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Comparative Analysis of Primary Stability and Crestal Bone Loss in Photo-Functionalized Surface Treated Implants Using Platelet Rich Fibrin: An In-Vivo Study

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ABSTRACT

Aim: The present study aimed to evaluate and compare the primary stability and crestal bone loss in photo-functionalized surface-treated implants with and without the use of Platelet-Rich Fibrin (PRF).

Methodology: A total of 40 patients were enrolled and divided into two main groups: Group I (control) received untreated implants, while Group II (case) received photo-functionalized implants. Each group was further subdivided into subgroups with and without PRF application (n = 10 each). PRF was prepared by centrifugation of 20-40 ml venous blood at 3000 RPM within 15 to 20 minutes, the middle layer was removed and used. Photo-functionalization was done by exposing the implants to ultraviolet (UV) light during 15 minutes before implantation. All implants were fixed by standard surgical procedure under local anesthesia and stitched by interrupted means. The temperature of the implantation was measured by Resonance Frequency Analysis (RFA) and bone loss was measured on the radiograph by Cone Beam Computed Tomography (CBCT) at 2, 3 and 6 months post operative.

Results: PRF and photo-functionalization increased implant stability (P = 0.001), and implant stability was highest in the photo-functionalized + PRF group. In this subgroup, the process of osseointegration was faster and stronger. The PRF and photo-functionalization groups showed significantly fewer cases of crestal bone loss than controls and the minimal resorption was observed in the photo-functionalized + PRF subgroup (P = 0.001).

Conclusion: The PRF-photo-functionalization combination shows a synergistic effect, and the stability of the implants and peri-implant bone is better. The protocol is a useful complement of clinical implantology that may maximize long-term results.

Keywords: *Implant Stability, Photo-Functionalized, Platelet-Rich Fibrin, Resonance Frequency Analysis, Ultra-Violet Treatment*

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1. INTRODUCTION

Tooth loss has also been significantly lower than in the 1970s. According to the National Health and nutrition examination survey (2011-2016), 2.2 per cent of adults (20 to 64 years) had no remaining teeth [1]. Tooth loss is normally occasioned by periodontal disease, trauma, dental caries or hereditary factors [2]. Besides causing physical loss of teeth, it can affect phonetics negatively, modify oral musculature, and negatively affect the location of adjacent teeth [3].

There are a handful of treatment options available to replace missing teeth, such as removable partial dentures (RPD), fixed partial dentures (FPD), and dental implants [4]. Dental implants are the most popular of these in that they look almost natural and work like natural teeth [5]. Nevertheless, in some populations, their application is constrained by high prices and damaged clinical statuses. Alloplastic items introduced surgically to the orofacial tissues with the aim of restoring function and esthetics are defined as dental implants [6]. Dental rehabilitation has recently driven much interest towards implants. However, despite their success, some complications, including peri-implantitis, implant failure and ailing implants have increasingly been reported [7]. Primary stability, osseointegration, systemic health, oral hygiene, and maintenance are the most important determinants of implant success. In this way, the long-term success depends on improving the process of osseointegration and its correct maintenance [8]. Platelet-Rich Fibrin (PRF) is a regenerative material that has been popularized because it is obtained by centrifugation of venous blood of a patient. PRF contains high levels of platelets, growth factors and cytokines and it offers a fibrin matrix that aids in angiogenesis, cellular migration and tissue regeneration [9]. It also finds use in sinus augmentation, periodontal regeneration, and soft tissue healing, and has become useful in implant dentistry by preventing crestal bone loss and enhancing peri-implant healing [10]. PRF increases bone repair significantly. Photo- functionalization, or surface treatment in which implants are subjected to ultraviolet (UV) light, is another development in the area of implantology. The process alters the surface of the implant to enhance its hydrophilicity and surface energy, leading to enhanced protein adsorption and cell attachment, and finally osseointegration [11]. Its potential has been demonstrated by the high success rates (97.6% of photo -functionalized vs. 96.3% of untreated implants) demonstrated by research by Akiyoshi et al. Primary stability during implant placement and long-term maintenance of crestal bone are critical in determining the success of implant therapy. Photo-treated surfaces reduce the bone loss through increased rate of osseointegration; PRF enhances bone regeneration and vascularization [12]. These strategies can be used in combination to provide a favorable biological and mechanical environment, which can help improve the stability of implants and the overall results. Despite the proven efficiency of each of these techniques individually, little research has been conducted to identify the synergy of these two techniques [13]. Research into such an approach is essential in seeking solutions to issues that have been stubborn in implant dentistry, especially loss of crest bone and peri-implant complications [14]. This study compares the primary stability and crestal bone loss of photo-functionalized surface treated implants in PRF. Specifically, the aims are to test the stability of the implants under different conditions of treatment: untreated implants, implants, which are based on PRF, implants, which are based on photo-functionalization or a blend of photo-functionalization and PRF. In addition to this, crestal bone loss will be evaluated in both of these treatment modalities and the outcomes of PRF with and without photo- functionalization will be compared to the outcomes of non-treated samples. This analytical discussion attempts to establish the best approach to reach the objective to enhance stability of implants and minimize crestal bone loss.

2. METHODOLOGY

Inclusion and Exclusion Criteria

Inclusion Criteria

1. Patients willing to participate in the study
2. Systemically healthy patients (ASA I)
3. Patients maintaining good oral hygiene
4. Patients with single or multiple missing teeth

Exclusion Criteria

1. Medically compromised patients (ASA II and ASA III)
2. Patients with a history of intravenous bisphosphonate therapy
3. Smokers

4. Patients with poor oral hygiene
5. Patients with defects requiring grafting procedures

Source of Data

The study was conducted in the Department of Prosthodontics and Crown & Bridge, Teerthanker Mahaveer Dental College and Research Centre, Moradabad.

Ethical Considerations

- **Consent:** Written informed consent was obtained from all patients.
- **Ethical Clearance:** Approval was granted by the Institutional Ethics Committee, Teerthanker Mahaveer University, under reference number TMDCRC/IEC/TH/22-23/PRO 05.

Study Design

Patients were selected from the outpatient department based on inclusion and exclusion criteria. They were divided into two groups:

- **Group I (Control):** Untreated implants (n = 20)
- **Group II (Case):** Photo- functionalized implants (n = 20)

Each group was further subdivided into two subgroups:

- With PRF (n = 10)
- Without PRF (n = 10)

Clinical Protocol

First visit

- Case history, clinical, and radiological examination.
- Pre-operative radiovisiography (RVG), panoramic radiograph, Cone Beam Computed tomography (CBCT), and blood investigations were performed.
- Written consent was obtained.

Preparation of PRF

- Peripheral venous blood (20–40 ml) was collected during surgery.
- Samples were transferred to 8.5 ml tubes without anticoagulant and centrifuged (Remi bench-top centrifuge) at 3000 RPM for 15–20 minutes.
- PRF was harvested from the middle layer, while red blood cells (RBCs) at the bottom and platelet-poor plasma at the top were discarded.

Surface Treatment of Implants (Photo-functionalization)

- Implants were exposed to UV light in a SteriCab UV cabinet for 15 minutes immediately prior to placement.

Surgical Procedure

- Surgery was performed under local anesthesia with aseptic precautions.
- Patients rinsed with 5 ml of 0.2% chlorhexidine solution.
- Extra oral and intraoral sites were disinfected with 5% povidone-iodine.
- Either untreated or photo-functionalized implants were placed (Osstem TS implants).
- The surgical site was sutured with simple interrupted sutures.

Follow-up visits

Group I (Untreated Implants)

- **Second visit:** Implant placement. Ten implants placed without PRF, ten with PRF. Resonance Frequency Analysis (RFA) values recorded.

- **Third visit (3–6 months):** Second-stage surgery; gingival former placed; RFA and CBCT recorded.
- **Fourth visit (2 weeks later):** Impressions made.
- **Fifth visit:** Prosthesis delivered; occlusion adjusted; home care instructions provided. Patients recalled after 6 months.
- **Sixth visit:** Prosthesis evaluated; RFA values and CBCT recorded.

Group II (Photo-functionalized Implants)

- **Second visit:** Implant placement. Ten photo-functionalized implants placed without PRF, ten with PRF. RFA values recorded.
- **Third visit (3–6 months):** Second-stage surgery; gingival former placed; RFA and CBCT recorded.
- **Fourth visit (2 weeks later):** Impressions made.
- **Fifth visit:** Prosthesis delivered; occlusion adjusted; home care instructions provided. Patients recalled after 6 months.
- **Sixth visit:** Prosthesis evaluated; RFA values and CBCT recorded.

Statistical Analysis

The results found in this research were examined by means of SPSS version 23.0 and Microsoft Excel 2007 data processing and initial arrangement. To summarize the data, descriptive statistics were estimated with means, standard deviations, frequencies and percentages. The Shapiro-Wilk test was utilized to determine the normality and Levene test was utilized to determine homogeneity of variances. All tests were taken to be of significance with a p value of less than 0.05. Independent t-tests were used to compare results between groups in case of intergroup comparisons. These strict statistical approaches guaranteed the accuracy, reliability and validity of the results and increased the credibility of the study and could offer meaningful contribution to the assessment of the implant stability and crestal bone loss.

3. RESULT

In comparing implant stability between untreated and untreated group with PRF, different results have been found at different time points (1st, 3rd, and 6th visits). The implant stability at the 2nd visit was in means of 70.4 (untreated group) and 71.0 (PRF-treated group) without statistically significant difference (P = 0.488). Further, the stability at the 3rd visit was 72.1 for the untreated group and again 73.0 for the PRF group had insignificant variances (P = 0.302).

But by the 6th visit, this difference became significantly different. The mean implant stability of the untreated group was 73.6 and 76.3 in the PRF group. The examination of the difference was statistically significant (P = 0.001), which indicated that PRF application enhanced implant stability while moving towards orthodontic stabilization [Table 1].

Table 1: Implant Stability In Untreated And Untreated With PRF Group At Different Time Intervals

	F1	N	Mean	Standard Deviation	Standard Error Mean	P value
2nd visit	Untreated	10	70.400	2.170	0.686	0.488 (Non-Significant)
	Untreated with PRF	10	71.000	1.490	0.471	
3rd visit	Untreated	10	72.100	1.911	0.604	0.302 (Non-Significant)
	Untreated with PRF	10	73.000	1.885	0.596	
	Untreated	10	73.600	1.349	0.426	0.001

6th visit	Untreated with PRF	10	76.300	1.567	0.495	(Significant)

To summarize, at the beginning (1st and 3rd visits), there were no differences between groups. On the other hand, by the 6th visit, the PRF-treated group had significantly better implant stability, indicating that PRF may contribute to better implant outcomes [Figure 1].

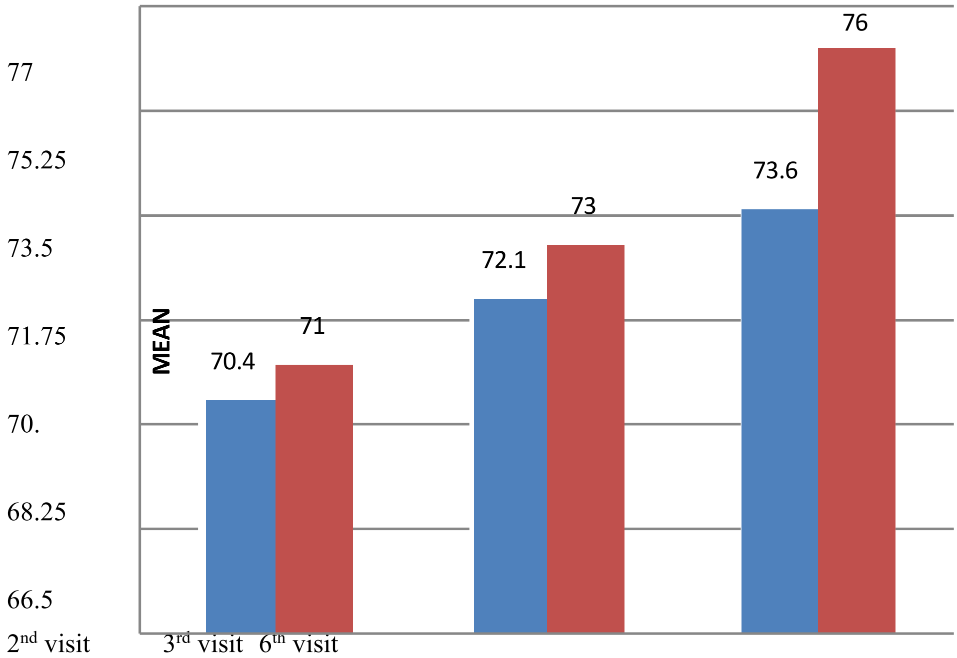

Figure 1: Differences between untreated and untreated groups with PRF at subsequent visits

There was statistically significant difference of bone loss between untreated group and PRF group. In the untreated group, a bone loss of 1.09 with standard deviation 0.087, with a standard error equal to 0.027. The average bone loss the group who received PRF was 0.85 with the standard deviation equal to 0.250 and the standard error mean equal to 0.079. Upon comparing these two sets of data, a 0.001 P value denotes a statistically significant difference [Table 2].

Table 2: Bone Loss in Untreated and Treated with PRF Groups

	N	**Mean**	**Standard Deviation**	**Standard Error Mean**	**P value**
Untreated	10	1.0900	0.087	0.027	0.001 (Significant)
Untreated with PRF	10	0.8500	0.250	0.079	

Therefore, it can be summarized that PRF included in the treatment group led to a reduction of bone loss when compared with an untreated group. There is an indication that PRF helps preserve bone around implants [Figure 2].

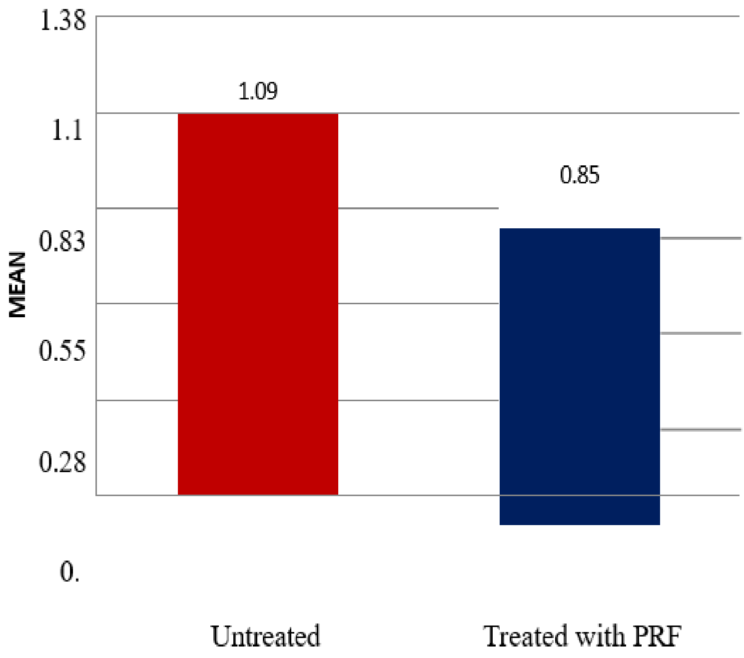

Figure 2: Comparison of average bone loss between untreated and treated with PRF groups

Importantly, through implant stability analysis comparing the photo-functionalized and photo-functionalized groups in combination with PRF at different time intervals, several findings are reported.

In the photo-functionalized with PRF group, the implants were shown to be more stable with a mean score of 72.6 and 76.5 in the photo-functionalized and PRF groups, respectively, after the second visit. This disparity was clearly statistically significant with a p value of 0.001, indicating that PRF had really added to the implants in making them stable.

At the 3rd visit, the photo-functionalized group showed the same trend of higher implant stability than the control group, highlighting a value of 81.6 in the photo-functionalized with PRF group and 78.9 in the photo-functionalized group. PRF again improved implant stability over time and this also reached statistical significance (P = 0.001).

Results indicated that the photo-functionalized with PRF group has better stability (mean=87.5) compared to the photo-functionalized group (mean=84.6) after several repeated visits. The P-value of 0.001 was below, which showed that this difference was still statistically significant [Table 3].

Table 3: Implant Stability in Photo-Functionalized Group and Photo-Functionalized with PRF Group at Different Time Intervals

		N	Mean	Standard Deviation	Standard Error Mean	P value
2nd visit	Photo-functional	10	72.600	4.526	1.431	0.001 (Significant)
	Photo-functional with PRF	10	76.500	3.027	0.957	

3rd visit	Photo-functional	10	78.900	3.071	0.971	0.001 (Significant)
	Photo-functional with PRF	10	81.600	2.221	0.702	
6th visit	Photo-functional	10	84.600	3.134	0.991	0.001 (Significant)
	Photo-functional with PRF	10	87.500	2.990	0.945	

In summary, statistical analysis of the outcomes showed that, at all-time intervals (2nd, 3rd, and 6th visits) during the study, the photo-functionalized with PRF group exhibited much better implant stability as compared to other groups and that it is possible that PRF may be beneficial in terms of increasing implant stability over time for photo-functionalized implants (Figure 3).

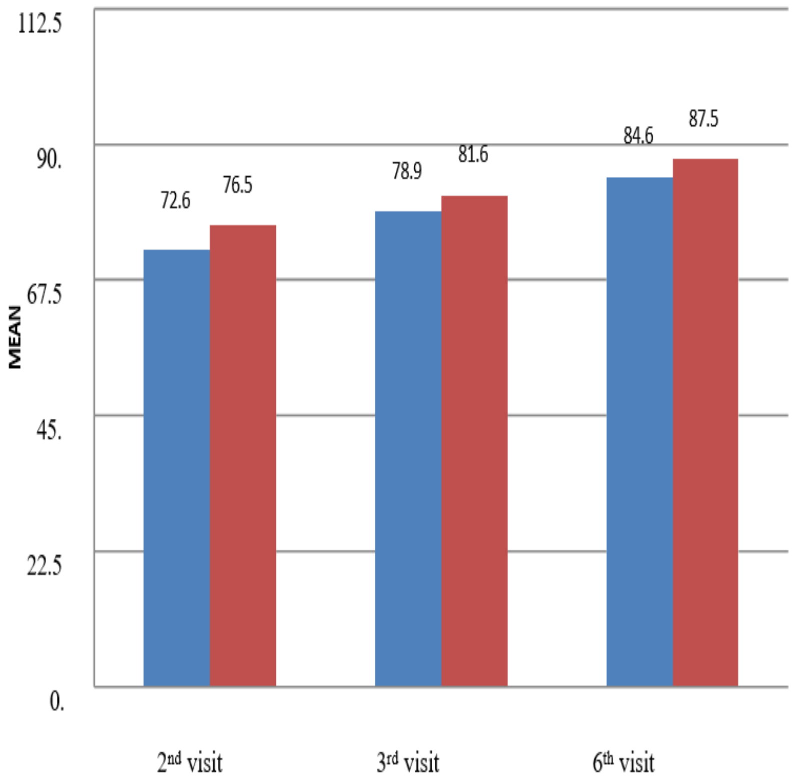

Figure 3: Bone Loss in Photo-Functional And Photo-Functional With PRF Group

A mean of 0.120, deviation of 0.122, and error of 0.038 was found for the photo- functionalized cluster's bone loss finding. Mean bone loss was 0.090, standard deviation was 0.110, and standard errors were 0.034 in the photo-functional with PRF cluster, in contrast (Table 4).

Table 4: Comparison Of Bone Loss in Photo-functional and Photo- functional with PRF

	N	Mean	Standard Deviation	Standard Error Mean	P value
Photo-functional	10	0.120	0.122	0.038	0.001 (Significant)
Photo-functional with PRF	10	0.090	0.110	0.034	

Therefore after statistical analysis, a significant (P = 0.001) difference between the two groups regarding the bone loss was revealed. From these findings, it appears that the presence of PRF within photo-functionalized with PRF helped in effect less bone loss as related to photo-functionalized.

In short, the result which we got that the addition of PRF to the photo-functionalized implants helps reduce bone loss, demonstrating the potential benefits of PRF in improving bone preservation around implants (Figure 4).

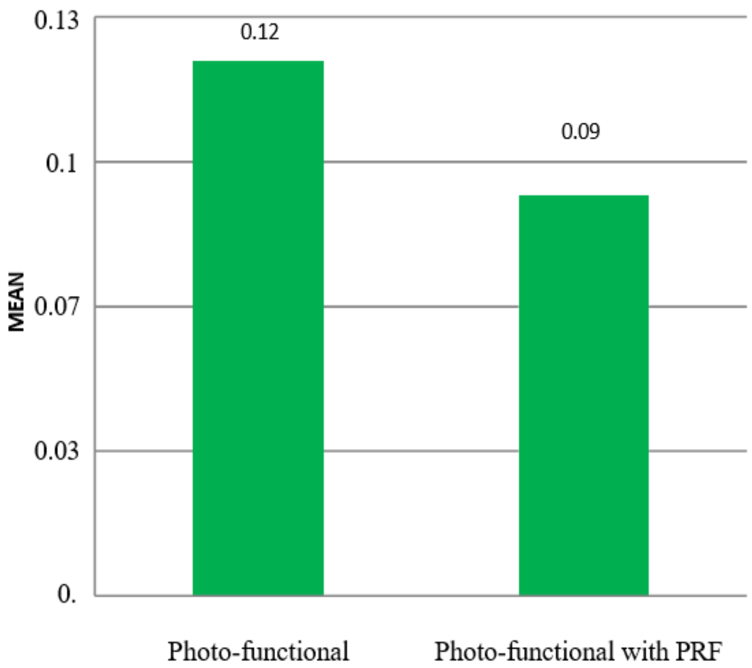

Figure 4: Comparison of Bone Loss in Photo- functional and Photo Functional with PRF

The comparison of implant stability between the untreated group and the photo- functionalized group at different time intervals revealed different findings at various visits:

2nd visit: Average implant stability of the untreated group was 70.4, standard deviation of 2.170, and standard error of 0.686. The study provided a mean stability of 72.6 with standard deviation of 4.526 and standard error of 1.431 in the photo- functionalized group while the other group was less stable. According to the statistical analysis, photo-functionalization improved implant stability (P=0.021).

3rd Visit: With a standard deviation of 1.911 and a standard error of 0.604, the untreated group achieved an average implant stability of 72.1. The photo-functionalized group, demonstrated, superior stability, with an average score of 78.9, a standard deviation of 3.071, and an error margin of 0.971. Highlights the photo-functionalized group's greater stability, the P-value of 0.001 demonstrates a statistically significant improvement.

6th Visit: The control group's avg. stability was 73.6, but the experimental cluster's was 73.4, 1.349, and 0.426. With an average stability of 84.6, standard deviation of 3.134, and std. error of 0.991, the photo-functionalized group stood out in the way. It is confirmed that photo-functionalization greatly enhances implant stability with time; since the P-value of 0.001 indicates a statistically significant difference (Table 5).

Table 5: Implant Stability in Untreated and Photo-functional Group

		N	Mean	Standard Deviation	Standard Error Mean	P value
2nd Visit	Untreated	10	70.400	2.170	0.686	0.021 (Significant)
	Photo -functional	10	72.600	4.526	1.431	
3rd Visit	Untreated	10	72.100	1.911	0.604	0.001 (Significant)
	Photo- functional	10	78.900	3.071	0.971	
6th Visit	Untreated	10	73.600	1.349	0.426	0.001 (Significant)
	Photo -functional	10	84.600	3.134	0.991	

Therefore, at all-time intervals (2^{nd}, 3^{rd}, and 6^{th} visits), the photo-functionalized group had consistently higher implant stability compared to the untreated group, where the differences observed were statistically significant. This may indicate that photo- functionalization tends to enhance stability of implants over time (Figure 5).

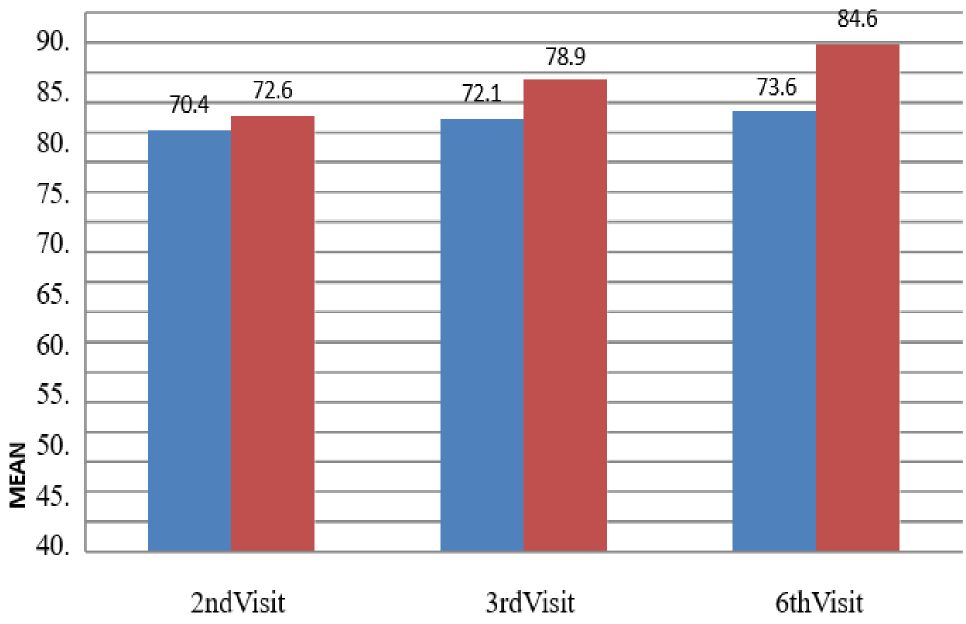

Figure 5: 2nd visit vs 3rd visit vs 6th visit

Untreated cluster standard deviation=0.087 and error=0.027, photo-functionalized cluster standard deviation=0.12 and error=0.38 shows much lower than its counterpart. The P-value of 0.001 confirms a statistically significant difference, indicating that the photo-functionalized group experienced substantially less bone loss compared to the untreated group [Table 6].

Table 6: Group Bone Loss in Untreated and Photo-functional

	N	Mean	Standard Deviation	Standard Error Mean	P value
Untreated	10	1.0900	0.087	0.027	0.001 (Significant)
Photo-Functional	10	0.120	0.122	0.038	

In conclusion, the photo-functionalized group showed significantly lower bone loss than the untreated group, suggesting that photo-functionalization may have a beneficial effect in reducing bone loss around implants.

The comparison of implant stability between the untreated with PRF and photo- functionalized with PRF groups at various time intervals (2nd, 3rd, and 6th visits) demonstrated significant differences in favor of the photo-functionalized with PRF group. The mean implant stability at the second visit was 71.000 in the untreated with PRF group and 76.500 in the photo-functionalized with PRF group; the difference was statistically significant (p = 0.001).The third visit data showed similar trends, with the untreated with PRF group averaging 73.000 and the photo-functionalized with PRF group averaging 81.600 (p 0.001). With a p-value of 0.001, the photo- functionalized with PRF group once again shown a higher mean of 87.500 by the sixth visit, compared to the untreated with PRF group's 76.300. These results indicate that photo-functionalization with PRF significantly enhances implant stability compared to the untreated PRF group, with consistently higher stability observed in the photo-functionalized with PRF group across all time intervals [Table 7].

Table 7: Implant Stability in Untreated with PRF And Photo-functional with PRF Group

		N	Mean	Standard Deviation	Standard Error Mean	P value
2nd visit	Un Treated with PRF	10	71.000	1.490	0.471	0.001 (Significant)
	Photo- functional with PRF	10	76.500	3.027	0.957	
3rd visit	Untreated with PRF	10	73.00	1.885	0.596	0.001 (Significant)
	Photo functional with PRF	10	81.600	2.221	0.702	
6th visit	Un Treated with PRF	10	76.300	1.567	0.495	0.001 (Significant)
	Photo functional with PRF	10	87.500	2.990	0.945	

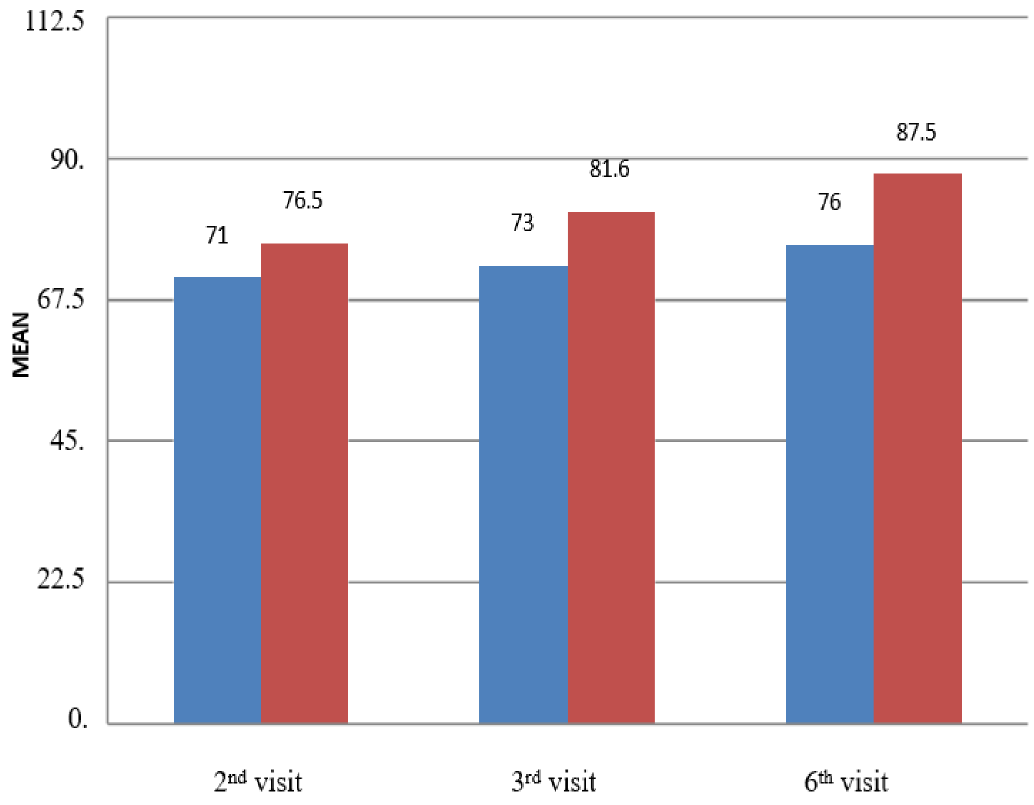

Figure 6: Bone Loss In Untreated with PRF And Photo-functional with PRF Group

The comparison of bone loss between the untreated with PRF and photo- functionalized with PRF groups revealed a significant difference. The bone loss rate in the group that was not given PRF was 0.8500 on average, with a standard deviation of 0.250 and a standard error of 0.079; this difference was found to be statistically significant (p = 0.001). At 0.0900, with a standard deviation of 0.110 and a standard error of 0.034, the photo-functionalized with PRF group showed significantly less bone loss compared to the other groups. The significant difference in bone loss suggests that the photo-functionalized with PRF treatment is highly effective in reducing bone loss compared to the Untreated with PRF group, indicating a potential advantage of this treatment in promoting better bone preservation around implants (Table 8).

Table 8: Comparison Of Bone Loss Between the Untreated with PRF and Photo- functionalized with PRF groups

	N	Mean	Standard Deviation	Standard Error Mean	P value
Un Treated with PRF	10	0.850	0.250	0.079	0.001 (Significant)
Photo-functional with PRF	10	0.090	0.110	0.034	

4. DISCUSSION

This research determined the effects of photo-functionalization and PRF on the stability of dental implants and on bone preservation around the implants. The results show that photo-functionalization and especially the application of PRF greatly improves the stability of implants and loss of bone in comparison with traditional methods. The analysis of untreated and PRF-treated implants showed that no significant difference was observed between the two groups during the second and third visits, but a statistically significant difference in the stability of the implants appeared during the sixth visit (p = 0.001). This implies that the bioactive effects of PRF take time to develop, and gradually improve the process of osseointegration. These findings are in line with the findings of Oncu and Alaaddinoglu (2015) [15] who emphasized PRF as a growth factor release and implant integration accelerator. Interestingly, photo-functionalized implants were always more stable at all the points of evaluation. Photo-functionalization, together with PRF gave the highest result, as the stability values increased by 87.5 at the sixth visit as opposed to 76.5 at the second visit. Such a synergy is probably indicative of complementary processes: photo-functionalization enhances surface biocompatibility and hydrophilicity of implants, whereas PRF provides growth factors (PDGF, TGF-b, IGF) and cytokines able to stimulate osteogenesis. Another proof of the excellence of the combination treatment was crestal bone preservation. The untreated group had the most bone loss (1.09 mm), and the photo-functionalized with PRF group had the least resorption (0.09 mm), which is almost twelve times less. These findings correspond to those of Prasad DK et al. (2018) [16] and Rani S et al. (2025) [17] that verified the contribution of photo-functionalization to improving bone-implant contact and mitigating marginal bone loss. These findings are biologically explained by increased protein adsorption, osteoblast differentiation and scaffold production by the fibrin matrix of PRF. Collectively, these interventions create a microenvironment that is very conducive to healthy osseointegration. This can result in a shortening of the healing period, increased early loading regimens, and elevated long-term prognosis, clinically. Moreover, considerable peri-implant bone preservation implies a minimal probability of peri-implantitis, implant failure, and related complications [18].

From a practical standpoint, the integration of photo-functionalization and PRF into routine protocols could benefit patients with compromised bone conditions, metabolic diseases, or a history of radiotherapy. Beyond clinical impact, broader public health implications include reduced treatment costs, fewer revisions, and improved patient satisfaction.

5. LIMITATIONS AND FUTURE DIRECTIONS

Despite promising results, this study had limitations. The small sample size restricted generalizability and precluded subgroup analyses. The relatively short follow-up duration (up to the sixth visit) limits conclusions regarding long-term success. Biological mechanisms were inferred rather than directly measured; future studies should incorporate histological and molecular analyses to clarify underlying pathways. Confounding factors such as implant location, bone density, and systemic conditions were not fully controlled.

Future research should therefore:

- Include larger, multi-center cohorts with extended follow-up periods (5–10 years).
- Investigate biological mechanisms through histomorphometric and molecular evaluations.
- Explore optimization of PRF preparation protocols and UV parameters.
- Assess cost-effectiveness and patient-reported outcomes.
- Compare these methods with other emerging implant surface modifications and biomaterials.

6. CONCLUSION

This study provides strong evidence that both photo-functionalization and PRF significantly improve dental implant outcomes, with their combination yielding the most favorable results. Implants treated with photo-functionalization and PRF demonstrated superior stability at all time points and the lowest crestal bone loss compared to other modalities.

The synergistic effect between the two interventions appears to arise from complementary mechanisms: photo-functionalization enhances surface biocompatibility and osseointegration, while PRF supplies bioactive molecules that promote bone healing and tissue regeneration. This results in progressive improvement in implant stability and near-elimination of bone loss.

Clinically, the findings suggest that these techniques can increase implant longevity, reduce complications, and potentially allow earlier loading. Their accessibility and relatively low cost also support their incorporation into routine practice, especially for patients with compromised bone or systemic conditions.

While the study's limitations necessitate further validation with larger samples and longer follow-ups, the magnitude and consistency of the results reinforce their clinical significance. These findings contribute to the growing body of evidence supporting biologically driven approaches in implant dentistry and align with the paradigm shift toward personalized, regenerative treatment strategies.

In summary, photo-functionalization and PRF, particularly in combination, significantly enhance implant stability and crestal bone preservation, making them valuable adjuncts in implant therapy. Future studies should aim to optimize protocols, investigate long-term outcomes, and evaluate translational aspects to establish their role as standard practice in implant dentistry.

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