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ASSESSMENT OF THE BIO- STIMULATORY IMPACT OF T-PRF COMPARED TO T-PRF AUGMENTED WITH DIODE LASER IN DENTAL IMPLANTS FOR THE REPLACEMENT OF POSTERIOR MANDIBULAR TEETH: A RANDOMIZED CONTROL TRIAL

Dr. Love Kumar Bhatia[1], Dr. Shwetank Dwivedi[2*], Dr. Shitij Srivastava[3], Dr. Abhinav Shekhar[4]

[1]Professor, Department of Prosthodontics, Sardar Patel Post Graduate Institute of Dental and Medical Sciences, Email ID: drlovebhatia12@gmail.com
[2*]Post Graduate, Department of Prosthodontics, Sardar Patel Post Graduate Institute of Dental and Medical Sciences, Email ID: shw205@gmail.com
[3]Professor and Head Department of Prosthodontics, Sardar Patel Post Graduate Institute of Dental and Medical Sciences, Email ID: shitijsrivastava@gmail.com
[4]Professor, Department of Prosthodontics, Sardar Patel Post Graduate Institute of Dental and Medical Sciences, Email ID: dental03doctor@gmail.com

ABSTRACT

Background: Successful dental implant therapy primarily depends on osseointegration, a biological process involving sequential bone healing and remodeling around the implant surface. Bio-stimulatory approaches such as Titanium-Prepared Platelet Rich Fibrin (T-PRF) and Low-Level Laser Therapy (LLLT) have gained attention because of their potential to enhance tissue regeneration, improve implant stability, and accelerate healing.

Aim: To assess and compare the bio-stimulatory impact of T-PRF alone and T-PRF augmented with diode laser therapy in dental implants placed for replacement of posterior mandibular teeth.

Materials and Methods: This prospective randomized controlled clinical trial included 50 patients with unilateral posterior mandibular edentulous spaces requiring implant-supported rehabilitation. Patients were randomly allocated into two equal groups: Group A received T-PRF alone, whereas Group B received T-PRF combined with LLLT. Implant stability was assessed using Resonance Frequency Analysis and Implant Stability Quotient (ISQ) values at baseline, 3 months, and 6 months. Bone density was evaluated using Cone Beam Computed Tomography (CBCT), while postoperative pain was assessed using Numerical Rating Scale (NRS) scores at different postoperative intervals. Statistical analysis was performed using SPSS software with $p<0.05$ considered statistically significant.

Results: Both groups demonstrated progressive improvement in implant stability and peri-implant bone density during follow-up. The T-PRF + LLLT group showed lower postoperative pain scores compared with T-PRF alone, with a statistically significant difference observed on postoperative Day 2 ($p<0.05$). However, no statistically significant differences were observed between groups regarding implant stability or bone density.

Conclusion: Adjunctive use of LLLT with T-PRF effectively reduced early postoperative pain but did not provide significant additional benefits regarding implant stability or bone density compared with T-PRF alone.

KEYWORDS: Bone Density; Dental Implants; Implant Stability; Low-Level Laser Therapy; Osseointegration; Postoperative Pain; Titanium-Platelet Rich Fibrin.

INTRODUCTION

Dental implants have emerged as one of the most predictable and successful treatment modalities for the replacement of missing teeth and rehabilitation of partially or completely edentulous patients. The long-term success of implant therapy is primarily dependent on successful osseointegration, which is defined as a direct structural and functional connection between living bone and the surface of a load-bearing implant. This biological process involves a sequence of events including blood clot formation, inflammatory response, angiogenesis, migration and proliferation of osteogenic cells, new bone formation, and subsequent bone remodeling around the implant surface [1,2]. Successful osseointegration is essential for long-term implant survival and functional stability.

Implant stability is considered a critical determinant of successful osseointegration and can be broadly categorized into primary and secondary stability. Primary stability is achieved through mechanical engagement of the implant with surrounding bone immediately after placement, whereas secondary stability develops through biological bone regeneration and remodeling processes during healing [3,4]. The transition from primary to secondary stability is a dynamic process that determines the overall prognosis of implant treatment. Although modern implant designs and surgical techniques have significantly enhanced implant success rates, delayed healing and compromised osseointegration continue to remain important clinical challenges, particularly in posterior mandibular regions subjected to increased occlusal loads and variations in bone quality [5].

In recent years, biomodulation strategies have gained considerable attention for their ability to accelerate biological healing and tissue regeneration around dental implants. Biomodulation refers to therapeutic approaches that stimulate cellular and molecular activities involved in tissue repair and regeneration. Among these approaches, Low-Level Laser Therapy (LLLT), also known as photobiomodulation (PBM), has emerged as a promising non-invasive therapeutic modality [6].

Low-Level Laser Therapy employs low-energy light wavelengths that stimulate intracellular photoreceptors, particularly mitochondrial chromophores, resulting in increased adenosine triphosphate (ATP) synthesis and enhanced cellular metabolism [7]. Increased ATP production promotes cell proliferation, protein synthesis, angiogenesis, and cellular differentiation, ultimately accelerating tissue repair and regeneration. The biological effects of photobiomodulation have been attributed to activation of cytochrome C oxidase within mitochondria, resulting in enhanced oxidative metabolism and improved cellular function [8].

Several studies have demonstrated that LLLT can positively influence bone metabolism by stimulating osteoblastic activity, increasing collagen synthesis, and promoting angiogenesis around implant sites [9]. Furthermore, photobiomodulation has been shown to reduce postoperative pain and inflammation through modulation of inflammatory mediators and alteration of neuronal pain transmission pathways [10]. Various wavelengths ranging from 600–980 nm have been investigated in implant dentistry, with diode lasers being most commonly employed due to their predictable tissue penetration, ease of application, and favorable biological effects. Despite encouraging findings, inconsistencies in laser parameters, irradiation protocols, and treatment durations have produced variable outcomes across studies.

Simultaneously, advancements in regenerative medicine have highlighted the significance of platelet concentrates in promoting tissue repair and bone regeneration. Platelet-Rich Plasma (PRP) was initially introduced as a concentrated source of autologous growth factors; however, limitations associated with rapid release kinetics and anticoagulant use led to the development of Platelet-Rich Fibrin (PRF), considered a second-generation platelet concentrate [11].

PRF forms a fibrin-rich scaffold capable of entrapping platelets, leukocytes, cytokines, and growth factors within a three-dimensional matrix. Unlike PRP, PRF does not require external additives or anticoagulants and allows a slow, sustained release of biologically active molecules over an extended period [12]. Growth factors released from PRF, including Platelet-Derived Growth Factor (PDGF), Transforming Growth Factor-beta (TGF-β), Vascular Endothelial Growth Factor (VEGF), and Bone Morphogenetic Proteins (BMPs), play crucial roles in angiogenesis, osteogenesis, and tissue regeneration.

Further modifications in platelet concentrate preparation techniques have resulted in the development of Titanium-Platelet Rich Fibrin (T-PRF), which represents a more advanced generation of platelet concentrates. T-PRF is prepared using titanium tubes instead of conventional glass tubes during centrifugation. Titanium demonstrates superior hemocompatibility properties and facilitates greater platelet activation, resulting in the formation of a thicker and more organized fibrin matrix. Histological studies have shown that T-PRF exhibits denser fibrin architecture and prolonged resorption characteristics compared with conventional PRF preparations [13].

The biological properties of T-PRF suggest its potential role in enhancing soft tissue healing, bone regeneration, and implant osseointegration. Similarly, LLLT independently exhibits beneficial effects on osteoblast proliferation and peri-implant bone healing. Because these two modalities function through different biological mechanisms, their combined use may provide synergistic regenerative effects capable of accelerating implant healing and improving clinical outcomes [14].

Despite substantial evidence supporting the individual effectiveness of T-PRF and LLLT, limited scientific literature exists regarding their combined bio-stimulatory impact in implant dentistry. Additionally, variations in treatment protocols and inconsistent clinical findings warrant further investigation to establish evidence-based clinical recommendations [15]. Therefore, the present randomized controlled trial was designed to assess the bio-stimulatory impact of Titanium-Platelet Rich Fibrin alone compared with Titanium-Platelet Rich Fibrin augmented with diode laser therapy in dental implants placed for replacement of posterior mandibular teeth. Clinical assessment of implant stability, radiographic evaluation of bone density, and assessment of postoperative pain may provide comprehensive insights regarding the regenerative potential of these bio-stimulatory modalities and contribute toward improved evidence-based implant therapies.

MATERIALS AND METHOD

Study Design and Study Setting

The present study was designed as a prospective randomized controlled clinical trial aimed at evaluating and comparing the bio-stimulatory impact of Titanium-Prepared Platelet Rich Fibrin (T-PRF) alone and T-PRF augmented with Low-Level Laser Therapy (LLLT) in dental implants placed for the replacement of posterior mandibular teeth. The study was conducted in the Department of Prosthodontics and Crown & Bridge, Sardar Patel Post Graduate Institute of Dental and Medical Sciences, Lucknow. The study protocol was reviewed and approved by the Research Advisory Council (RAC) and Institutional Ethical Committee (IEC), and all procedures were carried out according to ethical principles outlined in the Declaration of Helsinki.

Study Population and Sample Size Determination

The study population consisted of patients presenting with unilateral posterior mandibular edentulous spaces requiring dental implant rehabilitation. Sample size estimation was performed considering bone density as the primary outcome variable using values derived from a previously published study by Saleem et al. Based on an assumed pooled standard deviation of 10.42 and an expected effect size of 9.4 at 80% study power and 95% confidence interval, the calculated minimum sample size was approximately 20 participants per group. Considering a possible dropout rate of approximately

10%, the sample size was increased and rounded off to 25 patients in each treatment group. Consequently, a total of 50 patients were enrolled in the study.

Patient Selection Criteria

Inclusion Criteria: patients fulfilling the following criteria were included in the study:

Patients were considered eligible for participation in the present study if they fulfilled specific clinical and systemic criteria to ensure uniformity of the study population and minimize confounding factors affecting implant healing and osseointegration. Individuals aged between 21 and 60 years with unilateral posterior mandibular edentulous spaces requiring implant-supported rehabilitation were included in the study. Only patients with good general physical and mental health were considered suitable for participation. Furthermore, participants were required to possess adequate bone volume and moderate residual alveolar ridge dimensions sufficient for implant placement without the need for additional augmentation procedures.

Patients presenting with a healthy implant site without any evidence of local pathology or active disease were included. In addition, individuals willing to participate voluntarily and provide written informed consent after understanding the nature and purpose of the study were selected. To minimize factors that could interfere with peri-implant healing, only patients maintaining satisfactory oral hygiene and demonstrating adequate motivation toward implant treatment were enrolled in the study.

Exclusion Criteria: patients exhibiting any of the following conditions were excluded from the study:

Patients with conditions that could adversely affect wound healing, bone metabolism, or implant osseointegration were excluded from the study. Individuals with systemic diseases known to influence bone healing and regenerative capacity, such as uncontrolled diabetes mellitus, metabolic bone disorders, and autoimmune diseases, were not considered eligible for participation. Patients receiving recent corticosteroid therapy were also excluded because of its potential influence on inflammatory response and tissue healing.

Pregnant women were excluded due to ethical concerns and physiological changes that could potentially influence study outcomes. Chronic smokers, as well as individuals with alcohol or substance abuse habits, were excluded because of their known negative effects on vascularity, bone metabolism, and implant success rates. Patients exhibiting parafunctional habits such as bruxism were excluded owing to the possibility of excessive occlusal loading affecting implant stability.

Additionally, patients with narrow residual alveolar ridges that could compromise implant placement were excluded from the study. Individuals with active infectious diseases or those with known allergies to any materials or medications used during the study procedure were also excluded to avoid potential complications and ensure patient safety.

Randomization and Allocation of Study Groups

Following enrollment, patients were randomly allocated into two equal groups using a computer-generated randomization method:

Group A (T-PRF Group): Twenty-five patients underwent implant placement with Titanium-Prepared Platelet Rich Fibrin alone.

Group B (T-PRF + LLLT Group): Twenty-five patients underwent implant placement with Titanium-Prepared Platelet Rich Fibrin augmented with Low-Level Laser Therapy.

The allocation process ensured equal distribution of participants between both treatment groups.

Preoperative Assessment

All patients underwent detailed clinical and radiographic evaluation before implant placement. Medical and dental histories were recorded, followed by comprehensive intraoral examination. Study casts and radiographic templates were fabricated to assist in implant planning and determine accurate implant positioning.

Preoperative investigations included complete blood count, bleeding time, clotting time, prothrombin time (INR), blood glucose analysis, HbA1c levels, serum calcium levels, vitamin D3 estimation, lipid profile assessment, and viral screening tests including HBsAg and ELISA for HIV.

Radiographic examination consisted of Orthopantomogram (OPG) and Cone Beam Computed Tomography (CBCT) to evaluate available bone height, bone width, and bone quality for implant planning.

Preparation of Titanium-Prepared Platelet Rich Fibrin (T-PRF)

Titanium-Prepared Platelet Rich Fibrin was prepared using titanium tubes according to a standardized protocol. Approximately 9 mL of venous blood was collected from the antecubital vein of each patient using a sterile 25-gauge needle and immediately transferred into sterile titanium tubes.

The collected blood samples were centrifuged at 2800 rpm for 12 minutes using a standardized centrifuge machine. Centrifugation resulted in the formation of a fibrin-rich matrix containing concentrated platelets and leukocytes. The T-PRF obtained demonstrated a denser and more tightly organized fibrin structure, which provides sustained release of growth factors and promotes tissue regeneration. The prepared T-PRF clot was subsequently placed within the osteotomy site immediately before implant insertion **(Figure 1)**.

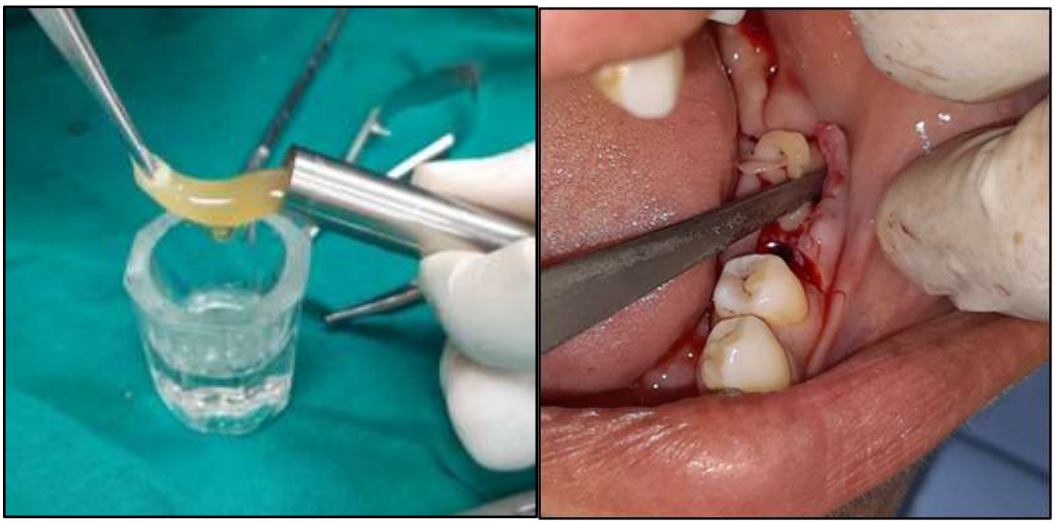

Figure 1: Titanium Vial With T-PRF Obtained After Centrifugation and Placement At Implant Site

Surgical Procedure

All implant surgical procedures were performed under aseptic conditions according to standard implant placement protocols described by Misch. Local anesthesia was achieved using 2% lignocaine hydrochloride with 1:80,000 adrenaline.

After antiseptic preparation with povidone iodine, a full-thickness mucoperiosteal flap was elevated at the implant site. Sequential osteotomy preparation was carried out using standard implant drills under copious sterile saline irrigation using a low-speed, high-torque implant surgical unit.

The implant dimensions were selected according to available bone dimensions and prosthetic requirements. Following osteotomy preparation, T-PRF was carefully inserted into the prepared implant site before implant placement. The dental implant was subsequently inserted and cover screws were placed. Flap closure was performed using interrupted sutures without tension **(Figure 2)**.

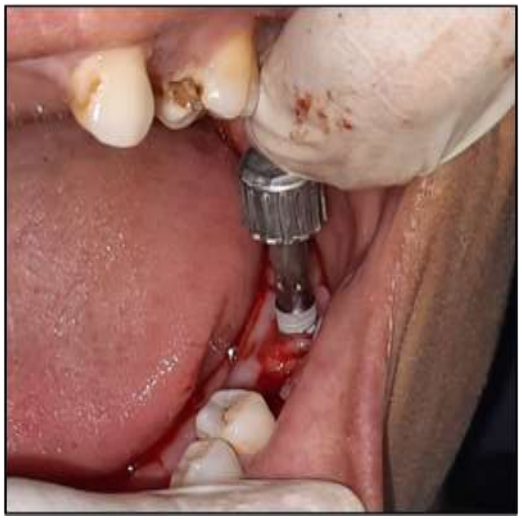

Figure 2: Implant Placement

Postoperative medications included Amoxicillin with clavulanic acid for seven days, Ibuprofen as required for pain management, and 0.12% chlorhexidine mouthwash three times daily for two weeks. Patients were advised regarding oral hygiene maintenance and were recalled after one week for suture removal.

Low-Level Laser Therapy Protocol

For patients allocated to Group B, Low-Level Laser Therapy (LLLT) was administered as an adjunctive bio-stimulatory modality following implant placement. Photobiomodulation was performed using a diode laser system operating at a wavelength of 660 nm, which falls within the red light spectrum and has been widely reported to exhibit favorable effects on cellular proliferation, angiogenesis, tissue repair, and bone regeneration. Laser irradiation was delivered in continuous wave mode under non-contact conditions to ensure uniform energy distribution and prevent direct thermal interaction with the soft tissues **(Figure 3)**.

Figure 3: Application Of Low Level Laser At Implant Site

The laser system was operated at a power output of 100 mW using a laser tip diameter of 8 mm, corresponding to a spot size of approximately 0.5028 cm². Irradiation was applied for 30 seconds at each designated point around the implant site. The laser beam was directed to two specific sites surrounding the implant region, namely the buccal and lingual surfaces, to ensure adequate coverage of the peri-implant tissues and maximize the photobiomodulatory effect.
The energy delivered at each irradiation point was standardized at 3 Joules, resulting in a total energy delivery of 6 Joules per treatment session. The calculated energy density applied to the treatment area was approximately 5.9 J/cm². These parameters were selected based on previously reported therapeutic protocols demonstrating favorable biological responses associated with enhanced bone healing and implant osseointegration.
Laser application was performed immediately following implant placement and subsequently at postoperative days 2, 4, 7, 10, and 14, resulting in a total of six treatment sessions. Appropriate laser safety protocols, including protective eyewear for both operator and patient, were maintained throughout the procedure.

Outcome Assessment

Assessment of Postoperative Pain

Postoperative pain was assessed using the Numerical Rating Scale (NRS-11), where patients rated pain intensity on a scale ranging from 0 (no pain) to 10 (maximum pain imaginable). Pain evaluation was performed on postoperative days 2, 4, 7, 10, and 14.

Assessment of Implant Stability

Implant stability was assessed using Resonance Frequency Analysis (RFA) with the Osstell device. Measurements were recorded immediately after implant placement and at 3-month and 6-month follow-up intervals **(figure 4)**. Implant Stability Quotient (ISQ) values were obtained and averaged for analysis.

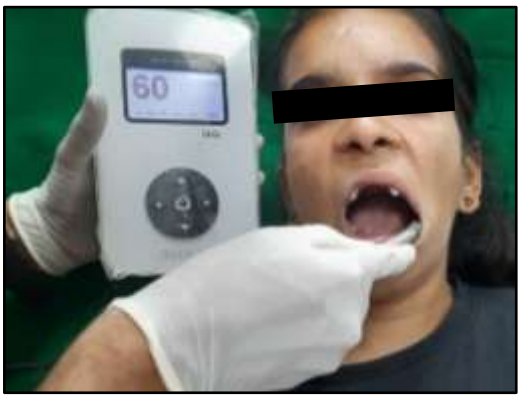

Figure 4: Implant Stability Checked With Ostell ISQ Machine

Assessment of Bone Density

Bone density was evaluated using CBCT imaging and analyzed using InVivo imaging software. Bone density values were measured in Hounsfield Units (HU) using standardized radiographic parameters before implant placement and at 3 and 6 months postoperatively **(Figure 5)**. The peri-implant region of interest was selected using standardized coordinates for consistency of measurements.

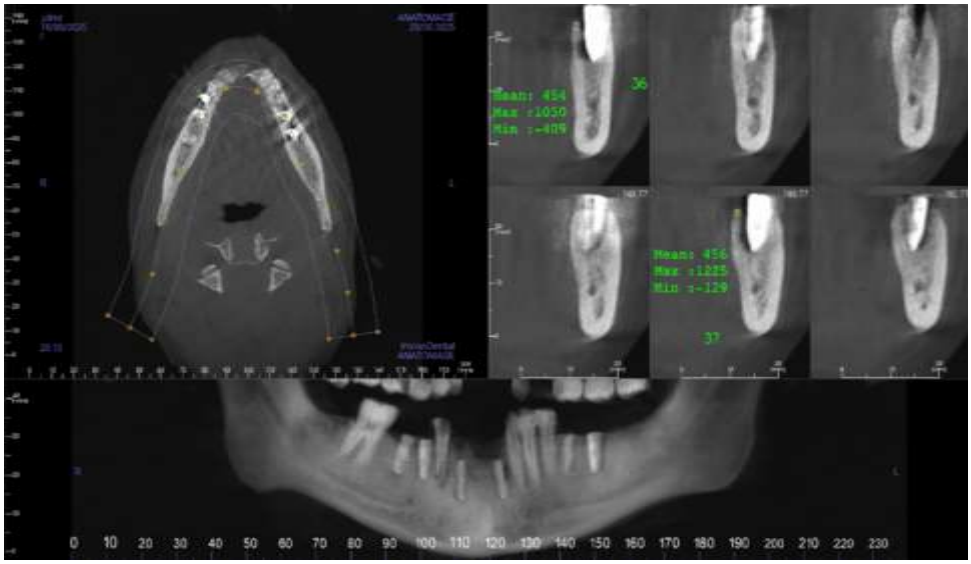

Figure 5: CBCT After Implant Placement for Bone Density

Statistical Analysis

Statistical analysis was performed using Statistical Package for Social Sciences (SPSS) software version 21.0. Continuous variables were expressed as mean ± standard deviation, while categorical variables were expressed as frequencies and percentages. Intergroup comparisons for continuous variables were analyzed using Student's independent t-test, whereas categorical variables were compared using Chi-square test. A p-value <0.05 was considered statistically significant.

RESULTS

The present randomized controlled trial was conducted to assess and compare the bio-stimulatory impact of Titanium-Prepared Platelet Rich Fibrin (T-PRF) and T-PRF augmented with Low-Level Laser Therapy (LLLT) in dental implants for replacement of posterior mandibular teeth. A total of 50 patients fulfilling the eligibility criteria were included and randomly allocated into two equal groups: Group A (T-PRF alone) and Group B (T-PRF + LLLT), comprising 25 patients each. The outcomes evaluated included demographic variables, postoperative pain, implant stability, and peri-implant bone density.

Demographic characteristics

The age of the study participants ranged from 21 to 60 years, with the majority of patients belonging to age groups above 40 years (70%). In Group A, 8.0% of patients belonged to the 21–30-year age group, 28.0% were between 31–40 years, 32.0% were between 41–50 years, and 32.0% were aged 51 years or above. Similarly, in Group B, 8.0% of participants were aged 21–30 years, 16.0% belonged to the 31–40-year age group, 40.0% were within the 41–50-year age category, and 36.0% were above 51 years of age. The mean age of participants in Group A was 45.08 ± 9.79 years, while Group B demonstrated a mean age of 46.08 ± 9.60 years. Although Group B showed a marginally higher mean age, the difference between the groups was statistically non-significant (t = –0.365, p = 0.717), indicating comparable age distribution across both study groups.

Gender distribution analysis demonstrated that out of the total 50 participants, 27 (54.0%) were males and 23 (46.0%) were females. In Group A, males constituted the majority of participants, accounting for 60.0% (n = 15), whereas females comprised 40.0% (n = 10). In contrast, Group B consisted of 48.0% (n = 12) males and 52.0% (n = 13) females. Despite minor variations in gender proportions between the groups, statistical analysis revealed no significant difference in gender distribution (χ^2 = 0.725, p = 0.395). Thus, both groups demonstrated adequate baseline comparability with respect to gender characteristics.

Overall, the demographic analysis confirmed that both treatment groups were homogeneous at baseline with respect to participant distribution, age, and gender characteristics. The absence of statistically significant differences between the groups suggests that any subsequent differences observed in clinical and radiographic outcomes can be attributed primarily to the intervention protocols rather than demographic variability.

Assessment of Postoperative Pain

Postoperative pain was assessed using the Numerical Rating Scale (NRS) at postoperative days 2, 4, 7, 10, and 14 **(Table 1)**.

Table 1: Intergroup comparison of Pain using NRS at different intervals

SN	Time Interval	Group A (n=25)		Group B (n=25)		Student's t-test	
		Mean	SD	Mean	SD	't'	'p'
1-	Day 2	3.76	1.13	3.04	0.89	2.506	0.016
2-	Day 4	2.56	1.12	2.20	0.76	1.327	0.191
3-	Day 7	1.56	0.96	1.28	0.74	1.156	0.253

4-	Day 10	0.64	0.70	0.36	0.57	1.552	0.127
5-	Day 14	0.20	0.41	0.04	0.20	1.760	0.085

Pain scores demonstrated a progressive reduction with increasing postoperative duration in both groups. Throughout all observation periods, Group B (T-PRF + LLLT) consistently exhibited lower pain scores than Group A (T-PRF alone). A statistically significant difference was observed only on postoperative Day 2 (p=0.016), indicating a beneficial role of LLLT in reducing pain during the early inflammatory phase following implant placement. Thereafter, differences gradually diminished and were statistically non-significant. By Day 14, pain had nearly resolved in both groups.

Assessment of Implant Stability

Implant stability was evaluated using resonance frequency analysis and expressed as Implant Stability Quotient (ISQ) **(Table 2)**.

Table 2: Intergroup comparison of Stability at different intervals

SN	Time interval	Group A (n=25)		Group B (n=25)		Student's t-test	
		Mean	SD	Mean	SD	't'	'p'
1-	Imm. After surgery	60.36	2.43	60.72	2.54	-0.512	0.611
2-	3 months	69.80	2.93	70.72	3.09	-1.080	0.285
3-	6 months	76.32	3.17	76.60	3.30	-0.306	0.761

Implant stability demonstrated progressive increases during the healing period in both groups. Immediately following surgery, mean ISQ values were approximately 60 in both groups, indicating adequate primary stability. At 3 months, ISQ values increased substantially, reflecting progression toward biological stability. By 6 months, ISQ values exceeded 76 in both groups, indicating excellent osseointegration and suitability for prosthetic loading. Intergroup comparisons revealed no statistically significant differences at any time interval (p>0.05).

Assessment of Peri-Implant Bone Density

Peri-implant bone density was evaluated using grayscale values obtained from CBCT imaging **(Table 3)**.

Table 3: Intergroup comparison of Stability at different intervals

SN	Time interval	Group A (n=25)		Group B (n=25)		Student's t-test	
		Mean	SD	Mean	SD	't'	'p'
1-	Pre-op	513.36	81.78	512.68	76.00	0.030	0.976
2-	Post-op (3 months)	569.08	83.33	579.32	74.65	-0.458	0.649
3-	Post-op (6 months)	585.13	85.62	608.00	74.96	-0.996	0.324

Both groups demonstrated an increase in bone density following implant placement, indicating active bone mineralization and remodeling around the implant site. Postoperative bone density values were slightly greater in Group B compared with Group A; however, the difference was not statistically significant (p=0.649 & p=0.324).

The findings of the present study indicate that the adjunctive use of LLLT with T-PRF resulted in significantly reduced postoperative pain during the initial healing phase, particularly on Day 2 following implant placement. However, no statistically significant additional benefits were observed regarding implant stability or peri-implant bone density during the six-month follow-up period. Both treatment approaches demonstrated favorable healing responses and successful osseointegration.

DISCUSSION

The present randomized controlled trial was undertaken to evaluate and compare the bio-stimulatory impact of Titanium-Prepared Platelet Rich Fibrin (T-PRF) alone and T-PRF augmented with Low-Level Laser Therapy (LLLT) in dental implants placed for the replacement of posterior mandibular teeth. The study investigated important clinical and radiographic parameters including postoperative pain, implant stability, and peri-implant bone density. The rationale behind combining these bio-stimulatory modalities was based on their individual regenerative properties and the possibility of obtaining synergistic effects capable of enhancing osseointegration and improving treatment outcomes.

Baseline demographic characteristics demonstrated no statistically significant differences between the study groups with respect to age and gender distribution, indicating homogeneity of the study population. Such baseline comparability is essential in randomized clinical studies to minimize potential confounding variables and ensure that differences observed

in outcomes are primarily attributable to the intervention rather than demographic variations. Similar demographic distributions have been reported in previous implant-related clinical studies evaluating regenerative approaches around dental implants.

One of the major findings of the present study was the significant reduction in postoperative pain observed in the T-PRF + LLLT group during the early postoperative period, particularly on Day 2 after implant placement. Patients receiving adjunctive laser therapy consistently reported lower Numerical Rating Scale (NRS) scores compared with those receiving T-PRF alone. However, the differences became statistically insignificant during later follow-up periods.

The reduction in postoperative pain associated with LLLT may be attributed to the photobiomodulatory effects of laser irradiation on inflammatory pathways and neural transmission mechanisms [16, 17]. Low-level laser therapy has been reported to increase ATP synthesis through stimulation of mitochondrial cytochrome-C oxidase, thereby promoting cellular metabolism and tissue repair while simultaneously reducing inflammatory mediator release and edema formation [18]. Additionally, laser therapy can modulate nerve conduction velocity and alter pain threshold mechanisms, resulting in improved patient comfort during the initial healing phase [19 -21].

The findings of the present study are consistent with those reported by Madi M and Mahmoud MM et al. [22], who observed significantly reduced postoperative discomfort and accelerated healing following diode laser application after gingivectomy procedures. Similarly, Seyyedi SA et al. [10] reported favorable outcomes of low-level laser therapy in reducing various forms of orofacial pain. Furthermore, Agan et al. [28] demonstrated significant reductions in postoperative pain and swelling when LLLT was used alone or in combination with PRF following third molar surgery.

However, the present results differ slightly from the findings of Saleem SSMEB et al. [14], who observed no significant differences in postoperative pain between PRF alone and PRF combined with laser therapy around dental implants. Such differences may be explained by variations in study design, laser wavelength, energy density, treatment schedules, implant sites, and patient characteristics [23-26].

Regarding implant stability, the present study demonstrated progressive increases in Implant Stability Quotient (ISQ) values in both groups during the healing period. Mean ISQ values increased from approximately 60 immediately after implant placement to greater than 76 after six months, indicating successful progression from primary mechanical stability to secondary biological stability and favorable osseointegration. Nevertheless, intergroup differences did not achieve statistical significance.

These findings suggest that while T-PRF and T-PRF combined with LLLT both support successful implant integration, adjunctive laser therapy did not provide a measurable additional benefit in implant stability during the observation period. Similar findings were reported by García-Morales JM et al. [16], who observed no significant effect of LLLT on implant stability assessed using resonance frequency analysis. Likewise, Torkzaban P et al. [20] found no substantial influence of diode laser application on implant stability during early healing.

Conversely, several investigations have reported beneficial effects of photobiomodulation on implant stability. Matys J et al. [9] demonstrated improved secondary stability and increased bone density following laser irradiation. Memarian J et al. [19] also reported improved implant stability with laser therapy. Differences among studies may result from heterogeneity in laser parameters including wavelength, energy dosage, application frequency, timing of irradiation, implant surface characteristics, and bone quality. This variability remains one of the major limitations affecting interpretation of photobiomodulation outcomes.

Radiographic assessment of peri-implant bone density in the present study revealed increased bone density values in both treatment groups during follow-up. Although slightly higher postoperative bone density values were observed in the T-PRF + LLLT group, these differences were not statistically significant. These findings indicate that both treatment modalities promoted bone remodeling and mineralization around implants but that the addition of LLLT did not produce a substantial enhancement in bone density.

The current findings correspond with those of Saleem SSMEB et al. [14], who similarly observed no statistically significant difference in bone density between PRF-treated and laser-augmented implant sites. Likewise, Bakry SA et al. [21] reported minimal effects of LLLT on peri-implant hard tissues.

In contrast, study by Attia MS et al. [27] reported significantly improved bone density and accelerated bone healing with photobiomodulation. The discrepancy may again be attributable to differences in patient populations, bone quality, follow-up duration, laser dosage protocols, and assessment methodologies.

The present study has certain limitations. The sample size was relatively small, which may have limited the ability to detect subtle differences between treatment groups. The follow-up duration of six months primarily assessed early osseointegration and may not adequately reflect long-term peri-implant tissue changes. In addition, only clinical and radiographic parameters were assessed; biological markers such as peri-implant crevicular fluid cytokines, growth factor levels, and histological outcomes were not evaluated. Variability in individual biological response to laser therapy and platelet concentrates may also influence treatment outcomes.

Future studies should include larger multicentric populations with longer follow-up periods to validate the present findings. Standardization of laser parameters including wavelength, power output, energy density, and treatment schedules is essential to minimize methodological heterogeneity. Further studies incorporating biochemical markers, histological evaluation, and molecular analyses may provide a better understanding of the biological mechanisms underlying combined T-PRF and photobiomodulatory therapy. Additionally, comparative evaluation of T-PRF with other platelet concentrates such as A-PRF and injectable PRF may help identify the most effective regenerative protocol for enhancing implant osseointegration.

Overall, the findings of the present study suggest that adjunctive LLLT may provide beneficial effects in reducing early postoperative discomfort; however, additional improvements in implant stability and peri-implant bone density were not

demonstrated within the study period. Both treatment approaches showed favorable healing characteristics and successful osseointegration, supporting their potential application as bio-stimulatory modalities in implant dentistry.

CONCLUSION

Within the limitations of the present randomized controlled trial, both Titanium-Prepared Platelet Rich Fibrin (T-PRF) alone and T-PRF augmented with Low-Level Laser Therapy (LLLT) demonstrated favorable outcomes in promoting implant healing and osseointegration in posterior mandibular dental implants. The adjunctive use of LLLT resulted in a significant reduction in postoperative pain during the early healing phase, particularly on the second postoperative day, suggesting a beneficial effect on patient comfort and immediate postoperative recovery.

However, no statistically significant additional advantages were observed with respect to implant stability or peri-implant bone density during the six-month follow-up period when compared with T-PRF alone. Both treatment modalities showed progressive improvement in implant stability and bone remodeling, indicating successful osseointegration and predictable clinical performance.

Therefore, T-PRF may be considered an effective bio-stimulatory adjunct for implant therapy, while the addition of LLLT appears to provide benefits primarily in reducing early postoperative discomfort rather than significantly enhancing long-term implant stability or bone density. Further large-scale studies with longer follow-up periods are recommended to validate these findings and establish standardized clinical protocols.

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