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Influence of Photobiomodulation on Early Marginal Bone Remodelling and Implant Stability Following Implant Placement

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ABSTRACT: Although dental implant treatment for the rehabilitation of missing teeth is a predictable treatment modality, the early healing period has been described as critical since a physiological decrease in stability and crestal bone remodeling are unavoidable and can jeopardize the results, which is why a non-invasive method such as photobiomodulation (PBM) has been proposed to modulate this healing period. This single blind, randomized, sham-controlled clinical trial investigated the effect of PBM on early marginal bone remodeling and implant stability after implant placement. A total of 40 patients who needed one posterior implant were randomly assigned to the PBM and sham groups (20 patients in each group). The PBM group received an 810 nm gallium-aluminium-arsenide (4 J per point, continuous mode, 100 mW) diode laser immediately after surgery and on days 3, 7 and 14. The implant stability quotient (ISQ) determined by resonance frequency analysis (RFA) was recorded at the baseline and at 4, 8 and 12 weeks and the MBL was measured on standardized periapical radiographs at baseline and at 12 weeks. ISQ values were similar across the groups at baseline, and the PBM group showed significantly higher ISQ scores at 4, 8 and 12 weeks, and did not experience the early stability decline seen in the sham group. PBM had significantly less mean MBL at 12 weeks compared to the sham group. In the settings that it was used, adjunctive PBM contributed to improved early implant stability and decrease in EMBL, which could help it to be used during the initial healing period within its limitations. Longer follow-up and larger multi-centre trials are warranted.

1. INTRODUCTION

Osseointegrated dental implants have been well documented and predictable methods for replacing missing teeth, and long-term success rates can often be greater than 95% when used in the appropriate patient population (Albrektsson et al., 1986; Das A et al., 2014). Osseointegration (Bhatt S et al.,2025) is the formation and maintenance of a direct structural and functional relationship between living bone and implant surface which governs the clinical performance of the implant. This is followed by two events of clinical importance during the first few weeks after implant placement: a decrease in implant stability and remodeling of the crestal bone around the implant neck.

Primary and secondary stability are the terms that conventionally describe stability of implants. There are two forms of primary stability: mechanical stability, which is created during the initial implantation of the implant into the bone, and biological stability, which is achieved by the deposition of woven bone and its subsequent remodeling at the implant-bone interface (Reddy KS, 2025). This shift from one kind of stability to the other results in a well-known "stability dip" which is most often noted between the second and fourth week of healing where there is a decrease in mechanical retention, which has not yet been matched by the establishment of new bone. It is considered as the most critical time in the life of the implant, and any attempt to reduce the depth and/or duration of the dip is clinically beneficial.

The remodeling of the marginal bone around the implant neck during initial healing should also be taken into account, since it has been linked to soft tissue recession, peri-implant disease and poor long term survival. Therefore, it is important to preserve the marginal bone during the early healing period in order to ensure implant success and esthetic outcome.

Photobiomodulation (PBM) or low level laser therapy is a non-thermal light therapy, which refers to the use of light at a range of wavelengths from the red to near infrared (NIR) that produce photochemical effects in the tissue being illuminated. The chief molecular target is the cytochrome c oxidase of the mitochondrial respiratory chain, photosensitisation of which boosts electron transport, ATP production and alters ROS and intracellular signalling (Karkar M, 2025; Hamblin, 2017). All of these events at the tissue level are beneficial to bone healing around implants, as they increase proliferation and differentiation of osteoblasts, stimulate angiogenesis and attenuate the inflammatory response.

Experimental research has given substantial evidence for the benefits of PBM in the field of implant dentistry. Irradiation has been found to enhance bone to implant contact, functional attachment and mineralization in animal studies (Nayyar A et al., 2026) and to increase secondary stability in animal studies using resonance-frequency and histomorphometric analysis. Clinical investigations have since reported increased implant stability quotient (ISQ) and decreased crestal bone loss after PBM, but with some studies finding no statistically significant difference (Gulati et al., 2020; Camolesi et al., 2023; Shenoy et al., 2024). Systematic review results have suggested that the irradiation of PBM may be useful for early implant stability, but a high degree of heterogeneity in the parameters, timing, and outcome measures of irradiation have been found, and well-designed randomized controlled trials (RCT) are recommended (Chen et al., 2019).

Due to the biological plausibility of the approach and the conflicting clinical evidence available, additional controlled data are needed to determine if there is a meaningful effect on the early healing phase. The purpose of the present randomized, sham-controlled clinical trial, was therefore, to assess the effect of PBM on early marginal bone remodeling and implant stability after implant placement. The null hypothesis tested was that there would be no difference between the ISQ or between early marginal bone loss between implants treated with PBM and sham-irradiated implants.

2. MATERIALS AND METHODS

2.1. Study design and ethical approval

This study was a randomized clinical trial with sham control, parallel group, and single-blinded design that was performed in compliance with the Declaration of Helsinki (2013 revision). The study protocol was reviewed and approved by the Institutional Research Ethics Committee. All candidates were informed about the nature, benefits and possible risks of the procedures and all participants gave written informed consent prior to enrolment. The CONSORT statement for RCTs was followed in preparing the manuscript.

2.2. Participants and eligibility criteria

The adult population was screened if they were systematically healthy and needed just one dental implant to replace a missing posterior tooth in the mandible or maxilla. Patients were included if they were between 20 and 60 years old, had sufficient residual bone volume for the installation of a dental implant with a diameter of at least 3.5 mm and a length of 8 mm, maintained good oral hygiene and were able to attend the follow-up visits scheduled. Exclusion criteria included uncontrolled systemic disease (including uncontrolled diabetes mellitus), current smoking, pregnancy or lactation, history of head and neck radiotherapy, current or recent bisphosphonate therapy, untreated periodontal disease, bruxism and any local condition which required bone augmentation at the time of placement.

2.3. Sample size and randomization

The sample size was estimated based on the ISQ as the primary outcome. If the difference in mean ISQ between groups was at least 3 units and the standard deviation was the same for both groups, then at least 17 implants per group were needed for a 2 sided test at 95 percent confidence level with 80 percent power. 20 participants were assigned to each group, with an additional 20 implants (total 40 implants) being used in case of dropouts. Participants were randomly allocated (1:1) to the PBM group or the sham group, by computer-generated random allocation sequence. Allocation was done in a way that was hidden in sequentially numbered, opaque, sealed envelopes opened after placement of implants. The outcome assessor and the statistician were blinded to the group allocation and due to the nature of the intervention, the operator delivering the laser therapy was not blinded.

2.4. Surgical procedure

The surgery for all implants was performed under local anaesthesia by a single experienced surgeon and in two stages, following a standardized procedure. A full-thickness mucoperiosteal flap was incised and elevated, and the osteotomy was prepared using the sequential drilling protocol recommended by the implant manufacturer, while irrigating freely with saline and the implant was inserted at an insertion torque of 30-45 Ncm and with a bone level implant. A cover screw was put on and the flap was re-positioned and sutured for submerged healing. Sutures were removed 7-10 days after surgery and standardised post-operative instructions, analgesics and 0.12% chlorhexidine mouthrinse were prescribed.

2.5. Photobiomodulation protocol

In the PBM group, the irradiation was carried out using an 810 nm gallium-aluminium-arsenide (GaAlAs) diode laser that had a continuous wave output power of 100 mW. The laser was used in non-contact mode with the probe placed at an angle of 90 degrees and at a distance of ~1 mm from the mucosa at 3 positions around the implant site (buccal, lingual/palatal and occlusal). Energy delivered per point (s) was 4 J/point and total per session was 12 J/session. Each application of PBM was done right after surgery and on days 3, 7 and 14, making four applications. The same handpiece was used in the same locations for the same time in the sham group, but the emission was turned off, thus maintaining the blinding of the participant. The parameters used in the irradiation are summarized in Table 1. Throughout standard laser safety precautions were taken, such as wearing protective eyewear by the patient and the operators.

Table 1. Photobiomodulation irradiation parameters used in the test group.

Parameter	Value
Device / active medium	Diode laser (gallium-aluminium-arsenide, GaAlAs)
Wavelength	810 nm (near-infrared)
Operating mode	Continuous wave
Output power	100 mW
Emission / probe	Non-contact, perpendicular to mucosa
Energy per point	4 J (40 s per point)
Irradiation points	Buccal, lingual/palatal, occlusal (3 points)
Energy per session	12 J
Treatment schedule	Immediately post-surgery and on days 3, 7 and 14
Number of sessions	4
Total energy delivered	48 J

2.6. Outcome measures

The main outcome was implant stability which was assessed by resonance frequency analysis (Osstell device) using a dedicated transducer screwed onto the implant and presented as implant stability quotient (ISQ). Two mutually perpendicular readings (buccolingual and mesiodistal) were taken at each time point and averaged. ISQ was measured at the time of implant placement (baseline) and at 4, 8 and 12 weeks after surgery. The secondary outcome was the determination of early marginal bone remodeling, defined as marginal bone loss (MBL) on standardized digital periapical radiographs obtained by using a bite index equipped with a standardized geometry and the paralleling technique. The distance between the implant shoulder and first bone to implant contact was determined from both the mesial side and the distal side of the implant and the average value was calculated and used for analysis with calibrated imaging software. All measurements were taken by the same examiner who was calibrated and blinded, and MBL was defined as the difference between the baseline and 12 weeks. All clinical procedures, complications and implant survival were also recorded.

2.7. Statistical analysis

The data were analyzed with the use of standard statistical software and the significance was taken at $p < 0.05$. Shapiro-Wilk tests were used to test the normalcy of the distributions. Data for continuous variables are presented as mean ± standard deviation. Independent-samples t-test was used to compare between-group differences at each time point, while repeated measures analysis of variance (ANOVA) was used to compare within and between group differences over time, with post-hoc correction. The chi-square or Fisher exact test was used to compare categorical variables, as appropriate.

3. RESULTS AND DISCUSSION

A total of 40 participants (20 in the PBM group and 20 in the sham group) completed the study, and no patient was lost to follow-up. The two groups were comparable at baseline with respect to age, sex distribution, implant location and implant dimensions, and no statistically significant differences were detected in these variables (Table 2). All 40 implants remained clinically osseointegrated at the 12-week evaluation, and no adverse events attributable to the laser therapy were observed, giving an implant survival rate of 100% over the observation period.

Table 2. Baseline characteristics of the study groups.

Characteristic	PBM group (n = 20)	Sham group (n = 20)	p-value
Age (years), mean ± SD	42.6 ± 9.8	43.9 ± 10.2	0.68
Sex (male / female)	11 / 9	10 / 10	0.75
Implant location (mandible / maxilla)	12 / 8	13 / 7	0.74
Implant diameter (mm), mean ± SD	4.1 ± 0.3	4.0 ± 0.3	0.29
Implant length (mm), mean ± SD	10.3 ± 1.1	10.1 ± 1.2	0.58
Insertion torque (Ncm), mean ± SD	37.8 ± 4.2	38.3 ± 4.5	0.72

The ISQ values recorded at each time point are presented in Table 3 and illustrated in Figure 1. At baseline, the mean ISQ was 71.2 ± 4.3 in the PBM group and 70.8 ± 4.6 in the sham group, with no significant difference between the two ($p = 0.78$), confirming comparable primary stability at the time of placement. At 4 weeks, the sham group exhibited a decline in mean ISQ to 69.1 ± 4.2, consistent with the physiological stability dip that accompanies the transition from primary to secondary stability, whereas the PBM group maintained and slightly increased its stability to 72.8 ± 3.9; this difference was statistically significant ($p = 0.01$). The divergence between groups became more pronounced at 8 weeks (76.1 ± 3.5 versus 72.0 ± 3.8; $p < 0.001$) and at 12 weeks (78.9 ± 3.1 versus 74.3 ± 3.6; $p < 0.001$). Repeated-measures ANOVA confirmed a significant group-by-time interaction, indicating that stability increased more rapidly in the irradiated implants.

Table 3. Implant stability quotient (ISQ) values at each time interval (mean ± SD).

Time interval	PBM group	Sham group	p-value
Baseline (placement)	71.2 ± 4.3	70.8 ± 4.6	0.78
4 weeks	72.8 ± 3.9	69.1 ± 4.2	0.01*
8 weeks	76.1 ± 3.5	72.0 ± 3.8	<0.001*
12 weeks	78.9 ± 3.1	74.3 ± 3.6	<0.001*

**Statistically significant (p < 0.05).*

Early marginal bone remodeling followed a comparable pattern (Table 4, Figure 2). At 12 weeks the mean marginal bone loss was 0.42 ± 0.18 mm in the PBM group and 0.79 ± 0.24 mm in the sham group, a difference that was statistically significant ($p < 0.001$). When the mesial and distal sites were analysed separately, both showed significantly less bone loss in the irradiated group, indicating a consistent circumferential effect rather than a site-specific artefact. The magnitude of crestal bone loss in both groups remained within the range considered compatible with implant health, but the reduction achieved with PBM is clinically relevant because early crestal preservation is associated with improved soft-tissue stability and long-term prognosis.

Table 4. Marginal bone loss (mm) from baseline to 12 weeks (mean ± SD).

Site	PBM group	Sham group	p-value
Mesial	0.40 ± 0.19	0.77 ± 0.25	<0.001*
Distal	0.44 ± 0.20	0.81 ± 0.26	<0.001*
Mean marginal bone loss	0.42 ± 0.18	0.79 ± 0.24	<0.001*

**Statistically significant (p < 0.05).*

The present trial rejected the null hypothesis: adjunctive PBM significantly improved early implant stability and reduced early marginal bone loss compared with sham irradiation. The most clinically meaningful finding was the behaviour of the two groups during the fourth week, when the sham implants displayed the expected stability dip while the irradiated implants did not. Because this interval represents the period of greatest susceptibility to failure, attenuation of the dip provides a plausible mechanism by which PBM may enhance the safety of early or accelerated loading protocols.

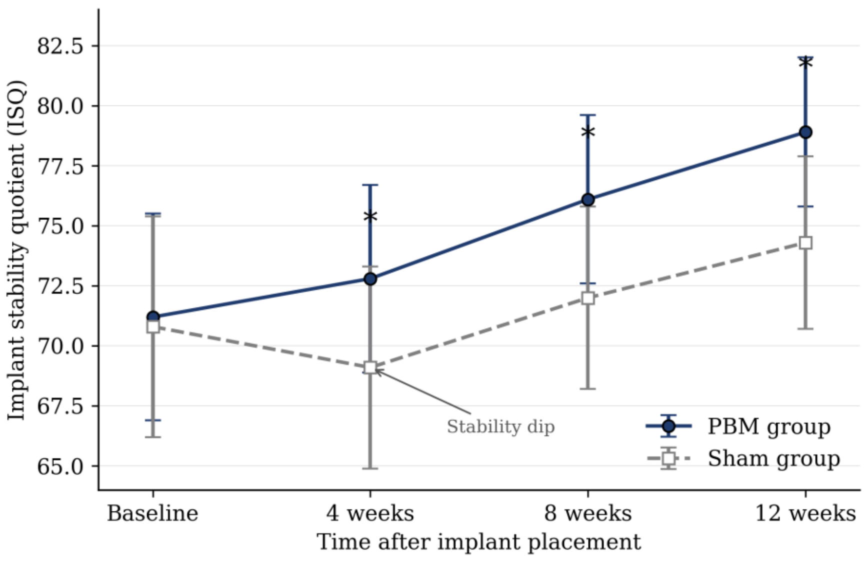

Figure 1. Mean implant stability quotient (ISQ) values in the photobiomodulation (PBM) and sham groups at baseline and at 4, 8 and 12 weeks after implant placement. Error bars represent one standard deviation; asterisks (*) indicate a statistically significant between-group difference ($p < 0.05$).

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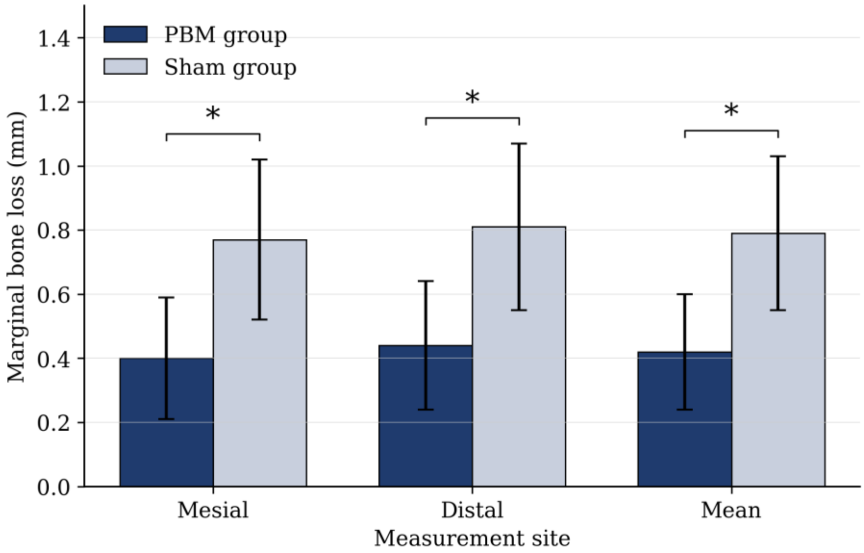

Figure 2. Mean marginal bone loss (mm) at the mesial and distal sites and overall mean from baseline to 12 weeks in the photobiomodulation (PBM) and sham groups. Error bars represent one standard deviation; asterisks (*) indicate a statistically significant between-group difference ($p < 0.05$).

DISCUSSION

The above observations are consistent with the mechanisms of action of PBM as described in the biological world. Near-infrared absorption by cytochrome c oxidase enhances adenosine triphosphate production in mitochondria and regulates redox signalling, which triggers proliferation and differentiation of osteoblasts, drives angiogenesis and suppresses the initial inflammatory response (Karkar M, 2025; Hamblin, 2017). Improved bone formation and mineralization around the implant promote the development of secondary stability and favor crestal bone preservation. The experimental findings of Nayyar A et al. (2026) that showed higher functional attachment, bone-to-implant contact, and calcium and phosphorus content in irradiated implants, directly supports the clinical improvements seen in the present study.

The clinical results presented here confirm those of a few earlier randomized studies. Shenoy et al. (2024) found that there was significantly higher ISQ in laser-treated implants at 2 weeks and 3 months, while Camolesi et al. (2023) noted that there were positive outcomes with PBM on stability and postoperative healing. The same was seen by Gulati et al. (2020) after performing low-level laser therapy on implants. The direction of effects for the present study are within the range of these reports as well as the systematic review by Chen et al. (2019), and the magnitude of effects in the present study are within the range of those in the two reports. It should, however, be noted that the literature is not consistent; some trials have not reported any significant effect of PBM on stability, which is generally thought to be due to differences in the wavelength, energy density, number of sessions and timing of irradiation, and even to the biphasic dose–response curve of PBM, where both too little and too much energy produces no therapeutic effect.

The advantages of this trial are that it was randomized, sham controlled, allocation concealment was used, outcome assessment was blinded, and there were no drop-outs, the surgical and radiographic protocols were standardized, and the trial was well conducted. However, there are several limitations to interpret the results. The follow-up period did not allow for conclusions about long-term marginal bone stability and implant survival, and was limited to the early healing period of 12 weeks. This sample was obtained from one center and included only patients with single posterior implants who were systemically healthy, and who did not smoke, and may not be generalizable. Lastly, one irradiation protocol was tried, but the best available conditions (wavelength, dose, frequency) of treatment have yet to be determined. In summary, additional multicentre trials with larger patient numbers, longer follow-up and uniform dosimetry with preferably the inclusion of biomarker and histological correlates are recommended to substantiate and consolidate the above results..

4. CONCLUSION

In the context of this randomized, sham-controlled clinical study, using 810 nm diode laser for adjunctive photobiomodulation had a favourable effect on the early phase of healing following implant placement. The values of the implant stability quotient were significantly higher for irradiated implants at 4, 8 and 12 weeks, and they did not show the physiological drop in implant stability at 8 weeks as was observed in the sham group of irradiated implants.The irradiated implants did not show the physiological decrease in implant stability at 8 weeks and had significantly less marginal bone loss at 12 weeks than did the other irradiated and sham groups. The findings suggest that PBM is safe and non-invasive and can provide a beneficial adjunct to improve initial implant stability and promote crestal bone conservation. Due to this heterogeneity of the previously reported protocols, further multicentre trials with homogeneous dosimetry and a longer follow-up period are needed to define the best irradiation parameters and to confirm the long-term benefit of the treatment.

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Author contributions

Karthi Kumar Murari: conceptualization, methodology, investigation and writing of the original draft. Muhamood Moothedath: methodology, formal analysis and writing (review and editing). S. Sai Himaja: investigation, surgical procedures and data curation. Md Kafeel Ahmed: investigation, resources and validation. Muzammil Moin Ahmed: formal analysis, statistical analysis and writing (review and editing). Salman Tarique Ansari: methodology, supervision and writing (review and editing). Rubeena Naaz: investigation, data curation and project administration. All authors read and approved the final version of the manuscript.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics statements

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Research Ethics Committee (approval number: [insert reference number]). Written informed consent was obtained from all individual participants included in the study.

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