

# ULTRAVIOLET PHOTOFUNCTIONALIZATION OF TITANIUM DENTAL IMPLANTS: A NARRATIVE REVIEW OF BIOLOGICAL, ANTIMICROBIAL, AND CLINICAL IMPLICATIONS

\* Uthara Balachandran, \*\* Prasanth V, \*\*\* Harsha Kumar K, \*\* Vivek V Nair

\*Postgraduate student, \*\*Professor, \*\*\*Vice Principal & Professor and HOD, Department of Prosthodontics and Crown & Bridge, Govt Dental College, Thiruvananthapuram. Corresponding Author: Dr. Uthara Balachandran, Email: dr.utharabpillai@gmail.com

<https://doi.org/10.55231/jpid.2026.v10.i01.02>

## Abstract

*Titanium dental implant surfaces undergo a well-documented process of "biological aging," in which atmospheric hydrocarbons progressively adsorb onto the oxide layer after manufacturing, reducing surface hydrophilicity and osteoconductivity over time. Ultraviolet (UV) photofunctionalization has emerged as a chairside-applicable method to reverse this aging process, restoring superhydrophilicity and enhancing both the osseointegration and antibacterial performance of titanium surfaces. This review synthesizes 30 articles spanning foundational photocatalysis research, in vitro and in vivo osseointegration studies, antibacterial and peri-implantitis-prevention literature, and recent clinical and translational work, including next-generation vacuum-UV protocols. The evidence indicates that photofunctionalization reliably improves early implant stability and bone-to-implant contact, while more robust, independently replicated clinical trials are needed to confirm its impact on long-term outcomes such as marginal bone loss and implant survival.*

**Keywords:** Ultraviolet photofunctionalization, titanium dental implants, osseointegration, implant surface modification, peri-implantitis

## Introduction

Osseointegration — the direct structural and functional connection between living bone and an implant surface — is the foundation of successful dental implant therapy. Early comparative work on implant surface characteristics established that the physical and chemical properties of the titanium surface strongly influence bone response<sup>4</sup>. Titanium implant surfaces are not static after manufacture, however. Titanium dioxide (TiO<sub>2</sub>) is a photoactive material whose wettability can be reversibly switched by light exposure<sup>1</sup>, and the same oxide layer that gives titanium its biocompatibility is also prone to progressive contamination by airborne hydrocarbons during storage — a phenomenon now termed the "biological aging" of titanium<sup>7</sup>. This aging reduces the surface's hydrophilicity and its capacity to support protein adsorption, osteoblast attachment, and bone apposition.

Ultraviolet (UV) photofunctionalization was developed as a means of reversing this

# PROSTHETIC AND IMPLANT DENTISTRY

Official Publication of Indian Prosthodontic Society  
Kerala State Branch

aging process. By exposing titanium to UV (and, more recently, vacuum-UV) light, adsorbed hydrocarbons are photocatalytically decomposed, restoring the surface to a superhydrophilic, bioactive state<sup>12,22</sup>. Over the past two decades, a substantial body of pre-clinical and clinical literature has examined both the osseointegration and antibacterial effects of this technique. This review synthesizes 30 articles addressing the mechanism, biological effects, antibacterial properties, and clinical translation of photofunctionalization, in order to provide an integrated picture of where the evidence currently stands.

## Biological Aging of Titanium

Titanium and titanium alloy implant surfaces are not static once manufactured — they undergo progressive changes during storage and shelf life. Over time, atmospheric hydrocarbons accumulate on the surface, converting it from hydrophilic to hydrophobic and reducing its bioactivity, a phenomenon termed “biological aging” of titanium<sup>7</sup>. This aging process compromises the initial cellular and molecular interactions that are critical for osseointegration, prompting the development of surface reactivation strategies — chief among them, photofunctionalization.

A recurring theme across the literature is that titanium implant surfaces degrade in bioactivity simply by sitting in ambient air after manufacture. Att et al.<sup>7</sup> demonstrated that titanium loses osteoconductivity in a time-dependent manner, attributing this to progressive hydrocarbon adsorption rather than any change in the underlying metal or oxide structure. This finding reframed decades of surface-science research: roughness, topography, and chemistry<sup>4,3</sup> remain important determinants of osseointegration, but their benefits can be substantially eroded by storage-related surface contamination.. Clinical

translation of this concern is evident in later work: Albassri<sup>17</sup> and Al Kabany et al.<sup>28</sup> showed that implants which had exceeded typical shelf-life (“expired” implants) exhibited altered surface characteristics that could nonetheless be restored through UV treatment. Taken together, these studies establish biological aging as the central clinical problem that photofunctionalization is designed to solve.

## Mechanism: UV-Induced Photocatalysis and Hydrophilicity

Photofunctionalization refers to the use of ultraviolet(UV)light to modify the physicochemical state of titanium oxide surfaces. The mechanism is rooted in the photocatalytic properties of TiO<sub>2</sub>: UV irradiation generates electron-hole pairs that drive reactions capable of decomposing adsorbed hydrocarbons and altering surface chemistry, producing a superhydrophilic, low-carbon surface state<sup>1</sup>. This light-induced wettability switch was first characterized on TiO<sub>2</sub> surfaces broadly<sup>1</sup> before being applied specifically to implant-grade titanium.

Different UV wavelengths have been studied — UVA, UVC, and combined-spectrum protocols — with UVC (~254 nm) showing particular relevance due to its established germicidal and photocatalytic effects<sup>6,20</sup>. Treatment protocols vary considerably across the literature in terms of lamp power (e.g., 6 W vs. 85 W), irradiation distance, and duration, all of which influence the degree of wettability change achieved<sup>22</sup>.

The physicochemical basis for photofunctionalization originates outside dentistry, in materials science research on TiO<sub>2</sub> photocatalysis. Miyau-chi et al.<sup>1</sup> first demonstrated that TiO<sub>2</sub> thin films could be reversibly switched between hydrophobic and superhydrophilic states through UV and visible-light irradiation, attributing the effect to changes in dissociated water adsorption at the

# PROSTHETIC AND IMPLANT DENTISTRY

Official Publication of Indian Prosthodontic Society  
Kerala State Branch

surface. Foster et al.<sup>9</sup> and Coohill and Sagripanti<sup>6</sup> further clarified the photocatalytic and DNA-damaging mechanisms by which UV light interacts with titanium dioxide and microorganisms, respectively — mechanisms that underlie both the wettability conversion and antibacterial effects seen in later dental-implant studies.

Applied specifically to titanium implants, UV photofunctionalization has been shown to decompose adsorbed hydrocarbons and convert surfaces from hydrophobic to superhydrophilic<sup>11,20</sup>. Hori et al.<sup>8</sup> demonstrated that this effect is not merely additive to existing nanotopographical features but amplifies the bioactivity benefits of nanoscale surface structuring. Nakhaei et al.<sup>21</sup> extended this mechanistic picture by showing that UV-mediated “decarbonization” also enhances oral epithelial cell attachment, extending the mechanism’s relevance from bone to peri-implant soft-tissue sealing.

## Effects on Osseointegration

A substantial body of work links photofunctionalization to enhanced biological performance:

- **Enhanced initial cell attachment and spreading:** Photo-induced hydrophilicity has been shown to improve early osteoblast behavior and accelerate bone apposition in animal models<sup>3,5</sup>.
- **Nanotopography synergy:** UV treatment appears to potentiate the bioactivity conferred by nanoscale surface features, suggesting a combined chemical-topographical effect<sup>8</sup>.
- **Soft-tissue integration:** Beyond osseointegration, UV-treated titanium enhances human oral epithelial cell attachment, adhesion, and retention — relevant to peri-implant mucosal sealing, not

just bone contact<sup>21</sup>.

- **Comparative surface science:** Reviews of endosseous implant surface modifications position photofunctionalization alongside other surface treatments (SLA, chemically modified SLA) as a means of improving osteoconductivity<sup>3,4,12,18</sup>.

A substantial body of in vitro and in vivo work links photofunctionalization to improved osseointegration. Sawase et al.<sup>5</sup> provided early evidence that photo-induced hydrophilicity enhances osteoblast behavior in vitro and early bone apposition in vivo, while Buser et al.<sup>3</sup> independently showed that a chemically modified, hydrophilic SLA titanium surface achieved significantly greater bone apposition than a standard SLA surface during early healing — underscoring hydrophilicity’s central role in osseointegration.

Clinically, evidence is concentrated heavily within research from the Ogawa group and collaborators. Chang<sup>25</sup>, in a narrative review of clinical studies, reported improved implant stability quotients and shortened healing timelines following photofunctionalization, while noting that the majority of clinical data originates from a small number of research teams. Photofunctionalization has also been shown to offset osseointegration deficits associated with systemic disease: Pinotti et al.<sup>24</sup> found that hydrophilic implant surfaces equalized osseointegration outcomes between normoglycemic and hyperglycemic rats, suggesting a potential benefit for medically compromised patients. The most recent contribution to this literature<sup>30</sup> describes a new generation of one-minute vacuum-UV (VUV) protocols and introduces the concept of “superosseointegration” — a biological state

# PROSTHETIC AND IMPLANT DENTISTRY

Official Publication of Indian Prosthodontic Society  
Kerala State Branch

exceeding that achievable with untreated or conventionally treated titanium.

## Antibacterial Properties and Peri-Implantitis Prevention

A second major theme connects photofunctionalization to the prevention of peri-implant disease.

- UVC irradiation at germicidal wavelengths (~254 nm) inactivates a broad range of bacteria, a foundational photobiological principle<sup>6</sup>.
- Photocatalytic TiO<sub>2</sub> surfaces exhibit direct antimicrobial activity through reactive oxygen species generation<sup>9</sup>.
- Pre-irradiation of titanium with UVC has been shown to reduce subsequent biofilm formation<sup>10</sup>, and UV-photofunctionalization measurably reduces oral bacterial attachment and biofilm development on implant material even in multi-species oral biofilm models<sup>13</sup>.
- Related photodynamic therapy (PDT) approaches — using photosensitizers activated by light rather than UV alone — have been explored as adjuncts for disinfection and biomodulation in implant dentistry, though feasibility and standardization remain open questions<sup>15,23</sup>.
- Nanostructured, crystallized titanium surfaces subjected to UV treatment show improvements in both biocompatibility and antibacterial properties simultaneously, suggesting these two benefits are mechanistically linked through the same decontamination/hydrophilicity pathway<sup>16</sup>.

Mabboux et al.<sup>2</sup> established that surface free energy and topography influence bacterial retention on saliva-coated implant materials, providing an early mechanistic link between

surface condition and biofilm formation. Because photofunctionalization both increases hydrophilicity and exerts a direct photocatalytic antibacterial effect<sup>6,9</sup>, several studies have examined its capacity to reduce bacterial colonization. Yamada et al.<sup>10</sup> showed that UVC pre-irradiation measurably reduces subsequent biofilm formation on titanium, and Dorigatti de Avila et al.<sup>13</sup> confirmed reduced attachment and biofilm formation by specific oral bacterial species following UV treatment. Hatoko et al.<sup>16</sup> similarly demonstrated that UV treatment of nanostructured titanium surfaces improves antibacterial performance alongside biocompatibility.

Related light-based antimicrobial technologies appear alongside photofunctionalization in this literature, including antimicrobial photodynamic therapy<sup>15,23</sup>, which combines light, a photosensitizer, and sometimes TiO<sub>2</sub> to achieve bactericidal effects against oral plaque bacteria and to biomodulate peri-implant tissue during disinfection.

## Clinical Implications

More recent literature has focused on translating the laboratory-demonstrated effect into practical, chairside-usable protocols. Sanchez-Perez et al.<sup>22</sup> compared low- and high-power UVC sources and irradiation times on resorbable blast media titanium, finding that both achieve superhydrophilicity, with power and duration primarily affecting the speed of conversion. Hurtado et al.<sup>29</sup> extended this practical focus by comparing photofunctionalization outcomes across different titanium grades and surface treatments, finding that hydrophilic conversion occurs broadly but its magnitude varies with the underlying material and treatment. Restoration of implants that have exceeded manufacturer shelf-life has emerged as a particularly practical

# PROSTHETIC AND IMPLANT DENTISTRY

Official Publication of Indian Prosthodontic Society  
Kerala State Branch

application, with both Albassri<sup>17</sup> and Al Kabany et al.<sup>28</sup> showing that UVC treatment can restore the surface hydrophilicity of "expired" implant stock, while David Raj et al.<sup>27</sup> confirmed enhanced surface bioactivity on photofunctionalized titanium discs more broadly. Complementary approaches combining photofunctionalization with biomimetic coatings<sup>19</sup> and broader surface-modification strategies<sup>18</sup> further illustrate the range of translational directions this technology has taken, alongside continued narrative synthesis of its clinical applications<sup>14,25</sup>.

## Limitations and Future Perspectives

Despite the consistency of pre-clinical findings, several limitations temper confidence in the clinical evidence base. Chang's<sup>25</sup> narrative review observed that the majority of clinical studies on photofunctionalization originate from a small number of research groups, limiting independent replication. It is also worth noting that one broader review of titanium and titanium alloys in dentistry included in this literature set<sup>26</sup> was subsequently retracted, and its findings should not be relied upon as evidence. Future research would benefit from larger, multi-center, independently conducted randomized trials examining long-term outcomes such as implant survival and marginal bone level, alongside continued mechanistic work on next-generation vacuum-UV protocols and their soft-tissue effects.

## Conclusion

The literature reviewed here traces a coherent arc: from the discovery that titanium dioxide surfaces can be reversibly switched between hydrophobic and hydrophilic states by light, through the recognition that titanium implants undergo time-dependent biological aging, to the development and clinical application of UV photofunctionalization as a means of reversing that aging and enhancing both osseointegration

and antibacterial performance. The weight of current evidence supports photofunctionalization as a low-cost, chairside-applicable technique capable of improving early implant stability, bone-to-implant contact, and resistance to bacterial colonization. However, the clinical evidence base remains concentrated among a small number of research groups, and long-term outcome data are still limited. Continued independent clinical investigation, alongside emerging vacuum-UV and soft-tissue-focused research, will be needed to fully define photofunctionalization's role in routine implant practice.

## References

1. Miyauchi M, Kieda N, Hishita S, Mitsuhashi T, Nakajima A, Watanabe T, Hashimoto K. Reversible wettability control of TiO<sub>2</sub> surface by light irradiation. *Surf Sci*. 2002;511:401–407.
2. Mabboux F, Ponsonnet L, Morrier JJ, Jaffrezic N, Barsotti O. Surface free energy and bacterial retention to saliva-coated dental implant materials: an in vitro study. *Colloids Surf B Biointerfaces*. 2004;39:199–205.
3. Buser D, Broggini N, Wieland M, Schenk RK, Denzer AJ, Cochran DL, et al. Enhanced bone apposition to a chemically modified SLA titanium surface. *Clin Oral Implants Res*. 2004;15:473–480.
4. Cochran DL. A comparison of endosseous dental implant surfaces. *J Periodontol*. 1999;70:1523–1539.
5. Sawase T, Jimbo R, Baba K, Shibata Y, Ikeda T, Atsuta M. Photo-induced hydrophilicity enhances initial cell behavior and early bone apposition. *Clin Oral Implants Res*. 2008;19:491–496.
6. Coohill TP, Sagripanti JL. Overview of the inactivation by 254 nm ultraviolet radiation of bacteria with particular relevance to biodefense. *Photochem Photobiol*. 2008;84:1084–1090.
7. Att W, Hori N, Takeuchi M, Ouyang J, Yang Y, Anpo M, Ogawa T. Time-dependent degradation of titanium osteoconductivity: An implication of biological aging of implant materials. *Biomaterials*. 2009;30:5352–5363.
8. Hori N, Iwasa F, Tsukimura N, Sugita Y, Ueno T, Kojima N, Ogawa T. Effects of UV photofunctionalization on the nanotopography-enhanced initial bioactivity of titanium. *Acta Biomater*. 2011;7:3679–3691.
9. Foster HA, Ditta IB, Varghese S, Steele A. Photocatalytic disinfection using titanium dioxide: spectrum and mechanism of antimicrobial activity. *Appl Microbiol Biotechnol*. 2011;90:1847–1868.
10. Yamada Y, Yamada M, Ueda T, Sakurai K. Reduction of biofilm formation on titanium surface with ultraviolet-C pre-irradiation. *J Biomater Appl*. 2013.
11. Ogawa T. Ultraviolet photofunctionalization of titanium implants. *Int J Oral Maxillofac Implants*. 2014;29:e95–e102.

# PROSTHETIC AND IMPLANT DENTISTRY

Official Publication of Indian Prosthodontic Society  
Kerala State Branch

12. Barfeie A, Wilson J, Rees J. Implant surface characteristics and their effect on osseointegration. *Br Dent J.* 2015;218:E9.
13. Dorigatti de Ávila E, Lima BP, Sekiya T, Torii Y, Ogawa T, Shi W, Lux R. Effect of UV-photofunctionalization on oral bacterial attachment and biofilm formation to titanium implant material. *Biomaterials.* 2015;67:84–92.
14. Flanagan D. Photofunctionalization of dental implants. *J Oral Implantol.* 2016;42:445–450.
15. Javali M, AlQahtani N, Ahmad I, Ahmad I. Antimicrobial photodynamic therapy: bactericidal effects analysis on oral plaque bacteria: an in vitro study. *Niger J ClinPract.* 2019;22:1654.
16. Hatoko M, Komasa S, Zhang H, Sekino T, Okazaki J. UV treatment improves the biocompatibility and antibacterial properties of crystallized nanostructured titanium surface. *Int J Mol Sci.* 2019;20:5991.
17. Albassri OA. Influence of ultraviolet photofunctionalization on the surface characteristics of expired and unexpired manufactured titanium dental implants [dissertation]. Freiburg imBreisgau: Albert-Ludwigs-Universität Freiburg; 2019.
18. Wang HL, et al. Current trends in dental implant surface modifications. *J Prosthodont Res.* 2020;64:1–9.
19. Dini C, Nagay BE, Cordeiro JM, Da Cruz NC, Rangel EC, Ricomini-Filho AP, De Ávila ED, Barão VA. UV-photofunctionalization of a biomimetic coating for dental implants application. *Mater Sci Eng C.* 2020;110:110657.
20. Pacheco VN, Nolde J, Quevedo AS, Visioli F, Ponzoni D. Improvement in the chemical structure and biological activity of surface titanium after exposure to UVC light. *Odontology.* 2020.
21. Nakhaei K, Ishijima M, Ikeda T, Ghassemi A, Saruta J, Ogawa T. Ultraviolet light treatment of titanium enhances attachment, adhesion, and retention of human oral epithelial cells via decarbonization. *Materials.* 2021;14:151.
22. Sanchez-Perez A, Cano-Millá N, Moya Villaescusa MJ, Montoya Carralero JM, Navarro Cuellar C. Effect of photofunctionalization with 6 W or 85 W UVC on the degree of wettability of RBM titanium in relation to the irradiation time. *Appl Sci.* 2021;11:5427.
23. Choe R, Balhaddad AA, Fisher JP, Melo MAS, Huang HC. Photodynamic therapy for biomodulation and disinfection in implant dentistry: is it feasible and effective? *PhotochemPhotobiol.* 2021;97:916–929.
24. Pinotti FET, Aron MAT, De Oliveira GJPL, Marcantonio E Jr, Marcantonio RAC. Implants with hydrophilic surfaces equalize the osseointegration of implants in normo- and hyperglycaemic rats. *Braz Dent J.* 2022;33:71–77.
25. Chang LC. Clinical applications of photofunctionalization on dental implant surfaces: a narrative review. *J Clin Med.* 2022;11:5823.
26. Hoque ME, Showva NN, Ahmed M, Rashid AB, Sadique SE, El-Bialy T, et al. RETRACTED: Titanium and titanium alloys in dentistry: current trends, recent developments, and future prospects. *Heliyon.* 2022;8:e11300. [Retracted 2024]
27. David Raj A, Rengasamy V, Muthukumar B. Effect of photofunctionalization on the bio-activity of titanium discs – an in vitro study. *EurChem Bull.* 2023;12:957–971.
28. Al Kabany M, Alqutub AW, Makki A, Youssef AR. Restoration of expired dental implants by ultraviolet-C photofunctionalization: an in vitro study. *Egypt Dent J.* 2023;69:937–948.
29. Hurtado A, Portacio B, Cruz C, Rivera. Effect of ultraviolet photofunctionalization on the hydrophilic capacity of implants with different titanium grades and surface treatments. *Genesis Journal of Dental Reports.* 2025;1(1):1-9.
30. Park G, Matsuura T, Komatsu K, Ogawa T. Multifaceted approach of UV photofunctionalization. *J Prosthodont Res.* 2025.