

Comparative Evaluation of Stability of Implants Placed with Photofunctionalization of Implants and Conventional Protocol by Resonance Frequency Analysis – A Pilot Study

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Abstract

The primary goal of modern dentistry is to restore normal contour, function, esthetics, speech, and health, whether replacing a single tooth or multiple missing teeth. Dental implants have become the global standard for managing tooth loss, offering predictable outcomes even in cases of bone atrophy, disease, or trauma. As Sir Per-Ingvar Brånemark, the father of implantology, famously said, “No one should die with their teeth in a glass of water.” Dental implants involve anchoring biocompatible materials into the jaw to support prosthetic teeth. However, implant success can be compromised by poor bone quality, quantity, and systemic health conditions that hinder osseointegration. To address this, implant designs have evolved through modifications in geometry and surface properties. Titanium, the most common implant material, undergoes “biological aging” shortly after manufacturing, losing hydrophilicity and bioactivity due to hydrocarbon accumulation. This aging reduces osteogenic cell attachment and prolongs healing. Photofunctionalization – a technique using ultraviolet (UV) irradiation – has emerged to counteract this process. By exposing titanium surfaces to UV light (200–400 nm), hydrophilicity is restored, osteogenic cell recruitment is enhanced, and bone-to-implant contact (BIC) is significantly increased. UV light alters the titanium dioxide surface chemistry, enhancing its biological activity. Notably, UVA (320–400 nm) has been identified as especially effective. Studies show that freshly manufactured implants show 90% BIC, while 4-week-old implants drop to 60%. Photofunctionalization rejuvenates aged surfaces, improving cell attachment and reducing healing time, offering a promising advancement in enhancing implant integration and clinical success.

Keywords: Dental implants, Photofunctionalisation, Resonance frequency analysis.

INTRODUCTION

The goal of modern dentistry is to restore the patient to normal contour, function, comfort, esthetics, speech, and health, whether restoring a single tooth with caries or replacing several teeth.^[1] Implants are considered as the first line of treatment for missing teeth worldwide.^[1] What makes implant dentistry unique is the ability to achieve this goal regardless of the atrophy, disease, or injury of the stomatognathic system.^[2] The father of Dental Implantology Sir Per Ingvar Branemark said “No One Should Die with their Teeth in Glass of Water.”

Thus came the discovery of Dental Implantology. Dental implantology is described as anchoring of alloplastic material into the jaws to provide support and retention for prosthetic replacement of teeth that have been lost.^[3,4]

The predictability and success of implant therapy in compromised case scenarios are challenging because of the

various risk factors which include suboptimal quality, quantity of bone, and unfavorable systemic conditions which affect osseointegration and duration of healing. Clinicians seek a design of implant that ensures enhanced osseointegration in such challenging cases. Attempts have been made to achieve this with changes in the geometric design and/or altering implant surface characteristics.^[5] Due to the inherent property of titanium, it undergoes biological aging within 7 days from the day of manufacturing. This is characterized by accumulation of hydrocarbons on titanium surfaces and loss of

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hydrophilicity over time, which correlates with their decreasing ability to osseointegrate. To overcome these inherent demerits, an innovative technique used is photofunctionalization. It is a process to alter the surface of implants by irradiating them with UV rays. Photofunctionalization regains this hydrophilicity, attracts osteogenic cells, facilitates cell attachment and adhesion, and increases bone formation around titanium subsequently increasing BIC thus reducing the overall healing time.^[6]

Ultraviolet (UV) rays and titanium

Human-visible light encompasses wavelengths in the range of 400–700 nm, while UV radiation spans from 10 to 400 nm and is subdivided into UVA (320–400 nm), UVB (290–320 nm), and UVC (10–290 nm). UV radiation predominantly exerts its effects photochemically. In particular, UVA has been identified as potentially the most active wavelength in enhancing the bioactivity of titanium dioxide (TiO₂) surfaces. Biological investigations typically utilize UV wavelengths ranging from 200 to 400 nm, encompassing all UVA, all UVB, and a portion of UVC.^[7]

Titanium dental implants achieve osseointegration with bone, a process referred to as “bioactivity.” Post-manufacture studies of dental implants have revealed that implants can experience significant loss of bioactivity and hydrophilicity within 4 weeks after production. Consequently, a 4-week-old implant may require double the healing time to attain the same bone-to-implant contact (BIC) as a newly manufactured implant. Research has shown that implants older than 4 weeks exhibit a BIC of 60%, compared to 90% for newly manufactured implants. *In vitro* studies have demonstrated that 4-week-old implants have only 20% osteogenic cell recruitment, attachment, settlement, and proliferation, in contrast to the 50% observed in new implant surfaces. This indicates that TiO₂ surfaces undergo bioactive aging and loss of hydrophilicity shortly after manufacturing, possibly within as little as 1 week.^[8]

Recent literature in dental implantology suggests that treating TiO₂ surfaces of dental implants with UV radiation within the 200–400 nm range may enhance BIC following the conventional healing period. UV radiation imparts energy to the surface electrons of TiO₂, potentially inducing reactions that make the surface super hydrophilic and enhance cell attachment and osteocyte interaction through hemidesmosomal chemistry. The photochemical action of UV radiation on titanium surfaces primarily increases their hydrophilicity, though the precise mechanism underlying this phenomenon remains incompletely understood. It is hypothesized that UV radiation energizes the molecular electron structure of TiO₂, thereby augmenting its biological reactivity and rendering the surface more conducive to cellular attachment.^[9]

MATERIALS AND METHODS

Patient selection

Two patients (two women) aged between 40 and 60 years (average, 50 years) visited Dr. G D Pol Foundations, YMT

Dental College during July and September 2023 for implant therapy and provided consent for documentation and public presentation of their cases. These patients met the following criteria that they were above 18 years of age, were able to provide consent, and had bilateral edentulous area in the same arch. Patients with any systemic diseases or metabolic disorders if any which may impact study, pregnant and lactating women, patients who are currently smoker or quitted smoking <1 year ago, those who have parafunctional habits, patients with uncontrolled periodontal disease, caries, or clinical or radiographic signs of infection within two adjacent teeth, and patients with current chemotherapy/radiotherapy were excluded from the study.

Clinical procedures and photofunctionalization of dental implants

Ethical clearance was obtained from the institutional Ethical Committee of YMT Dental College and Hospital before the commencement of the study.

Standardized consultation and diagnostic procedures were performed, and a treatment plan was presented and approved by each patient. This study was conducted in the Department of Prosthodontics and Crown and Bridge. Patients were provided with information regarding both the types of implants including their characteristics, material, and cost. Implant placement procedure was done by conventional method without any type of bone augmentation. Antibiotic regimen was started 24 h before the procedure. All the implants were placed according to the strict surgical protocol. After the administration of local anesthetic agent (Lignocaine hydrochloride with Adrenaline, 1:200000), a mid-crestal incision was given in the selected site using surgical Bard Parker blade #15. With the help of Molt's periosteal elevator #9, a full thickness flap was reflected, and osteotomy of the desired size was prepared successively with sharp drills under continuous saline irrigation. On the one side, the implant was placed with conventional protocol. On the other side before placing, the implant was subjected to UV rays for 20 s in a dedicated UV chamber. Healing abutments were placed. The flap was readapted with interrupted sutures. Appropriate antibiotic regimen and anti-inflammatory medications were prescribed post-implant insertion. Patients were recalled periodically. All the patients had to report for follow-up after implant insertion at the following times post-insertion: 1 week, 4 weeks, 8 weeks, 12, weeks which was judiciously followed.

Assessment of osseointegration

Implant stability quotient (ISQ) value which is a function of bone implant stiffness (N/μm) was recorded using Osstell instrument that uses resonance frequency analysis that measures the frequency with which a device vibrates. The prescribed smart peg for implant was directly connected to the implant head. The reading on the device was recorded during each follow-up. The transducer was placed buccally, lingually, and mesial/distally, and the average of these readings were derived and noted.

CASE REPORTS

Case 1

A 44-year-old female patient presenting with missing teeth in right and left mandibular posterior region visited the college for potential implant treatment. After clinical and radiographic examination, treatment plan and implant sizes were decided. The implants in first premolar and first molar region were placed on the right side according to standard surgical protocol. The implants in first premolar and first molar region on left side were photofunctionalized in the dedicated UV chamber before placing into the prepared osteotomy. Primary stability was assessed with Osstell meter immediately after placement, 1 month and 3 months.

Case 2

A 41-year-old female patient presenting with missing teeth in right and left mandibular posterior region visited the college for potential implant treatment. After clinical and radiographic examination, treatment plan and implant sizes were decided. The implant in first molar region was placed on the right side according to standard surgical protocol. The implant in first molar region on left side was photofunctionalized in the dedicated UV chamber before placing into the prepared osteotomy. Primary stability was assessed with Osstell meter immediately after placement, 1 month and 3 months.

RESULTS

The results of the study show a comparative analysis of osseointegration between conventional and photofunctionalized dental implants using ISQ values, measured at three different time points: At the time of placement, after 1 month, and after 3 months. Here is a summary of the findings.

The ISQ value findings [Table 1]

Analysis

Initial placement

Photofunctionalized implants showed higher ISQ values compared to conventional implants at the time of placement for all cases and types of implants.

Progression over time

After 1 month

Photofunctionalized implants exhibited a significantly greater increase in ISQ values compared to conventional implants across all cases and implant types.

After 3 months

Photofunctionalized implants continued to show higher ISQ values than conventional implants, indicating better stability and osseointegration over time.

Overall trends

The photofunctionalized implants consistently demonstrated higher stability and osseointegration rates compared to conventional implants at all measured time points [Figure 1]. This suggests that photofunctionalization may enhance the early and long-term stability of dental implants.

These results indicate that photofunctionalized implants not only start with a higher level of stability but also exhibit a more favorable progression in osseointegration compared to conventional implants.

DISCUSSION

The objective of this study is to evaluate the impact of photofunctionalization on the osseointegration and stability of dental implants compared to conventional implant placement methods. The results demonstrated that photofunctionalization appears to offer a significant advantage in both the initial stability and the progression of osseointegration over a 3-month period.

At the time of placement, photofunctionalized implants consistently exhibited higher ISQ values compared to their conventional counterparts. This initial advantage in stability is likely attributed to the enhanced surface properties achieved through UV light treatment. The UV treatment is known to promote a more favorable surface energy and increase the hydrophilicity of the implant, which can improve the initial BIC and promote better primary stability.^[10] This finding aligns with previous studies suggesting that surface modifications, including photofunctionalization, can positively affect early implant stability. One-month post-implantation, photofunctionalized implants showed a greater increase in ISQ values compared to conventional implants.^[8,9] This suggests that the initial benefits of photofunctionalization extend into the early stages of healing, contributing to enhanced bone-implant integration. The higher ISQ values observed at this stage may be indicative of a more rapid or effective osseointegration process, which could potentially reduce the time required for implant loading and restore function earlier than conventional methods.

By 3 months, photofunctionalized implants continued to demonstrate superior stability compared to conventional implants. The sustained higher ISQ values suggest that the benefits of photofunctionalization are not merely transient but provide a prolonged enhancement in implant stability. This sustained improvement may be due to the ongoing positive interaction between the photofunctionalized implant surface and the surrounding bone, facilitating a more robust and durable osseointegration.

Funato *et al.* reported that the ISQ for UV-treated dental implants increased by 8.0 ISQ units during monthly testing, compared to literature reports of 1.8–2.8 increases for untreated implants.^[11] Suzuki *et al.* confirmed the enhanced and accelerated osseointegration of UV-treated implants.

Hirota *et al.* found that a 12-min UV conditioning of machined titanium mesh produced a superhydrophilic surface and reduced surface carbon from 15% to 8%. The photofunctionalization led to a 2.5-fold increase in albumin protein adsorption on the UV-conditioned TiO surface. Osteoblasts on conditioned surfaces were larger, with clear

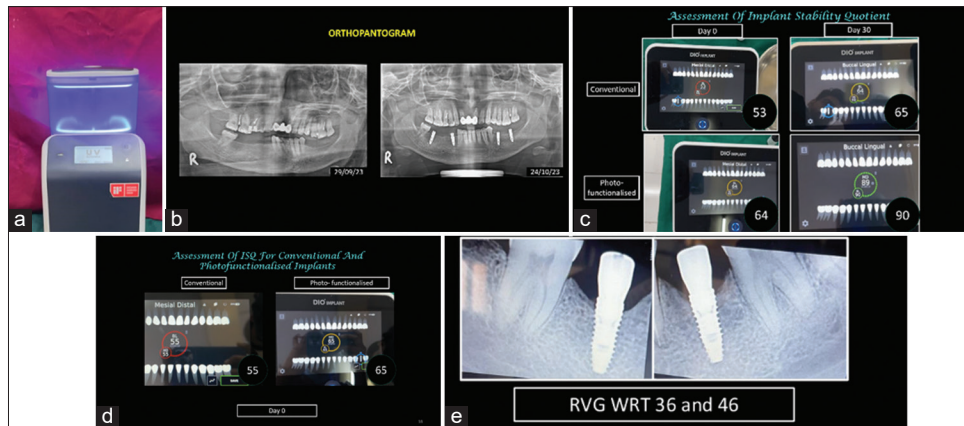


Figure 1: (a) Ultraviolet chamber for photofunctionalization. (b) OPGs for case 1. (c) Implant stability quotient (ISQ) values for case 1. (d) ISQ values for case 2. (e) RVGs for case 2

Table 1: Comparison of ISQ values at different time intervals

Cases	At the time of placement		After 1 month		After 3 months	
	Conventional	Photofunctionalized	Conventional	Photofunctionalized	Conventional	Photofunctionalized
Case 1						
Premolar	53	67	65	90	90	94
Molar	65	69	67	93	92	98
Case 2						
Molar	55	65	66	87	88	90

lamellipodia-like elongations and cytoskeletal fibers. Untreated surfaces had rounded osteoblasts with rare elongations. After 24 h, cells on conditioned surfaces were larger with extensive actin fibers, and after 4 days, conditioned surfaces had significantly more cells with increased calcium deposition. At 3 weeks, conditioned surfaces had thick, dense mineralized bone layers, 2.5 times that of unconditioned surfaces, with increased alkaline phosphatase activity indicating enhanced osteoblastic activity. Photofunctionalized TiO surfaces, being electropositive, caused direct cell contact and increased cellular recruitment and attachment, producing enhanced bone formation.^[12]

In a study involving UVC-treated implants in rabbits, a higher BIC was observed after 4 months of healing compared to untreated implants. This study also found a decrease in carbon surface impurities and lower water contact angles, indicating increased hydrophilicity. Hydrophilicity enhances the initial attachment of osteoblast-like cells to the implant surface.

Further research demonstrated that in rats, UV-treated dental implants achieved BIC as high as 100%. UV treatment led to a threefold increase in protein adsorption, osteoblast spread, attachment, proliferation, and differentiation. Another study found a 57% increase in BIC after 24 h of UV treatment of branded dental implants in rabbit tibias. UV treatment dramatically decreased the water contact angle from 43.58 to 0.58, indicating increased hydrophilicity. During bone integration, cellular lamellipodia elongation preceded increased cell attachment, flattening, and proliferation. Control

trial cells were round and spherical, indicating less attachment and hydrophilicity. However, one proprietary brand did not show increased BIC after UV treatment.

Kitajima and Ogawa recently found that photofunctionalization for 15 min rapidly increased stability for implants placed with low or no primary stability. Photofunctionalization was more effective for implants with lower initial stability, showing a high success rate after 2 years. The average ISQ for all implants tested was 50.4, which increased to 74.3 after an average of 7 months of healing. Implants with no primary stability at placement attained an ISQ of 75 or greater, indicating photofunctionalization's particular efficacy for implants with compromised initial stability.^[13]

UV treatment enhances initial osteoblast attachment and osseointegration capacity. Ishijima *et al.* found that rat marrow osteoblasts cultured on new and UV-treated TiO surfaces were super-hydrophilic, whereas more than 4-week-old surfaces were hydrophobic. Protein adsorption was higher on new and UV-treated surfaces, with more numerous attached cells and enhanced spreading behavior.^[14]

Saita *et al.* demonstrated that photofunctionalization enabled faster TiO surface deposition of nanoscale biomimetic apatite, improving biological capability compared to similarly prepared apatite-deposited titanium without photofunctionalization. UV-treated TiO surfaces with biomimetic apatite deposition may effectively enhance microroughened titanium surfaces without altering their microscale morphology.^[15]

In summary, UV treatment and photofunctionalization of dental implants significantly improve their hydrophilicity, stability, and osseointegration, as evidenced by increased BIC, protein adsorption, and osteoblast activity. Further studies in human subjects are warranted to validate these findings.

Clinical implications

The findings of this study have several clinical implications. The enhanced stability of photofunctionalized implants could potentially allow for earlier implant loading and reduce the overall treatment time for patients. This could be particularly advantageous in cases where patients require faster restoration or suboptimal clinical conditions. In addition, improved osseointegration could reduce the risk of implant failure and increase the longevity of dental implants.

CONCLUSION

UV radiation has profound chemical and biological effects on TiO₂ surfaces that significantly enhance osseointegration. By imparting a slight positive surface energy and increasing hydrophilicity, UV treatment rejuvenates the biological reactivity of titanium dental implants, which may be diminished after manufacturing and prolonged storage in air. This photofunctionalization process leads to accelerated healing and a marked increase in BIC.

Despite the promising results, most evidence supporting these benefits arises from animal studies or *in vitro* experiments, raising questions about their direct applicability to human clinical scenarios. However, for the discerning clinician, a brief 15-min photofunctionalization treatment of implants before placement could be considered a prudent step to potentially enhance clinical outcomes. Identifying the optimal exposure duration and wavelength for UV treatment remains a priority for future research.

To substantiate the efficacy of this approach, long-term, randomized, blinded clinical trials are imperative. These studies are essential to confirm whether UV photofunctionalization of dental implants can consistently deliver the observed benefits

in human subjects, thereby cementing its place in routine clinical practice.

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