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Effectiveness of low-level laser therapy on temporomandibular disorders. A systematic review of randomized clinical trials

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ABSTRACT

Objective: This study aimed to systematically evaluate the efficacy of LLLT in the management of TMD, focusing on its impact on pain reduction and functional improvement. Additionally, this review sought to identify the most effective laser parameters (wavelength, energy density, and duration of therapy) and compare LLLT outcomes with conventional treatment modalities.

Methods: A comprehensive search was conducted across PubMed, Scopus, Web of Science, and EBSCO databases until December 2024. Randomized controlled trials (RCTs) that evaluated LLLT's effects on pain (via Visual Analog Scale) and vertical aperture (VA) were included. The risk of bias was assessed using Cochrane's RoB 2 tool.

Results: This systematic review analyzed 44 randomized clinical trials (RCTs) with 1,816 participants, confirming that low-level laser therapy (LLLT) significantly reduces pain intensity (60–70 % decrease on the Visual Analog Scale) and improves mandibular function (10–20 % increase in maximum mouth opening). The most effective laser wavelengths ranged from 810 to 940 nm, with energy densities of 3–12 J/cm^2. Longer treatment durations (>4 weeks) provided more sustained benefits. Compared to occlusal splints, NSAIDs, and TENS, LLLT showed superior or comparable pain relief with fewer side effects. However, variability in laser parameters and protocols remains a limitation.

Conclusion: LLLT is a safe and effective non-invasive treatment for TMD, offering substantial benefits in pain management and functional recovery. Standardized protocols based on optimized dosimetry are needed to enhance clinical outcomes further.

1. Introduction

Temporomandibular disorders (TMDs) are a group of pathologies affecting the temporomandibular joint (TMJ) and masticatory muscles [1]. Patients with TMD often present with pain, jaw dysfunction, limited jaw movements, and joint noises [2,3], which can affect daily activities, psychosocial functioning, and quality of life [4,5]. It has been described that injuries to TMJ components can lead to biochemical changes within the joint, producing oxidative stress, free radicals, and degeneration of these structures [6]. On the other hand, musculature disorders are characterized by the presence of taut bands and trigger points, altering muscle composition and function [7].

The etiology of TMD is intricate and multifactorial, encompassing a range of mechanical, metabolic, infectious, neuropathic, and inflammatory factors [4]. Among these, contributing elements include bruxism associated with sleep and wakefulness, onychophagia, occlusal

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discrepancies, and psychoemotional factors such as stress and anxiety [2,8]. Given its complexity, multidisciplinary treatment is ideal for managing TMD [6,8]. This approach includes conservative treatments, such as the use of occlusal splints, physiotherapy, cognitive behavioral therapy, and pharmacological interventions [2,7], as well as invasive treatments like intra-articular injections, dry needling, acupuncture, and surgical procedures. The primary goals of these treatments are to alleviate pain, restore function, and improve the individual's quality of life [3].

Laser therapy is regarded as a conservative or non-invasive treatment option and has demonstrated beneficial effects in the management of TMD [5]. This therapy works by stimulating cytochrome C in the cellular mitochondria, which leads to increased ATP synthesis. Additionally, it reduces oxidative stress in hypoxic cells, enhances tissue repair and cellular respiration, promotes vasodilation, decreases inflammation, and raises pain thresholds [6,9]. Consequently, patients experience improved mouth opening, reduced pain, and enhanced recovery of function [8,9]. Furthermore, studies show good efficacy of this therapy in TMD of both myogenic and joint origin [3,6], it is also easy to apply and has few contraindications [6]. However, there is still no consensus on the application protocol, the type of laser, the wavelength, and the duration of each application [3,7].

Temporomandibular joint involvement is highly prevalent in patients with systemic inflammatory conditions such as juvenile idiopathic arthritis (JIA) and systemic sclerosis (SSc), significantly impacting mandibular function and craniofacial growth[10]. In JIA, persistent synovitis leads to cartilage degradation and impaired condylar development, predisposing patients to facial asymmetry and occlusal dysfunction [10]. Similarly, in SSc, progressive fibrosis affects periarticular tissues, leading to restricted mandibular movement and increased TMJ stiffness[11]. These pathological mechanisms further emphasize the necessity of non-invasive interventions such as laser therapy to improve joint function and alleviate symptoms in these patient populations.

1.1. Rationale and aim of the study

Despite the promising results of low-level laser therapy (LLLT) in TMD management, discrepancies exist regarding its clinical effectiveness due to variability in treatment parameters, including wavelength, energy density, frequency of application, and total treatment duration. Furthermore, the absence of standardized protocols complicates its adoption in routine clinical practice. Current literature lacks a comprehensive synthesis of randomized clinical trials (RCTs) that objectively evaluate the efficacy of LLLT across different TMD subtypes, considering both myogenic and arthrogenic components.

The present systematic review aims to analyze the current evidence regarding the effectiveness of LLLT in the management of TMD. By synthesizing data from RCTs, this study seeks to: (1) identify the mechanisms of action of LLLT in TMD treatment, (2) assess its impact on clinical outcomes such as pain reduction and improvement in vertical mouth opening, and (3) propose recommendations for optimizing clinical protocols. By addressing these knowledge gaps, this review aspires to provide evidence-based guidance for clinicians and researchers, facilitating the development of standardized therapeutic approaches that enhance patient outcomes.

2. Materials and methods

2.1. Protocol and registration

The protocol for this systematic review was designed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[12], and the review protocol was detailed and registered in the International Prospective Register of Systematic Reviews (PROSPERO), receiving the registration number CRD42025646377.

2.2. PICO question

Based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines, the focused question was created according to the Participants, Intervention, Control, Outcomes (PICO) principle. The question was as follows:

What is the effectiveness of low-potential laser therapy (I) when compared to conventional treatments or placebo (C) in improving clinical outcomes, such as pain reduction and vertical aperture (O) in patients with temporomandibular disorders (P)?

2.3. Eligibility criteria

A search for relevant studies was conducted without language and time restrictions; the last search was performed on December 27, 2024. The selection of studies for this systematic review was based on predefined inclusion and exclusion criteria to ensure a rigorous evaluation of the effectiveness of low-level laser therapy (LLLT) in the management of temporomandibular disorders (TMD). Articles were included if they met the following criteria: (1) randomized clinical trials (RCTs) with a minimum of 10 adult patients ($\geq$18 years old) reporting the use of LLLT for TMD treatment; (2) studies providing details on the laser device settings and treatment protocols; (3) studies evaluating the effect of LLLT before and after treatment, specifically assessing pain using the visual analog scale (VAS) and/or mandibular function using vertical aperture (VA) measurements in millimeters; (4) studies that applied LLLT in more than one session to assess cumulative therapeutic effects; (5) studies reporting case resolutions; and (6) articles published in English, Portuguese, or Spanish to ensure accessibility and consistency in data interpretation.

Conversely, studies were excluded if they met any of the following criteria: (1) clinical prospective and retrospective cohort studies, case-control studies, case series, or case reports, as they do not meet the methodological rigor of RCTs; (2) reviews, animal studies, cadaveric research, in vitro investigations, technical notes, or communications, as these do not provide direct clinical evidence; (3) studies published in languages other than English, Portuguese, or Spanish, to maintain the feasibility of analysis; (4) studies involving patients under 18 years of age; (5) articles that did not align with the primary research question or lacked relevance to the focus of this systematic review; and (6) previous investigations reporting on the same patient population, which could introduce data duplication and bias. By adhering to these strict inclusion and exclusion criteria, this review ensures a high level of evidence, focusing on clinically relevant and methodologically sound research.

2.4. Search strategy

A systematic search was conducted using the PubMed (MEDLINE), Scopus, Web of Science, and EBSCO databases with keywords relevant to the focused question. The specific search terms used are documented in an additional file. The search included articles published up to December 27, 2024. The search strategy and terms were adjusted based on the PubMed search, utilizing MeSH terms. Additionally, a manual search was performed on the reference lists of selected articles found through Google Scholar. Reference lists of potentially relevant original and review articles were hand-searched to identify any studies that may have been overlooked in the previous steps. The completed search queries are available in Table S1 (Supplementary File).

2.5. Study selection

After eliminating duplicate entries, three reviewers (LD, LR, and EV) independently screened the titles and abstracts of all studies identified through the aforementioned search strategy, voting on whether to

include or exclude each study. Any disagreements were resolved through discussions with an additional reviewer (EF). Following this, two reviewers (LD and LR) conducted an independent full-text screening of the selected studies. Any conflicts that arose during the full-text review were resolved by consensus. A Cohen's κ test was performed using Microsoft Excel 2022 (Microsoft Corporation, Redmond, USA) to evaluate inter-rater agreement at both stages, with the results interpreted according to the categories established by Landis and Koch in 1977[13].

2.6. Data extraction

The following data were independently extracted by the reviewers (LD and LR) from each study and subsequently verified by a peer reviewer:

a. Study characteristics: Authors, year of publication, and country.
b. Characteristics and number of patients.
c. Pain (VAS Scale) and vertical opening (mm) measurements at the beginning and end of treatment.
d. Laser device settings and frequency of sessions.
e. Follow-up time.

If needed, the corresponding authors were contacted for further clarification of the reported data, missing data, or data acquisition (two attempts, with a time frame of 14 days).

2.7. Risk of bias

In this systematic review, we conducted a risk of bias assessment for RCTs utilizing Cochrane's Risk of Bias 2 (RoB 2) tool. This method classifies studies as having a high risk, low risk, or "some concerns" regarding bias, addressing several critical aspects: the randomization process, deviations from intended interventions, missing outcome data, the precision of outcome measurements, and the selection of reported results[14]. Two reviewers (LD and ACG) performed the assessment independently, with any discrepancies resolved through consensus discussion.Table 1

3. Results

3.1. Study selection

A total of 672 studies were retrieved from the comprehensive electronic database search and 15 through a manual search in Google Scholar. After removing duplicates, 501 articles were screened on the basis of Title & Abstract, leaving 106 reports eligible (substantial agreement, κ=0.86). After full-text reading and a subsequent search for relevant citations, 44 RCTs were included in this systematic review. The reviewers (LD and LR) agreed 100 % on the final selection of studies. Of the 106 articles reviewed, 62 were excluded from the final analysis. The excluded articles and their reasons are shown in Table S2 (Supplementary file), and The PRISMA flow diagram of the screening process is shown in Fig. 1.

NR: Not Reported; F: Female; M: Male; VAS: Visual Analogue Scale; TVO: Total Vertical Opening: MAO: Maximum Assisted Opening; G1: Group 1; G2: Group 2; G3: Group 3; G4: Group 4; WL: Wave Length; ED: Energy Density; TE: Total Energy; IR: Irradiance; OP: Output Power; TPP: Time per point; L: Left; R: Right; RL: Red Laser; IRR: Infrared Laser; ID: Incomplete Data; NSAID: Nonsteroidal Anti-Inflammatory Drugs; TENS: Transcutaneous Electric Nerve Stimulation; ARA: Anterior Repositioning Appliance; EMT: Electromagnetic Therapy; MPR: Manual Pressure Release; MENS: Microelectric Neurostimulation; *: Statistically significant difference (reported by the study); ** Same Laser device and settings.

3.2. Characteristics of the included studies and sample

A total of 44 RCTs were included in this systematic review, encompassing a diverse patient population diagnosed with TMD. The total number of participants across studies was 1816, with 85.5 % female and 14.5 % male, with an age range of 18–74 years. The studies were conducted across multiple countries, including Austria[20], Brazil[15, 17–19,22–26,28,38,39,51], Egypt[45,47,50,53,55,57] India[36,42,47], Iran[27,29,30,33,34,52,58], Iraq[56], Italy[21,37,46], Portugal[41], Saudi Arabia[49] and Turkey[16,22,31,32,35,40,43,44,54], ensuring a geographically diverse dataset.

Patients were divided into treatment groups receiving low-level laser therapy (LLLT) at various wavelengths and control groups, which included placebo treatments, occlusal splints, NSAIDs, MENS/TENS therapy, and other conventional interventions. The studies varied significantly in laser parameters, treatment duration, and follow-up periods, contributing to a heterogeneous dataset.

3.3. Pain reduction

One of the primary outcomes assessed across studies was the reduction of pain intensity, measured using the Visual Analog Scale (VAS) from 0 to 100 mm. The baseline VAS scores among participants ranged from 13.5 to 97.8, with post-treatment values showing a significant decrease across most studies.

In relation to pain reduction in myogenic TMD, Conti et al [15]. reported an average reduction from 56.0 to 20.0 in the myogenous pain group ($p < 0.05$), while Kulekcioglu et al [16]. observed a decline in pain scores from 42.8 ± 27.0 to 5.5 ± 17.9 in the laser group, with statistical significance over control groups. Moreover, regarding patients with arthrogenic TMD, Venezian et al [21]. assessed different energy doses and found a statistically significant pain reduction in all laser groups, with the most effective setting being 60 J/cm^2, 60 mW, applied for 40 s. Additionally, Shobha et al [36]. reported pain scores dropping from 50.0 ± 14.86 to 4.5 ± 9.9, confirming LLLT's analgesic properties. Overall, LLLT resulted in a mean VAS score reduction of approximately 60–70 %, confirming its efficacy in both myogenic and arthrogenic TMD. The most effective wavelengths for pain reduction were 810 nm[30,34,36,37,55, 56], 830 nm[15,17–19,24,53], and 940 nm[16,35,44,45,52], suggesting their optimal absorption by neuromuscular and joint tissues.

3.4. Improvement in vertical aperture

Vertical aperture or mouth opening (measured in mm) was another key parameter used to assess treatment effectiveness. Patients with TMD typically present with limited mandibular movement due to muscle tension or joint dysfunction. This review reported initial oral opening ranges of 4.8 - 49.59 mm. Particularly, Conti et al [15]. reported an increase from 40.5 mm to 44.6 mm in treated groups ($p < 0.05$), Kulekcioglu et al [16]. found an improvement in vertical aperture from 36.0 ± 8.0 mm to 43.7 ± 7.4 mm, showing a significant functional gain, Da Silva et al [23]. noted that laser therapy groups achieved a 7–10 mm increase in mouth opening, outperforming control groups and Keskin Tunç et al [44]. observed that patients receiving 940 nm LLLT exhibited a 25 % greater increase in VA compared to placebo-treated groups. On average, LLLT contributed to a 10–20 % improvement in VA, depending on wavelength and dosage, with 830 nm and 940 nm lasers demonstrating superior effectiveness.

3.5. Treatment frequency and duration

The treatment protocols varied considerably among studies, with frequencies ranging from 2 to 5 sessions per week and treatment durations spanning 3 weeks to 6 months. Short-term protocols (≤ 4 weeks) produced rapid pain relief, but long-term effects were variable and Longer protocols (> 8 weeks) were associated with sustained functional

Table 1
Characteristics of the included studies.

Study	Country	Patients (F/M)	Mean Age (range)	Groups	Pain Assessment (VAS Scale, mm)		Vertical Aperture (mm)		Frequency (number of sessions)	Laser settings	Follow-up time
					Initial VAS	Final VAS	Initial	Final			
Conti, 1997 [15]	Brazil	20 (18F/2 M)	TOTAL: 39.85	G1: yMyogenouys Pain, Laser (5) G2: Arthrogenous Pain Laser (5) G3: Myogenous Pain, Control (5) G2: Arthrogenous Pain, Control (5)	G1: 56.0 G2: 60.0 G3: 44.0 G4: 54.0 Total: 53.5	G1: 20.0* G2: 34.0 G3: 46.0 G4: 30.0 Total: NR	G1: 44.0 G2: 36.0 G3: 40.0 G4: 41.2 Total: 40.5	G1: NR G2: 41.4* G3: 44.6* G4: NR Total: NR	1/week for 3 weeks (3 sessions)	WL: 830 nm ED: NR TE: 4 J IR: NR OP: 0.1 W TPP: 40 s	3 weeks
Kulekcioglu et al., 2003 [16]	Turkey	35 (28F/7 M)	TOTAL: 37.0 ± 12.3 (20–59)	G1: Laser (20) G2: Control (15)	G1: 42.8 ± 27.0 G2: 35.3 ± 29.0	G1: 5.5 ± 17.9* G2: 5.3 ± 6.4*	G1: 36.0 ± 8.0 G2: 37.4. ± 11.2	G1: 43.7 ± 7.4* G2: 40.8. ± 8.9	(15 sessions)	WL: 940 nm ED: 3 J/cm^2 TE: NR IR: NR OP: 0.017 W TPP: 180 s	1 month
Kogawa et al., 2005 [17]	Brazil	19 (19F)	TOTAL: 26.4	G1: Laser (9) G2: MENS (10)	G1: 66.1 G2: 44.0	G1: 4.4* G2: 6.0*	G1: 43.0 G2: 46.3	G1: 47.6 G2: 49.4	3/week for 4 weeks (10 sessions)	WL: 830–904 nm ED: 4 J/cm^2 TE: NR IR: NR OP: 0.1 W TPP: 60 s	1 month
Kato et al., 2006 [18]	Brazil	18 (16F/2 M)	G1: 25.8 G2: 25.4 TOTAL: 25.6 (25–40)	G1: Laser (9) G2: TENS (9)	G1: 66.1 G2: 57.2	G1: 7.8* G2: 4.4*	G1: 43.0 G2: 42.0	G1: 47.6* G2: 47.2*	3/week for 4 weeks (10 sessions)	WL: 830–904 nm ED: 4 J/cm^2 TE: NR IR: NR OP: 0.1 W TPP: NR	1 month
Da Cunha et al., 2008 [19]	Brazil	40 (39F/1 M)	G1: 40.15 G2: 46.6 (20–68)	G1: Laser (20) G2: Control (20)	G1: 68.7 ± 21.2 G2: 66.0 ± 25.7	G1: 36.2 ± 24.5* G2: 46.7 ± 19.0*	NR	NR	1/week for 4 weeks (4 sessions)	WL: 830 nm ED: 100 J/cm^2 TE: 4 J IR: NR OP: 0.5 W TPP: 20 s	1 month
Emshoff et al., 2008 [20]	Austria	52 (42F/10 M)	G1: 44.1 ± 16.6 G2: 41.8 ± 11.2 TOTAL: 42.9 (18–58)	G1: Laser (26) G2: Control (26)	G1: 38.2 ± 7.6 G2: 39.7 ± 12.2	G1: 12.3 ± 16.1* G2: 11.8 ± 16.8*	NR	NR	2–3/week for 8 weeks (20 sessions)	WL: 638.2 nm ED: 1.5 J/cm^2 TE: NR IR: NR OP: 0.03 W TPP: 120 s	2 months
Venezian et al., 2010 [21]	Italy	48 (43F/5 M)	TOTAL: 41.58 (18–60)	G1: 25J/cm2, 50 mW, 20 s (Laser) (12) G2: 25J/cm2, 50 mW, 20 s (Control) (12) G3: 60J/cm2, 60 mW, 40 s (Laser) (12) G4: G3: 60J/cm2, 60 mW, 40 s (Control) (12)	Anterior Temporalis: G1: 54.1 (R) / 59.1 (L) G2: 76.6 (R) / 76.6 (L) G3: 60.0 (R) / 53.3 (L) G4: 65.8 (R) / 64.1 (L) Upper Masseter: G1: 45.0 (R) / 60.8 (L) G2: 63.3 (R) / 60.0 (L) G3: 49.1 (R) / 55.8 (L) G4: 54.1 (R) / 55.8 (L) Medium Masseter: G1: 53.3 (R) / 52.5 (L) G2: 81.6 (R) / 78.3 (L) G3: 54.1 (R)	Anterior Temporalis: G1: 48.3 (R) / 50.8 (L) G2: 50.0 (R) * / 52.5 (L)* G3: 50.8 (R) * / 51.6 (L) G4: 43.3 (R) * / 39.1 (L)* Upper Masseter: G1: 30.0 (R) * / 48.3 (L)* G2: 37.5 (R) * / 43.3 (L)* G3: 47.5 (R) / 55.0 (L) G4: 20.8 (R) * / 30.0 (L)* Medium Masseter: G1: 49.1 (R) / 47.5 (L) G2: 54.1 (R) * / 55.0 (L)* G3: 50.0 (R)	NR	NR	2/week for 4 weeks (8 sessions)	WL: 780 nm ED: 25–60 J/cm^2 TE: NR IR: NR OP: 0.05–0.06 W TPP: 20–40 s	1 month

(*continued on next page*)

Table 1 (*continued*)

					/ 70.0 (L) G4: 67.5 (R) / 80.0 (L) Lower Masseter: G1: 60.8 (R) / 52.5 (L) G2: 80.0 (R) / 67.5 (L) G3: 43.3 (R) / 52.5 (L) G4: 61.6 (R) / 59.1 (L)	/ 56.6 (L) G4: 35.0 (R) * / 42.5 (L)* Lower Masseter: G1: 53.3 (R) / 47.5 (L) G2: 52.5 (R) * / 45.8 (L)* G3: 40.0 (R) / 46.6 (L) G4: 42.5 (R) * / 40.8 (L)*					
Öz et al., 2010 [22]	Turkey	40 (34F/6 M)	G1: 31.25 ± 8.23 G2: 34.52 ± 12.82 TOTAL: 32.84 ± 10.70	G1: Laser (20) G2: Occlusal splint (20)	G1: 48.5 G2: 52.7	G1: 16.8* G2: 31.6*	G1: 44.2 ± 6.14 G2: 43.2. ± 5.57	G1: 47.2. ± 5.51* G2: 44.55 ± 5.90*	2/week for 5 weeks (10 sessions)	WL: 820 nm ED: 3 J/cm^2 TE: NR IR: NR OP: 0.03 W TPP: 10 s	3 months
Da Silva et al., 2012 [23]	Brazil	45 (30F/15 M)	TOTAL: 39.7 (25–53)	G1: 52.5 J/cm2, Laser (15) G2: 105.0 J/cm2, Laser (15) G3: 0 J/cm2, Control (15)	Anterior Temporalis: G1: 74.0 ± 17.8 G2: 72.0 ± 18.3 G3: 73.3 ± 19.9 Masseters: G1: 70.0 ± 17.9 G2: 76.0 ± 17.4 G3: 70.7 ± 18.1	Anterior Temporalis: G1: 46.7 ± 14.9 G2: 38.0 ± 16.0 G3: 82.0 ± 13.3 Masseters: G1: 46.7 ± 13.5 G2: 43.4 ± 15.8 G3: 78.0 ± 18.3	G1: 32.0 ± 5.20 G2: 32.3 ± 4.70 G3: 31.9 ± 4.40	G1: 35.8 ± 4.98 G2: 34.8. ± 4.42 G3: 30.87 ± 4.11	2/week for 5 weeks (10 sessions)	WL: 780 nm ED: 52.5–105.0 J/cm^2 TE: NR IR: NR OP: 0.07 W TPP: 30–60 s	5 weeks
Catão et al., 2013 [24]	Brazil	20 (18F/2 M)	(19–58)	G1: Laser (Infrared) (10) G2: Laser (Red) (10)	G1: 84.0 G2: 81.0	G1: 14.0* G2: 19.0*	G1: 41.35 G2: 46.34	G1: 46.16* G2: 50.05*	3/week for 4 weeks (12 sessions)	WL: 830 (G1), 660 (G2) nm ED: 4 J/cm^2 TE: NR IR: NR OP: 0.04 (G1), 0.03 (G2) W TPP: 100 (G1), 133 (G2) s	1 month
Ferreira et al., 2013 [25]	Brazil	40 (40F/ 0 M)	G1: 32.1 ± 8.2 G2: 36.2 ± 9.3 TOTAL: 34.17 ± 8.83	G1: Laser (20) G2: Control (20)	G1: 76.5 ± 16.3 G2: 73.0 ± 20.0	G1: 0.05 ± 0.22* G2: 2.75 ± 2.71*	NR	NR	1/week for 3 months (12 sessions)	WL: 780 nm ED: 112.5 J/cm^2 TE: 4.5 J IR: 1250 W/cm^2 OP: 0.05 W TPP: 90 s	3 months
De Carli et al., 2013 [26]	Brazil	32 (29F/3 M)	G1: 33.67 ± 13.00 G2: 29.4 ± 10.58 G3: 34.00 ± 15.55 TOTAL: 43.4 (18–58)	G1: Laser + placebo piroxicam (11) G2: Control + piroxicam (10) G3i: Laser + piroxicam (11)	G1: 36.27 ± 26.47 G2: 41.3 ± 29.73 G3: 48.00 ± 16.66	G1: 24.1 ± 24.19* G2: 15.44 ± 25.64* G3: 13.27 ± 15.12*	G1: 49.36 ± 8.77 G2: 48.4 ± 6.8 G3: 49.59 ± 4.62	G1: 47.7 ± 9.44 G2: 49.57 ± 9.20 G3: 50.45 ± 6.33	2/week for 10 days (4 sessions)	WL: 808 nm ED: 100 J/cm^2 TE: 56 J IR: NR OP: 0.1 W TPP: 28 s	1 month
Amanat et al., 2013 [27]	Iran	60 (43F/17 M)	TOTAL: 47.22	G1: Control (30) G2: Laser (30)	G1: 77.0 ± 19.0 G2: 75.0 ± 23.0	G1: 35.0 ± 28.0 G2: 38.0 ± 37.0	NR	NR	3/week for 3 weeks (10 sessions)	WL: 980 nm ED: 12.73 J/cm^2 TE: 3.6 J IR: 0.042 w/cm^2 OP: 0.012 W TPP: 300 s	4 months

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Table 1 (*continued*)

Pereira et al., 2014 [28]	Brazil	19 (15F/4 M)	TOTAL: 35.0 (21–55)	G1: Laser, Red laser hemi-face (19) G2: Laser, Infrared laser hemi-face (19)	G1: 73.8 ± 17.0 G2: 69.1 ± 16.0	G1: 49.5 ± 29.0* G2: 37.3 ± 26.0*	NR	NR	1 every 48 h (3 sessions)	WL: 660 nm (RL), 795 (IRRL) ED: 4–8 J/cm^2 TE: NR IR: NR OP: NR TPP: NR	6 months
Madani et al., 2014 [29]	Iran	20 (19F/1 M)	(35–60)	G1: Laser (10) G2: Control (10)	Anterior Temporalis: G1: 19.3 ± 24.4 G2: 18.0 ± 22.9 Middle Temporalis: G1: 18.0 ± 31.5 G2: 13.5 ± 17.9 Posterior Temporalis: G1: 14.0 ± 20.7 G2: 15.7 ± 23.3 Masseter Origin: G1: 24.2 ± 37.5 G2: 20.7 ± 33.6 Masseter Body: G1: 24.5 ± 31.2 G2: 40.0 ± 27.4 Masseter Insertion: G1: 18.0 ± 27.5 G2: 15.2 ± 17.2 Internal Pterygoid: G1: 39.5 ± 30.6 G2: 51.7 ± 36.1	Anterior Temporalis: G1: 14.0 ± 26.6 G2: 13.0 ± 19.8 Middle Temporalis: G1: 12.7 ± 19.0 G2: 8.0 ± 10.2 Posterior Temporalis: G1: 7.0 ± 17.5 G2: 12.7 ± 16.2 Masseter Origin: G1: 13.2 ± 15.9 G2: 9.0 ± 16.6 Masseter Body: G1: 15.0 ± 21.2* G2: 18.7 ± 17.8* Masseter Insertion: G1: 15.0 ± 25.9 G2: 14.2 ± 18.2 Internal Pterygoid: G1: 27.5 ± 25.0 G2: 35.5 ± 34.1	G1: 29.2 G2: 23.5	G1: 31.7 G2: 24.7	2/week for 4 weeks (8 sessions	WL: 808 nm ED: 70 J/cm^2 TE: 1.9 J IR: NR OP: 0.1 W TPP: 19 s	1 month
Ahrani et al., 2014 [30]	Iran	20 (20F/0 M)	TOTAL: 35.5	G1: Laser (10) G2: Control (10)	ID	ID	G1: 21.3 ± 11.26 G2: 26.9 ± 7.78	G1: 30.4 ± 9.35* G2: 29.3 ± 6.46	3/week for 1 month (12 sessions)	WL: 810 nm ED: 3.4 J/cm^2 TE: 6 J IR: NR OP: 0.05 W TPP: 120 s	1 month
Sancakli et al., 2015 [31]	Turkey	30 (21F/9 M)	TOTAL: 39.2 ± 2.8	G1: Laser (10)** G2: Laser (10)** G3: Control (10)	G1: 62.65 ± 10.42 G2: 58.38 ± 7.25 G3: 53.31 ± 8.79	G1: 31.46 ± 7.14* G2: 44.05 ± 7.14* G3: 49.75 ± 9.54	NR	NR	3/week for 1 month (12 sessions)	WL: 820 nm ED: 3 J/cm^2 TE: NR IR: NR OP: 0.3 W TPP: 10 s	1 month
Demirkol et al., 2015 [32]	Turkey	30 (NR)	NR	G1: Occlusal splint (10) G2: Laser (10) G3: Control (10)	G1:64.5 ± 17.07 G2: 66.0 ± 15.06 G3: 74.0 ± 24.59	G1: 15.0 ± 22.73* G2: 20.0 ± 23.09* G3: 26.0 ± 23.19	NR	NR	1/day for 10 days (10 sessions)	WL: 1064 nm ED: 8 J/cm^2 TE: NR IR: NR OP: 0.25 W TPP: 20 s	3 weeks
Khalighi et al., 2016 [33]	Iran	40 (30F/10 M)	TOTAL: 36 ± 12.34	G1: Laser + drugs (20) G2: Naproxen + Placebo laser (20)	G1: 72.5 ± 15.1 G2: 60.0 ± 15.0	G1: 3.1 ± 5.8* G2: 52.4 ± 16.4	G1: 31.63 ± 7.35 G2: 33.95 ± 3.85	G1: 42.26 ± 4.78* G2:	5/first week: 0.5, 0.4, 0.3, 0.2, 0.1 (W). 3/second week: 0.2,	WL: 810 nm ED: NR TE: NR IR: NR OP: 0.5 W TPP: 60 s	2 months

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Table 1 (*continued*)

								34.60 ± 3.85	0.3, 0.4 (W). 2/third week: 0.3, 0.2 (W). 2/fourth week: 0.1, 0.2 (W). (12 sessions)		
Seifi et al., 2017 [34]	Iran	40 (NR)	(18–50)	G1: TENS (10) G2: Placebo TENS (10) G3: Laser (10) G4: Placebo Laser (10)	G1: 44.95 ± 5.74 G2: 43.73 ± 5.16 G3: 44.58 ± 4.34 G4: 44.24 ± 3.32	G1: 32.05 ± 5.64 G2: 40.45 ± 4.31 G3: 34.29 ± 4.34 G4: 41.26 ± 5.11	G1: 35.20 ± 2.48 G2: 35.30 ± 1.78 G3: 36.20 ± 2.87 G4: 35.90 ± 1.64	G1: 37.30 ± 2.10 G2: 37.55 ± 1.84 G3: 38.11 ± 2.33 G4: 36.99 ± 1.34	4/week (6 sessions)	WL: 810 nm ED: NR TE: NR IR: NR OP: 0.5 W TPP: 60 s	1 month
Hosgor et al., 2017 [35]	Turkey	40 (36F/4 M)	TOTAL: 30.35 ± 1.97 (18–59)	G1: Occlusal splint (10) G2: Arthrocentesis (10) G3: NSAID (10) G4: Laser (10)	G1: 70.0 ± 6.3 G2: 74.0 ± 3.0 G3: 60.0 ± 4.2 G4: 64.0 ± 6.8	G1: 32.0 ± 11.2* G2: 26.0 ± 7.3* G3: 28.0 ± 7.4* G4: 24.0 ± 7.4*	G1: 39.0 ± 2.6 G2: 28.4 ± 2.11 G3: 36.1 ± 2.66 G4: 38.1 ± 2.66	G1: 43.0 ± 1.75 G2: 35.7 ± 2.75* G3: 39.1 ± 2.68 G4: 44.1 ± 1.52	3/week for 4 weeks (12 sessions	WL: 1064 nm ED: 321 J/cm^2 TE: NR IR: NR OP: 0.5 W TPP: 180 s	6 months
Shobha et al., 2017 [36]	India	40 (31F/9 M)	G1: 30.85 ± 6.31 G2: 27.55 ± 4.58 (18–40)	G1: Laser (20) G2: Control (20)	G1: 50.0 ± 14.86 G2: 43.5 ± 17.5	G1: 4.5 ± 9.9* G2: 9.5 ± 15.3*	G1: 43.05 ± 6.329 G2: 45.25 ± 4.447	G1: 45.30 ± 5.768* G2: 46.65 ± 4.522*	2–3/week (8 sessions)	WL: 810 nm ED: 6 J/cm^2 TE: NR IR: NR OP: 0.1 W TPP: 60 s	1 month
Manfredini et al., 2018 [37]	Italy	30 (30F/ 0 M)	TOTAL: 35.3 ± 9.4	G1: Laser (10) G2: Oral appliance therapy (10) G3: Counseling (10)	G1: 46.0 G2: 42.0 G3: 50.0	G1: 33.0* G2: 30.0* G3: 41.0*	NR	NR	3/week for 3 weeks (9 sessions)	WL: 810–905 nm ED: NR TE: 100–200 IR: NR OP: 1.1–25 W TPP: NR	6 months
De Souza et al., 2018 [38]	Brazil	66 (62F/4 M)	TOTAL: 46.14 ± 10.91	G1: Laser (33) G2: Anesthetic infiltration (33)	G1: 78.5 ± 22.2 G2: 80.8 ± 20.3	G1: 28.5 ± 17.7* G1: 31.8 ± 18.7*	NR	NR	2/week for 6 weeks (12 sessions)	WL: 780 nm ED: 50 J/cm^2 TE: 2 J IR: NR OP: 0.05 W TPP: 40 s	6 weeks
Rodrigues et al., 2019 [39]	Brazil	21 (21/ 0 M)	G1: 43.63 G2: 47.5	G1: Occlusal splint (11) G2: Laser (10)	G1: 40.0 ± 50.0 G2: 50.0 ± 25.0	G1: 0.00 ± 10.0* G2: 0.00 ± 0.00*	G1: 32.82 ± 7.08 G2: 33.70 ± 7.20	G1: 39.27 ± 9.90* G2: 39.50 ± 7.70*	1/week for 8 weeks (8 sessions)	WL: 904 nm ED: 4 J/cm^2 TE: NR IR: NR OP: 0.05 W TPP: 24 s	2 months
Altindiş and Güngörmüş, 2019 [40]	Turkey	20 (20F/ 0 M)	G1: 27.8 ± 4.13 G2: 28.75 ± 3.45	G1: Occlusal splint (10) G2: Laser (10)	G1: 69.0 ± 7.3 G2: 71.0 ± 6.4	G1: 39.0 ± 11.0* G2: 36.0 ± 7.4*	NR	NR	3/week for 3 weeks (10 sessions)	WL: 970 nm ED: NR TE: 5 J IR: NR OP: 0.5 W TPP: 10 s	3 months
Monteiro et al., 2020 [41]	Portugal	42 (32F/10 M)	G1: 29.1 ± 11.0 G1: 25.6 ± 8.0 TOTAL: 27.4 ± 9.71	G1: Laser (22) G2: Control (20)	G1: 45.9 ± 23.6 G2: 44.5 ± 26.0	G1: 6.30 ± 3.60* G2: 40.5 ± 23.9	G1: 36.73 ± 9.91 G2: 38.10 ± 7.54	G1: 42.14 ± 5.8* G2: 39.45 ± 5.3	1/week for 4 weeks (4 sessions)	WL: 635 nm ED: 8 J/cm^2 TE: 4 J IR: 0.4 W/cm^2 OP: 0.2 W TPP: 20 s	1 month

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Chellappa and Thirupathy, 2020 [42]	India	60 (NR)	NR	G1: Laser (30) G2: TENS (30)	G1: 79.0 G2: 84.0	G1: 38.6* G2: 53.0*	G1: 41.2 G2: 33.8	G1: 42.74* G2: 40.37*	2/week for 3 weeks (6 sessions)	WL: 672 nm ED: NR TE: 3 J IR: NR OP: 0.05 W TPP: 120 s	6 weeks
Abbasgholizadeh et al., 2020 [43]	Turkey	45 (38F/7 M)	TOTAL: 29.9 ± 9.20 (18–53)	G1: Occlusal splint (15) G2: Occlusal splint + athrocentesis (15) G3: Occlusal splint + Laser (15)	G1: 73.3 ± 13.5 G2: 71.3 ± 9.2 G3: 73.3 ± 10.4	G1: 4.0 ± 13.5* G2: 1.3 ± 3.5* G3: 6.7 ± 8.2*	G1: 32.67 ± 3.15 G2: 32.66 ± 2.47 G3: 31.0 ± 4.02	G1: 41.06 ± 2.74* G2: 43.56 ± 3.58* G3: 40.93 ± 2.13*	3/week for 4 weeks (12 sessions)	WL: 1064 nm ED: 321 J/cm^2 TE: NR IR: NR OP: 0.5 W TPP: 60 s	6 months
Keskin Tunç et al., 2020 [44]	Turkey	40 (30F/10 M)	G1: 23.1 ± 4.9 G2:21.3 ± 4.8 TOTAL: 22.35 (18–60)	G1: Control (20) G2: Laser (20)	G1: 55.0 ± 14.0 G2: 45.0 ± 18.0	G1: 32.0 ± 13.0* G2: 7.0 ± 18.0*	G1: 41.9 ± 9.5 G2: 49.55 ± 10.1	G1: 43.9 ± 9.4* G2: 51.85 ± 8.7*	2/week for 4 weeks (8 sessions)	WL: 940 nm ED: 2.14 J/cm^2 TE: NR IR: NR OP: 0.3 W TPP: 20 s	3 months
Shousha et al., 2021 [45]	Egypt	112 (112F)	G1: 26.21 ± 0.64 G2. 25.73 ± 2.77 G3: 27.33 ± 0.42 (21–30)	G1: Laser (37) G2: Occlusal Splint (37) G3: Control (38)	G1: 84.1 ± 3.1 G2: 73.5 ± 7.8 G3: 65.1 ± 13.6	G1: 21.1 ± 4.1* G2: 32.2 ± 1.9* G3: 51.4 ± 2.6*	NR	NR	3/week (10 sessions)	WL: 940 nm ED: 2.5 J/cm^2 TE: 2 J IR: NR OP: 0.2 W TPP: 10 s	1 year
Del Vecchio et al., 2021 [46]	Italy	86 (74F/12 M)	G1: 39.04 ± 15.29 G2: 46.18 ± 16.21 G3: 42.45 ± 12.52 TOTAL: 42.55 ± 14.84 (18–73)	G1: Laser (30) G2: Placebo (30) G3: Drug therapy (18)	G1: 65.52 ± 17.44 G2: 58.57 ± 15.57 G3: 74.48 ± 13.25	G1: 30.34 ± 20.44 G2: 36.43 ± 21.29 G3: 37.59 ± 23.09	NR	NR	2/day for 7 days (14 sessions)	WL: 808 nm ED: NR TE: 40 J IR: NR OP: 0.25 W TPP: 460 s	1 week
Desai et al., 2022 [47]	India	60 (38F/22 M)	G1: 38.27 ± 8.4 G2: 39.63 ± 8.78 TOTAL: 38.4 (25–54)	G1: Placebo (30) G2: Laser (30)	G1: 86.0 ± 8.1 G2: 85.7 ± 8.6	G1: 52.0 ± 7.6* G2: 32.3 ± 10.1*	G1: 23.63 ± 3.4 G2: 23.60 ± 2.4	G1: 25.73 ± 3.0* G2: 35.34 ± 2.0*	2–3/week for 8 weeks (20 sessions)	WL: 632.8 nm ED: NR TE: NR IR: NR OP: 0.03 W TPP: NR	2 months
Yehia et al., 2022 [48]	Egypt	30 (30F)	G1: 28.33 ± 3.68 G2: 28.13 ± 3.25 TOTAL: 28.2 ± 3.4 (19–47)	G1: Laser (15) G2: Control (15)	G1: 70.0 ± 19.3 G2: 76.0 ± 20.3	G2: 46.7 ± 29.9* G2: 20.7 ± 14.9*	NR	NR	3/week for 4 weeks (12 sessions)	WL: 808 nm ED: 16 J/cm^2 TE: NR IR: NR OP: NR TPP: 14 s	1 month
Nambi et al., 2022 [49]	Saudi Arabia	36 (NR)	G1: 31.3 ± 2.1 G2: 30.5 ± 2.6	G1: Laser (18) G2: Placebo (18)	G1: 71.0 ± 6.0 G2: 69.0 ± 5.0	G1: 3.0 ± 0.6* G2: 32.0 ± 2.0*	G1: 4.8 ± 0.6 G2: 5.2 ± 0.5	G1: 36.5 ± 0.9* G2: 20.5 ± 0.8*	3/week for 4 weeks (12 sessions)	WL: 905 nm ED: NR TE: 1.5–6 J IR: NR OP: 0.025 W TPP: 60–240 s	6 months
Rady et al., 2022 [50]	Egypt	27 (25F/2 M)	G1: 24.22 ± 2.9	G1: ARA (9) G2: Botulinum	G1: 95.6 G2: 96.7 G3: 97.8	G1: 17.8* G2: 8.9* G3: 1.00*	NR	NR	3/week for 3 months	WL: 780 nm ED: 1.4 J/cm^2	3 months

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Table 1 (*continued*)

			G2: 23.33 ± 2.1 G3: 23.22 ± 2.1	toxin (9) G3: Laser (9)					(36 sessions)	TE: NR IR: NR OP: 0.1 W TPP: 30 s	
De Oliveira et al., 2022 [51]	Brazil	18 (13F/5 M)	G1: 30.1 ± 10.9 G2: 23.6 ± 4.0	G1: Laser (10) G2: Placebo (8)	NR	NR	G1: 40.0 ± 3.1 G2: 43.1 ± 5.4	G1: 45.7 ± 6.6* G2: 44.6 ± 7.4	1/48 h (2 sessions)	WL: 808 nm ED: 80 J/cm^2 TE: NR IR: NR OP: 0.1 W TPP: 22 s	1 month
Palizgir et al., 2023 [52]	Iran	22 (20F/2 M)	G1: 40.36 ± 10.15 G2. 36.27 ± 8.03	G1: TENS (11) G2: Laser (11)	G1: 59.1 ± 15.78 G2: 76.8 ± 25.33	G1: 3.6 ± 0.1206* G2: 0.9 ± 3.020*	G1: 45.55 ± 7.258 G2: 41.45 ± 5.820	G1: 46.27 ± 6.930* G2: 42.82 ± 5.828*	3/week for 3 weeks (10 sessions)	WL: 940 nm ED: 105 J/cm^2 TE: 20 J IR: 0.0026 W/cm^2 OP: 0.5 W TPP: 40 s	1 month
Al-Azab et al., 2023 [53]	Egypt	120 (NR)	G1: 38.67 ± 5.59 G2: 38.4 ± 5.08 G3: 37.4 ± 4.23 (26–41)	G1: Control (Oral medication) (40) G2: Medication + Laser (40) G3: Medication + EMT (40)	G1: 77.33 ± 10.33 G2: 76.67 ± 10.47 G3: 75.33 ± 9.15	G1: 66.6 ± 15.4* G2: 40.0 ± 18.9* G3: 56.6 ± 20.2*	NR	NR	3/week for 2 months (24 sessions)	WL: 830 nm ED: NR TE: NR IR: 0.15–0.17 W/cm^2 OP: 0.015 W TPP: NR	2 months
Tanhan et al., 2023 [54]	Turkey	59 (46F/13 M)	G1: 20.45 ± 1.50 G2: 21.41 ± 4.30 G3: 20.95 ± 1.83	G1: Exercises (17) G2: Laser (20) G3: MPR (22)	NR	NR	G1: 39.9 ± 6.2 G2: 43.0 ± 4.9 G3: 42.4 ± 6.2	G1: 44.8 ± 6.2* G2: 47.4 ± 5.2* G3: 46.5 ± 5.2*	3/week for 4 weeks (12 sessions)	WL: 808 nm ED: 10 J/cm^2 TE: 2.5–4 J IR: NR OP: 1.2 W TPP: NR	1 month
El-Shaheed et al., 2023 [55]	Egypt	42 (35F/7 M)	G1: 26.5 ± 6.6 G2: 26.2 ± 7.0 G3: 26.3 ± 6.9	G1: Occlusal splint + Laser (14) G2: Laser (14) G3: Occlusal splint (14)	G1: 68.6 ± 6.6 G2: 68.9 ± 6.56 G3: 67.1 ± 9.55	G1: 0.0 ± 0.0* G2: 15.0 ± 6.5* G3: 21.4 ± 7.7*	G1: 29.21 ± 2.46 G2: 29.43 ± 2.95 G3: 28.57 ± 1.70	G1: 41.36 ± 1.65* G2: 38.57 ± 2.47* G3: 38.14 ± 1.41*	2/week for 5 weeks (10 sessions)	WL: 810 nm ED: NR TE: NR IR: NR OP: 0.5 W TPP: 120 s	6 months
Al-Quisi et al., 2023 [56]	Iraq	60 (50F/10 M)	G1: 22.6 G2: 22.7 G3: 21.9 TOTAL: 20.6 (19–22)	G1: Placebo (20) G2: LED (20) G3: Laser (20)	G1: 38.5 ± 17.9 G2: 38.0 ± 12.4 G3: 39.5 ± 20.5	G1: 37.0 ± 17.9 G2: 22.5 ± 18.1* G3: 21.5 ± 21.6*	NR	NR	1/week for 4 weeks (4 sessions)	WL: 810 nm ED: NR TE: NR IR: NR OP: 1 W TPP: 10 s	1 month
Mahmoud et al., 2024 [57]	Egypt	90 (75F/15 M)	G1: 34.83 ± 12.43 G2: 34.33 ± 13.36 G3: 38.57 ± 12.01 TOTAL: 35.9 ± 12.6	G1: Laser, 1/week for 4 weeks (30) G2: Laser, 2/week for 4 weeks (30) G3: Laser, 3/week for 4 weeks (30)	G1: 75.0 ± 9.7 G2: 69.3 ± 9.4 G3: 70.0 ± 9.1	G1: 10.7 ± 3.7*G2: 5.3 ± 5.7* G3: 4.3 ± 5.0*	G1: 30.3 ± 1.77 G2: 30.47 ± 1.45 G3: 30.89 ± 0.92	G1: 40.0 ± 1.23* G2: 40.89 ± 1.32* G3: 41.09 ± 1.59*	1,2,3/week for 4 weeks (4,8,12 sessions)	WL: 940 nm ED: 4 J/cm^2 TE: NR IR: NR OP: 1 W TPP: 60 s	2 months
Chamani et al., 2024 [58]	Iran	42 (37F/5 M)	G1: 36.0 ± 14.6 G2: 38.2 ± 9.7 G3: 32.0 ± 10.4 TOTAL: 30.9 ± 5.4 (18–60)	G1: Laser (14) G2: Placebo (15) G3: Control (13)	G1: 52.1 ± 30.7 G2: 41.5 ± 26.19 G3: 57.3 ± 25.0	G1: 19.9 ± 17.8* G2: 10.4 ± 13.67* G3: 19.7 ± 24.93*	G1: 49.5 ± 2.82 G2: 47.42 ± 4.68 G3: 46.42 ± 6.71	G1: 51.0 ± 7.58 G2: 49.57 ± 4.17 G3: 47.21 ± 6.17	2/week for 5 weeks (10 sessions)	WL: 808 nm ED: 0.13–0.76 J/cm^2 TE: 3–18 J IR: NR OP: 0.3 W TPP: 10 s	5 weeks

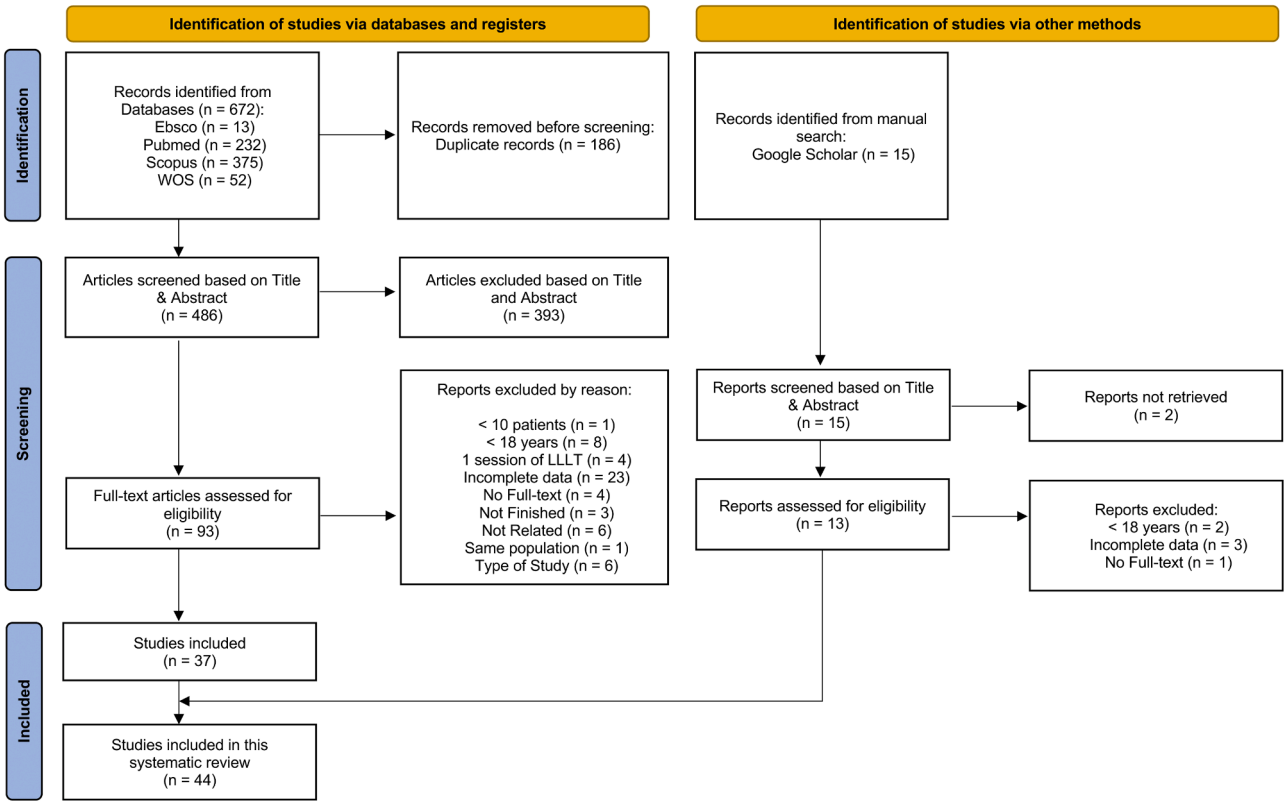

Fig. 1. PRISMA flow diagram for the systematic review.

improvements, particularly in VA.

Among the most outstanding results are the studies of Da Cunha et al [19]., with 4 sessions over 4 weeks, led to sustained pain reduction and functional improvement ($p < 0.01$), El-Shaheed et al [55]. with 10 sessions over 5 weeks with 810 nm laser, resulted in significantly greater VA improvement compared to occlusal splint therapy and Mahmoud et al [57]., who increased the number of LLLT sessions (4, 8, or 12 sessions over 4 weeks), proportionally improved treatment outcomes, suggesting a dose-dependent effect.

3.6. *Effectiveness of different laser parameters*

A range of laser settings was employed, with key variables including wavelength, energy density, and power output. In relation to these parameters, wavelengths between 632.8 - 660 nm showed mild to moderate improvement in superficial myofascial pain, between 780 - 810 nm stronger pain relief and improved vascular response, between 830 - 940 nm better response for deep tissue penetration and the highest improvement in MMO, and for 1064 nm there is limited evidence but effective in chronic cases. In relation to power output, it ranged from 0.03 W to 1 W, with the highest power (0.5–1 W) yielding the best results in arthrogenic TMD. Finally, energy densities between 3 and 12 J/cm^2 provided the most consistent results, and lower doses (< 2 J/cm^2) had negligible effects, confirming the importance of adequate energy delivery.

3.7. *Comparison with other therapies*

Some studies included control groups receiving alternative treatments, such as occlusal splints, NSAIDs, and transcutaneous electrical nerve stimulation (TENS). Compared to occlusal splints Öz et al [22]. found that laser therapy (820 nm, 3 J/cm^2) led to greater pain relief than occlusal splints, and Shousha et al [45]. reported that LLLT-treated groups had a 40 % faster pain recovery than splint therapy. Compared to NSAIDs Hosgor et al [35]. found that LLLT (1064 nm) reduced pain more effectively than NSAID therapy over a 6-month period, and compared to TENS therapy Kato et al [18]. reported that LLLT and TENS had comparable pain reduction, but LLLT showed greater improvement in VA. These findings suggest that LLLT is an effective alternative to conventional therapies, particularly when combined with splint therapy or manual physiotherapy.

3.8. *Safety and adverse effects*

LLLT was well tolerated across all studies, with no severe adverse events reported. The most commonly noted side effects were transient erythema (3–5 % of cases)and mild discomfort at the application site (<2 %). These findings confirm LLLT's high safety profile, making it suitable for repeated use in chronic TMD patients.

Conducting a meta-analysis in this context is not advisable due to the significant heterogeneity observed across the included randomized controlled trials (RCTs). The studies vary widely in terms of laser parameters, including wavelength (ranging from 632.8 nm to 1064 nm), energy density, power output, frequency of sessions, and total treatment duration. Additionally, differences in patient populations, such as TMD subtypes (myogenic vs. arthrogenic), severity of symptoms, and baseline characteristics, introduce variability that makes direct comparisons challenging. Another critical limitation is the divergence in outcome measurement methodologies—some studies use the Visual Analog Scale (VAS) for pain assessment, while others rely on maximum mouth opening (MMO) in millimeters or electromyographic (EMG) recordings, leading to inconsistencies in reported effects. Furthermore, the risk of bias varies among studies, with some displaying inadequate randomization, lack of blinding, or high dropout rates. Given these factors, pooling data for a meta-analysis could yield misleading conclusions, as statistical aggregation may obscure important clinical nuances. Instead, a qualitative synthesis provides a more appropriate approach, allowing for a nuanced interpretation of results while acknowledging the inherent

variability among studies.

3.9. Risk of bias

The risk of bias assessment, evaluated using Cochrane's Risk of Bias 2 (RoB 2) tool[14], revealed variability in study quality, with some trials demonstrating high methodological rigor, while others exhibited potential sources of bias. According to Fig. 2, 15 studies were categorized as having a low risk of bias, indicating strong adherence to randomization procedures, blinding strategies, and robust outcome reporting. Additionally, some concerns were raised in a few studies regarding incomplete outcome data and selective reporting of results, which could influence the validity of findings. Importantly, the majority of studies showed adequate allocation concealment and consistent reporting of pain reduction and functional outcomes, reinforcing the reliability of the overall conclusions. Future research should aim to improve methodological consistency, particularly in areas such as blinding, standardized treatment protocols, and long-term follow-up evaluations, to further enhance the robustness of LLLT evidence in TMD management.

4. Discussion

4.1. Interpretation of findings

The results of this systematic review confirm that LLLT is an effective, non-invasive treatment for TMD, significantly reducing pain and improving vertical aperture. The studies analyzed demonstrated statistically significant reductions in pain intensity, averaging a 60–70 % decrease in VAS scores, and a mean increase in vertical aperture of 10–20 %. These findings align with the hypothesized photobiomodulation (PBM) effects of LLLT, which improve tissue healing, decrease inflammation, and modulate nociceptive pathways [59,60]. The results of this systematic review demonstrated that LLLT led to a mean pain reduction of 60–70 % on the Visual Analog Scale (VAS) and an improvement of 10–20 % in vertical aperture (VA), with the most effective wavelengths ranging between 810 and 940 nm. Notably, treatment protocols exceeding four weeks were associated with more sustained functional improvements, emphasizing the potential cumulative effects of photobiomodulation.

Pain relief was more pronounced in myogenic TMD compared to arthrogenic TMD, indicating that muscle-related dysfunctions respond more favorably to LLLT. In contrast, patients with joint degeneration required longer treatment durations and higher energy densities for measurable improvements, suggesting a different therapeutic threshold. These results support the hypothesis that LLLT modulates biochemical markers such as interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF-α), and reactive oxygen species (ROS), promoting neuromuscular relaxation and joint tissue regeneration[61–63]. However, despite promising results, significant variability in treatment protocols, laser parameters, and patient selection criteria necessitate further standardization to optimize clinical application.

4.2. Comparison with existing literature

The findings of this review align with previous meta-analyses and systematic reviews on the efficacy of LLLT in managing musculoskeletal and neuropathic conditions. Zhang et al [6]. conducted a meta-analysis of LLLT in orofacial pain management and reported an average VAS reduction of 3.5 to 5.0 points, comparable to the results observed in this review. Similarly, Rady et al [5]. found that LLLT was superior to occlusal splints for pain management but required more frequent sessions to achieve sustained relief. However, discrepancies exist in reported effectiveness across studies due to heterogeneity in treatment protocols. The present review highlights a lack of consensus regarding the optimal wavelength, energy density, and number of treatment sessions, which has been a longstanding limitation in LLLT research. Furthermore, while previous studies have emphasized pain reduction as the primary outcome, our review suggests that functional improvements (e.g., VA, neuromuscular coordination) are equally critical in assessing LLLT's clinical impact. This underscores the need for multidimensional evaluation metrics beyond subjective pain scales to capture the full therapeutic potential of LLLT in TMD treatment.

4.3. Influence of laser parameters on treatment outcomes

One of the most notable findings of this review is the significant variation in laser parameters across studies, which directly impacts treatment efficacy. The most effective wavelengths for pain reduction were 810 nm[30,34,36,37,55,56], 830 nm[15,17–19,24,53] and 940 nm[16,44,45,52,57], as they demonstrated superior penetration into deep musculoskeletal and joint structures. In contrast, shorter wavelengths (632.8–660 nm)[20,28,41,47] were less effective in managing deep tissue pain but showed moderate efficacy in superficial myofascial pain syndromes. Energy density was another key factor influencing outcomes. Studies using 3–12 J/cm^2[16–18,22,24,28,30–32,36,39,41] consistently reported better pain relief and functional improvements, while lower energy densities (<2 J/cm^2)[20,44,45] showed minimal therapeutic effects. This suggests a dose-dependent response, wherein insufficient energy delivery fails to stimulate cellular repair mechanisms, whereas excessive energy may induce inhibitory effects.

The number of sessions and total treatment duration also played a crucial role. Protocols exceeding 4 weeks resulted in more sustained improvements, particularly in arthrogenic TMD, where joint tissue healing requires longer intervention periods. Studies with short treatment durations (≤3 weeks) often reported transient improvements that diminished post-treatment, reinforcing the importance of ongoing maintenance therapy in chronic cases. These findings highlight the need for standardized LLLT protocols, as current clinical guidelines lack consensus on the ideal combination of laser wavelength, energy density, power output, and frequency of application. Future studies should focus on large-scale, multicenter trials comparing different dosimetry parameters to establish optimal clinical guidelines.

4.4. Mechanistic insights: how LLLT modulates TMD pathophysiology

The biological mechanisms underlying LLLT's effectiveness in TMD treatment involve a combination of analgesic, anti-inflammatory, and regenerative effects[64,65]. PBM exerts its primary action on mitochondrial cytochrome c oxidase, leading to increased ATP synthesis, modulation of oxidative stress, and enhanced cellular respiration [59,66]. Several studies have demonstrated that LLLT reduces pro-inflammatory cytokine levels (e.g., TNF-α, IL-1β) and upregulates anti-inflammatory mediators (e.g., IL-10, transforming growth factor-beta, TGF-β). These effects translate into reduced nociceptor activation, lower pain perception, and improved muscle function [67–70].

Additionally, LLLT promotes collagen synthesis and fibroblast proliferation[71,72], which is particularly relevant in arthrogenic TMD where cartilage and connective tissue degeneration contribute to pain and dysfunction. The vasodilatory effects of LLLT further enhance oxygenation and nutrient delivery to affected tissues, accelerating the healing process[73,74]. Given these biological effects, it is evident that LLLT should not be viewed merely as a symptomatic treatment but rather as a modulator of disease progression in TMD. Its ability to reduce inflammation, restore neuromuscular function, and promote tissue regeneration positions it as a valuable adjunctive therapy in both acute and chronic TMD cases.

4.5. Comparison with alternative therapies

A notable advantage of LLLT over conventional therapies such as occlusal splints, NSAIDs TENS is its non-invasiveness and lack of

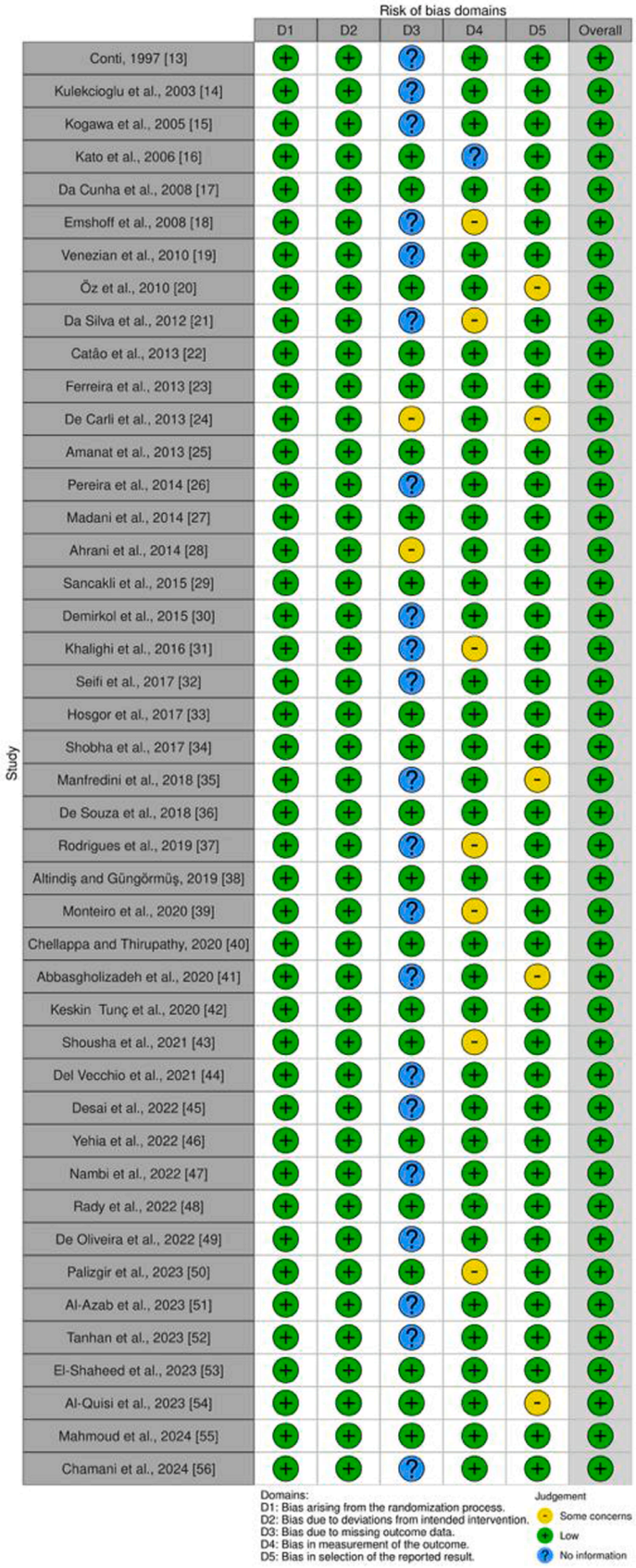

Fig. 2. Risk of Bias of the included studies.

systemic side effects. Studies comparing LLLT to alternative treatments found that LLLT provided faster pain relief than occlusal splints [44], particularly in myogenic TMD; compared to NSAIDs, LLLT exhibited similar or superior analgesic effects without gastrointestinal side effects [33]; and when combined with manual therapy or occlusal splints[22,32,35,37,39,40,43,45,54,55], LLLT enhanced overall treatment outcomes, suggesting synergistic effects with multimodal approaches. Despite these advantages, LLLT is not a universal replacement for conventional treatments but should be integrated into a comprehensive, multidisciplinary management strategy for TMD.

Recent research has highlighted the role of oral appliances in the management of TMD, particularly in patients with osteoarthritic changes in the TMJ. Cone-beam computed tomography (CBCT) studies have demonstrated that oral appliances can contribute to structural adaptations in the TMJ, improving joint space, reducing stress on the condyle, and mitigating degenerative changes[75]. Additionally, CBCT has proven to be an essential tool for assessing osseous changes, cortical integrity, and joint remodeling in response to treatment, providing valuable insights into how oral appliances influence joint health[76,77]. However, despite these promising findings, there is no consensus on the extent to which these appliances can prevent or reverse degenerative changes. Further studies integrating LLLT and oral appliance therapy are needed to determine their combined effectiveness in reducing pain and improving TMJ function and their impact on long-term joint stability.

4.6. Limitations and future directions

Despite its promising results, this review identifies several limitations that warrant consideration:

- Heterogeneity in Study Design: Variability in laser settings, treatment durations, and patient populations complicates direct comparisons across studies.
- Short Follow-up Periods: Many studies lack long-term assessments (>6 months), limiting the ability to evaluate sustained efficacy.
- Small Sample Sizes: Several trials included fewer than 30 participants, reducing statistical power.
- Lack of Standardized Outcome Measures: Many studies relied solely on subjective pain scales, highlighting the need for objective functional assessments (e.g., EMG, MRI, joint kinematics).

Future research should focus on large-scale, multicenter RCTs with standardized protocols to establish evidence-based guidelines for LLLT in TMD. Additionally, studies investigating the molecular mechanisms of LLLT's effects on TMJ cartilage and muscle repair will enhance our understanding of its long-term therapeutic potential.

4.7. Clinical implications

The findings of this review have important clinical implications for the integration of LLLT into routine TMD management:

- LLLT should be considered a first-line or adjunctive therapy, particularly in patients who do not respond to conventional treatments.
- Personalized dosimetry protocols should be developed, tailoring wavelength, energy density, and treatment duration to individual patient needs.
- Multimodal approaches (LLLT + occlusal splints, manual therapy, or physiotherapy) should be prioritized to optimize clinical outcomes.
- Given its high safety profile, ease of application, and effectiveness in pain reduction and functional improvement, LLLT represents a valuable addition to contemporary TMD treatment strategies.

5. Conclusions

In light of the findings discussed in this systematic review, LLLT has demonstrated significant efficacy in managing TMD, particularly in reducing pain and improving mandibular function. The results indicate that LLLT provides superior or comparable outcomes to conventional treatments, such as occlusal splints and NSAIDs, while offering the advantage of being a non-invasive and well-tolerated therapy. The most effective treatment protocols were those that utilized wavelengths between 810 and 940 nm, energy densities of 3–12 J/cm^2, and treatment durations exceeding four weeks, suggesting that LLLT has cumulative therapeutic effects over time.

Despite these promising findings, the variability in laser parameters, study methodologies, and outcome measures across trials highlights the need for standardization. Furthermore, the integration of CBCT imaging has provided valuable insights into TMJ structural adaptations, underscoring the potential role of oral appliances in modifying joint morphology. However, more well-controlled, high-quality RCTs with long-term follow-ups are needed to establish definitive clinical guidelines for LLLT application in TMD treatment.

In conclusion, while LLLT represents an effective and safe therapeutic approach, further refinement of treatment protocols, integration with multimodal therapies, and objective imaging assessments are required to optimize its clinical implementation. By addressing these gaps, future research can contribute to evidence-based guidelines that enhance patient outcomes and facilitate broader adoption of LLLT in TMD management.

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Patient consent statement

Not Applicable. Patient consent was not required for this systematic review

Consent for publication

All authors confirm consent for publication.

Data availability

Data can be made accessible upon publication following approval of a proposal and a signed data access agreement through the corresponding author.

CRediT authorship contribution statement

Leonardo Díaz: Writing – review & editing, Writing – original draft, Visualization, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Lukas Restelli:** Writing – review & editing, Writing – original

draft, Software, Resources, Project administration, Methodology. **Emilia Valencia:** Writing – review & editing, Writing – original draft, Software, Resources. **Damla Ilhan Atalay:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation. **José Manuel Abarca:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Alain Chalple Gil:** Investigation, Data curation, Writing – original draft, Writing – review & editing. **Eduardo Fernández:** Conceptualization, Methodology, Investigation, Formal analysis, Supervision, Writing – original draft, Writing – review & editing, Project administration.

Declaration of competing interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.pdpdt.2025.104558.

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