Review Article

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Dentistry Section

Effects of Photofunctionalisation on Osseointegration and Stability of Dental Implants: A Systematic Review

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ABSTRACT

Introduction: Dental implant osseointegration is crucial for the long term success of implant-supported restorations. Photofunctionalisation (PF), a novel surface modification technique, has been proposed as a means to enhance implant osseointegration.

Aim: To evaluate the current evidence regarding the effects of PF on dental implant osseointegration.

Materials and Methods: A comprehensive search was conducted in electronic databases, including PubMed, Directory of Open Access Journals, and Google Scholar, for studies published up until August 2022. The search strategy combined keywords related to dental implants, PF, and osseointegration. Two independent reviewers screened the titles, abstracts, and full texts of the identified studies, following predefined inclusion and exclusion criteria. Data extraction and quality assessment using the Cochrane Collaboration's tool for randomised clinical trials, the ROBINS-I tool for non randomised studies, and the The Newcastle-Ottawa Scale (NOS) for observational studies were performed.

Results: A total of five studies met the inclusion criteria and were included in the systematic review. The outcomes assessed included implant stability, osseointegration, and survival rates. The findings of the included studies suggested that PF of dental implants may promote osseointegration by enhancing early bone formation, increasing implant stability, and improving Bone-To-Implant (BIC) contact.

Conclusion: The available evidence suggests that PF of dental implants may have a positive impact on osseointegration. However, due to the limited number of studies, further research is needed to provide more definitive conclusions regarding the clinical benefits of photofunctionalised dental implants in pathologically compromised bone sites.

Keywords: Implant stability, Photofunctionalised implants, Ultraviolet treatment

INTRODUCTION

The use of dental implants for rehabilitating edentulous areas has been extensively documented and shown to yield predictable results over the years [1,2]. Effective osseointegration is a crucial element for achieving clinical success in dental implant therapy [1]. The rate and quality of osseointegration depend on the surface characteristics of implants, including their composition, roughness, and hydrophilicity, which play essential roles in the interaction between implants and tissues, consequently influencing osseointegration. However, these surface characteristics are affected soon after the manufacturing of titanium implants, as the titanium surface inevitably begins to undergo biological ageing [3]. This phenomenon affects both the smooth machine surface and the acid-etched surface. As the ageing of the titanium surface progresses, the original titanium dioxide surface becomes covered with hydrocarbon [4]. Studies show that aged titanium surfaces have over 50% carbon content [3,5]. When the titanium surface is fresh, the Bone-to-implant Contact (BIC) exceeds 90%. However, as carbon accumulation increases, the BIC reduces to approximately 60%, resulting in compromised osteoblast attachment, cell proliferation, and calcification [4,5]. This reduced BIC due to hydrocarbon accumulation leads to impaired osseointegration, further reducing the survival rates of implants, especially in areas with suboptimal bone quality or in situations where bone grafting is performed [6-8]. Thus, achieving higher BIC values significantly improves the osseointegration of dental implants.

Numerous innovative surface treatments are available to effectively aid in rehabilitating patients with dental implants, demonstrating reliable rates of success. These techniques include ion beam-assisted deposition sputter coating, pulsed laser deposition, electrostatic spray deposition, Photofunctionalisation (PF), and Platelet-Rich Plasma (PRP) [4].

The process of PF applied to titanium implants, which involves a broad spectrum of physical, chemical, and biological changes resulting from exposure to Ultraviolet (UV) light, has garnered significant curiosity and fascination within the domain of titanium implant-based treatments [9,10]. PF entails subjecting implants to UV radiation to improve osteoconductivity and reduce the amount of hydrocarbons on the titanium surface [5,6]. This leads to an increase in surface energy and the hydrophilicity of implants, allowing osteogenic cells to adhere and attach better to the implant surface [7,8]. Studies suggests that PF has the capability to enhance BIC up to 98.2%, resulting in a more than threefold increase in the strength of bone-implant fusion during the initial phase of healing. Moreover, this heightened BIC has been proven to play a role in the uniform distribution of mechanical stress within the peri-implant marginal bone, thereby reducing stress levels [5,7,8,11]. All these advantages make PF a viable and effective surface treatment option.

The need for optimum osseointegration, especially in D3 and D4 bone, requires enhanced levels of BIC to reduce the risk of failures and improve long term success rates. Therefore, this systematic review aimed to assess the role of PF in improving the osseointegration and stability of dental implants in patients requiring rehabilitation of missing teeth.

MATERIALS AND METHODS

A systematic review of the literature was conducted. This study adhered to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines [12], the Cochrane Handbook for Systematic Reviews of Interventions, version 5.1.0, and the 4th Edition of the JBI Reviewer's Manual. The study was registered at PROSPERO under the registration code CRD42022344071.

Eligibility Criteria

Inclusion criteria:

a. Population:
   i. Studies including participants with partial/complete edentulism for implant placement.

b. Intervention:
   i. Studies with participants treated with photofunctionalised implants.

c. Outcome:
   i. Implant stability measured by Implant Stability Quotient (ISQ), osseointegration, implant survival.

d. Study design:
   i. Studies published in the English language only.
   ii. Studies published between January 1, 2000, and August 31, 2022.
   iii. Randomised Controlled Trials (RCTs), quasi-experimental studies, cross-sectional studies, retrospective studies, non randomised trials.
   iv. Studies with full-text articles to be included.
   v. Studies providing a numeric value or enough data to calculate atleast one of the outcome measures, such as implant stability, osseointegration, implant survival.

Exclusion criteria:

   vi. Studies involving patients who have not provided informed consent.
   vii. Studies involving other methods of implant treatment like Platelet-rich Plasma (PRP)-treated, etc.
   viii. Review reports, case series, in-vitro, and animal studies will be excluded.
   ix. Studies with only an abstract available and not the full text.

Search Strategy

Studies were selected based on the inclusion criteria in the review protocol. Potentially eligible studies were identified by assessing the titles and abstracts by two independent reviewers. Any queries were discussed with a third reviewer. The exposure was PF treated implant, with or without comparison with a control group. In the advanced search option, Boolean operators were utilised in conjunction with keywords and MeSH terms, as shown in [Table/Fig-1].

Population	Exposure	Outcome	Study design
Adult dental implant	UV treatment Photofunctionalisation (PF)	Bone height, implant stability, implant survival	Randomised clinical trials, comparative studies, non randomised trials

[Table/Fig-1]: Terms imported in the search strategy.

Focused review question: What is the effect of PF on osseointegration and stability of dental implants?

Search strategy in PubMed: ("osseointegration" [MeSH Terms] OR "osseointegration" [All Fields]) AND (photofunctionalisation [All Fields] AND implants [All Fields]) AND (("dental implants" [MeSH Terms] OR ("dental" [All Fields] AND "implants" [All Fields]) OR "dental implants" [All Fields] OR ("dental" [All Fields] AND "implant" [All Fields]) OR "dental implant" [All Fields]) AND photofunctionalisation [All Fields]) AND ("osseointegration" [MeSH Terms] OR "osseointegration" [All Fields]).

Entry terms used in Google Scholar: PF, Osseointegration, Implant stability.

Selection of studies: The titles and abstracts of each study were reviewed and critically evaluated by two independent reviewers. The selection criteria were applied using the following methods:

i. Consolidation of search results to remove duplicate entries.
ii. Review of titles and abstracts to eliminate clearly irrelevant articles.
iii. Retrieval of the full text for potentially relevant articles.
iv. Grouping and collecting multiple articles of the same study.
v. Thorough examination of the full text of articles to assess their alignment with the eligibility criteria.
vi. Contacting researchers, if necessary, to clarify the study's eligibility.
vii. Determining whether to include the study and proceeding with data collection.

Data extraction: After narrowing down to five articles from all the databases, two reviewers independently collected data from the included studies. Any differences in their findings were addressed through discussion. The data collection process involved using a checklist of items deemed essential for data extraction.

Critical Appraisal

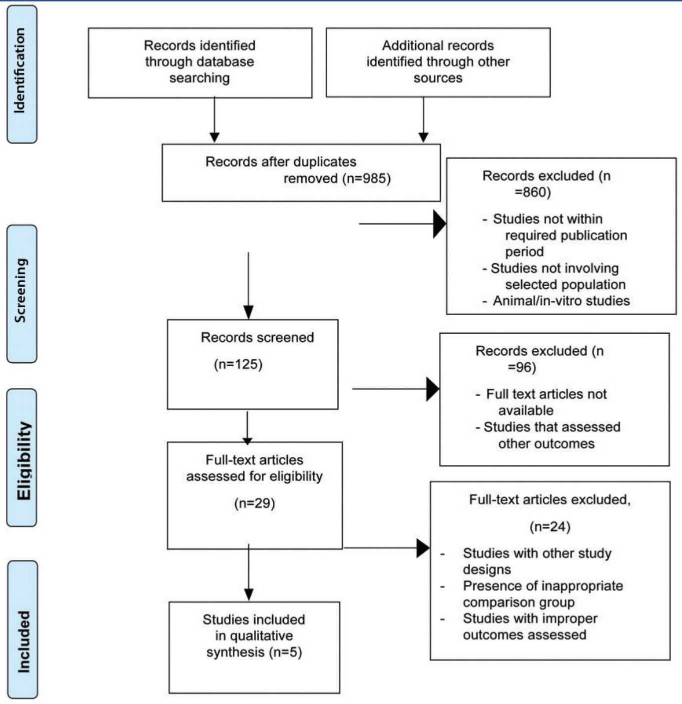
The quality assessment of randomised clinical trials was assessed using Cochrane collaboration's tool [13]. The overall risk of bias is considered low when there is a low risk of bias for all key domains, and when bias, if present, is not likely to alter the results [13].

The methodological quality of non randomised studies was evaluated using the ROBINS-I tool [14]. This tool consists of seven domains to evaluate the risk of bias: bias due to confounding, selection of participants, misclassification, deviation from intended interventions, missing data, measurement of outcomes, selection of the reported result.

For observational studies, the The Newcastle-Ottawa Scale (NOS) [15] was used. The NOS assigns up to a maximum of nine points for the least risk of bias in three domains: 1) selection of study groups (four points), 2) comparability of groups (two points), and 3) ascertainment of exposure and outcomes (three points) for case control and cohort studies, respectively.

RESULTS

Study selection: The PRISMA guidelines were followed for the methodology. The study selection process is summarised in [Table/Fig-2] (PRISMA flow chart). The initial electronic database search on PubMed/MEDLINE and Cochrane Library resulted in 5,249 titles. The 985 articles were identified as duplicates. After screening the abstracts, 125 relevant titles were selected by two independent reviewers. Following examination and discussion by the reviewers, 29 articles were chosen for full-text evaluation. Hand searching of the reference lists of the selected studies did not yield additional papers. After pre-screening, applying the inclusion and exclusion criteria, and addressing the PICO (population, intervention, comparison, and outcomes) questions, five studies were included in the qualitative synthesis.



[Table/Fig-2]: PRISMA study flow diagram.

Study characteristics: Five studies were included in the qualitative synthesis, and their general characteristics are presented in [Table/Fig-2-5]. Two studies were randomised controlled trials, two were non randomised prospective studies, and one was a retrospective study. The studies were conducted in different parts of the world, with two in Japan [8,16], one in the USA [17], one in India [18], and one in Korea [19].

Risk of bias applicability: The Cochrane collaboration's tool was used for the quality assessment of randomised controlled trials [Table/Fig-6]. Two studies were included, and both had a low risk of bias. The allocation concealment domain was unclear in both studies [18,19].

The ROBINS-I tool was used for non randomised studies [Table/Fig-7]. Two studies were included, one showing a moderate risk and one showing a high-risk of bias [16,17]. The study conducted by Suzuki S et al., exhibited a high-risk due to selective reporting of results [16].

The Newcastle-Ottawa Tool tool was used for quality assessment of the observational study [Table/Fig-8]. One study was included, which showed a moderate risk of bias [8].

DISCUSSION

In the past 50 years, implant dentistry has evolved from an experimental treatment to a highly predictable option for replacing

S. No.	Title	Authors	Year	Region	Study design	Inclusion criteria
1	Success rate, healing period, and implant stability of photofunctionalised dental implants	Funato A et al., [8]	2013	Japan	Retrospective study	• Minimum 20 years old. • Adhering to oral healthcare instructions and essential appointments. • Gave consent for the recording and public sharing of their clinical data.
2	Implant stability change and osseointegration speed of immediately loaded photofunctionalised implants	Suzuki S et al., [16]	2013	Japan	Prospective study	• At least 20 years old. • Adhering to oral healthcare instructions and essential appointments. • Indicated for immediate loading in the edentulous maxilla.
3	UV mediated Photofunctionalisation (PF) of Dental Implant: A 7 year results of a prospective study	Hirota M et al., [17]	2020	USA	Prospective study	• ≥20 years of age. • Signed written informed consent. • At least one missing tooth in the jaws.
4	Biological and aesthetic outcome of immediate dental implant with the adjunct pretreatment of immediate implants with Platelet-Rich Plasma (PRP) or Photofunctionalisation (PF): A randomised controlled trial	Shah SA et al., [18]	2021	India	RCT	• ≥18 years of age. • Able to provide informed consent. • One or more teeth indicated for extraction for immediate implant in maxillary anterior area (13-23). • Adjacent teeth having healthy periodontium. • There should be a minimum of 1.5 mm of bone between the dental implant and adjacent teeth as well as on facial side, whereas 0.5 mm bone should be remaining on the palatal side. • A minimum of 4 mm bone apical to root apex of extracting tooth.
5	Effects of Photofunctionalisation (PF) on early osseointegration of titanium dental implants in the maxillary posterior region: A randomised double-blinded clinical trial	Choi B et al., [19]	2021	Korea	RCT	• Edentulous area on the posterior maxillary region

[Table/Fig-3]: Demographic characteristics related to the included studies, study designs, and inclusion criteria.

S. No.	Authors	Average age	Sample size	Test group	Control group	Follow-up
1	Funato A et al., [8]	≥20 years	390	Photofunctionalised implants	Untreated implants	Follow-up period of 2.5 years
2	Suzuki S et al., [16]	At least 20 years old	33	Photofunctionalised implants	Not mentioned	11 weeks
3	Hirota M et al., [17]	34-70 years	70	Photofunctionalised implants	Not mentioned	7 years
4	Shah SA et al., [18]	≥18 years	90	Photofunctionalised implants	PRP treated implants	2,4 weeks 2,4,6,12 months
5	Choi B et al., [19]	Not mentioned	78	Photofunctionalised implants	Untreated implants	1 year

[Table/Fig-4]: Characteristics of included studies.

S. No.	Authors	Outcomes assessed	Conclusions
1	Funato A et al., [8]	Implant stability, success, complications	Despite a significantly reduced healing time of 3.2 months prior to loading, the implementation of PF led to a high success rate of 97.6%, surpassing that of untreated implants.
2	Suzuki S et al., [16]	Implant Stability Quotient (ISQ), Osseointegration Speed Index (OSI)	The process of PF expedited and improved osseointegration, opening up new and practical possibilities for advancements in implant therapy.

3	Hirota M et al., [17]	Implant Stability Quotient (ISQ)	PF demonstrated promising outcomes in regular and complex cases where the residual bone was unaffected by oral cancer treatment. However, in cancer-related sites, PF was unable to achieve long term success.
4	Shah SA et al., [18]	Bone loss, implant stability, aesthetic stability, success	The utilisation of PF and Platelet-Rich Plasma (PRP) surface treatment on commercial dental implants may yield significantly improved results in immediately placed implants in the anterior maxilla compared to standard tapered root form implants with no pre-treatment.
5	Choi B et al., [19]	Implant stability, marginal bone loss	The application of UV irradiation to the implant surface demonstrated consistent results with respect to initial stability in the posterior maxilla.

[Table/Fig-5]: Assessed outcomes and conclusions.
PF: Photofunctionalisation

S. No.	Authors	Random sequence generation	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Other bias	Risk of bias
1.	Shah SA et al., 2021 [18]	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Low risk
2.	Choi B et al., 2021[19]	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Low risk

[Table/Fig-6]: Risk of bias according to Cochrane collaboration's tool for randomised controlled trials.

S. No.	Authors	Confounding bias	Selection bias	Bias in classification of interventions	Bias due to deviation from intended interventions	Bias due to missing data	Bias due to selective reporting of results	Bias due to measurement of outcomes	Risk of bias
1.	Suzuki S et al., 2013 [16]	Low risk	Unclear	Unclear	Unclear	Unclear	High risk	High risk	High risk
2.	Hirota M et al., 2020 [17]	Low risk	Low risk	Low risk	Unclear	Unclear	Low risk	Moderate risk	Moderate risk

[Table/Fig-7]: Risk of bias according to ROBINS-I tool for non randomised trials.

Authors	Selection				Comparability		Outcome		Total score	Risk of bias
	Representativeness of sample	Sample size	Non responders	Ascertainment table of exposure	Main factor	Additional factor	Assessment of outcome	Statistical test		
Funato A et al., 2013 [8]	*	-	-	*	*	-	*	*	5	Moderate

[Table/Fig-8]: Risk of bias according to New-Castle Ottawa tool for cross-sectional studies.

missing teeth with implant-supported prosthesis. Modern implant therapy is a popular treatment method for fully or partially edentulous patients, as it offers functional and biological benefits that traditional removable or fixed prostheses cannot provide. Additionally, numerous studies with over 10 years of follow-up have demonstrated success and survival rates of implant therapy exceeding 95% [1,2].

The core of (PF) is to cleanse titanium surfaces, which tend to accumulate natural hydrocarbon contamination, in order to enhance their hydrophilicity and optimise their capacity to promote osseointegration, regardless of their initial surface characteristics [5-8]. Carbon accumulation on aged titanium surfaces is reduced to less than 20%, revealing the original titanium dioxide surface. Photofunctionalised titanium surfaces enhance osteoblast attachment and can achieve nearly 100% (BIC) [17]. This leads to reduced healing time, improved primary stability, and a decrease in stability dip during the healing period [20]. These benefits are particularly advantageous in complex cases, where PF can facilitate optimum osseointegration in a shorter time compared to conventional longer healing periods [16,17].

This systematic review aims to evaluate the effect of PF on the osseointegration and stability of dental implants in patients requiring the rehabilitation of missing teeth. The goal is to gain a better understanding of the applications and benefits of PF in achieving optimal osseointegration and reduced healing periods.

The study conducted by Funato A et al., revealed a significant increase in Implant Stability Quotient (ISQ) between the initial and subsequent measurements for photofunctionalised implants, ranging from 10.7 to 26.2 [8]. This increase was notably higher compared to values reported in existing literature, which typically ranged from -5.0 to 4.6. Additionally, the monthly ISQ increase for photofunctionalised implants, ranging from 2.0 to 8.7, exceeded the figures documented in prior studies, which generally ranged from -1.8 to 2.8.

In the present study, all photofunctionalised implants with initial ISQ <50 demonstrated successful osseointegration. Prior to functional loading, the failure rate for photofunctionalised implants was 0%, whereas it was 3.15% for untreated implants. This suggests that none of the photofunctionalised implants exhibited detrimental changes in peri-implant bone during the initial healing phase. Due to carbon removal by PF, the implants in the present study may have regained their maximum inherent osteoconductive potential, resulting in minimal variation in osseointegration capability between the implants [8].

The study conducted by Suzuki S et al., showed that the initial Implant Stability Quotient (ISQi) exhibited a wide range, spanning from 65 to 85 [16]. However, by week 6, the ISQ values had converged to a higher level. A noticeable pattern was observed where implants with lower initial ISQ values had a greater increase in ISQ. As a result, all implants had an ISQ value of 75 or higher by week 6.

The Osstell Stability Index (OSI) in the 65 to 70 ISQ group was 6.3±0.9, which was approximately twice as high as that in the 71 to 75 ISQ group (3.1±1.2). The study's three major findings were as follows: 1) There was a more substantial rise in ISQ values between the initial and secondary measurements for photofunctionalised implants compared to what is reported in existing literature; 2) significantly higher OSI of photofunctionalised implants compared to the literature; and 3) the secondary ISQ values between 77.5 and 78.1 surpassed all previously documented values in the literature, even within a comparatively brief healing period of 1.5 months.

It is common for ISQ values to initially be high (around 70 to 80) and then decrease or show a dip during the healing period. However, in this study, implants with very high initial ISQ values (above 78) did not experience a dip or notable decrease in stability during the healing period. This finding strongly supports the feasibility of immediate loading [16].

The ISQ value at the first measurement (ISQ1) was 52.6 for all sites combined, and it varied as follows: 67.2 for regular sites, 30.5 for complex sites, and 62.1 for cancer-related sites. The overall ISQ increased by 13.7, and by 3.2 and 21.9 in regular and complex sites, respectively, while it decreased by 3.5 in cancer-related sites. This demonstrated that PF can improve the secondary stability of implants, even in cases of low initial stability or inadequate bone support. Clinically, good results have been observed in cases where initial bone support was lower than 25% of implant length or initial ISQ was less than 30 [17].

In the study conducted by Shah SA et al., at 2, 4, 6, and 12 months, implant stability showed a statistically significant difference in the PF group and PRP group compared to the control group (p-value <0.001) [18]. The control group had higher success and survival rates (96.42%) compared to the PF group (92.59%) and PRP group (93.01%) [18].

Choi B et al., reported notable variations in ISQ between the UV treated group and the control group at four weeks (p-value=0.004) and four months (p-value=0.017) postoperatively in bone quality Group-III (300-500 grayscale) [19]. The UV treated group exhibited a significantly greater difference in ISQ compared to the control group. At 4 weeks postoperatively, the UV treated group showed significantly less bone loss than the control group (p-value=0.037) [19].

Kitajima H and Ogawa T demonstrated the effectiveness of photofunctionalised implants, even in complicated cases [20]. The success rate was supported by a quantitative evaluation of implant stability, showing consistent improvement from the initial placement to the stage two surgery [20].

Puisys A et al., demonstrated that photofunctionalised implants exhibit increased resistance to removal torque forces compared to untreated implants [21]. This implies significantly greater implant stability, particularly during the initial healing phase. This study also showed an absence of a “stability dip” for photofunctionalised implants, supporting the application of early loading [21].

Dini C et al., reported that PF of implants alters the physical and chemical surface of titanium implants, leading to improved protein adsorption and decreased bacterial colonisation. This improves the implant-host interaction and reduces the healing period, allowing for early loading protocols [22].

Based on the outcomes reviewed in this study, PF appears to play a significant role in reducing the healing period, even in complex situations [8]. PF can accelerate and enhance the process of osseointegration in commercially available dental implants [21]. This increases the rate of achieving implant stability, even when initial stability is relatively low. In cases where initial stability is high, the ISQ remains consistently high, avoiding the commonly observed phenomenon of a stability dip. In both instances, the level of stability that implants may experience is significantly increased [16,17]. These findings suggest that PF offers a promising and feasible opportunity to enhance implant therapy by expanding its indications, reducing healing time, and increasing survival rates, especially in complex cases [8,16].

Limitation(s)

The studies included in this systematic review had varying durations of follow-up. One study did not mention the follow-up period [8], whereas another study had a follow-up period of less than one year [16]. Another limitation is that all studies reported variations in the control groups. Two studies did not mention the control group [16,17]. Two studies compared photofunctionalised implants with untreated implants [8,19], whereas one study used PRP treated implants as the control group [18].

CONCLUSION(S)

The results obtained from the studies included in this systematic review lead to the conclusion that PF is an effective method for enhancing osseointegration by increasing Bone-To-Implant contact and the level of stability of dental implants. It also significantly reduces healing periods, thereby opening the possibility for early loading of photofunctionalised implants compared to untreated implants.

Further research and development of additional techniques for PF may yield promising results, even in complicated situations such as pathophysiologically compromised sites. Nevertheless, the current state of advancement in PF can certainly assist clinicians in achieving more predictable outcomes in most, if not all, clinical situations.

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