 Phase 2: 0.36, 0.51, 0.51 and 0.61 J/cm2 Phase 3: 0.36, 0.41 and 0.51 J/cm2	Phase 1: 0.36, 0.41 and 0.51 J/cm2 Phase 2: 0.61 J/cm2 Phase 3: 0.36, 0.41 and 0.51 J/cm2
Energy delivered (J)	Phase 1: 500 J (166, 167 and 167 J) Phase 2: 33,1 J (6.3, 9, 10 and 7.8 J) Phase 3: 500 J (166, 167 and 167 J) ED = 1,033.1 J per side	Phase 1: 500 J (166, 167 and 167 J) Phase 2: 33,1 J (6.3, 9, 10 and 7.8 J) Phase 3: 500 J (166, 167 and 167 J) ED = 1,033.1 J per side	Phase 1: 500 J (166, 166 and 166 J) Phase 2: 60 J (10 J per point) Phase 3: 500 J (166, 167 and 167 J) ED = 1.060 J per side
Application technique (with spacer)	Phase 1: contact, slow scan for 100 cm2 Phase 2: contact, punctual technique for 3 points per side Phase 3: contact, fast scan for 100 cm2	Phase 1: contact, slow scan for 100 cm2 Phase 2: contact, punctual technique for 3 points per side Phase 3: contact, fast scan for 100 cm2	Phase 1: contact, slow scan for 100 cm2 Phase 2: contact, punctual technique for 3 points per side Phase 3: contact, fast scan for 100 cm2

Abbreviations: ED- energy delivered; Hz- hertz; J- Joules; MTrPs- myofascial trigger points; Nd:YAG- Neodymium-doped Yttrium Aluminum Garnet laser; NS- not specified; TMJ- temporomandibular joint; μs- microseconds; W- watts

AMMO after treatment (MD = -0.6 cm, 95% CI: -2.7,4.0; p = 0.71; EG [197], CG [200]) (Fig. 4B) and for the follow-up evaluation (MD = 0.4 cm, 95% CI: -2.2,3.0; p = 0.78; EG [197], CG [200]) (Fig. 4D).

Disability (JFSL-20). The results show that there are no significant differences between the groups for the reduction of disability at the end of treatment (MD = 3.7, 95% CI: -4.0,11.3; p = 0.35; EG [197], CG [200]) (Fig. 5A) and at 12 weeks of follow-up (MD = 6.8, 95% CI: -1.6,15.3; p = 0.11; EG [197], CG [200]) (Fig. 5B). No differences between groups are observed when analyzing the dimensions of chewing limitation (MD = 0.9, 95% CI: -1.0, 2.9; p = 0.35; EG [197], CG [200]) (Fig. 5C) and vertical jaw movement (MD = -1.9, 95% CI: -4.8, 1.0; p = 0.20; EG [197], CG [200]) (Fig. 5D) at the end of the treatment. Only a statistically significant improvement in favor of the control group is observed for the communication dimension (MD = 4.5, 95% CI: 1.3, 7.6; p < 0.05; EG [197], CG [200]) (Fig. 5E).

QoL (OHIP-14). No differences are evident between HILT and controls in terms of improvement in QoL at the end of

Table 3 Outcomes and statistical comparisons for HILT groups in the included RCTs

Study	Group	Outcome	T0: baseline mean (±SD)	T1: post-treatment mean (±SD)	T2: follow-up mean (±SD)	*p*-value intragroup T0—T1	*p*-value intragroup T0—T2	Efficacy
Ekici et al. [19] 2022	HILT	Pain intensity (VAS)	60.9 (±22.0)	27.7 (±19.0)	26.4 (±24.4)	< 0.01*	< 0.01*	Y
		Jaw Function (VAS)	54.5 (±21.4)	72.3 (±16.0)	73.6 (±19.4)	< 0.01*	< 0.01*	Y
		MMO (mm)	31.6 (±8.0)	38.8 (±5.9)	41.1 (±5.3)	< 0.01*	< 0.01*	Y
		AMMO (mm)	35.2 (±8.4)	41.0 (±5.7)	42.5 (±5.7)			
		Disability (JFLS-20: mastication)	24.7 (±16.4)	17.1 (±10.6)	18.9 (±12.5)	< 0.01*	< 0.01*	Y
		Disability (JFLS-20: vertical jaw mobility)	17.7 (±11.1)	11.6 (±6.7)	13.4 (±8.2)			
		Disability (JFLS-20: communication)	30.2 (±28.2)	21.5 (±17.9)	20.1 (±16.7)			
		Disability (JFLS-20: total)	72.2 (±47.2)	50.2 (±11.7)	52.4 (±12.5)			
		QoL (OHIP-14: total)	45.5 (±12.2)	NS	NS	NS		
	Placebo HILT	Pain intensity (VAS)	59.3 (±20.5)	56.8 (±19.7)	55.0±18.8	< 0.01*	< 0.01*	Y
		Jaw Function (VAS)	46.6±22.1	49.1 (±21.1)	51.6 (±21.5)	< 0.01*	< 0.01*	Y
		MMO (mm)	33.1 (±7.1)	33.6 (±6.4)	34.2 (±6.1)	< 0.01*	< 0.01*	Y
		AMMO (mm)	38.1 (±5.9)	38.6 (±5.4)	39.1 (±5.1)			
		Disability (JFLS-20: mastication)	18.4 (±13.3)	18.0 (±12.8)	17.6 (±12.3)	< 0.01*	< 0.01*	Y
		Disability (JFLS-20: vertical jaw mobility)	15.7 (±9.8)	15.2 (±9.2)	15.0 (±9.0)			
		Disability (JFLS-20: communication)	19.5 (±19.8)	18.8 (±18.7)	18.7 (±18.7)			
		Disability (JFLS-20: total)	53.5 (±33.9)	52 (±13.6)	51.3 (±13.3)			
		QoL (OHIP-14: total)	46.1 (±11.0)	NS	NS	NS		

Table 3 (continued)

Study	Group	Outcome	T0: baseline mean (±SD)	T1: post-treatment mean (±SD)	T2: follow-up mean (±SD)	*p*-value intragroup T0—T1	*p*-value intragroup T0—T2	Efficacy
Ekici et al. [20] 2022	HILT	Pain intensity (VAS)	53.1 (±22.9)	26.4 (±18.3)	18.2 (±17.8)	< 0.01*	< 0.01*	Y
		Jaw Function (VAS)	60.0 (±20.9)	67.9 (±20.8)	79.9 (±19.3)	< 0.01*	< 0.01*	Y
		MMO (mm)	30.5 (±8.2)	39.7 (±5.6)	35.5 (±4.4)	< 0.01*	< 0.01*	Y
		AMMO (mm)	34.6 (±8.1)	38.0 (±6.1)	41.2 (±5.2)			
		Disability (JFLS-20: mastication)	19.1 (±15.1)	13.3 (±9.6)	14.4 (±11.0)	< 0.01*	< 0.01*	Y
		Disability (JFLS-20: vertical jaw mobility)	13.0 (±9.6)	8.3 (±5.0)	9.5 (±6.2)			
		Disability (JFLS-20: communication)	24.1 (±27.6)	17.1 (±17.0)	15.7 (±14.7)			
		Disability (JFLS-20: total)	56.1 (±48.0)	38.8 (±31.0)	39.6 (±32.0)			
		QoL (OHIP-14: total)	15.2 (±7.4)	11.7 (±6.3)	11.4 (±6.0)			
	Occlusal splint	Pain intensity (VAS)	39.4 (±26.4)	22.5 (±17.3)	19.5 (±19.3)	< 0.01*	< 0.01*	Y
		Jaw Function (VAS)	64.7 (±24.2)	78.2 (±19.4)	77.4 (±20.3)	< 0.01*	< 0.01*	Y
		MMO (mm)	38.8 (±7.5)	39.5 (±7.3)	41.0 (±8.7)	< 0.01*	< 0.01*	Y
		AMMO (mm)	39.1 (±7.2)	41.1 (±7.3)	44.3 (±7.8)			
		Disability (JFLS-20: mastication)	10.9 (±8.3)	9.9 (±7.4)	8.9 (±6.6)	< 0.01*	< 0.01*	Y
		Disability (JFLS-20: vertical jaw mobility)	9.2 (±11.8)	8.2 (±10.5)	6.7 (±8.2)			
		Disability (JFLS-20: communication)	10.0 (±11.8)	8.8 (±10.1)	6.9 (±7.7)			
		Disability (JFLS-20: total)	30.1 (±22.7)	26.8 (±22.0)	22.5 (±17.5)			
		QoL (OHIP-14: total)	16.1 (±8.7)	15.0 (±6.5)	13.2 (±7.0)			
	US	Pain intensity (VAS)	46.9 (±23.5)	24.4 (±18.0)	9.2 (±11.4)	< 0.01*	< 0.01*	Y
		Jaw Function (VAS)	55.6 (±26.4)	83.8 (±10.1)	89.2 (±11.4)	< 0.01*	< 0.01*	Y
		MMO (mm)	35.8 (±7.3)	40.9 (±7.5)	42.9 (±7.2)	< 0.01*	< 0.01*	Y
		AMMO (mm)	38.7 (±7.7)	43.2 (±7.8)	44.9 (±7.1)			
		Disability (JFLS-20: mastication)	15.5 (±9.2)	12.3 (±7.0)	12.0 (±7.0)	< 0.01*	< 0.01*	Y
		Disability (JFLS-20: vertical jaw mobility)	13.6 (±9.2)	10.8 (±7.1)	10.6 (±6.7)			
		Disability (JFLS-20: communication)	11.4 (±11.1)	10.0 (±9.4)	9.1 (±7.2)			
		Disability (JFLS-20: total)	40.6 (±32.8)	33.0 (±26.6)	31.6 (±25.0)			
		QoL (OHIP-14: total)	11.4 (±6.0)	9.0 (±6.0)	8.8 (±5.4)			
	Home exercise + education	Pain intensity (VAS)	58.8 (±21.4)	56.6 (±20.9)	55.1 (±20.1)	> 0.05	> 0.05	N
		Jaw Function (VAS)	47.1 (±22.1)	50.0 (±21.1)	52.2 (±21.7)	< 0.01*	< 0.01*	Y
		MMO (mm)	33.4 (±7.2)	33.8 (±6.6)	34.3 (±6.3)	< 0.01*	< 0.01*	Y
		AMMO (mm)	38.2 (±6.0)	38.8 (±5.5)	39.3 (±5.1)			
		Disability (JFLS-20: mastication)	17.7 (±12.2)	17.3 (±11.7)	17.1 (±11.3)	> 0.05	> 0.05	N
		Disability (JFLS-20: vertical jaw mobility)	16.1 (±9.8)	15.6 (±9.2)	15.5 (±9.1)			
		Disability (JFLS-20: communication)	21.6 (±21.2)	20.9 (±20.0)	20.1 (±20.0)			
		Disability (JFLS-20: total)	55.3 (±47.3)	53.9 (±44.1)	53.3 (±42.1)			
		QoL (OHIP-14: total)	16.9 (±8.2)	16.3 (±8.1)	16.0 (±8.0)	> 0.05	> 0.05	N

Table 3 (continued)

Study	Group	Outcome	T0: baseline mean (±SD)	T1: post-treatment mean (±SD)	T2: follow-up mean (±SD)	*p*-value intragroup T0—T1	*p*-value intragroup T0—T2	Efficacy
Ekici et al. [21] 2022	HILT + EP	Pain intensity (VAS)	68.2 (±18.2)	35.3 (±18.2)	34.5 (±27.0)	< 0.01*	< 0.01*	Y
		Jaw Function (VAS)	49.4 (±20.4)	68.2 (±19.5)	68.2 (±17.9)	< 0.01*	< 0.01*	Y
		MMO (mm)	32.6 (±7.6)	41.1 (±7.4)	42.4 (±5.7)	< 0.01*	< 0.01*	Y
		AMMO (mm)	35.7 (±8.5)	43.6 (±6.0)	42.2 (±6.5)			
		Disability (JFLS-20: mastication)	29.6 (±15.8)	20.5 (±10.2)	23.0 (±12.3)	< 0.01*	< 0.01*	Y
		Disability (JFLS-20: vertical jaw mobility)	21.8 (±10.7)	14.5 (±6.6)	16.9 (±8.0)			
		Disability (JFLS-20: communication)	35.5 (±27.6)	25.4 (±17.8)	23.9 (±17.3)			
		Disability (JFLS-20: total)	86.9 (±44.3)	60.4 (±39.5)	63.8 (±41.1)			
		QoL (OHIP-14: total)	21.2 (±9.2)	17.0 (±8.4)	16.8 (±8.0)	< 0.01*	< 0.01*	Y
	TENS + EP	Pain intensity (VAS)	61.1 (±18.6)	48.1 (±23.3)	37.7 (±27.4)	< 0.01*	< 0.01*	Y
		Jaw Function (VAS)	38.8 (±21.8)	54.4 (±23.5)	63.1 (±24.8)	< 0.05*	p < 0.01*	Y
		MMO (mm)	33.1 (±6.0)	37.2 (±5.5)	41.8 (±5.6)	< 0.01*	< 0.01*	Y
		AMMO (mm)	36.1 (±6.0)	39.6 (±6.1)	43.2 (±5.1)			
		Disability (JFLS-20: mastication)	21.6 (±13.1)	17.5 (±10.5)	18.1 (±10.9)	< 0.01*	< 0.01*	Y
		Disability (JFLS-20: vertical jaw mobility)	14.0 (±9.8)	11.2 (±7.8)	11.7 (±8.1)			
		Disability (JFLS-20: communication)	20.9 (±21.0)	16.6 (±15.7)	15.6 (±15.0)			
		Disability (JFLS-20: total)	56.4 (±40.1)	45.4 (±31.0)	45.4 (±31.1)			
		QoL (OHIP-14: total)	24.3 (±10.2)	21.4 (±9.9)	21.0 (±9.3)	< 0.01*	< 0.01*	
	EP	Pain intensity (VAS)	58.2 (±20.4)	58.1 (±18.4)	57.0 (±18.9)	0.792	0.052	N
		Jaw Function (VAS)	47.1 (±23.0)	47.8 (±21.7)	47.9 (±21.5)	0.205	0.081	N
		MMO (mm)	32.6 (±7.5)	32.7 (±7.2)	33.0 (±6.8)	0.361	0.070	N
		AMMO (mm)	37.5 (±6.1)	37.6 (±5.5)	37.9 (±5.5)	0.598	0.067	
		Disability (JFLS-20: mastication)	19.9 (±13.8)	19.0 (±13.6)	18.9 (±0.8)	0.062	0.083	N
		Disability (JFLS-20: vertical jaw mobility)	16.9 (±10.0)	15.8 (±9.9)	15.9 (±9.6)	0.086	0.242	
		Disability (JFLS-20: communication)	18.9 (±19.4)	17.9 (±19.5)	18.1 (±19.3)	0.609	0.825	
		Disability (JFLS-20: total)	55.7 (±33.8)	52.7 (±31.7)	52.8 (±31.7)	0.061	0.083	
		QoL (OHIP-14: total)	15.9 (±9.0)	14.7 (±8.9)	14.4 (±8.7)	0.152	0.086	N

Abbreviations: AMMO- Assisted maximum mouth opening; EP- exercise program; JFLS-20- jaw functional limitation scale; mm- millimeters; MMO- maximum mouth opening; OHIP-14- Oral Health Impact Profile-14; QoL- quality of life; TENS- transcutaneous electrical nerve stimulation; US- therapeutic ultrasound; VAS- visual analog scale. Efficacy: Y= yes; N = no (Efficacy is determined by statistical changes between evaluations). *$p < 0.05$

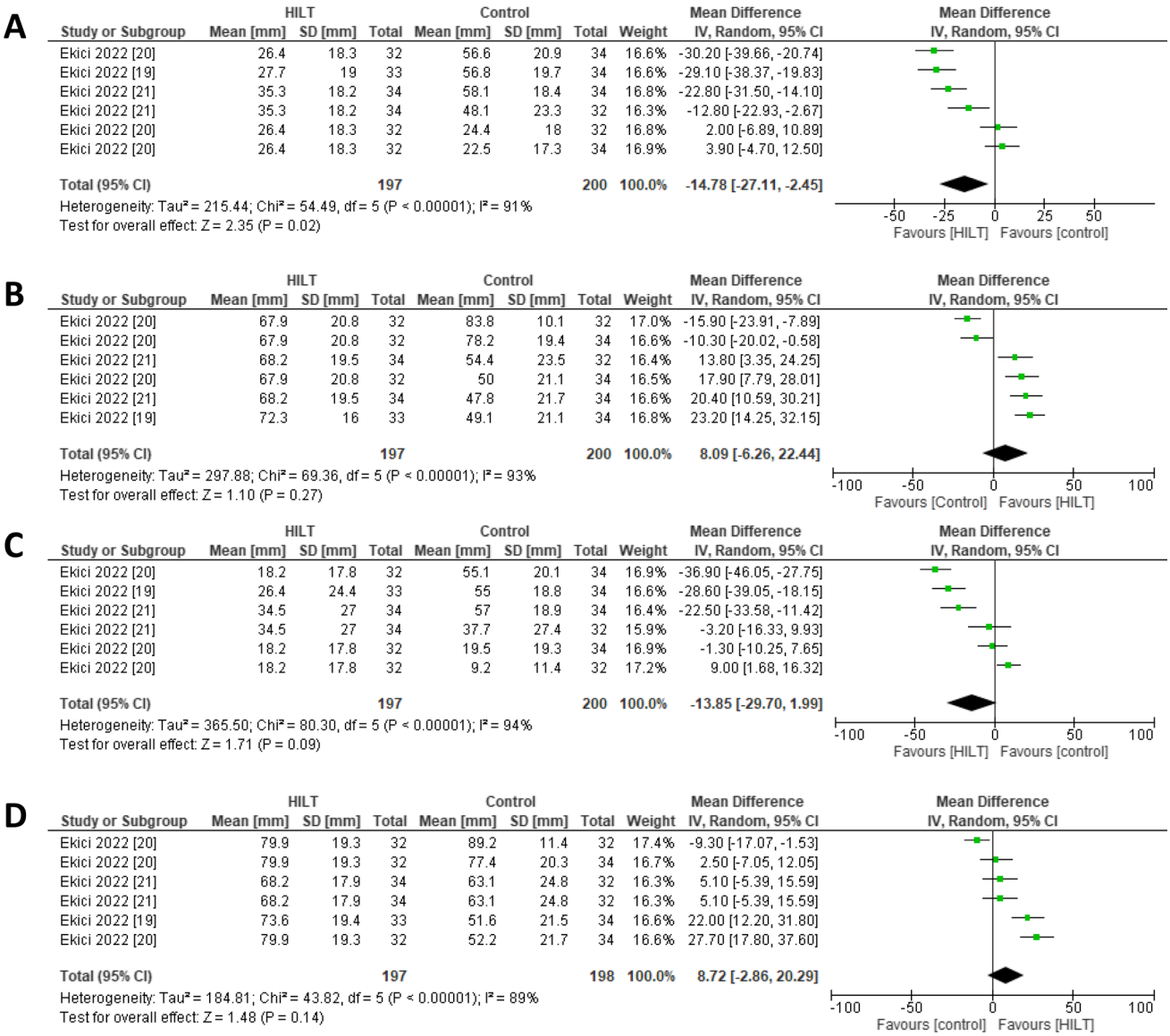

Fig. 3 Forest plots for pain intensity at the end of treatment (VAS) (3**A**), jaw function at the end of treatment (adapted VAS) (3**B**), pain intensity at follow-up at week 12 (VAS) (3**C**), and jaw function at follow-up at week 12 (adapted VAS) (3**D**)

treatment (MD = -1.4, 95% CI: -4.7,1.8; p = 0.39; EG [164], CG [166]) (Fig. 6A) or for the follow-up period (MD = -1.1, 95% CI: -4.1,2.0; p = 0.05; EG [164], CG [166]) (Fig. 6B).

Evidence assessment (GRADE)

Table 4 provides an overview of the quality of evidence assessed using the GRADE framework for the variables of pain intensity and MMO at the conclusion of the treatment phase. Notably, these variables were the only ones to exhibit statistical significance in the meta-analysis [29]. The quality of evidence for pain intensity was rated as important but with low certainty. Moreover, the quality of evidence for MMO was deemed critical, with a moderate level of certainty.

Discussion

This SR assesses the efficacy of HILT in TMD patients compared to placebo or conventional treatments such as occlusal splints, therapeutic ultrasound, and transcutaneous electrical nerve stimulation (TENS). The primary findings suggest that HILT is effective in reducing pain at rest and improving maximum mouth opening (MMO) after the treatment period. However, it is crucial to approach these results with caution due to the observed heterogeneity across studies and potential bias in specific criteria evaluated by the Cochrane RoB tool, such as participant and therapeutic blinding. Considering the limited number of RCTs, it becomes apparent that

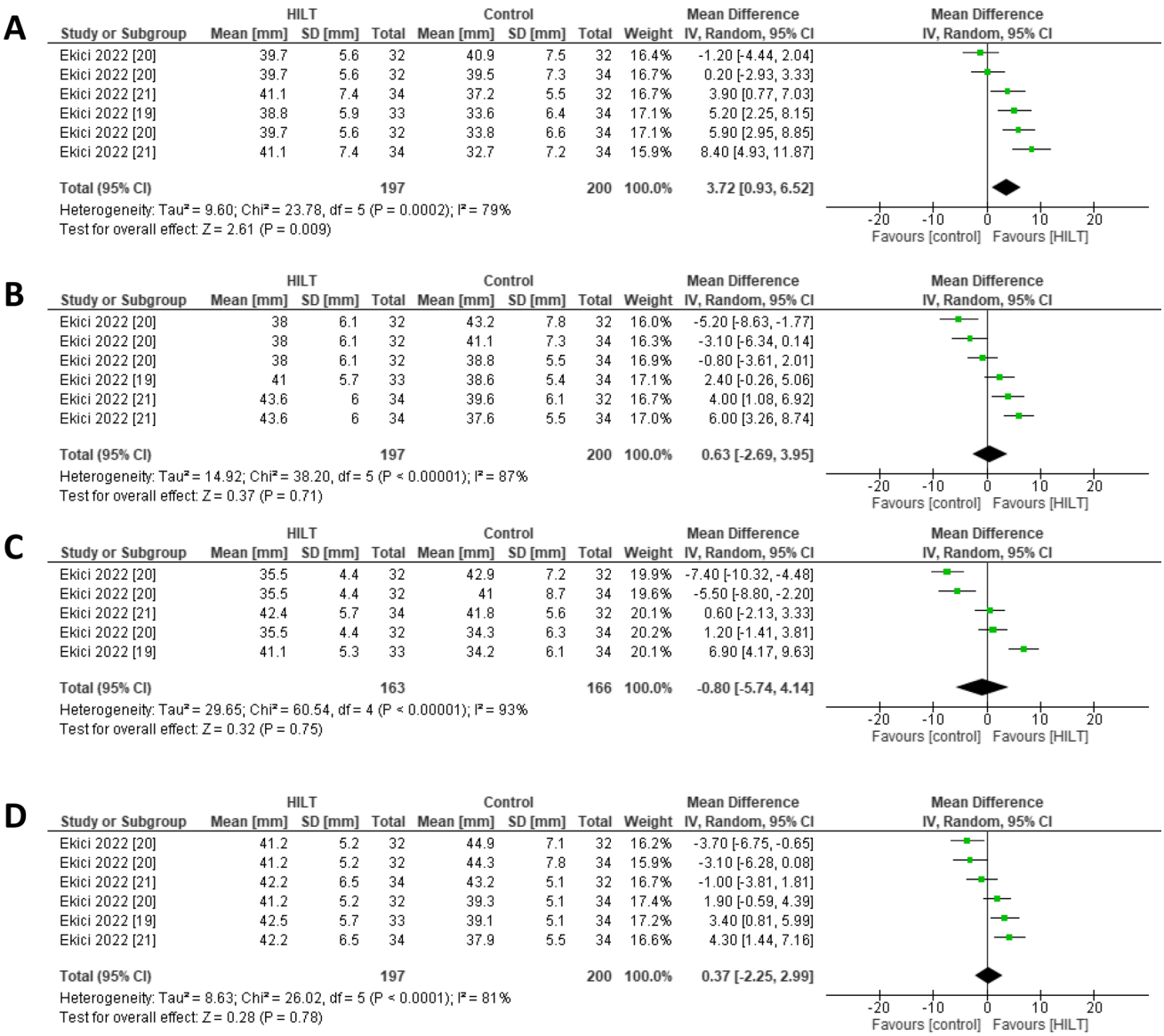

Fig. 4 Forest plots for maximum mouth opening at the end of treatment (millimeters) (4**A**), assisted maximum mouth opening at the end of treatment (millimeters) (4**B**), maximum mouth opening at follow-up at week 12 (millimeters) (4**C**), and assisted maximum mouth opening at follow-up at week 12 (millimeters) (4**D**)

further research is necessary to establish more robust and comprehensive conclusions in this specific domain.

Observed heterogeneity

The observed heterogeneity in this systematic review arises from influential factors impacting applied interventions and study designs. The coefficient of heterogeneity can impact the interpretation of meta-analysis results, particularly when it is high, as in the case of pain intensity and mouth opening. This may indicate that studies differ from one another, potentially complicating the interpretation of results and hindering the ability to draw reliable conclusions about treatment effects. Variations in HILT application and comparator interventions introduce significant differences among studies, leading to diverse participant responses and potential result heterogeneity. The existence of multiple treatment groups intensifies the diversity in therapeutic strategies, resulting in variable responses within the study population and further amplifying heterogeneity [28, 51]. Differences in study design elements, including treatment duration and trial methodology, contribute to complexity and play a crucial role in generating result heterogeneity. The significance of interactions between treatments is highlighted, especially in studies with multiple treatment groups, where potential interactions between therapeutic modalities, such as splints,

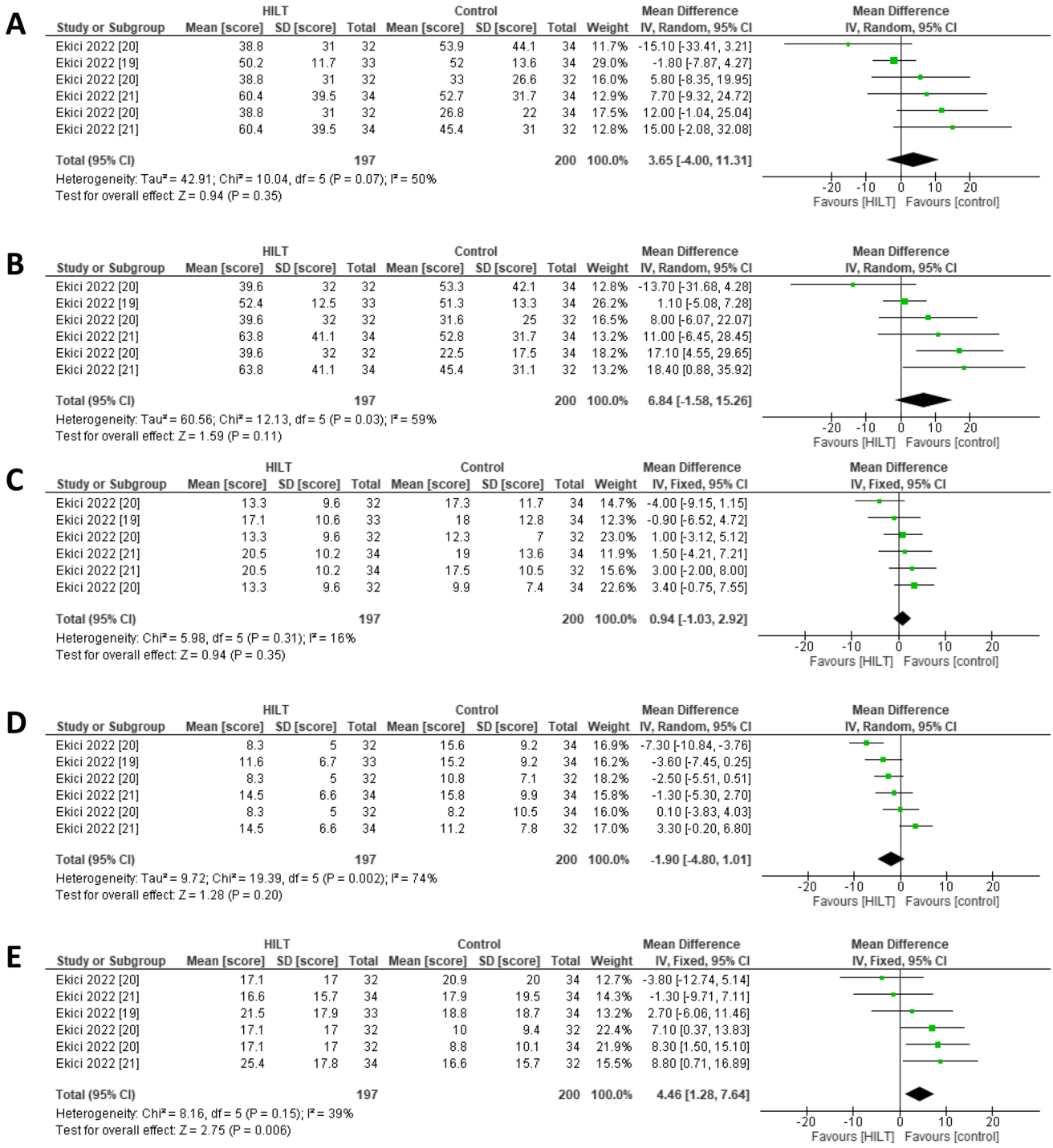

Fig. 5 Forest plots for disability at the end of treatment (JFLS-20) (5**A**), disability at follow-up at week 12 (JFLS-20) (5**B**), mastication at the end of treatment (JFLS-20) (5**C**), vertical jaw at the end of treatment (JFLS-20) (5**D**), and communication at the end of treatment (JFLS-20) (5**E**)

exercises, or education, add complexity beyond binary comparisons, exacerbating heterogeneity [51].

Limitations in generalization arise from the inclusion of a limited number of studies, impacting sample representativity and restricting broader applicability. The inclusion or exclusion of a single study disproportionately influences overall results, enhancing the perception of heterogeneity [28, 51]. The inherent random variability due to the limited number of studies underscores the need for cautious result interpretation, as apparent differences between studies may be more pronounced in a small sample, contributing to the perceived heterogeneity in this SR.

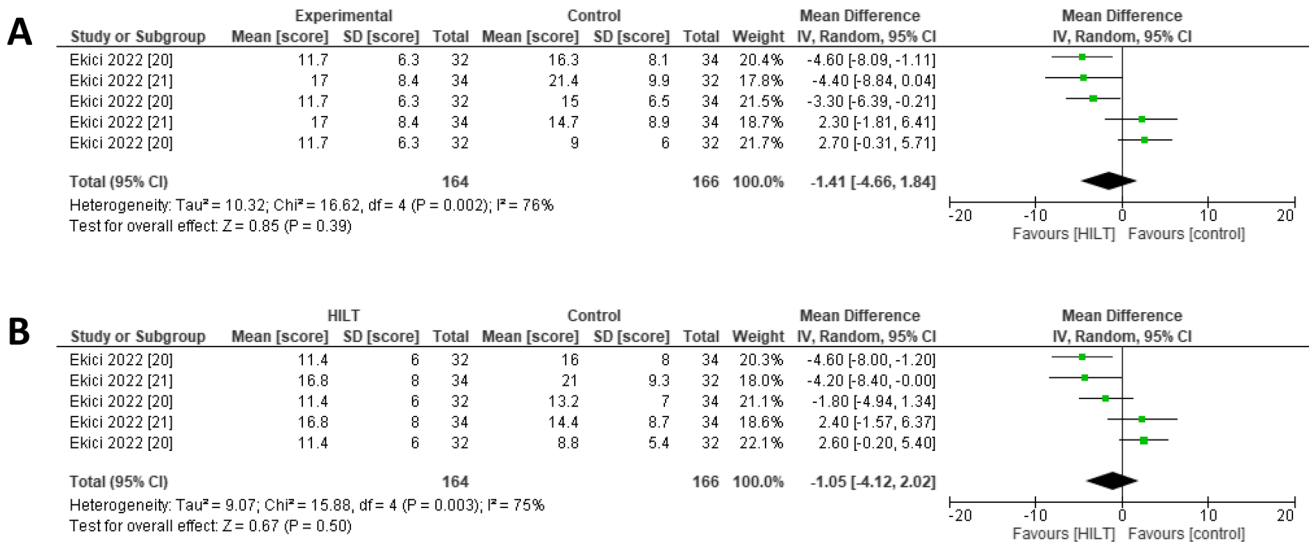

Fig. 6 Forest plots for quality of life at the end of treatment (OHIP-14) (6**A**), and quality of life at follow-up at week 12 (OHIP-14) (6**B**)

HILT in temporomandibular pain

HILT has demonstrated its effectiveness in reducing pain at rest at the end of treatment in patients with TMDs when compared to the use of placebo, therapeutic ultrasound (US), TENS, exercises, and occlusal splints. An average reduction of 14.8 mm on VAS was observed (95% CI: -27.1, -2.45), which aligns with and supports the findings reported individually in the RCTs [19–21]. Similarly, although a statistically significant effect is observed, the wide confidence intervals signify substantial variability in the results. This variability diminishes the reliability of the High-Intensity Laser Therapy (HILT) effect, implying that the therapy may exert pronounced effects in some patients and less so in others. This variability could stem from various factors, such as sample size, participant heterogeneity, or variability in the measurement of the variables of interest [52].

It is highlighted that HILT has demonstrated superiority over physical treatments like TENS and US when it comes to pain reduction. This suggests that the combined effects of photobiomodulation and thermal laser may surpass the analgesic mechanisms of TENS or US when delivered individually, pointing towards the greater effectiveness of HILT in this context [33, 34]. While analgesia with TENS relies on mechanisms like gate-control (described by Melzack and Wall) and the release of endogenous opioid peptides [35, 36], photobiomodulation operates by reducing inflammatory mediators, slowing nociceptive conduction velocity, releasing β-endorphins, and facilitating the removal of nociceptive substances through circulation [11, 12, 14]. Furthermore, these effects are further enhanced by the thermal aspects of HILT. The elevation in temperature induced by HILT has the potential to induce muscle relaxation and desensitize vanilloid receptors (TRPV-1) when exposed to higher temperatures [37, 38]. Regrettably, no combination of both techniques was identified in the RCTs, preventing an assessment of the potential for an amplified analgesic effect through their integration.

Occlusal splints are primarily designed to induce relaxation in the chewing muscles, and their analgesic impact appears to be primarily indirect. This is achieved by promoting muscle relaxation, which in turn interrupts the muscle spasm-pain cycle and reduces joint compression [39–41]. In comparison to HILT, which directly influences nociception and nociceptive transmission, it is anticipated that occlusal splints will have a comparatively milder impact on pain reduction in patients with TMDs.

It is worth noting that the analgesic effect attained through HILT aligns with the clinically important difference (MCID) for VAS, which has been established at -13 mm (95% CI: -9,-15), irrespective of the initial pain severity [42]. This underscores the clinical effectiveness of HILT. These findings are consistent with the pain relief achieved with LLLT in TMDs, which has been documented as -14.1 mm (VAS) (95% CI: -25.7,-2.4) [43].

During follow-up sessions, pain relief remains consistent, with an average reduction of -13.9 mm on VAS (95% CI: -29.7,2.0). However, there are no significant differences between HILT and other treatments, suggesting that HILT's short-term analgesic efficacy endures and that other treatments may match it in the long term.

HILT in temporomandibular function

HILT shows no advantages over control treatments in terms of improving jaw function (VAS) [19–21]. Mandibular function, involving jaw mobility during activities like chewing and speaking, is evaluated subjectively by patients. This subjective assessment may yield clearer effects, as even minor

Table 4 Summary-of-findings and quality of evidence (GRADE) for interesting outcomes

Certainty assessment							№ of patients		Effect		Certainty	Importance
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	HILT	Conventional physical therapy	Relative (95% CI)	Absolute (95% CI)		
Pain intensity (assessed with: VAS; Scale from: 0 to 100 mm)												
3	RCTs	not serious[a]	very serious[b]	not serious[c]	not serious[d]	none	199	201	-	MD 14.8 mm lower (27.1 lower to 2.46 lower)	⨁⨁◯◯ Low	IMPORTANT
Maximum mouth open (MMO) (Scale from: 0 to 10)												
3	RCTs	not serious[a]	serious[e]	not serious[c]	not serious[d]	none	199	201	-	MD 3.7 mm more (0.94 more to 6.51 more)	⨁⨁⨁◯ Moderate	CRITICAL

CI: confidence interval; MD: mean difference

Explanations:

(a) The high risk of bias was primarily related to the outcome assessment blinding of participants and personnel (66.6%). Moreover, all RCTs rated random sequence generation, blinding of outcome assessment, selective reporting, incomplete outcome data, and other biases as low-risk; (b) The heterogeneity was evaluated as very serious because the I2 test showed considerable heterogeneity 80–100%); (c) Because the studies directly compared the interventions and outcomes in relation to the study issue, it was decided that the indirect evidence was not significant; (d) The width of the confidence interval and the crossing of the no-effect line served as the criteria for evaluating imprecision; (e) The heterogeneity was evaluated as serious because the I2 test showed considerable heterogeneity 50–80%)

improvements are noticeable due to the subtlety of changes in jaw mobility. Interestingly, there is no inverse relationship between pain reduction and improved mandibular function, emphasizing the nuanced nature of these outcomes.

HILT in maximum mouth openning and assisted maximum mouth opening

HILT demonstrates a substantial increase in MMO at the end of treatment, with an average improvement of 3.7 mm (95% CI: 0.9, 6.5). This improvement corresponds to approximately 10% of the average normal MMO value, which is typically 40 mm (± 10) [44]. The RCTs show that participants started with a baseline MMO of 30 to 35 mm. A 3.7 mm improvement is clinically relevant, bringing them closer to the average functional mandibular opening levels [44]. It is interesting that the results with HILT are better than those with occlusal splints or exercises, which also report improvements in MMO according to the literature [39, 45]. The impact of HILT on MMO can be attributed to both pain reduction and the relaxation of masticatory muscles. Notably, this effect is more pronounced in TMDs of myogenic origin, where MMO exhibits a greater degree of change compared to TMDs of joint origin [19–21]. It can be considered that combining HILT with exercises, splints, or manual therapy could enhance MMO outcomes in TMD treatment [41, 45, 46].

When analyzing the MMO in the follow-up sessions, no significant differences were seen between the groups. This suggests that, as with analgesia, HILT is most effective in the short term, and other treatments could match its long-term effects.

Regarding AMMO, no significant differences are noted at the end of treatment or during follow-up sessions, suggesting the overall benefit of all interventions. It is worth emphasizing that AMMO assessment is a passive evaluation with limited muscular influence on mandibular movement, where connective tissues primarily act as the main restricting elements. The findings above may suggest the significance of HILT's effects on the masticatory muscles, leading to improved results in MMO compared to AMMO. This raises the possibility of exploring the use of HILT in TMDs associated with trismus.

The width of the mandibular opening and the position of the occlusal plane are influenced by the position of the cervical spine. This, in turn, affects the position of the base of the skull, which can vary depending on posture, whether in a lying or upright position [47]. An RCT limitation is the absence of position specification when measuring MMO and AMMO. This imprecision may lead to underestimation or overestimation of results depending on whether assessments were conducted with the patient in a sitting or supine position. A suggestion for future research could be to incorporate other dynamic assessments, such as mandibular laterality

and protrusion movements, as they also provide valuable information on function.

HILT in disability and quality of life

The findings suggest that, at the end of treatment and in subsequent follow-up sessions, HILT does not exhibit superiority over control treatments in reducing overall disability (JFLS-20) or enhancing QoL (OHIP-14). This indicates that all the treatments may be equally effective in addressing these aspects. Even the exercise program and the use of occlusal splints demonstrate significant improvements compared to the use of HILT in the communication of patients with TMDs (JFLS-20). Although no differences are observed in QoL between HILT and the comparator treatments, intragroup comparisons reveal a statistically and clinically significant improvement. This improvement suggests a change of three points, which is considered a clinically relevant difference for OHIP-14, and it is observed consistently across all experimental groups and some controls [53].

It is important to note that both JFLS-20 (test–retest reliability = 0.87, internal consistency $\alpha = 0.87$) and OHIP-14 (test–retest reliability = 0.94; internal consistency $\alpha = 0.81$) are validated instruments used to assess patients with diverse functional limitations in the jaw resulting from orofacial disorders [54, 55]. Indeed, JFLS-20 encompasses three critical aspects for evaluating the functionality of the masticatory system, whereas OHIP-14 offers a comprehensive biopsychosocial assessment covering a wide range of dimensions related to oral health. This multifaceted approach enhances the overall value and utility of these assessment instruments [48, 49].

Irrespective of the results, the inclusion of functional assessments holds significant relevance as they mirror the tangible challenges patients encounter in their daily lives. Disability and QoL have gained prominence in RCTs as key outcomes to address. Effective treatments should not solely target symptoms but also their real impact on daily functionality. This underscores the importance of continuing to incorporate these outcomes in future research.

While the primary objective of HILT is pain reduction, the noteworthy secondary impact on disability and QoL, as reported individually in the RCTs, cannot be overlooked. It is plausible that combining HILT with complementary interventions like exercise, occlusal splints, or manual therapy may yield a more substantial effect in reducing disability and enhancing quality of life for patients, as evidenced in most studies.

Recommendations

This SR successfully identified a standardized dosing regimen for HILT in RCTs, allowing the authors to establish specific dosing recommendations for 1,064 nm wavelength equipment. These recommendations align with the protocols proposed by Dündar et al. in previous studies on myofascial pain [56]. The session parameters have been categorized into three distinct phases: An average power of 10.5 W; pulsed mode for phases 1 and 2, and continuous mode for phase 3; scanning application for phases 1 and 3 (treatment on the mandibular ramus) and spot application for phase 2 (treatment on painful points of the masseter and temporalis); energy of 500 J for phases 1 and 3, and 6 to 10 J for phase 2. Additionally, it is recommended to conduct a minimum of 15 treatment sessions spanning a three-week timeframe [19–21]. The authors recommend combining laser treatment with occlusal splinting and exercises, as well as incorporating manual therapy into the treatment sessions. This approach could potentially enhance the effects of HILT, given that these therapies have demonstrated effectiveness for managing TMDs [10, 39, 41, 45]. Additionally, the authors propose conducting future studies that combine these therapies alongside laser treatment, comparing them with occlusal splints and exercise to assess the impact of HILT.

It is crucial that therapeutic applications of HILT be administered or supervised exclusively by physical therapists who have the necessary training to use these resources in the treatment of pain and tissue recovery. This guarantees the safety and effectiveness of the treatments while respecting the specialization and training of these professionals [50].

Furthermore, it's important to highlight that, based on the inclusion of only three studies and the level of heterogeneity observed, the recommendation is to conduct larger, meticulously designed RCT. These trials should employ standardized outcome measures and extended follow-up durations in order to provide more robust evidence.

Limitations

In this SR, the authors highlight the approach based on the PRISMA guidelines and the protocol registration in PROSPERO to evaluate and present the evidence. However, the researchers have identified some limitations:

(1) Despite an exhaustive search in eight databases, the possible inclusion of articles in different languages cannot be definitively ruled out due to the geographical origin of RCTs, which come from Turkey.
(2) The high RoB related to the lack of blinding of participants and treaters can lead to biases in the results due to the influence of knowledge of the treatment received on behavior and data collection. This can compromise the internal validity of the study and the interpretation of its results.
(3) The presence of multiple control groups in the included studies adds complexity to result interpretation, possibly leading to the introduction of confounding variables and impacting the reliability of the meta-analysis conclusions.

(4) Despite the statistically and clinically significant improvements noted in pain intensity and jaw opening, the heterogeneity observed among the RCTs constitutes a limiting factor in both the quality and recommendation of the evidence. This variability is likely attributed to the limited number of RCTs that have addressed this specific topic.
(5) It was not feasible to conduct a sensitivity analysis by performing multiple meta-analyses to address heterogeneity due to the limited number of studies, which would determine those that contribute most to the heterogeneity.
(6) The review underscores the lack of dedicated RCTs investigating this aspect, emphasizing the need for additional high-quality research to enhance the robustness of the evidence base in this domain.

Conclusion

This systematic review indicates that HILT effectively alleviates pain and improves MMO in patients with TMDs. This improvement may have a positive impact on quality of life by facilitating activities such as chewing, jaw mobility, and communication. HILT's efficacy compares favorably to other treatments like occlusal splints, TENS, US, and exercises. These positive effects are particularly pronounced in the short term, although they tend to equalize with other treatments in the long term. However, it is crucial to note that while the evidence supporting HILT's effectiveness is significant, its certainty level falls within the low to moderate range due to heterogeneity. This review highlights the need for further research in the field of HILT for TMDs to enhance the quality of evidence and provide more robust recommendations.

Additionally, the review suggests that combining HILT with occlusal splints, manual therapy, and therapeutic exercises holds promise as a potentially beneficial approach to optimizing treatment outcomes for individuals with TMDs. This multidisciplinary strategy has the potential to yield even more favorable results and enhance the overall management of TMDs.

Appendix 1. Search strategy (last updated on July 18, 2024).

	KEYWORDS	Identification of studies via databases and registers							Identification of studies via other methods	
		PUBMED	SCOPUS	WOS	EBSCO-host	SCIENCE DIRECT	COCHRANE	PEDro	Google Scholar	**TOTAL**
1	*"Lasers"*	4,956	1,119,998	158,779	11,178	1,000,000	25,094	171		2,320,176
2	*"Laser Therapy"*	4,345	32,149	10,747	12,654	8,586	7,431	581		76,493
3	*"Phototherapy"*	1,842	26,823	10,496	4,945	10,380	3,918	80		58,484
4	*"High-Intensity Laser Therapy"*	67	148	120	86	24	195	65		705
5	*"Class IV laser"*	6	34	36	14	60	29	5		184
6	*S1 OR S2 OR S3 OR S4 OR S5*	9,383	1,141,538	176,658	25,312	1,019,050	28,585	902		2,401,428
7	*"Musculoskeletal Pain"*	1,116	14,223	11,728	4,942	10,433	3,111	441		45,994
8	*"Temporomandibular Joint Disorders"*	732	15,665	1,294	5,016	1,786	1,398	21		25,912
9	*"Temporomandibular Joint Dysfunction Syndrome"*	227	4,274	101	4,937	133	471	5		10,148
10	*"Craniomandibular Disorders"*	58	645	528	78	543	54	20		1,926
11	*S7 OR S8 OR S9 OR S10*	2,083	33,090	13,563	9,985	12,627	4,707	487		76,542
12	*S6 OR S11*	86*	375*	94*	111*	654*	240*	65**	81***	1,706

*Search algorithm used for formal databases: ("Lasers" OR "Laser Therapy" OR "Phototherapy" OR "High-Intensity Laser Therapy" OR "Class IV laser") AND ("Musculoskeletal Pain" OR "Temporomandibular Joint Disorders" OR "Temporomandibular Joint Dysfunction Syndrome" OR "Craniomandibular Disorders")

**For the PEDro database, only the term "High-intensity laser therapy" was used

***For the Google Scholar search engine, the search algorithm employed was: ("High-Intensity Laser Therapy" OR "Class IV laser") AND ("Temporomandibular Joint Disorders" OR "Temporomandibular Joint Dysfunction Syndrome" OR "Craniomandibular Disorders")

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Declarations

Conflict of interests The authors have no conflict of interest to declare.

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