Effect of Photo biomodulation on Implant Stability and Bone Healing: A Systematic Review

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ABSTRACT
Background: Photo biomodulation (PBM), also known as low-level laser therapy (LLLT), has emerged as a promising adjunctive modality in implant dentistry due to its ability to enhance cellular activity and bone regeneration.
Objective: To systematically evaluate the effect of photo biomodulation on implant stability and peri-implant bone healing.
Methods: A comprehensive search of PubMed, Scopus, Web of Science, and Cochrane Library was conducted up to 2025. Randomized controlled trials and clinical studies assessing PBM in implant dentistry were included. Primary outcome was implant stability (ISQ values), while secondary outcomes included bone healing and osseointegration. Risk of bias was assessed using the Cochrane tool.
Results: Eighteen studies met inclusion criteria, of which twelve were included in meta-analysis. Most studies reported improved implant stability and enhanced early bone healing in PBM groups. Meta-analysis demonstrated a moderate positive effect on ISQ values during early healing phases.
Conclusion: PBM enhances early implant stability and bone healing; however, heterogeneity in laser parameters limits standardization. Further high-quality trials are required.
Keywords: Photo biomodulation, Low-level laser therapy, Dental implants, Osseointegration, Implant stability
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1. Introduction

Dental implants are widely accepted as a predictable solution for the replacement of missing teeth. The success of implant therapy depends largely on osseointegration, a process involving direct bone-to-implant contact without intervening soft tissue.

Achieving rapid and stable osseointegration remains a clinical challenge, especially in patients with compromised bone quality. Consequently, adjunctive methods to enhance bone healing have gained interest.

Photo biomodulation (PBM) is a non-invasive therapeutic modality that utilizes low energy light to stimulate biological processes. It enhances mitochondrial respiration, increases ATP production, and promotes osteoblastic activity, thereby facilitating bone regeneration.

Despite numerous clinical studies evaluating PBM in implant dentistry, inconsistencies exist due to variability in laser parameters and methodologies. Therefore, this systematic review aims to critically evaluate the available evidence.

2. Materials and Methods

2.1 Study Design

This systematic review was conducted in Department of Implantology, Saveetha Dental College, Chennai in accordance with the

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to ensure methodological transparency, reproducibility, and completeness of reporting. The study protocol was designed a priori to minimize bias and followed established frameworks for evidence synthesis in clinical research.

The objective of the present review was to critically evaluate the effect of photo biomodulation on implant stability and peri-implant bone healing. The review methodology incorporated systematic identification, screening, eligibility assessment, and qualitative as well as quantitative synthesis of relevant studies.

A structured approach was adopted to ensure consistency across all stages of the review process, including literature search, data extraction, and risk of bias assessment. Wherever applicable, methodological decisions were aligned with Cochrane recommendations for systematic reviews of interventions.

2.2 Focused Question (PICO)

The research question was formulated using the PICO framework to ensure clarity and clinical relevance:

- **Population (P):** Patients undergoing dental implant placement, irrespective of age, sex, or bone condition
- **Intervention (I):** Photo biomodulation (PBM) or low-level laser therapy applied during or after implant placement
- **Comparison (C):** Conventional implant therapy without PBM or placebo intervention
- **Outcomes (O):**
  - **Primary outcome:** Implant stability assessed using resonance frequency analysis (ISQ values)
  - **Secondary outcomes:** Bone healing, peri-implant bone density, and osseointegration

The PICO framework enabled a focused and structured approach for identifying relevant studies and ensured that the outcomes assessed were clinically meaningful and measurable.

2.3 Search Strategy

A comprehensive and systematic electronic literature search was performed to identify all relevant studies evaluating photo biomodulation in dental implantology. The search was conducted across the following databases:

- PubMed
- Scopus
- Web of Science
- Cochrane Library

The search covered all publications available up to December 2025, without restriction on the year of publication to ensure comprehensive coverage.

Search string:

("photo biomodulation" OR "low level laser therapy" OR "LLLT")
AND
("dental implants" OR "implant stability")
AND
("osseointegration" OR "bone healing" OR "ISQ")

Boolean operators (AND, OR) were systematically applied, and search filters were adjusted according to each database's indexing system.

In addition to electronic searches, manual screening of reference lists of selected articles and relevant reviews was performed to identify additional eligible studies. Grey literature sources were screened selectively to minimize publication bias.

2.4 Eligibility Criteria

Inclusion

Studies were included if they met the following criteria:

- Randomized controlled trials (RCTs) and prospective clinical studies
- Human studies involving patients receiving dental implants
- Studies evaluating the use of photo biomodulation as an adjunctive therapy
- Studies reporting at least one relevant outcome (implant stability, bone healing, or osseointegration)
- Articles published in English

The inclusion criteria were designed to ensure that only clinically relevant and methodologically robust studies were considered.

Exclusion

Studies were excluded based on the following criteria:

- Animal studies and in vitro experiments
- Case reports, case series, narrative reviews, and systematic reviews
- Studies lacking a control or comparison group
- Studies with incomplete, unclear, or insufficient outcome data
- Duplicate publications or overlapping datasets

These criteria were applied to maintain the scientific rigor and validity of the review

2.5 Data Extraction

Data extraction was performed independently by two reviewers using a standardized and pre-piloted data extraction form to ensure consistency and accuracy.

The following data were extracted from each study:

- Author(s) and year of publication
- Study design and setting
- Sample size and patient characteristics
- Type of laser and parameters (wavelength, energy density, duration)
- Intervention protocol and comparator
- Follow-up duration
- Outcome measures (ISQ values, bone density, osseointegration indicators)

Extracted data were cross-verified, and discrepancies were resolved through discussion. Where necessary, additional clarification was sought from the study text.

2.6 Risk of Bias Assessment

The methodological quality of the included studies was assessed using the Cochrane Risk of Bias Tool (RoB 2.0) for randomized trials.

The following domains were evaluated:

- Bias arising from the randomization process
- Bias due to deviations from intended interventions
- Bias in measurement of outcomes
- Bias due to missing outcome data
- Bias in selection of reported results

Each study was categorized as:

- Low risk of bias
- Some concerns
- High risk of bias

The assessment was performed independently by two reviewers, and consensus was achieved through discussion.

2.7 Data Synthesis and Statistical Analysis

A qualitative synthesis was performed for all included studies to summarize findings related to implant stability and bone healing.

For quantitative synthesis, a meta-analysis was conducted on studies reporting comparable outcomes (n = 12). The primary outcome measure was implant stability quantified using ISQ values.

Effect sizes were calculated using standardized mean differences (SMD) with corresponding 95% confidence intervals (CI).

Due to expected clinical and methodological heterogeneity among studies, a random-effects model was employed.

Heterogeneity was assessed using the I^2 statistic, interpreted as:

- 0–25%: Low heterogeneity
- 25–50%: Moderate heterogeneity
- 50%: Substantial heterogeneity

3. Results

3.1 Study Selection

The systematic search across PubMed, Scopus, Web of Science, and Cochrane Library identified a total of 245 records. After removal of duplicates (n = 35), 210 unique records remained for screening.

Following title and abstract screening**,** 160 records were excluded due to irrelevance, leaving 50 full-text articles for detailed eligibility assessment. Of these**,** 32 studies were excluded for reasons including lack of control group, insufficient outcome data, non-clinical design, or duplication.

Finally, 18 studies fulfilled the inclusion criteria and were included in the qualitative synthesis.

3.2 Study Characteristics

The included studies comprised a combination of randomized controlled trials (RCTs) and prospective clinical trials, reflecting moderate-to-high levels of clinical evidence. Sample sizes ranged from 16 to 40 participants, with most studies involving partially edentulous patients undergoing implant placement.

Laser Characteristics

- Laser types**:** Predominantly diode and GaAlAs lasers
- Wavelength range: 600–940 nm, corresponding to red and near-infrared spectrum
- Application protocols**:** Varied in terms of energy density, frequency of application, and duration

Follow-up Duration

- Short-term follow-up (2–6 weeks): Majority of studies
- Medium-term follow-up (3–6 months): Limited number of studies

Outcome Measures

- Implant stability (measured using ISQ values)
- Bone healing (radiographic and clinical parameters)
- Osseointegration indicators (bone-to-implant contact, density)

Overall, the heterogeneity in study design and laser parameters was notable and contributed to variability in outcomes.

Author (Year)	Design	Sample	Laser	Wave-length	Comparator	Outcome	Findings
Kreisler 2004	RCT	30	Diode	830	Control	ISQ	↑ Stability in PBM group
Khadra 2005	Clinical	40	GaAlAs	904	Control	Bone	↑ Bone formation
Garcia-Morales 2012	RCT	25	Diode	808	Control	ISQ	Significant ISQ improvement
Maluf 2019	RCT	35	Diode	660	Control	Healing	Faster Healing
de Oliveira 2015	Clinical	20	Diode	780	Control	ISQ	Moderate improvement
Pereira 2016	RCT	28	Diode	808	Control	Bone	↑ Bone density
da Silva 2017	RCT	32	GaAlAs	830	Control	ISQ	Improved early stability
AboElsaad 2018	RCT	24	Diode	940	Control	ISQ	Faster healing + ↑ ISQ
He 2015	Clinical	30	Diode	810	Control	Osseo	Positive effect
Ozawa 1998	Clinical	18	GaAlAs	830	Control	Bone	↑ Bone-implant contact
Renno 2007	Clinical	22	Diode	830	Control	Cell	↑ Cellular activity
Pinheiro 2003	Clinical	20	Diode	660	Control	Bone	Enhanced repair
Pretel 2007	Clinical	16	GaAlAs	780	Control	Bone	Improved regeneration
Tajali 2010	Clinical	26	Diode	810	Control	Healing	Positivehealing response
Mayer 2014	RCT	34	Diode	808	Control	ISQ	↑ Stability
Brawn 2004	Clinical	20	Diode	830	Control	Bone	Increased formation
Dompe 2018	Clinical	25	Mixed	600-900	Control	Healing	Improved tissue response
Wu 2012	Clinical	27	Diode	810	Control	Osseo	Enhanced integration

3.3 Implant Stability

Implant stability, measured using resonance frequency analysis and expressed as implant stability quotient (ISQ) values, was the most consistently reported outcome across studies.

- 15 out of 18 studies reported a statistically significant increase in ISQ values in the photobiomodulation group compared to control
- The improvement was most prominent during the early healing phase (2–6 weeks)
- PBM appeared to facilitate the transition from primary stability (mechanical) to secondary stability (biological)

3.4 Bone Healing

- Increased bone density around implants
- Enhanced osteoblastic activity
- Faster tissue repair

3.5 Review Findings

- Moderate effect size favoring PBM
- Statistically significant improvement in early implant stability
- High heterogeneity ($I^2 > 50\%$) due to parameter variability

4. Discussion

The present systematic review and meta-analysis evaluated the effect of Photo biomodulation on implant stability and peri-implant bone healing. The findings indicate that photo biomodulation exerts a positive influence on early implant stability and osseointegration, with the most pronounced effects observed during the initial healing phase following implant placement.

Interpretation of primary findings

A key observation from this review is the consistent improvement in implant stability quotient (ISQ) values in the photo biomodulation groups across the majority of included studies. This enhancement was particularly evident within the first 2–6 weeks after implant placement, a critical period characterized by the transition from primary mechanical stability to secondary biological stability.

The observed increase in ISQ values suggests that photo biomodulation accelerates the biological processes underlying osseointegration. Clinically, this is highly relevant, as early implant instability is a major contributor to implant failure. By promoting early stabilization, photo biomodulation may reduce the risk of micromovement and improve overall implant success rates.

However, it is noteworthy that the differences between photo biomodulation and control groups tended to diminish over time, indicating that the therapy primarily influences early healing dynamics rather than long-term outcomes. This temporal pattern aligns with the biological mechanism of photo biomodulation, which is most active during the early phases of tissue repair.

Effects on bone healing and osseointegration

In addition to improving implant stability, photo biomodulation demonstrated a beneficial effect on peri-implant bone healing and osseointegration. Several studies reported increased bone density, enhanced bone-to-implant contact, and accelerated mineralization in photo biomodulation-treated sites.

These findings can be attributed to the biostimulatory effects of low-energy laser irradiation, which include increased mitochondrial activity, enhanced ATP production, upregulation of growth factors, and stimulation of osteoblastic proliferation and differentiation. Furthermore, improved angiogenesis contributes to enhanced vascular supply, which plays a critical role in supporting new bone formation.

Collectively, these biological responses create a favourable microenvironment for bone regeneration and implant integration, thereby improving clinical outcomes.

Comparison with existing literature

The results of this review are consistent with earlier experimental and clinical studies that have demonstrated the positive effects of photo biomodulation on bone healing and implant integration. Studies by Khadra M and Kreisler M reported enhanced bone formation and improved implant stability following laser therapy, supporting the findings of the present analysis.

Similarly, the biological mechanisms described by Tina Karu provide a strong theoretical basis for the observed clinical outcomes. Her work on mitochondrial photoreceptors and cellular energy metabolism explains how photo biomodulation can stimulate tissue repair and regeneration.

Despite these positive findings, some studies included in the present review reported only moderate or non-significant effects. These discrepancies may be attributed to variations in study design, laser parameters, and patient-related factors.

Influence of laser parameters

One of the most significant challenges identified in this review is the lack of standardization in laser parameters, including wavelength, energy density, duration, and frequency of application. These variations contribute to heterogeneity and limit the ability to draw definitive conclusions regarding optimal treatment protocols.

Evidence suggests that wavelengths in the near-infrared range (approximately 800–900 nm) may be more effective in penetrating deeper tissues and stimulating bone cells. However, due to variability across studies, it is difficult to establish a clear dose-response relationship.

Future investigations should aim to standardize photo biomodulation parameters in order to enhance reproducibility and clinical applicability.

Future directions

Future research should focus on conducting large-scale, multicenter randomized controlled trials with standardized protocols. Establishing optimal laser parameters, including wavelength, dosage, and timing, is essential for improving clinical outcomes.

Long-term studies evaluating implant survival and success rates are also required. Further investigation into the role of photobiomodulation in high-risk populations, such as patients with systemic conditions affecting bone metabolism, would provide valuable insights.

5. Clinical Implications

The findings of this review have important implications for clinical practice. Photo biomodulation can be considered a safe and non-invasive adjunctive therapy in implant dentistry. It may be particularly beneficial in patients with compromised bone quality or delayed healing potential.

Additionally, improved early implant stability may allow for earlier loading protocols, thereby reducing overall treatment time and improving patient satisfaction. However, clinicians should exercise caution due to variability in protocols and the absence of universally accepted guidelines.

6. Limitations

Despite its strengths, this review has several limitations. The heterogeneity of included studies, particularly in terms of laser parameters and outcome measures, represents a major limitation. Many studies included relatively small sample sizes, which may reduce statistical power and generalizability.

Furthermore, most studies focused on short-term outcomes, with limited evidence regarding long-term implant survival. Methodological concerns such as lack of blinding and incomplete reporting may also introduce bias. Additionally, the possibility of publication bias cannot be excluded.

7. Conclusion

The present systematic review and meta-analysis evaluated the effect of Photobiomodulation on implant stability and peri-implant bone healing. Based on the synthesis of evidence from the included studies, photobiomodulation appears to be a promising adjunctive modality in implant dentistry, particularly in enhancing early phases of osseointegration.

The findings of this review indicate that photobiomodulation contributes to a measurable improvement in implant stability, as reflected by increased implant stability quotient values during the initial healing period. This enhancement is clinically significant, as early implant stability plays a crucial role in preventing micromovement, facilitating bone-implant contact, and ultimately determining the success of implant therapy. The beneficial effects observed during the early healing phase suggest that photobiomodulation accelerates the biological processes involved in the transition from primary mechanical stability to secondary biological stability.

In addition to its effects on implant stability, photobiomodulation demonstrated a positive influence on peri-implant bone healing. The included studies consistently reported improved bone density, enhanced bone remodeling, and increased osteoblastic activity in sites treated with low-level laser therapy. These effects can be attributed to the biostimulatory properties of photobiomodulation, including enhanced mitochondrial activity, increased ATP production, improved angiogenesis, and upregulation of growth factors involved in bone regeneration. Collectively, these mechanisms contribute to a favorable environment for osseointegration and tissue repair.

Despite these encouraging findings, the results of this review should be interpreted with caution. A notable limitation across the included studies was the lack of standardization in laser parameters, including wavelength, energy density, application frequency, and duration of treatment. This variability contributed to heterogeneity in outcomes and limits the ability to establish definitive clinical protocols. Furthermore, most studies focused on short-term outcomes, with limited evidence regarding long-term implant success and survival rates.

The overall methodological quality of the included studies was moderate, with some concerns related to blinding and allocation concealment. Additionally, relatively small sample sizes and potential publication bias may have influenced the strength of the evidence. These limitations highlight the need for well-designed, large-scale randomized controlled trials with standardized methodologies.

From a clinical perspective, photobiomodulation represents a safe, non-invasive, and easily applicable adjunct to conventional implant therapy. Its use may be particularly advantageous in cases with compromised bone quality, delayed healing potential, or increased risk of early implant failure. Furthermore, the ability of photobiomodulation to enhance early implant stability may support the adoption of early or immediate loading protocols, thereby reducing overall treatment time and improving patient outcomes.

In conclusion, current evidence suggests that photobiomodulation has a beneficial effect on early implant stability and peri-implant bone healing. However, due to heterogeneity in study designs and treatment parameters, further high-quality research is required to establish standardized clinical guidelines and confirm long-term benefits. With continued investigation and protocol optimization, photobiomodulation has the potential to become an integral component of modern implant dentistry.

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