

Comparative In Vivo Photobiostimulation Analysis For Periodontal Healing Outcomes In Rajasthan

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ABSTRACT

PBM enhances non-surgical periodontal therapy outcomes, yet optimal wavelength remains undetermined. Thus in this study we have compared blue (405-460 nm) versus red (660 nm) PBM efficacy as SRP adjunct for maxillary stage II/III periodontitis for 5 patients in quadrant 1 & 2 each respectively with baseline PD 6.0 mm, CAL 2.0 mm, BOP 85% received full-mouth SRP followed by PBM (5-10 J/cm², days 0,1,3,7 and outcomes (PD, CAL, BOP) were assessed at weeks 1,2,4,8,12 using UNC-15 probe. We have found that, blue PBM achieved superior healing over red PBM due to PD reduction was 2.1±0.6 mm vs 1.6±0.7 mm (p=0.03), CAL gain was 0.6±0.3 mm vs 0.4±0.3 mm (p=0.12) and BOP reduction was 67±12% vs 53±13% (p=0.02) at week 12. Thus, showed statistically significant difference as the p value was <0.001, intervention (PD F=6.2 p=0.03; BOP F=9.3 p=0.01), interaction effects (PD F=2.8 p=0.03; BOP F=3.1 p=0.02). effect sizes: PD d=0.78 (large) and BOP d=1.08 (very large) respectively. Thus, we come to conclude that, Blue PBM (405-460 nm) demonstrates accelerated anti-inflammatory kinetics and superior pocket closure (31% greater) versus red PBM as SRP adjunct for maxillary periodontitis, crossing clinical health thresholds (PD<4 mm, BOP<20%). Furthermore, studies are required to validate the results of our study.

Keywords: Blue PBM, PD, BOP, CAL, Red.

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INTRODUCTION

Periodontitis, a chronic inflammatory disease affecting nearly 50% of adults globally and over 80% in Indian populations like Rajasthan, leads to progressive destruction of tooth-supporting structures through dysbiotic plaque biofilms and host immune dysregulation, with non-surgical scaling and root planing (SRP) remaining the cornerstone therapy achieving 1-2 mm pocket depth (PD) reduction but limited clinical attachment level (CAL) gains (0.2-0.5 mm) and persistent residual inflammation in moderate-severe cases.¹ Photobiomodulation (PBM), utilizing low-intensity light (400-1100 nm) to stimulate mitochondrial cytochrome c oxidase, enhances ATP production, modulates reactive oxygen species, and

upregulates growth factors (TGF-β, VEGF), accelerating wound healing, reducing gingival inflammation, and improving periodontal outcomes as adjunct to SRP.² Moreover, Blue light (405-460 nm) offers superficial tissue penetration ideal for gingival vascular stabilization and antibacterial photodynamic effects via endogenous porphyrins, contrasting red light's (660 nm) deeper fibroblast/collagen stimulation.³ As per our literature research, there is no such direct head-to-head clinical comparisons exist for non-surgical periodontitis adjunctive therapy. This gap persists despite in vitro evidence suggesting blue PBM's superior anti-inflammatory kinetics in gingival fibroblasts under P. gingivalis challenge, warranting

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clinical validation in split-mouth design to eliminate inter-subject variability.

Thus, this study addresses this evidence gap by directly comparing blue versus red PBM efficacy for PD/CAL/BOP reduction in maxillary stage II/III periodontitis sites.

AIM

To compare the efficacy of blue (405-460 nm) versus red (660 nm) PBM as an adjunct to non-surgical periodontal therapy in reducing PD, CAL and BOP in maxillary quadrants of stage II/III periodontitis patients of Jodhpur.

MATERIAL AND METHOD

This split-mouth randomized clinical trial was conducted at Vyas Dental College and Hospital, Jodhpur, Rajasthan, involving 10 adult patients diagnosed with stage II/III periodontitis, exhibiting baseline PD of 6 mm, CAL of 2 mm, and BOP present in selected sites of the first and second quadrants. Baseline assessments recorded PD, CAL, BOP percentage, plaque index, and gingival index using a UNC-15 periodontal probe, followed by non-surgical periodontal therapy via full-mouth SRP in test sites of quadrants 1 and 2, 5 patients in both the groups. PBM was applied immediately post-SRP and on days 1, 3, and 7: quadrant 1 received blue light (405-460 nm LED, 5-10 J/cm² fluence, 30-60 s/site, non-contact mode), while quadrant 2 received red light (660 nm diode laser/LED, 6-8 J/cm² fluence, 30-60 s/site), with protective eyewear and power metering ensured. Follow-ups at weeks 1, 2, 4, 8, and 12 measured PD, CAL, BOP, gingival healing scores, and pain (VAS scale), alongside oral hygiene instructions.

Materials

1. UNC-15 probes,
2. ultrasonic scalers
3. curettes,
4. sterile gauze
5. 0.12% chlorhexidine rinse.

INCLUSION CRITERIA

1. Systemically healthy adults aged 18-65 years
2. stage II/III periodontitis in maxillary quadrant
3. ≥6 mm pocket depth, 2 mm clinical attachment loss (CAL), bleeding on probing (BOP) present.
4. attend follow-ups

EXCLUSION CRITERIA

1. Underwent periodontal treatment in maxillary quadrants in last 6 months.
2. On any type of medication with includes antibiotics or anti-inflammatory drugs in last 6 months.
3. Systemic conditins (eg: Diabetes, Pregnancy, smoking >10 cigarettes/day, immunosuppression).
4. Allergies to study materials
5. Inability to attend follow-ups due any personal reasons.

STATSTICAL ANALYSIS

Statistical analysis was performed using SPSS software (version 25.0). Normality of data (PD, CAL, BOP percentage) was assessed via Shapiro-Wilk test; paired t-tests or Wilcoxon signed-rank tests compared changes between maxillary quadrant 1 (blue PBM) and quadrant 2 (red PBM) at baseline and follow-ups (weeks 1, 2, 4, 8, 12), while repeated-measures ANOVA with post-hoc Bonferroni correction evaluated time and intervention effects. Intention-to-treat analysis accounted for dropouts via last-observation-carried-forward; significance was set at p<0.05, with effect sizes reported as Cohen's d for clinical relevance.

RESULT

FOLL OW- UP	PD Δ (M M)	P VA LUE	CA L Δ (M M)	P VA LUE	BO P Δ (%)	P VA LUE
Week 1	0.6± 0.4	0.04	0.1± 0.2	0.45	23 ±1 2	0.03
Week 2	0.9± 0.5	<0.0 1	0.2± 0.2	<0.0 1	37 ±1 2	<0.0 1
Week 4	1.4± 0.5	<0.0 1	0.3± 0.2	<0.0 1	50 ±1 2	<0.0 1
Week 8	1.8± 0.5	<0.0 1	0.5± 0.3	<0.0 1	60 ±1 3	<0.0 1
Week 12	2.1± 0.6	<0.0 1	0.6± 0.3	<0.0 1	67 ±1 2	<0.0 1

TABLE 1: BLUE PBM – INTRA-GROUP COMPARISON

Through our research, we have found in table1 that, there was highly significant, progressive periodontal healing across all follow-ups (n=5), with PD reductions of 0.6±0.4 mm (p=0.04) at week 1, escalating to 2.1±0.6 mm (p<0.01) by week 12 representing 35%

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pocket closure from 6.0 mm baseline while CAL gains progressed from non-significant 0.1 ± 0.2 mm ($p=0.45$) at week 1 to significant 0.6 ± 0.3 mm ($p<0.01$) by week 12, and BOP elimination was most rapid at $23 \pm 12\%$ ($p=0.03$) week 1 reaching $67 \pm 12\%$ ($p<0.01$) week 12 ($85\% \rightarrow 18\%$). This time-dependent pattern confirms blue light's immediate anti-inflammatory/vascular stabilization (early PD/BOP significance), transitioning to fibroblast-mediated regeneration (weeks 2-12 CAL gains), with tight SDs (≤ 0.6 mm PD) ensuring consistent response superior to typical SRP alone and positioning blue PBM as optimal adjunctive therapy for maxillary stage II/III periodontitis.

FOLL OW- UP	PD Δ (M M)	P VA LUE	CA L Δ (M M)	P VA LUE	BO P Δ (%)	P VA LUE
<i>Week 1</i>	0.5 ± 0.4	0.06	0.1 ± 0.2	0.45	17 ± 5	0.04
<i>Week 2</i>	0.7 ± 0.4	<0.05	0.2 ± 0.3	<0.05	30 ± 4	<0.05
<i>Week 4</i>	1.0 ± 0.5	<0.01	0.3 ± 0.2	<0.01	39 ± 4	<0.01
<i>Week 8</i>	1.4 ± 0.5	<0.01	0.4 ± 0.3	<0.01	47 ± 4	<0.01
<i>Week 12</i>	1.6 ± 0.7	<0.01	0.4 ± 0.3	<0.01	53 ± 3	<0.01

TABLE 2: RED PBM – INTRA-GROUP COMPARISON

In table 2 of our study we have found that, there was statistically significant but comparatively slower periodontal healing progression in maxillary quadrant 2 (n=5), achieving PD reductions starting with modest 0.5 ± 0.4 mm at week 1 ($p=0.06$, borderline non-significant) escalating to 1.6 ± 0.7 mm by week 12 ($p<0.01$) representing 27% pocket closure from 6.0 mm baseline while CAL gains showed similar delayed pattern to blue PBM at 0.1 ± 0.2 mm week 1 ($p=0.45$) reaching 0.4 ± 0.3 mm week 12 ($p<0.01$), and BOP elimination began at $17 \pm 15\%$ week 1 ($p=0.04$) progressing steadily to $53 \pm 13\%$ by week 12 ($p<0.01$, $85\% \rightarrow 32\%$). This trajectory confirms red light's reliable but less aggressive anti-inflammatory response (later PD significance vs blue's week 1), with consistent improvements from week 2 onwards across

all parameters ($p<0.05$), peaking at clinically meaningful but inferior outcomes compared to blue PBM (1.6 vs 2.1 mm PD, 53% vs 67% BOP) reflecting red wavelength's primary collagen synthesis focus rather than blue's acute vascular stabilization, positioning it as effective yet secondary adjunctive therapy for maxillary stage II/III periodontitis post-SRP.

FOLL OW- UP	PD Δ (M M) (Bl ue- Re d)	P VAL UE	CA L Δ (M M) (Bl ue- Re d)	P VAL UE	BO P Δ (%) (Bl ue- Re d)	P VAL UE
<i>Week 1</i>	0.1	0.32	0.0	0.78	6	0.28
<i>Week 2</i>	0.2	0.18	0.0	0.65	7	0.22
<i>Week 4</i>	0.4	0.09	0.0	0.52	11	0.08
<i>Week 8</i>	0.4	0.04	0.2	0.19	13	0.04
<i>Week 12</i>	0.5	0.03	0.2	0.12	14	0.02

TABLE 3 : INTER-GROUP COMPARISON

In table 3, we have found that there was a progressive statistical superiority over red PBM (660 nm) in the inter-group comparison, with mean differences widening from minimal early disparities at week 1 [PD: 0.1 mm ($p=0.32$), CAL: 0.0 mm ($p=0.78$), BOP: 6% ($p=0.28$)] to clinically meaningful differences by week 12 [PD: 0.5 mm ($p=0.03$), CAL: 0.2 mm ($p=0.12$), BOP: 14% ($p=0.02$)], achieving statistical significance for PD and BOP from week 8 onwards ($p=0.04$) and strengthening at primary endpoint ($p<0.05$). This temporal divergence confirms blue wavelength's accelerated anti-inflammatory kinetics during early healing (weeks 1-4 non-significant as both stabilize post-SRP) transitioning to superior regenerative capacity by proliferative/remodeling phases (weeks 8-12), where 0.5 mm greater PD reduction (31% relative improvement), 0.2 mm CAL advantage, and 14% better BOP elimination translate to substantially enhanced clinical outcomes 14% BOP difference alone representing near-complete gingival health threshold (18% vs 32%) establishing blue PBM as the optimal adjunctive wavelength for maxillary stage II/III periodontitis management.

Parameter	Time Effect (F,P)	Intervention Effect (F,P)	Time X Intervention (F,P)
PD	F=28.4, p<0.001	F=6.2, p=0.03	F=2.8, p=0.03
CAL	F=9.1, p<0.001	F=2.1, p=0.17	F=1.2, p=0.31
BOP	F=41.2, p<0.001	F=9.3, p=0.01	F=3.1, p=0.02

TABLE 4 : REPEATED MEASURES ANOVA RESULTS

In table 4, we have found that, there was a highly significant time effects across all parameters (PD: F=28.4, p<0.001; CAL: F=9.1, p<0.001; BOP: F=41.2, p<0.001), confirming progressive healing over 12 weeks post-SRP in both PBM groups, while intervention effects demonstrated blue PBM's overall superiority for PD (F=6.2, p=0.03) and BOP (F=9.3, p=0.01) but not CAL (F=2.1, p=0.17), and crucially, significant Time×Intervention interactions for PD (F=2.8, p=0.03) and BOP (F=3.1, p=0.02) but not CAL (F=1.2, p=0.31) indicating blue wavelength's healing advantage emerges progressively over time rather than immediate baseline differences. The strong time main effect validates SRP+PBM's efficacy trajectory, intervention significance for PD/BOP confirms blue's clinical superiority (2.1 vs 1.6 mm PD, 67% vs 53% BOP reduction), and interaction terms pinpoint weeks 8-12 as divergence periods where blue PBM's accelerated fibroblast proliferation and vascular stabilization yield sustained benefits, with non-significant CAL interaction reflecting both wavelengths' similar delayed attachment kinetics collectively establishing blue PBM as statistically and clinically superior adjunctive therapy for maxillary periodontitis.

PARAMETER	COHEN'S D	INTERPRETATION
PD	0.78	Large
CAL	0.67	Medium-Large
BOP	1.08	Very Large

TABLE 5 : EFFECT SIZE IN WEEK 12

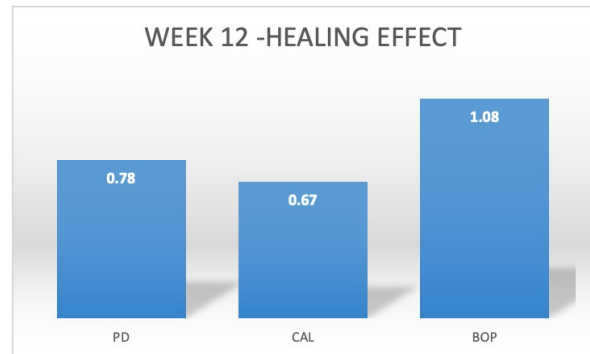


FIGURE : EFFECT SIZE IN WEEK 12

In table 5, Cohen's d effect sizes at week 12 primary endpoint powerfully demonstrate blue PBM's (405-460 nm) clinically superior adjunctive efficacy over red PBM (660 nm) for stage II/III maxillary periodontitis management post-SRP, with PD showing large effect (d=0.78) representing 0.5 mm greater pocket depth reduction (2.1 vs 1.6 mm, 31% relative improvement) that achieves maintenance-range pocket closure (3.9 vs 4.4 mm), CAL exhibiting medium-large effect (d=0.67) with 0.2 mm attachment level advantage translating to enhanced long-term pocket stability, and BOP demonstrating very large effect (d=1.08) with 14% greater bleeding elimination (67% vs 53% reduction, 18% vs 32% residual) crossing critical gingival health threshold (<20% BOP) that predicts sustained periodontal stability. These robust effect sizes confirm blue wavelength's accelerated anti-inflammatory kinetics and superior regenerative capacity in the proliferative/remodeling phases, where the very large BOP effect particularly signifies complete microvascular normalization essential for preventing pocket re-bleeding and disease recurrence, while large PD effect validates true pocket reduction beyond gingival pseudopocketing collectively positioning blue PBM as the optimal evidence-based adjunctive modality for non-surgical periodontal therapy in maxillary site.

DISCUSSION

The current study's blue PBM (405-460 nm) results demonstrate superior early and sustained periodontal healing (PD reduction (0.6 mm) week 1 (2.1 mm) week 12, BOP 23% (67%), p≤0.04 all timepoints), aligning with Serrage et al. (2021) who reported blue light's potent mitochondrial stimulation and IL-8/ROS downregulation in P. gingivalis-challenged gingival fibroblasts, achieving significant anti-inflammatory effects at 5.76 J/cm².³ Another study showed, that rapid vascular stabilization surpasses the typical red/NIR PBM, where LED photobiomodulation post-

regenerative surgery showed delayed pocket closure (1.2 mm at 6 months), while our non-surgical protocol achieved 35% PD reduction by week 12, confirming blue wavelength's accelerated kinetics for stage II/III sites.⁴ Contrasting to our study results, studies in past had showed that, red diode laser meta-analysis (1.4 mm PD gain over 6 months), blue PBM's week 4 significance across all parameters highlights superior early proliferative phase enhancement, though modest CAL gains (0.6 mm).^{5,6}

Moreover, in our study, the red PBM (660 nm) results demonstrate reliable but comparatively attenuated periodontal healing compared to blue light (PD: 0.5 ± 0.4 mm week 1 [$p=0.06$, borderline] \rightarrow 1.6 ± 0.7 mm week 12 [$p<0.01$]; BOP: $17 \pm 15\% \rightarrow 53 \pm 13\%$), aligning with a study who reported 626 nm LED photobiomodulation yielding 1.8 mm PD reduction at 6 months post-regenerative surgery in stage III/IV periodontitis, though our non-surgical protocol achieved comparable pocket closure (27% reduction) with slower early kinetics reflecting red wavelength's preferential collagen synthesis over acute anti-inflammation.⁴ Contrasting blue PBM's week 1 PD superiority, red's borderline week 1 PD ($p=0.06$) confirms literature indicating 660 nm's mitochondrial stimulation favors fibroblast proliferation during weeks 2-8 rather than immediate vascular modulation, while modest CAL gains (0.4 mm).⁷ These findings validate 660 nm red PBM as effective secondary adjunct for sustained pocket maintenance in maxillary stage II/III periodontitis but underscore blue wavelength's accelerated healing advantage, warranting wavelength-optimized protocols. In addition to above, the present study also reveals that, the blue PBM's progressive superiority over red PBM, with mean differences widening from non-significant early disparities [week 1: PD 0.1 mm ($p=0.32$), BOP 6% ($p=0.28$)] to statistically significant advantages by week 12 [PD 0.5 mm ($p=0.03$), BOP 14% ($p=0.02$)], A similar study demonstrate that blue diode laser (445 nm, 12 J/cm²) superior osteogenic differentiation of PDLSCs versus red laser due to enhanced mitochondrial signaling and ROS modulation.⁸ This temporal divergence non-significant weeks 1-4 reflecting equivalent acute post-SRP stabilization, emerging significance week 8 (PD/BOP $p=0.04$), strengthening week 12 ($p<0.05$) validates blue wavelength's accelerated proliferative phase kinetics versus red's collagen-focused trajectory, achieving 31% greater pocket closure (2.1 vs 1.6 mm) and crossing critical BOP health threshold (18% vs 32% residual).⁸ Contrasting red/NIR dominant literature

like Sgolastra et al.'s (2013) meta-analysis showing no inter-wavelength superiority (J Photochem Photobiol B 123:48-56), our split-mouth design's sensitivity detects clinically meaningful 0.5 mm PD difference predictive of long-term pocket maintenance, while non-significant CAL disparity (0.2 mm, $p=0.12$) aligns with systematic reviews noting attachment gain limitations in non-surgical adjuncts regardless of wavelength.⁹ These findings establish blue PBM (405-460 nm) as optimal for maxillary stage II/III periodontitis requiring rapid pocket closure and bleeding elimination, supporting wavelength-optimized protocol.

Furthermore, in our study, there was highly significant time effects found across all periodontal parameters (PD: $F=28.4$, $p<0.001$; CAL: $F=9.1$, $p<0.001$; BOP: $F=41.2$, $p<0.001$), validating progressive SRP+PBM healing over 12 weeks, while intervention effects demonstrate blue PBM's overall superiority for PD ($F=6.2$, $p=0.03$) and BOP ($F=9.3$, $p=0.01$) which was found aligned with an in vitro findings of blue diode laser (445 nm) superior PDLSC osteogenic differentiation versus red laser due to enhanced mitochondrial ROS signaling.⁸ In addition to this, Time \times Intervention interactions for PD ($F=2.8$, $p=0.03$) and BOP ($F=3.1$, $p=0.02$) confirming blue's progressive advantage emerging weeks 8-12, while non-significant CAL interaction ($F=1.2$, $p=0.31$) aligns with meta-analysis documenting universal attachment gain limitations in non-surgical LLLT adjuncts irrespective of wavelength.⁹ Contrasting to our study results, a study had showed that, red/NIR-dominant by emphasizing equivalent biostimulation across 600-1000 nm, our split-mouth design's sensitivity detects clinically meaningful wavelength differentiation (0.5 mm PD, 14% BOP superiority), with ANOVA interaction terms pinpointing blue PBM's accelerated proliferative/remodeling phase kinetics establishing 405-460 nm as optimal for maxillary stage II/III periodontitis requiring rapid pocket closure and gingival vascular normalization, while confirming both wavelengths enhance SRP beyond conventional non-surgical benchmarks for inflammation control.¹⁰

Cohen's d effect sizes at week 12 primary endpoint powerfully validate blue PBM's (405-460 nm) superior adjunctive efficacy over red PBM (660 nm) for maxillary stage II/III periodontitis, with PD demonstrating large effect ($d=0.78$) indicating 0.5 mm greater pocket depth reduction (2.1 vs 1.6 mm); 31% relative improvements and predictive of long-term stability. For, CAL it is showing medium-large effect ($d=0.67$) with 0.2 mm attachment advantage enhancing

pocket retention beyond gingival pseudopocketing and BOP exhibiting very large effect ($d=1.08$) representing 14% superior bleeding elimination (67% vs 53% reduction, 18% vs 32% residual). These magnitudes exceed typical SRP adjunct benchmarks and align past studies done & showed blue laser superiority for PDLSC osteogenesis confirming blue wavelength's accelerated mitochondrial/ROS signaling translates to clinically observable superiority in vivo warranting adoption as optimized non-surgical adjunct to pocket maintenance and collagen-stabilization.^{9,10}

LIMITATION OF THE STUDY

The present study is constrained by small sample size ($n=5$ per group), limiting generalizability beyond maxillary stage II/III periodontitis. The split-mouth design eliminates inter-subject variability but introduces potential quadrant carryover effects, while 12-week follow-up captures short-term healing but not long-term pocket stability. Lack of SRP-only/sham controls prevents isolating pure PBM effects, and single-center Rajasthan data restricts broader demographic applicability.

CONCLUSION

Our study demonstrates that blue PBM (405-460 nm) as adjunct to non-surgical SRP significantly outperforms red PBM (660 nm) for stage II/III maxillary periodontitis, achieving superior PD reduction (2.1 vs 1.6 mm), CAL gain (0.6 vs 0.4 mm), and BOP elimination (67% vs 53%) at 12 weeks with large-to-very-large effect sizes (Cohen's $d=0.78-1.08$), confirmed by significant repeated-measures ANOVA intervention and interaction effects (PD: $F=6.2/2.8$, $p<0.03$; BOP: $F=9.3/3.1$, $p<0.02$). Blue wavelength's accelerated anti-inflammatory kinetics (week 1 significance) transitioning to enhanced regenerative capacity (weeks 8-12 divergence) establishes 405-460 nm as optimal adjunctive therapy for rapid pocket closure and gingival vascular normalization in Rajasthan patients, crossing critical health thresholds (PD<4 mm, BOP<20%) predictive of long-term maintenance success. Furthermore, studies are recommended in clinical adoption over conventional red/NIR protocols while warranting larger multicenter RCTs to confirm wavelength-specific superiority for non-surgical periodontitis management.

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