Outcomes of Mandibular Overdentures Supported by Four Short Implants Combined with Photobiomodulation Therapy

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Purpose: The aim of this study was to clinically and radiographically evaluate mandibular overdentures supported by four short implants combined with two different doses of photobiomodulation (PBM). ***Materials and Methods:*** A split-mouth design was applied; six completely edentulous male subjects received four short implants in the canine and second premolar area. Short implants were inserted via a digital fully guided approach with a stereolithographic surgical guide. All patients received five PBM sessions immediately after surgery and every 48 hours. Group A (n = 6) implants on the right side received a dose of 3.75 J/cm^2, and group B (n = 6) implants on the left side received a dose of 7.5 J/cm^2. Evaluation of peri-implant probing depth (PIPD), modified Gingival Index (MGI), and vertical bone loss was performed at the time of prosthetic loading and 6 and 12 months later. The implant stability quotient (ISQ) was also assessed 6 and 12 months after loading. ***Results:*** There was no significant difference between both groups regarding PIPD values. However, a minor but significant increase from the baseline ($P < .001$) was observed in PIPD values in both groups after 12 months. The MGI scores at the different time intervals were very low for both groups. The mean vertical bone loss after 12 months was minimal for both groups but statistically significant from the baseline ($P < .001$). ISQ values for both groups after 12 months revealed a significant increase from the baseline, and group B values were significantly higher than those of group A. ***Conclusion:*** Within the limitations of this study, a mandibular overdenture supported by four short implants is a valid treatment modality for atrophic mandibles, and a PBM dose of 7.5 J/cm^2 has a potential positive influence on implant healing and osseointegration. *Int J Oral Maxillofac Implants 2021;36:379–387. doi: 10.11607/jomi.8909*

Keywords: atrophic mandible, guided implant surgery, photobiomodulation, short dental implant

Edentulism continues to be a debilitating and distressing condition for millions of adults across the globe. The repercussions of edentulism on general and oral health are well documented. These include: altered normal physiology, impaired mastication, and functional and sensory deficiencies of the oral mucosa and oral muscles.[1] In long-term denture wearers, alveolar bone resorption may be extensive, and after several years, the alveolar ridge may be entirely resorbed and only the basal bone is left. Due to the diminished surface area, the anatomy, and the unreliable peripheral seal, atrophic mandibular edentulous ridges present numerous challenges for rehabilitation.[2]

A well-documented treatment option is to place dental implants to support a mandibular overdenture.[3,4] Nevertheless, anatomical limitations may hamper implant placement. Consequently, additional aggressive surgical procedures, such as block bone grafting, alveolar distraction osteogenesis, and nerve repositioning, are mandatory to overcome the anatomical limitations and the vertical bone deficits for placement of a standard-length implant. These procedures are technique sensitive, time consuming, and involve higher cost to the patient, in addition to increased surgical morbidity and devastating complications, such as infection, hemorrhage, and nerve injury.[5,6]

Placement of short implants may be considered a valid alternative to advanced bone augmentation surgeries.[7–11] According to the 11th European Consensus Conference in 2016, implants are denoted as short if their designed intrabony length measures ≤ 8 mm with diameters ≥ 3.75 mm.[12] Short implant placement is in alignment with the ongoing notable trend in the medical arena toward minimally invasive surgical techniques. These techniques are advocated to genuinely increase patient comfort during the postoperative period while reducing morbidity and complications. Minimally invasive approaches also include virtual presurgical planning and flapless implant insertion by computer-guided implant surgery. It allows predictable implant placement and decreases human error

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intraoperatively, thereby reducing the possibility of damage to the adjacent vital structures. Furthermore, the available bone can be utilized optimally, and bone grafting can be evaded, or at least planned in advance in the best possible way.[13–15]

Another promising modality is photobiomodulation (PBM) therapy, which has been demonstrated to be potentially effective in accelerating the healing process and new bone formation. The logic behind that is its efficacy on the cellular level to stimulate biochemical and molecular processes involved in tissue healing. It can accelerate healing around the surgical site via an increasing ATP synthesis and angiogenesis, in addition to promoting osteoblast proliferation and reducing inflammation.[16–20] Therefore, it is being studied intensively to accelerate the healing of peri-implant bone, in an attempt to shorten the healing time before definitive prosthesis insertion, thus improving the prognosis and the clinical service.[21]

Therefore, this study aimed to evaluate and compare the outcomes in terms of implant stability and peri-implant hard and soft tissues change of four short implants supporting mandibular overdentures combined with two different doses of PBM. The null hypothesis set for this study was that there would be no difference between the two PBM doses investigated, in regard to the clinical and radiographic parameters assessed for four short implants supporting a mandibular overdenture.

MATERIALS AND METHODS

The study protocol was approved by the research ethics committee of the Faculty of Dentistry, Alexandria University, Egypt (No. 01032018). This study was conducted in accordance with the guidelines of good clinical practice and adhered to the principles outlined in the Declaration of Helsinki for clinical research. The study is registered in www.ClinicalTrials.gov (ID: NCT03540316).

Participant Selection

Six edentulous male subjects were recruited from the outpatient clinic, Department of Prosthodontics, Faculty of Dentistry, Alexandria University, Alexandria, Egypt. This sample size was calculated using the PASS program (version 20) in reference to Guljé et al,[22] and was found to be adequate to estimate the expected outcome needed for this study. The mean age of the selected participants was 55 years (range: 45 to 65 years). The selected subjects were required to be free from systemic disorders and to have healthy mucosa. Subjects presented with a resorbed mandibular ridge (minimum bone height: 9 mm; bone width: 7 mm) and complained of persistent retention problems with their conventional mandibular complete dentures resulting from the reduced denture support area. Participants were excluded if they were smokers, diabetic, suffered osteoporosis, or had undergone radiotherapy to the head and neck region. The selected subjects were informed of the aim of the study, and all the procedures were explained to them. All participants provided written informed consent prior to enrollment in the trial and agreed to participate in a postoperative control program for ongoing care and data collection.

Surgical and Prosthetic Procedures

All enrolled subjects received new maxillary and mandibular complete dentures. They were given instructions to follow strict oral hygiene measures and denture care. A preoperative panoramic radiograph and CBCT were done for every patient to locate important anatomical landmarks and evaluate the potential implant placement sites. A dual scan technique was performed. Radiopaque gutta-percha markers were placed on the polished surface of the mandibular denture to act as a radiographic template. Two CBCT scans were subsequently taken. The first CBCT scan was of the patient wearing the radiographic template and biting on an interocclusal bite registration rigid silicone index in the correct centric relation with the occlusal plane parallel to the axial slices. The second scan was for a radiographic template only using the same CBCT scanner settings and the same orientation as in the patient's mouth. The two scans were superimposed by the planning software (OnDemand, Cybermed).

A customized stereolithographic surgical guide was then fabricated by 3D printing (Form 2, Formlabs) with the scanned radiographic template as reference.[23] It was used to place the implants in a predictable and accurate parallel manner. An antibiotic (1 g of amoxicillin and clavulanic acid orally/12 hours) was prescribed 1 day preoperatively to prevent the onset of infection at the site of implant placement and continued for 6 days postoperatively. Also, 0.12% chlorhexidine rinse was prescribed 2 days preoperatively; it was used twice daily and continued postoperatively.

Each patient received four short dental implants (7 mm length; 5.5 mm intrabony, 1.5 mm soft tissue, Dentium) in the canine and second premolar areas. Implants were placed under local anesthesia via flapless computer fully guided implant surgery aided by a customized surgical guide such that the smooth/rough interface was at the bone level. The osteotomy site was prepared using the appropriate preplanned drill sequence according to the 3D planning, and a guided surgery sequential drilling report was provided.[23] All implants were placed by the same clinician (S.M.Z.).

After implants were placed, the surgical guide was removed, and the implant primary stability was assessed by an Osstell ISQ instrument (Integration Diagnostics);

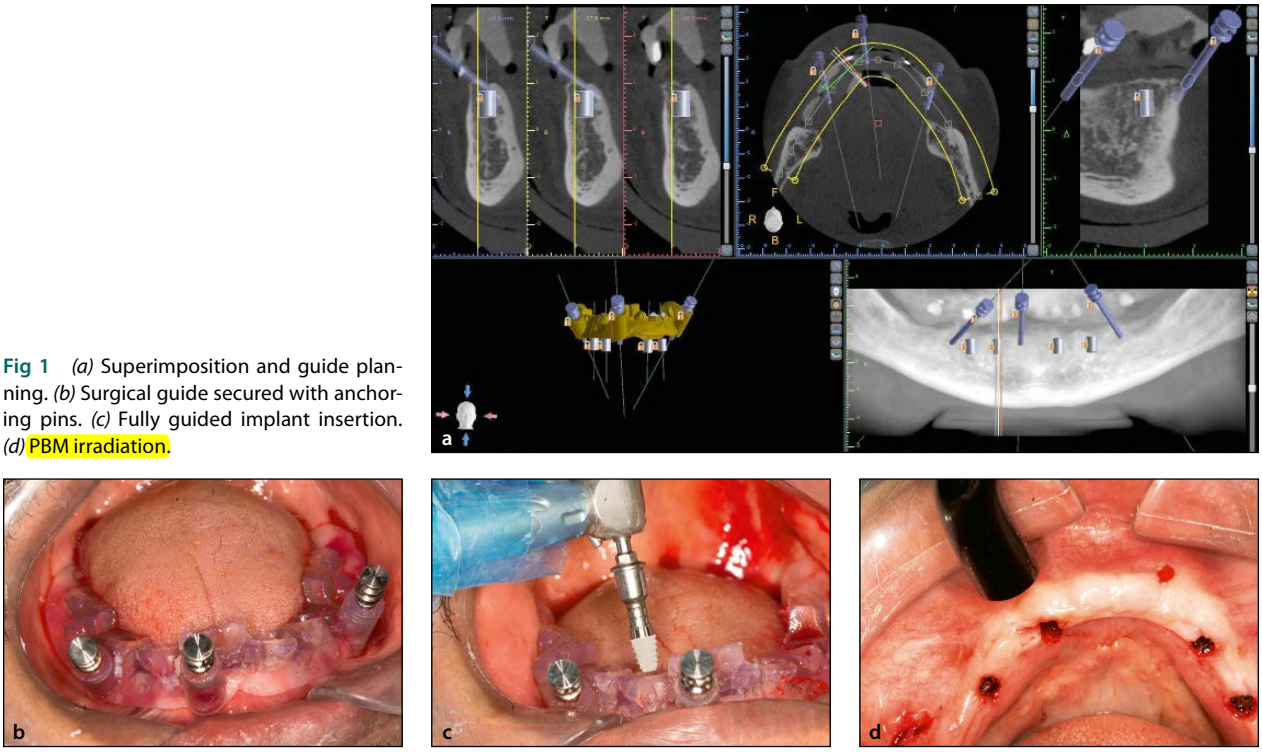

Fig 1 *(a)* Superimposition and guide planning. *(b)* Surgical guide secured with anchoring pins. *(c)* Fully guided implant insertion. *(d)* PBM irradiation.

finally, cover screws were fastened on the implants. Patients were instructed to complete the prescribed medications and given detailed instructions with regard to oral hygiene measures. Moreover, to avoid loading of the surgical area, patients were not allowed to wear the mandibular denture for 2 weeks postsurgically, and later, the denture was adjusted to accommodate the cover screws and implants.

The implants were left unloaded for 3 months; then, the second prosthetic phase started. The maxillary complete dentures remained, and the mandibular dentures were converted into implant-supported overdentures. The implants were exposed, and the cover screws were removed under local anesthesia by the same investigator. Self-aligning positioner abutments (Superline, Dentium) of 2 mm transmucosal cuff height were screwed into the implants. The abutments were then attached to the dentures by matching self-aligning positioner stud attachments (Superline, Dentium) by means of a chairside processing method; direct pickup of the female housings in the fitting surface of the mandibular denture was performed.

Laser Irradiation (PBM) Protocol

PBM by laser irradiation started immediately postsurgically and repeated every 48 hours for 10 days, such that each patient underwent five sessions in total. They received PBM by a semiconductor diode laser (SiroLaser blue, Dentsply Sirona). The wavelength used was 660 ± 5 nm, with an output power of 25 mW, the operating mode was continuous wave (CW), and the beam area was 8 mm.

At this stage, the split-mouth design was implemented, and patients were blinded to the PBM doses. Group A was the right-side implants that received PBM for 120 seconds, which is the default of the device for healing. The group B left-side implants (same patient) received PBM for 240 seconds. The energy per session was 3 Joules (J) for group A and 6 J for group B. The energy density (dose) was 3.75 J/cm^2 and 7.5 J/cm^2 for group A and group B, respectively. Implants were irradiated intraorally, orthoradially to the implant's longitudinal axis in noncontact mode by a handheld probe (multitip) 1 to 2 mm away from the implants (Fig 1). Biosafety standards for infection control and waste disposal were strictly implemented throughout all therapy sessions.

Evaluation Phase

Evaluation was performed by an operator (M.G.N.E.) blinded to the procedure and the PBM doses. Implant stability, peri-implant bone, and soft tissue changes were evaluated.

Clinical Evaluation. *Peri-implant probing depth (PIPD).* It is the distance measured between the marginal border of the gingival margin and the most apically probable part. PIPD was measured at four sites around each implant (mesially, distally, labially/buccally, and lingually). Then, the mean record for every implant was calculated. It was measured at the time of prosthetic loading (baseline) and 6 and 12 months later.

Modified Gingival Index (MGI). To qualify the peri-implant inflammation, a modified Gingival Index (modified Löe and Silness index) was carried out. It was measured at four sites around each implant (mesially, distally, labially/buccally, lingually); then, the mean record was calculated for each implant. MGI was evaluated at the time of prosthetic loading (baseline) and 6 and 12 months later. The scoring criteria were as follows:

- Score 0: Normal peri-implant mucosa
- Score 1: Mild inflammation, slight change in color, and slight edema
- Score 2: Moderate inflammation, redness, edema, and glazing
- Score 3: Severe inflammation, marked redness, edema, and ulceration

Implant Stability Test. To assess the process of osseointegration, implant stability was measured by resonance frequency analysis (RFA). It was carried out at the time of implant insertion 6 and 12 months after prosthetic loading. RFA was done using the Osstell ISQ instrument, a noninvasive objective system that does not jeopardize the healing process. The transducer was directly screwed to the implant with no soft tissue interposition. Measurements were done at buccal/labial, mesial, and distal sites for each implant. Each Osstell measurement was repeated until the same ISQ value was recorded twice; it was then accepted as the authentic value. Then, the mean ISQ value for each implant was calculated.

Radiographic Evaluation. Radiographic evaluation was carried out to detect peri-implant vertical marginal bone loss (MBL) over time. Standardized digital periapical radiographs via the paralleling technique with a sensor holder were performed. Peri-implant vertical MBL was measured using Sidexis 4 software (version 4.1, Dentsply, Sirona). In this study, the baseline radiographs were taken at the time of prosthetic loading when the transmucosal part pierces the mucosal tissues. The reference line for bone-level evaluation was the threaded intrabony border of the implant (smooth/rough interface of the implant). After 6 and 12 months, measurements were done at the mesial and distal surface of each implant; then, the mean values were calculated.

Statistical Analysis

Data were analyzed using IBM SPSS statistical software (version 23). The significance was set at $P < .05$. All variables showed normal distribution, so means and standard deviations (SD) were calculated, and parametric tests were used. The *t* test was used for comparing the two study groups at each time point. Repeated-measures analysis of variance (ANOVA) was used for comparing variables in each group at different time points. These were followed by Bonferroni adjustment for multiple pairwise comparisons using adjusted significance levels.[24]

RESULTS

All the subjects enrolled in the present study received the intended treatment and successfully completed the study protocol. All the placed short dental implants were clinically stable and free of symptoms. Radiographically, no pathologic MBL was observed around the implants. The short dental implant success rate was 100%. All implants were followed up and considered for the analysis. The implants and related prostheses were stable, and no complications were observed during the follow-up period.

Clinical Parameters

Peri-implant Probing Depth. Tables 1 and 2 depict the comparison between group A and group B with regard to the change in the mean scores of PIPD from the baseline up to the 12-month follow-up. At the baseline, there was no significant difference ($P = .50$) between both groups: 1.09 ± 0.30 mm and 1.12 ± 0.38 mm for groups A and B, respectively. Similarly, the PIPD scores between both groups across the observation times of 6 months and 12 months were found to be insignificantly different ($P > .05$). The highest increase in the PIPD mean score from the baseline (0.59 ± 0.21 mm) was recorded in group A after the 12-month follow-up, and it was insignificantly different ($P = .82$) from that of group B (0.58 ± 0.25 mm). However, within both groups, the PIPD scores at 6 months and 12 months were statistically significant ($P < .001$) compared with the baseline. The changes of PIPD across time are shown in Fig 2.

Modified Gingival Index. All patients meticulously maintained good oral hygiene throughout the study period. No statistically significant difference was noticed between both groups after 6 months ($P = .28$); the mean values were 0.54 ± 0.40 and 0.48 ± 0.45 for groups A and B, respectively (Tables 3 and 4). Moreover, no significant differences ($P = .17$) were observed after the 12-month follow-up between mean scores of both group A (0.63 ± 0.38) and group B (0.48 ± 0.39). Although these values were clinically insignificant, they were statistically significant from the baseline. Group A demonstrated a higher mean difference from the baseline (0.63 ± 0.38). Both groups revealed no significant increase in MGI scores from the 6-month and 12-month follow-up period (Fig 3).

Table 1 Comparison of PIPD Between Group A and Group B

	Group A Mean ± SD	Group B Mean ± SD	*t* test (*P* value)
Baseline	1.09 ± 0.30	1.12 ± 0.38	0.70 (.50)
6 mo	1.42 ± 0.34	1.51 ± 0.40	1.06 (.31)
12 mo	1.68 ± 0.33	1.70 ± 0.37	0.28 (.79)
Mean difference (12 mo from baseline)	0.59 ± 0.21	0.58 ± 0.25	0.24 (.82)
Repeated-measures ANOVA (*P* value)	43.98 (< .001*)	39.58 (< .001*)	

*Statistically significant at $P < .05$.

Table 2 Post Hoc Multiple Comparisons Using Bonferroni Adjustment (Within Group)

Group		Compared to	*P* value
Group A	Baseline	6 mo	.001*
		12 mo	< .001*
	6 mo	12 mo	.001*
Group B	Baseline	6 mo	< .001*
		12 mo	< .001*
	6 mo	12 mo	.003*

*Statistically significant at $P < .02$.

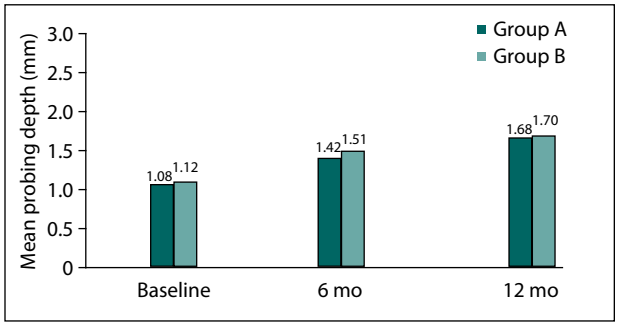

Fig 2 PIPD in groups A and B across time.

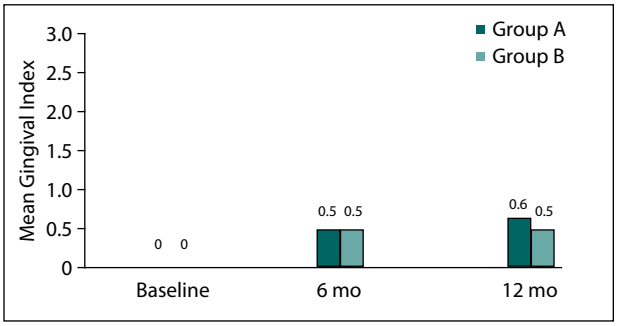

Fig 3 MGI in groups A and B across time.

Table 3 Comparison of MGI Between Group A and Group B

	Group A Mean ± SD	Group B Mean ± SD	*t* test (*P* value)
Baseline	0.00 ± 0.00	0.00 ± 0.00	N/A
6 mo	0.54 ± 0.40	0.48 ± 0.45	1.15 (0.28)
12 mo	0.63 ± 0.38	0.48 ± 0.39	1.47 (0.17)
Mean difference (12 mo from baseline)	0.63 ± 0.38	0.48 ± 0.39	1.47 (0.17)
Repeated-measures ANOVA (*P* value)	18.77 (< .001*)	14.78 (< .001*)	

*Statistically significant at $P < .05$.

Table 4 Post Hoc Multiple Comparisons Using Bonferroni Adjustment (Within Group)

Group		Compared to	*P* value
Group A	Baseline	6 mo	.004*
		12 mo	< .001*
	6 mo	12 mo	.72
Group B	Baseline	6 mo	.009*
		12 mo	.002*
	6 mo	12 mo	.63

*Statistically significant at $P < .02$.

Implant Stability Measurement. According to Tables 5 and 6, at the baseline, the mean ISQ values revealed no significant difference ($P = .09$) between both groups. At the baseline, the values were 69.06 ± 6.76 and 71.64 ± 3.59 for groups A and B, respectively. ISQ mean values between the two groups across the observation times of 6 months and 12 months were found to be statistically significant; higher mean ISQ values were recorded for group B. However, the mean difference of 12 months from the baseline between both groups was insignificant ($P = .32$). After 6 months, the mean ISQ values in group A increased from the baseline to be 76.69 ± 2.23, whereas in group B, the mean values climbed to 78.75 ± 2.94. Later, these mean values insignificantly decreased after 12 months to be 75.19 ± 2.43 and 77.97 ± 3.09 for groups A and B, respectively (Fig 4).

Radiographic Parameters

Digital periapical radiographs showed normal periimplant bone structure with no signs of continuous radiolucency around the implant threads during the observation period. At the time of prosthetic loading after the healing period and bone remodeling, bone levels were stable at the reference line, the threaded intrabony border of the implant (smooth/rough interface of the implant). As shown in Tables 7 and 8, at the 6-month follow-up, the recorded mean MBL values ($P = .08$) for groups A and B were 0.28 ± 0.13 mm and 0.24 ± 0.10 mm,

Table 5 Comparison of ISQ Between Group A and Group B

	Group A Mean ± SD	Group B Mean ± SD	*t* test (*P* value)
At surgery (baseline)	69.06 ± 6.76	71.64 ± 3.59	1.83 (.09)
6 mo	76.69 ± 2.23	78.75 ± 2.94	2.71 (.02*)
12 mo	75.19 ± 2.43	77.97 ± 3.09	2.33 (.04*)
Mean difference (12 mo from baseline)	6.14 ± 5.63	6.33 ± 2.90	1.03 (.32)
Repeated-measures ANOVA (*P* value)	46.09 (< .001*)	28.20 (< .001*)	

*Statistically significant at $P < .05$.

Table 6 Post Hoc Multiple Comparisons Using Bonferroni Adjustment (Within Group)

Group		Compared to	*P* value
Group A	Baseline	6 mo	< .001*
		12 mo	< .001*
	6 mo	12 mo	.06
Group B	Baseline	6 mo	< .001*
		12 mo	.001
	6 mo	12 mo	1.00

*Statistically significant at $P < .02$.

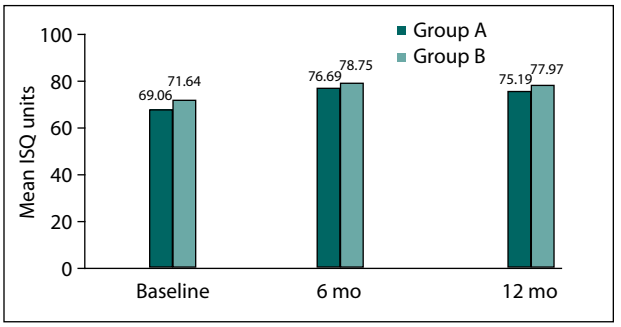

Fig 4 ISQ in groups A and B across time.

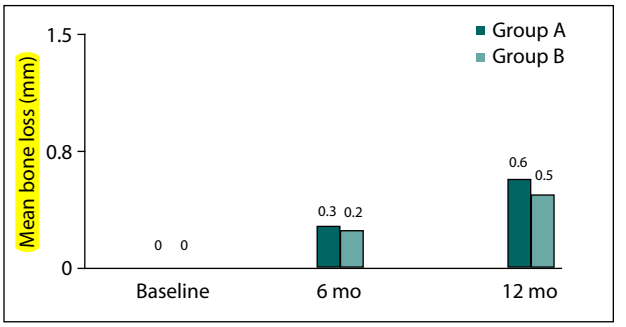

Fig 5 MBL in groups A and B across time.

Table 7 Comparison of MBL Between Group A and Group B

	Group A Mean ± SD	Group B Mean ± SD	*t* test (*P* value)
Baseline	0.00 ± 0.00	0.00 ± 0.00	N/A
6 mo	0.28 ± 0.13	0.24 ± 0.10	1.92 (.08)
12 mo	0.58 ± 0.21	0.48 ± 0.21	3.28 (.007*)
Mean difference (12 mo from baseline)	0.58 ± 0.20	0.48 ± 0.21	3.28 (.007*)
Repeated-measures ANOVA (*P* value)	58.30 (< .001*)	62.60 (< .001*)	

*Statistically significant at $P < .05$.

Table 8 Post Hoc Multiple Comparisons Using Bonferroni Adjustment (Within Group)

Group		Compared to	*P* value
Group A	Baseline	6 mo	< .001*
		12 mo	< .001*
	6 mo	12 mo	< .001*
Group B	Baseline	6 mo	< .001*
		12 mo	< .001*
	6 mo	12 mo	< .001*

*Statistically significant at $P < .02$.

respectively. On the other hand, at the 12-month follow-up, the mean MBL value for group A was 0.58 ± 0.21 mm, which was significantly higher ($P = .007$) than that of group B, 0.48 ± 0.21 mm. The MBL mean values slightly increased over time for groups A and B ($P < .001$), with significant differences between the observation times ($P < .001$). Within both groups, mean MBL at the baseline and across the observation times was found to be statistically significant ($P < .001$; Fig 5).

DISCUSSION

The advent of dental implants to support removable prostheses significantly resolves the functional deficiencies associated with conventional dentures.[25] However, severe forms of ridge resorption are regarded to be beyond the scope of implant dentistry. Thus, several aggressive surgical treatment options have been proposed to resolve this issue, but the associated morbidity and potential postoperative complications result in clinicians and patients refraining from such perilous options.[26]

In light of contemporary advances in implant dentistry, coupled with patients' high treatment expectations, there is a current trend toward minimally invasive approaches. Short dental implants were introduced as salvation from the aggressive surgical procedures, and computer-guided implant placement can significantly reduce postoperative complications and morbidity.

PBM was also proven to increase the blood flow, reinforce the revitalization process, decrease the risk of infection, reinforce metabolic activities, and enhance the healing of injured tissues.[27]

Therefore, this study investigated the outcomes of mandibular overdentures supported by four short implants as a potential alternative to other high-risk procedures. Implants were placed by a flapless fully guided surgical approach that permits implants to be placed in a prosthetic and biologically driven manner into sufficient hard and soft tissue, so that implants can be placed in the correct prosthetic positions and evade injury of vital anatomical structures. Additionally, since the flapless approach evades the need for flap reflection and suturing, it can preserve the soft tissue architecture and maintain the periosteum intact on both the buccal and lingual aspects of the alveolar ridge. The supraperiosteal plexus is also kept intact, therefore preserving the osteogenic potential and blood supply to the underlying bone and implant, which consequently reduces bone resorption. Moreover, this may facilitate the formation of a biologic seal between the soft tissues and the implant-abutment interface.[28,29] PBM was utilized in this study, as there is compelling scientific evidence sufficient to prove its significance in proliferation and differentiation of osteoblasts, bone healing and revitalization, induction of mitosis in cultured cells, collagen production, and it can boost cellular processes such as synthetization of ATP and synthesis of DNA and RNA.[30–36]

In this study, PBM was performed using a diode laser of 660 ± 5 nm, since PBM in a range of 600 to 1,100 nm (optical window) results in deeper tissue penetration and consequently induces a broader cell-light response.[37] The dose-dependent effects of PBM are described by the Arndt-Schultz curve, which suggests that the usage of an insufficient dose has no biologic effect, but if excessive energy is used, a biosuppressive effect may occur.[34] It has been reported that fluence within the range of 1 to 10 J/cm^2 is best to achieve an optimum biologic response.[38] Nevertheless, up to the present time, there has been no standardized PBM clinical dose or delivery protocol to promote the healing and osseointegration of dental implants.[39] Hence, this study also compared the effect of two different doses of PBM; the default of the device as the manufacturer-recommended dose of 3.75 J/cm^2 was used for group A, and the other dose of 7.5 J/cm^2 was utilized for group B. A split-mouth study design was adopted because PBM was shown to evoke a systemic effect in distant areas.[40] The frequency of sessions every 48 hours was determined based on the literature, as PBM was demonstrated to have a reversible positive effect on the initial stages of implant osseointegration and may last only 48 hours.[41,42]

The findings of this study revealed that after 12 months of prosthetic loading, no biologic or mechanical complications were reported. There was no significant difference between both groups regarding PIPD values. However, a minor but significant increase from the baseline ($P < .001$) was observed in PIPD values in both groups after 12 months, but it was still within the accepted values of healthy peri-implant tissues.[43] The MGI scores at the different time intervals were very low for both groups, and no inflammation or edema were reported. The radiographic evaluation at the time of implant loading revealed that the bone level was stable at the reference line threaded intrabony border of the implant with almost no bone loss, which may be attributed to PBM. After 12 months of loading, a statistically significant MBL ($P < .001$) from the reference line was observed: 0.58 ± 20 and 0.48 ± 21 mm for group A and group B, respectively. The ISQ values for both groups revealed a significant increase from the time of surgery until 12 months after loading. Group B values were significantly higher than those of group A. Thus, the null hypothesis proposed in this study was rejected.

The results reported with group B (dose of 7.5 J/cm^2) may be attributed to the possibility of a more effective dose reaching the target tissue, considering the amount of energy reflected by the off-contact mode of application. The present study reported the merits of using a 660-nm diode laser postsurgically, which related to maintaining and/or improving secondary implant stability. In the red to the near-infrared spectrum (600 to 1,500 nm), light scattering is more prevalent, and absorption has less impact. The red laser has lower penetration depth in comparison to the infrared one. Yet, for the wavelength employed in the present study (660 nm), the minimum penetration depth is approximately 3 mm.[44] Therefore, because of the lower penetration depth of the red laser, it is suggested to use energy close to the maximum dose specified by the Arndt-Schultz curve but < 10 J/cm^2.

To the best of the authors' knowledge, this is the first study that has investigated the outcome of mandibular overdentures supported by four short dental implants placed with a fully guided protocol and irradiated with PBM. Thus, direct comparison of the results of this study with those of other studies is not valid since no similar prospective studies have yet been published. Furthermore, the published studies that applied PBM clinically displayed wide diversity. This diversity is due to the variability in the parameters used: energy density, number of applications, wavelength, and power. Besides, in many studies, the parameters used were not reported at all or inaccurately reported, and the doses applied ranged from 6.2 to 92.1 J/cm^2, reflecting an absence of uniformity in the dose of PBM for promoting osseointegration and healing of dental implants. Additionally,

when interpreting the findings, it is imperative to consider the biphasic dose response, as well as the inherent heterogeneity among patients. Thus, meaningful comparison with other studies is invalid.

Although the present study included a relatively small number of patients, well-defined eligibility criteria of patients were given vigilant attention. To boost the design of the trial, a strict PBM protocol was followed, the same implants (brand, surface, length, and diameter) were used for each participant, the same edentulous region was selected, and it had the same study population. It is worth noting that the results of the present study are limited to the specific methodology; outcomes may vary in different bone conditions, other methodologies, different PBM protocols and in different follow-ups. Therefore, further randomized controlled long-term clinical trials and larger sample sizes are required to support the results of this study.

CONCLUSIONS

Within the limitations of this study, it can be concluded that overdentures supported by four short implants can be a valid treatment modality for extensively resorbed mandibular ridges, and a PBM dose of 7.5 J/cm^2 has a potential beneficial effect on the healing and osseointegration of dental implants.

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The authors declare that they have no conflicts of interest.

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