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Photobiomodulation in Temporomandibular Dysfunction: a Systematic Review

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SUMMARY

Background. Temporomandibular disorder (TMD) is defined as a set of painful or dysfunctional conditions involving masticatory muscles and the temporomandibular joint (TMJ). Photobiomodulation (PBM) is a non-invasive and non-pharmacological therapy method that can prove to be an alternative treatment and generate benefits for the treatment of TMD-related pain.
Methods. The authors conducted a systematic literature review to assess the effectiveness of photobiomodulation (PBM) in the treatment of TMD. Selection criteria included: 1) studies in human subjects, 2) articles without language restriction, and 3) placebo versus control randomized clinical trials. The review covered articles published over the past five years in the databases PubMed, Cochrane Library, Science Direct, and PEDro. Methodological quality assessment followed the PEDro criteria.
Results. A total of 12 articles were included in the review. In these studies, photobiomodulation reduced myogenic and arthrogenic pain. The predominant sites of application of PBM were either predetermined or painful areas of the masseter and temporal muscles and the TMJ. The application of infrared spectrum radiation (wavelength ranging from 790 to 905 nm), with low doses of energy per application point (3 to 8 J/cm^2), three times a week for 8 to 12 weeks, showed the best results.
Conclusions. Based on the results of this review, it is risky to draw definitive conclusions about the effectiveness of PBM for the treatment of TMD.

KEY WORDS

Temporomandibular Joint Disorders; laser therapy; low intensity light therapy; facial pain; lasers.

BACKGROUND

Temporomandibular disorder (TMD) is defined as a set of painful or dysfunctional conditions involving masticatory muscles and the temporomandibular joint (TMJ) (1-3). Muscle dysfunctions are the most prevalent conditions (4). The pain reported by patients with TMD is usually felt in the preauricular region, masticatory muscles, and the temporomandibular region (4). The signs and symptoms are diverse and may include difficulties in chewing, speech, and other orofacial functions (3). Notwithstanding, the most frequent symptoms include tenderness in the masticatory muscles, pain in one or both TMJs, and limited mandibular joint mobility (2). About 40 to 75% of the population shows at least one TMD sign throughout their lives (4). Although TMD occurs in both sexes, women are more susceptible to temporomandibular disorders, with proportions ranging from two to six women for each man (3). The most prevalent age range varies between 20 and 40 years (3). Poor posture, occlusal problems, harmful oral habits, and other clinical abnormalities may lead to TMD, which can also correlate with psychological factors (2). Among these, reports include anxiety, depression, and sleep bruxism (5, 6).
There are several conservative treatment options for TMD reported in the literature (7). Among these options we can mention myorelaxative splints in isolation or associated with

physical therapies, acupuncture, cognitive behavioral therapies and hyaluronic acid injections (7). Photobiomodulation (PBM) is a noninvasive and nonpharmacological therapy method that has shown great benefits for the treatment of TMD-related pain (8). This method uses light radiation within the infrared and visible red light spectrum of electromagnetic waves (8). Whether through low level laser or light emitting diode (LED), PBM is one of the most used noninvasive therapeutic methods by health professionals, such as physiotherapists and dentists, for the treatment of TMD (9). Phototherapy has been used more and more in the field of dentistry in the last thirty decades for its analgesic, anti-inflammatory, and biostimulant effect (10). However, it is not yet fully defined what these effects are and how they are best produced considering the different parameters of PBM used and addressed in the current literature.
Thus, we conducted a search in the scientific literature through a critical analysis of the effectiveness of photobiomodulation in temporomandibular disorder.

MATERIALS AND METHODS

This systematic review was conducted according to the PROSPERO protocol, registered under the number CRD 42020205039. This study meets the ethical standards of Muscles, Ligaments and Tendons Journal (11).

Inclusion and exclusion criteria

The review included randomized clinical trials (RCTs) from the last five years, which addressed the use of photobiomodulation with light emitting diode (LED) or low intensity laser for chronic myogenic and/or arthrogenic pain. The studies should provide a description of the type of LED or laser used, application time, and administration parameters. There was no language restriction. As a comparator, different types of laser, placebo laser, and no treatment (control) were accepted. The main outcome measures were chronic myogenic and/or arthrogenic temporomandibular pain, mandibular range of motion in patients with TMD, and joint function.

Search strategy

Four electronic databases were searched (Cochrane Library, PubMed, PEDro, and Science Direct) from June to November 2020. The search strategies are described in **table I**. Thus, from the published findings, we gathered the most relevant data for the construction of this study (**table I**).

Literature review and eligibility criteria

To determine the eligibility of the identified articles, two of the five collaborators (AMPF, AGB, RBD, RF, MBD) independently selected titles, abstracts, and made the last analysis of the titles and contents. Any disagreement between authors on the study eligibility was resolved by discussion and adjudication by a third reviewer (MBD) as necessary.

Risk of bias

Risk of bias was assessed using the PEDro scale (12). Two authors independently assessed the risk of bias. Disagreements were resolved by discussion and adjudication by the lead author (MBD) as necessary. The results of the methodological quality of the RCTs included in the review are shown in **table II**.

Study analysis

Two of the following five collaborators (AMPF, AGB, RBD, RF, MBD) extracted data on sample characteristics, intervention design, and estimates of the effect of PBM in each study. The studies were described in terms of trial design (sample size, follow-up period, PEDro score), sample characteristics (population, allocation groups), and intervention components (PBM application site, application time, wavelength, treatment frequency, power of the equipment, dosimetry, outcome measures, and outcomes). Estimates of the effect of PBM on TMJ symptoms and function were extracted from each clinical trial.

RESULTS

The electronic search resulted in 120 articles (**figure 1**). After screening, 103 eligible RCTs were excluded for not meeting the eligibility criteria and five for duplication, resulting in 12 trials that provided data and were included in the review. The characteristics of these trials are shown in **table III**.

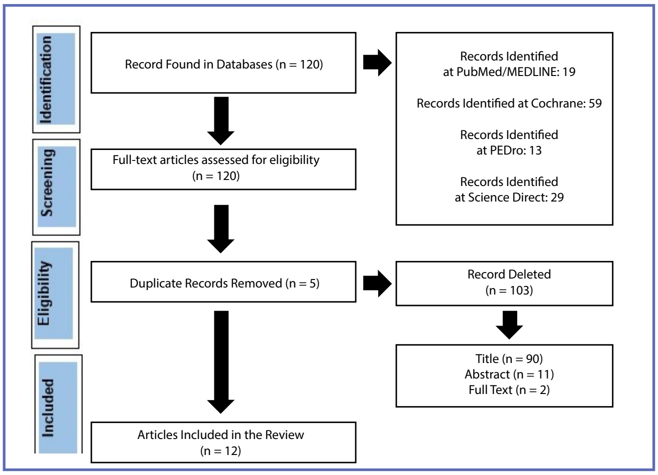

Figure 1. Flowchart with the search strategy used to search tor articles.

Table I. Flowchart of the literature search strategy.

Database	Strategy	Terms
Pubmed/Medline Cochrane Library	#1	"Temporomandibular joint disorders" [Mesh] OR "Disorder, Temporomandibular Joint" [Mesh] OR "Disorders, Temporomandibular Joint" [Mesh] OR "Joint Disorder, Temporomandibular" [Mesh] OR "Joint Disorders, Temporomandibular" [Mesh] OR "Temporomandibular Joint Disorder" [Mesh] OR "TMJ Disorders" [Mesh] OR "Disorder, TMJ" [Mesh] OR "Disorders, TMJ" [Mesh] OR "TMJ Disorder" [Mesh] OR "Temporomandibular Disorders" [Mesh] OR "Disorder, Temporomandibular" [Mesh] OR "Disorders, Temporomandibular" [Mesh] OR "Temporomandibular Disorder" [Mesh] OR "Temporomandibular Joint Diseases" [Mesh] OR "Disease, Temporomandibular Joint" [Mesh] OR "Diseases, Temporomandibular Joint" [Mesh] OR "Joint Disease, Temporomandibular" [Mesh] OR "Joint Diseases, Temporomandibular" [Mesh] OR "Temporomandibular Joint Disease" [Mesh] OR "TMJ Diseases" [Mesh] OR "Disease, TMJ" [Mesh] OR "Diseases, TMJ" [Mesh] OR "TMJ Disease" [Mesh] OR
	#2	"Low-Level Light Therapy" [Mesh] OR "Light Therapies, Low-Level" [Mesh] OR "Light Therapy, Low-Level" [Mesh] OR "Low Level Light Therapy" [Mesh] OR "Low-Level Light Therapies" [Mesh] OR "Therapies, Low-Level Light" [Mesh] OR "Therapy, Low-Level Light" [Mesh] OR "Photobiomodulation Therapy" [Mesh] OR "Photobiomodulation Therapies" [Mesh] OR "Therapies, Photobiomodulation" [Mesh] OR "Therapy, Photobiomodulation" [Mesh] OR "LLLT" [Mesh] OR "Laser Therapy, Low-Level" [Mesh] OR "Laser Therapies, Low-Level" [Mesh] OR "Laser Therapy, Low Level" [Mesh] OR "Low-Level Laser Therapies" [Mesh] OR "Laser Irradiation, Low-Power" [Mesh] OR "Irradiation, Low-Power Laser" [Mesh] OR "Laser Irradiation, Low Power" [Mesh] OR "Low-Power Laser Therapy" [Mesh] OR "Low Power Laser Therapy" [Mesh] OR "Laser Therapy, Low-Power" [Mesh] OR "Laser Therapies, Low-Power" [Mesh] OR "Laser Therapy, Low Power" [Mesh] OR "Low-Power Laser Therapies" [Mesh] OR "Low Level Laser Therapy" [Mesh] OR "Low-Power Laser Irradiation" [Mesh] OR "Low Power Laser Irradiation" [Mesh] OR "Laser Biostimulation" [Mesh] OR "Biostimulation, Laser" [Mesh] OR "Laser Phototherapy" [Mesh] OR "Phototherapy, Laser" [Mesh] OR
	#3	Combining #1 and #2.
Science Direct	#1	"Temporomandibular joint disorders" OR "Temporomandibular joint disorders" OR "TMJ Disorders" OR "TMJ Disorder" OR "Temporomandibular disorders" AND "Photobiomodulation Therapy" OR "Photobiomodulation Therapies" OR "Low Level Laser Therapy" OR "LLLT"
PEDro	#1	"Temporomandibular joint disorders" OR "Temporomandibular joint disorders" AND "Photobiomodulation Therapy"
	#2	"Temporomandibular joint disorders" OR "Temporomandibular joint disorders" AND "Low Level Laser Therapy"

Table II. Quality assessment of the articles included in the review.

	Sancakli *et al.,* **2015 (13)**	**Costa** *et al.,* **2017 (14)**	**Demirkol** *et al.,* **2017 (15)**	**De Oliveira** *et al.,* **2017 (16)**	**Magri** *et al.,* **2017 (17)**	**Magri** *et al.,* **2017 (18)**	**Shobha** *et al.,* **2017 (19)**	**Borges** *et al.,* **2018 (20)**	**Rodrigues** *et al.,* **2020 (21)**	**Magri** *et al.,* **2019 (22)**	**Herpich** *et al.,* **2020 (23)**	**Maracci** *et al.,* **2020 (24)**
1. Eligibility criteria	●	●	●	●	●	●	●	●	●	●	●	●
2. Random distribution	●	●	●	●	●	●	●	●	●	●	●	●
3. Blind allocation				●	●	●			●		●	●
4. Equality between pretreatment groups	●	●	●	●				●	●		●	
5. Blind participants				●	●	●	●	●	●	●	●	●
6. Blind interventionists										●		
7. Blind assessors	●	●		●	●	●	●	●	●	●	●	●
8. Results in 85% of the sample	●	●	●				●	●	●		●	●
9. All subjects received the sorted treatment	●	●	●	●	●	●			●	●	●	●
10. Statistics	●	●	●	●	●	●	●	●	●	●	●	●
11. Measures of precision and variability	●	●	●		●	●	●	●		●	●	●
12. PEDro score	**7**	**7**	**6**	**7**	**7**	**7**	**6**	**7**	**8**	**7**	**9**	**8**

Table III. Characteristics of the studies included in the review.

Author, year	Population	Site of Application of PBM	Subjects	Application Time	Wavelength	Treatment Frequency	Power	Dosimetry	Outcome Measure	Outcome
Sancakli *et al.*, 2015 (13)	30 subjects (21 women and 9 men), mean age: 39.2	LGI: LLLT at the points of greatest pain in the related muscle (masseter and/or temporal); LGII: LLLT at 3 predetermined points in the masseter muscle (upper, middle, and lower points) and three points in the temporal muscle (anterior, middle, and posterior points); PLG: laser device connected, but not programmed	Laser Group I LGI (n=10), laser at the point of greatest pain; Laser Group II LGII (n=10), laser at pre-established points; Placebo Laser Group PLG (n=10)	10 sec per point	820 nm	3 x week; 30 days; Total of 12 sessions	300 mW	3 J/cm² per point	RDC/TMD; Pressure pain threshold PPT); Subjective pain intensity (VAS)	Pain intensity decreased in both laser groups. PPTs of the examined muscles increased in the LLLT groups, but not in the PLG; Vertical movement, lateral excursions, and protrusion improved significantly in the LLLT groups; Pre- and post-treatment VAS scores differed significantly in the LLLT groups, but not in the PLG; LLLT can be an alternative treatment modality in the management of masticatory muscle pain.
Costa *et al.*, 2017(14)	60 subjects with myalgia in the masseter and temporal masticatory muscles	5 irradiation points on each side of the face (anterior, middle, and posterior temporal muscle; superior and inferior superficial masseter muscle)	Group A: Placebo PBM (n=30); Group B: Active PBM (n=30);	28 sec per point	830 nm	Not informed	100 mW	2.8 J per point; Energy density of 100 J/cm²	Pain (VAS); Maximum mouth opening; RDC/TMD	Significant improvement in pain between Groups A and B in the left posterior temporal muscle ($p = 0.025$), left superior masseter muscle ($p = 0.036$), inferior masseter muscle ($p = 0.021$), total pain (left side) ($p = 0.009$), total masseter muscle (left side) ($p = 0.014$), total temporal (left side) ($p = 0.024$), and total pain ($p = 0.035$); No differences between groups for maximum mouth opening.
Demirkol *et al.*, 2017 (15)	46 patients with subjective tinnitus and TMD	External auditory canal	Nd:YAG Laser Group (n=15); 810 nm Laser Group (n=16); Placebo Laser Group (n=15).	Nd:YAG Laser: 20 sec; 810 nm Laser: 9 sec	810 nm or 1064 nm	10 sessions; 5 x week; 2 weeks	25 mW in both	8 J/cm² in both;	VAS; RDC/TMD	There were statistically significant differences in the groups Nd:YAG laser ($p = 0.001$) and 810 nm diode laser ($p = 0.005$), but no difference in the placebo group ($p = 0.065$); Both lasers were effective in treating subjective TMD-related tinnitus.

Author, year	Population	Site of Application of PBM	Subjects	Application Time	Wavelength	Treatment Frequency	Power	Dosimetry	Outcome Measure	Outcome
De Oliveira *et al.*, 2017 (16)	19 subjects, 15 women and 4 men, aged 21-55 years (mean age: 35)	Muscle trigger points; Painful points in the TMJ	660 nm Laser Group (n = not informed) 790 nm Laser Group (n = not informed)	1.06 sec; 0.33 sec	660 nm or 790 nm	3 sessions with 48 hour intervals between them	120 mW	8 J/cm²; duration: 1.06 s; power: 120 at trigger points; 4 J/cm² in the TMJ	Pain (NPS)	Regarding pain levels, there were no statistical differences ($p > 0.05$) between groups at baseline, 24 h, 30 and 90 days. At 180 days, there was a significant difference between group 660 nm and group 790 nm ($p = 0.039$); In the 660 nm group, 75.4% of the painful points had pain recurrence, and 24.6% were treated. For the 790 nm group, 69.1% of the painful points had pain recurrence, and 30.9% were treated; Both treatments showed significant results ($p < 0.001$).
Magri *et al.*, 2017 (17)	91 women (18-60 years), 61 diagnosed with myofascial pain and 30 controls	10 points: masseter (three points: upper, middle, and lower); anterior temporal (three points: upper, middle, and lower); TMJ region (four points forming a cross and a central point)	Laser Group (n=31); Placebo Group (n=30); Control Group (n=30)	Time per point: 10 sec	780 nm	8 sessions; 2 x week	20 mW for masseter and temporal; 30 mW for TMJ;	5 J/cm² for masseter and anterior temporal; 7.5 J/cm² for TMJ	Pain (VAS); Pain sensation (PPT); SF-MPQ Questionnaire	VAS reduction in the LLLT group ($p < 0.05$); No change in PPT in the LLLT group in relation to the control; Active and placebo LLLT were effective in reducing pain and improving the SF-MPQ score in the same way.
Magri *et al.*, 2017 (18)	64 women with TMD	Masseter (three points: upper, middle, and lower); Anterior temporal (three points: upper, middle, and lower); TMJ region (four points forming a cross and a central point)	Laser Group (n=20) Placebo Laser Group (n=21) Control Group (n=23)	Time per point: 10 sec	780 nm	8 sessions; 2 x week	20 mW for masseter and temporal; 30 mW for TMJ;	5 J/cm² for masseter and anterior temporal; 7.5 J/cm² for TMJ	Pain (VAS); Anxiety (Beck Anxiety Inventory); Salivary cortisol; Menstrual cycle	Laser group: 80% pain reduction, placebo: 85%, control: 43%; Women with severe anxiety and in the premenstrual period did not reduce pain with any LLLT; Active and placebo LLLT had similar efficacy during treatment; Women with moderate anxiety, cortisol levels above 10 ng/ml, and without using contraceptives maintain analgesia for longer with active LLLT than with placebo LLLT.

Author, year	Population	Site of Application of PBM	Subjects	Application Time	Wavelength	Treatment Frequency	Power	Dosimetry	Outcome Measure	Outcome
Shobha *et al.*, 2017 (19)	40 patients aged 18-40 years	Center of the upper articular space, approximately 1 cm in front of the tragus and at trigger points	Group 1, Active Laser (n=20) Group 2, Placebo Laser (n=20)	Not provided	Al-GaAs (810 nm)	8 sessions; 2-3 x week	100 mW	6 J/cm²	Pain on movement and at rest (VAS) Mouth opening	Pain reduction in both active and placebo LLLT groups on day 0 ($P = 0.000$), on the 8th session ($P = 0.000$), and at 1 month ($P = 0.001$), with no differences between groups on day 0 ($P = 0.214$), on the 8th session ($P = 0.806$), and at 1 month ($P = 0.230$); Increased mouth opening in both Group 1 ($P = 0.006$) and Group 2 ($P = 0.021$), with no difference between groups before and after treatment ($P = 0.247$ and $P = 0.330$).
Borges *et al.*, 2018 (20)	44 subjects with TMD	4 points in the preauricular region and external auditory meatus	Group 8 J/cm² (n=11); Group 60 J/cm² (n=11); Group 105 J/cm² (n=11);	8 J/cm²: 32 sec; 60 J/cm²: 240 sec; 105 J/cm²: 420 sec	Al-GaAs (830 nm)	10 sessions; 3 x week	30 mW	8 J/cm² and 7.68 J; 60 J/cm² and 57.6 J; 105 J/cm² and 101.12 J	Joint mobility; VAS Fonseca Anamnesis Questionnaire;	All groups decreased pain after intervention ($p < 0.05$); 830 nm PBM was effective in reducing TMD pain and symptoms at all doses tested; Only the dose of 8 J/cm² was effective for maximal opening and protrusion of the mandible.
Rodrigues *et al.*, 2020 (21)	89 women aged 18-60 years (31.94 ± 9.57)	Upper, middle, and lower portions of the masseter muscle; Anterior, middle and posterior bundles of the anterior temporal muscle; 5 points on the lateral portion of the TMJ (lateral pole of the mandible head: lateral, superior, anterior, posterior, and inferior regions)	Active Laser Group (n=34) Placebo Laser Group (n=33)	Continuous mode; TMJ = 50 sec; Masseter and temporal muscles = 20 sec	Al-GaAs (780 nm)	8 sessions; 2 x week	50, 60, and 70 mW	30 J/cm² in the masseter and temporal; 75 J/cm² in the TMJ;	Spontaneous Pain (VAS); Bilateral TMJ Pressure Pain Threshold (PPT);	No correlation was found between myofunctional orofacial condition (MOC) and the perception of TMD pain or severity ($p > 0.05$); Active and placebo LLLT reduced masticatory pain and improved recovery at rest ($p > 0.05$), with no differences between MOC groups.
Magri *et al.*, 2019 (22)	41 women with painful TMD (31.7 ± 5.2 years)	Three points on the masseter (upper, middle, and lower); Three points on the anterior temporal (upper, middle, and lower); Four points in the TMJ region; Distance between points = 1 cm	Laser Group (n=20) Placebo Laser Group (n=21)	Continuous mode; Masseter and temporal muscles = 10 sec; TMJ = 10 sec	Al-GaAs (780 nm)	8 sessions; 2 x week; 4 weeks	20 and 30 mW	5 J/cm² Masseter and anterior temporal; 7.5 J/cm² for TMJ	Spontaneous pain (VAS); RDC/TMD;	At the end of treatment and 6 months later, both active and placebo LLLT were effective in reducing pain ($p < 0.05$); Active LLLT was more effective in reducing pain on palpation ($p = 0.001$) and referred pain ($p = 0.04$) in the TMJ region; Active and placebo LLLT are effective against painful TMD of muscle origin in the short term.

Author, year	Population	Site of Application of PBM	Subjects	Application Time	Wavelength	Treatment Frequency	Power	Dosimetry	Outcome Measure	Outcome
Herpich *et al.*, 2020 (23)	30 women with myogenic TMD	Intraoral application corresponding to the region of the pterygoid muscle	Active PBM Group (n=15) Sham PBM Group (n=15)	300 sec	Portable nine-diode cluster: one laser diode (905 nm), four red LED diodes (670 nm), and four infrared LED diodes (875 nm)	6 sessions; 2 weeks	0.9, 15, and 17.5 mW	Total delivered energy of 39.27 J per point; Energy density per point of 99.67 J/cm²	Pain intensity (VAS) Mandibular ROM Patient-Specific Functional Scale	Active PBM was more effective than sham PBM after 48 h (MD = - 1.57, 95% CI - 3.10 to 2.32) and after six sessions (MD = - 2.70, 95% CI - 4.22 to 1.18); Active PBM was only better after six sessions; No results were found for mandibular range of motion; Improved function between the pretreatment assessment and the assessment after six sessions in the active PBM group (p < 0.04).
Maracci *et al.*, 2020 (24)	30 patients with orofacial pain	LLLT sites in the musculature and TMJs pre-established through manual palpation of the 24 points identified by the RDC/TMD. Sites that presented painful sensitivity were irradiated	Group I, Occlusal Splint (n=10) Group II, LLLT (n=10) Group III, Placebo LLLT (n=10)	22 sec	Al-GaAs (808 nm)	Two LLLT sessions with an interval of 48 hours between them	100 mW	80 J/cm²	RDC/TMD; OHRQoL - Oral Health Questionnaire, Impact Profile for Temporomandibular Disorders (OHIP/TMD);	Group I reduced spontaneous myofascial pain (p = 0.008); Groups II and III did not significantly reduce myofascial pain; Remission of pain on palpation in Group I (p = 0.014) between experimental times; Groups II and III did not improve pain (p = 0.093 and p = 0.069); Groups I and II with reduced OHIP/TMD scores (p = 0.005 and p = 0.005).

TMJ: temporomandibular joint; LLLT: low level laser therapy; NPS: numeric pain scale; sec: seconds; TMD: temporomandibular disorder; PBM: photobiomodulation; ROM: range of motion; Al-GaAs: Aluminum Gallium Arsenide; nm: namometers.

Table IV. Suggested protocol by the authors in TMD approach using FBM.

Parameter	Suggestion
Laser type	AsGaAl or its combination with visible red laser (LEDs).
Wavelength	780 at 803 nm or this combined at 660 nm
Radiation power	100 to 300 mW
Energy (J)	2 to 6 J per point
Energy density	3 to 8 J/cm² per application point.
Application location	Pain points in the masseter and temporal muscles and in TMJ
Frequency	8 to 12 sessions 3 times a week

TMD: temporomandibular disorder; AsGaAl: Aluminum Galium Arsenide; Nm: namometers; J: joule; TMJ temporomandibular joint.

Site of application of photobiomodulation

Among the twelve selected studies, seven applied PBM to the masseter muscle and temporal muscle in association with application to the TMJ (16-19, 21, 22, 24). The most used sites for irradiation were predefined points on the belly of the upper, middle and lower masseter muscle and on the anterior, middle and posterior temporal muscle (17, 18, 21, 22). Another three studies applied PBM to the trigger points of muscle pain (16, 19, 24). Only one study used PBM on the external auditory canal (15). Two studies used PBM only on the muscle belly of the masseter and temporal muscles (13, 14). One study used PBM at defined points in the TMJ region (preauricular region and external auditory meatus) (20). Finally, a study used PBM intraorally on the belly of the pterygoid muscle (22).

Number and duration of photobiomodulation applications

Most studies used PBM treatment twice a week for eight sessions, totaling four weeks of intervention (17-19, 21, 22). One study did not report the time and duration of treatment (14). The other studies included different protocols such as three times a week in a total of twelve sessions (13), ten sessions twice a week (15), three sessions with an interval of 48 hours between them (16), three times a week for ten sessions (17), three times a week for six sessions (23), and two sessions with an interval of 48 hours between them (24).

Photobiomodulation characteristics

Five studies used laser in the 800-830 nm range (13, 14, 19, 20, 24). In these studies, the power ranged from 30 to 300 mW, and the energy density per point ranged from 2.8 J/cm² to 105 J/cm². Four studies used laser irradiation in the range of 780 nm (17, 18, 21, 22). In these studies, the power ranged from 20 to 70 mW, and the energy density per point was 5 to 75 J/cm². Two studies compared different irradiation wavelengths, one comparing the ranges 810 nm and 1064 nm (14) and the other comparing the ranges 660 nm and 790 nm (16). The power ranged from 25 mW (1064 nm) to 120 mW (660 and 790 nm) (16), with dosimetry ranging from 3 to 8 J/cm². Finally, only one study used a laser cluster with irradiation spectra of 670, 875, and 905 nm, with power ranging from 0.9 to 17.5 mW and energy from 39.27 to 99.67 J (24).

Outcome measures

The main outcome measure used in the studies was pain. Ten studies used the visual analog scale (VAS) in their outcome measures (13-15, 17-23). Four studies used the pressure pain threshold (PPT) (13, 17, 18, 21). Only one study used the Numeric Pain Scale (NPS) (16).

Four studies evaluated mouth opening mobility (14, 19, 20, 23). To assess function, five studies used the RDC/TMD questionnaire (13-15,22, 24) and one used the OHIP/TMD (24) questionnaire. In addition to these main measures, a study assessed quality of life using the SF-MPQ questionnaire (17) and a study assessed the level of anxiety, salivary cortisol, and menstrual cycle (18).

Outcomes

All ten studies that assessed pain showed its significant improvement after PBM intervention (13-20, 22, 23). Two out of the four studies that assessed TMJ range of motion (ROM) found an improvement in this outcome (13,20); in the study by Borges *et al*. (20), only the dosimetry of 8 J/cm² improved the variable. Finally, function improved only in the study by Demirkol *et al*. (15).

Risk of bias

The mean PEDro score obtained in the studies was 7.2. Of the included studies, all met the random allocation criteria (100%). Six did not provide information on blind allocation criteria (50%). Eleven studies met the criteria for blind assessment (91.7%), nine for blind participants (75%), and one for blind interventionist (8.3%). Eight studies met the criterion for the descriptions of losses and exclusions, (66.7%). The criteria for the analysis by treatment intention were met in ten studies (83.3%). The results of the risk of bias assessment are shown in **table II**.

DISCUSSION

Temporomandibular disorder (TMD) is defined as a set of disorders originating in the temporomandibular joint region, masticatory muscles, and related structures (9, 13, 14, 16, 17, 18, 22). These disorders correlate with changes in emotional state, behavioral changes, and social interactions (9, 13, 14, 16, 17, 20, 22). The etiology is multifactorial and parafunctional (15). This condition is usually triggered by occlusal conditions, emotional stress, traumas, parafunctional habits (jaw tightness and bruxism), instability in maxillary and mandibular relations, joint laxity, comorbidity of rheumatic or musculoskeletal diseases (15). In this systematic review, we conducted a search in the scientific literature through a critical analysis of the effectiveness of PBM on TMD symptoms, aiming to verify what are the best parameters to achieve this effectiveness.

Photobiomodulation (PBM) is a noninvasive treatment technique used in the clinical practice of both physiotherapy and dentistry for pain relief and tissue regeneration. This technique has shown beneficial results in the TMD approach (16). Many clinical studies have investigated the effects of PBM on TMD, whether of myogenic or arthrogenic origin, through objective and subjective measures to assess pain in these regions (13, 24). Pain is a complex and multidimensional phenomenon based on the individual report of the lived experience. It is susceptible to a variety of factors that can interfere with its perception (21). However, other factors may be more relevant to the perception of pain intensity during mandibular function, such as joint diagnosis, pain catastrophizing, anxiety, previous painful experiences, among others (21).

Photobiomodulation is effective in the treatment of temporomandibular disorder, especially on pain, given its analgesic and anti-inflammatory effects. In this review, ten studies directly assessed the level of joint and muscle pain. All of them demonstrated positive effects of PBM. Pain reduction can be justified by the reduction in the expression of inflammatory cytokines, as well as by the stimulation of local microcirculation in the irradiated area (16, 23). Animal model studies have shown that PBM can reduce proinflammatory substances in TMJ (22). Notwithstanding, the analgesic effect may stem from different endogenous mechanisms such as the release of endogenous opioids, increased production of ATP, reduced production of prostaglandins (especially COX-2), reduced lymphatic metabolism, and secretion of histamine, kinins, and cytokines (16, 19, 22). In association, an increase in the release of endorphins and encephalins can lead both to the modulation of nociceptors and to changes in the transmission of painful nerve impulses (14, 16, 22).

The main mechanism of PBM, however, consists of metabolic activation through the stimulation of the mitochondrial respiratory chain (14-16, 19, 22). This phenomenon increases vascularization and improves oxygen supply in hypoxic cells (15, 16, 22). At the cellular level, PBM releases protons into the cytoplasm. This reduces the permeability of the channels to Na^+ and K^+ ions, decreasing the frequency of the action potential (15). It also accelerates the functional and morphological recovery of severely injured nerve tissues, including damaged cells in the auditory system, and provides therapeutic effects in patients with inner ear disorders (14, 15).

The effects of PBM on the control of moderate pain in patients with painful TMD are quite significant for the improvement of functional patterns of mandibular mobility. Eight of the included studies assessed TMJ function. However, only three of these showed improvement in these variables. The RDC/TMD criteria for Axes I and II have been widely used in clinical studies to characterize physical, psychological, and psychosocial factors associated with TMD. Likewise, the relationship between these factors and RDC/TMD has been suggested as a model for diagnosis and assessment of all clinical conditions of chronic pain (19). Failure to improve function in some studies can be attributed to kinesiophobia associated with the presence of pain rather than to the actual functional limitation of these patients with myofascial pain (18). Herpich *et al.* (23) state that the number of treatment sessions can influence functional improvement, and suggest a greater number of treatment sessions.

Photobiomodulation with infrared light was used in isolation in ten studies included in the review. Two studies used a combination of visible red and infrared laser. The effectiveness of PBM seems to be more pronounced when using infrared laser associated with application protocols involving higher levels of irradiation (energy density and/or power density), greater number of sessions, and higher frequency of application (18, 19).

It is noteworthy that, regarding the treatment of TMD, there is no consensus in the scientific literature on PBM dosimetry, application area, duration, and protocols. This hinders research standardization and comparison of results. In some studies, the technique used consists of applying the laser on the points of greatest pain. Others use laser at predetermined points. Most studies used a protocol with eight to twelve sessions, two to three times a week.

Maracci *et al*. (24) stated that infrared laser applications with an interval of 48 hours between sessions was not enough to remit painful symptoms. In comparison to the placebo treatment, the effects of PBM on the symptomatology of TMD patients can be mitigated after eight sessions (24).

Another important factor is that PBM is not a lasting and permanent treatment for TMD, as the results showed a high rate of pain recurrence. Identifying the etiology of TMJ disorders is extremely important to treat and prevent TMD symptoms. Using PBM in association with other treatment modalities (invasive or not), considering the clinical condition of each patient, seems to be the best alternative (16).

A placebo effect was found in four studies included in the review. This is defined as beneficial health outcomes not directly related to the biological effects of an intervention, but rather to an inert agent (18). Magri *et al*. (17) believe that patients with TMD are susceptible to placebo effects due to the psychological component involved. Moreover, the desire to feel better seems to influence physiological processes, thus leading to a favorable result (20). These effects correlate with beneficial cognitive effects such as stress reduction and modulatory mechanisms of mesolimbic and mesocortical areas related to the expected cure/improvement generated by the proposed intervention (18). The brain mechanisms activated by the placebo effect are similar to those activated by drugs (18).

The psychosomatic context of the patient during any therapy can change the biochemical and neural pathway, generating satisfactory clinical results very similar to those of the proposed effective intervention, although without any intervention (18). The response to placebo differs substantially depending on the characteristics of the pain, with chronic pain being much more susceptible to positive responses than acute pain (17).

CONCLUSIONS

Based on the results of this review, it is risky to draw definitive conclusions about the effectiveness of PBM for the treatment of TMD. The studies have shown many methodological differences, mainly in relation to the number, location, and duration of laser applications, as well as in relation to the characteristics of the laser beam (wavelength, frequency, output, dosimetry). It is therefore not possible to standardize guidelines for effective treatment with PBM. However, it seems clear to us that the use of PBM in the infrared spectrum or its association with red laser, with low energy (J) and energy density (J/cm^2) applications, in the range of 3 to 8 J/cm^2 per point of application, with a total of eight to twelve sessions three days a week, produced more significant effects on pain relief. The effects of PBM on TMJ mobility and function are not yet clear.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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