



# Photofunctionalization: Revitalizing the Biological Activity of Dental Implant Surfaces

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## ABSTRACT:

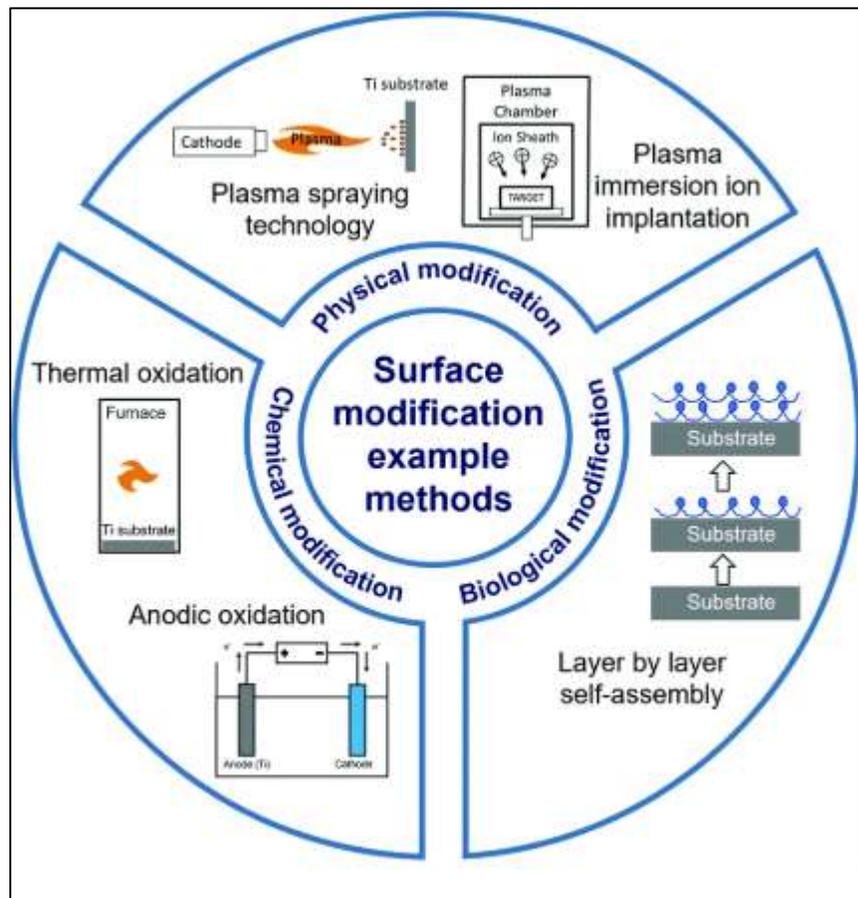
Photo functionalization is an innovative surface modification process that uses ultraviolet (UV) radiation to increase the biological activity of titanium dental implants. Titanium implants age biologically during storage as hydrocarbons accumulate on the surface, reducing bioactivity and cell attachment potential. UV photo functionalization eliminates these impurities and changes the implant's surface from hydrophobic to super hydrophilic, boosting surface energy and improving protein adsorption and osteoblast adhesion. These physicochemical changes facilitate faster and stronger bone-implant contact, resulting in improved osseointegration and early implant stability. Photo functionalization, as a simple and effective method, has demonstrated remarkable promise in expediting healing and enhancing the outcome of dental implant therapy.

**KEYWORDS:** Photo functionalization, surface modification, hydrophilicity

## INTRODUCTION:

Dental implants have become a widely accepted solution for the rehabilitation of missing teeth due to their long-term functional and esthetic success. Because of its long-term functional and aesthetic success, dental implants have gained widespread acceptance as a rehabilitation option for lost teeth. They are a good choice for individuals who are either fully or partially edentulous since they offer a fixed prosthetic solution that maintains surrounding tooth structure.[1] Osseointegration, which is characterized as a direct structural and functional link between live bone and the implant surface without the interposition of soft tissue, is a crucial factor in determining the effectiveness of implants.[2] Biological mechanisms including bone remodeling and regeneration provide secondary stability, whereas mechanical interlocking during implantation provides primary stability.[3] Improving these biological connections is crucial for long-term implant effectiveness, especially when early or rapid loading methods are used.

By increasing the biological activity at the bone-implant interface, a number of surface modification approaches have been developed to encourage osseointegration. In order to promote cell adherence and proliferation, conventional techniques like grit-blasting, acid-etching, and calcium phosphate coatings seek to enhance surface roughness and energy. To further improve bone growth at the implant interface, cutting-edge techniques including nanostructuring and the addition of bioactive chemicals have been investigated in recent years.[4]



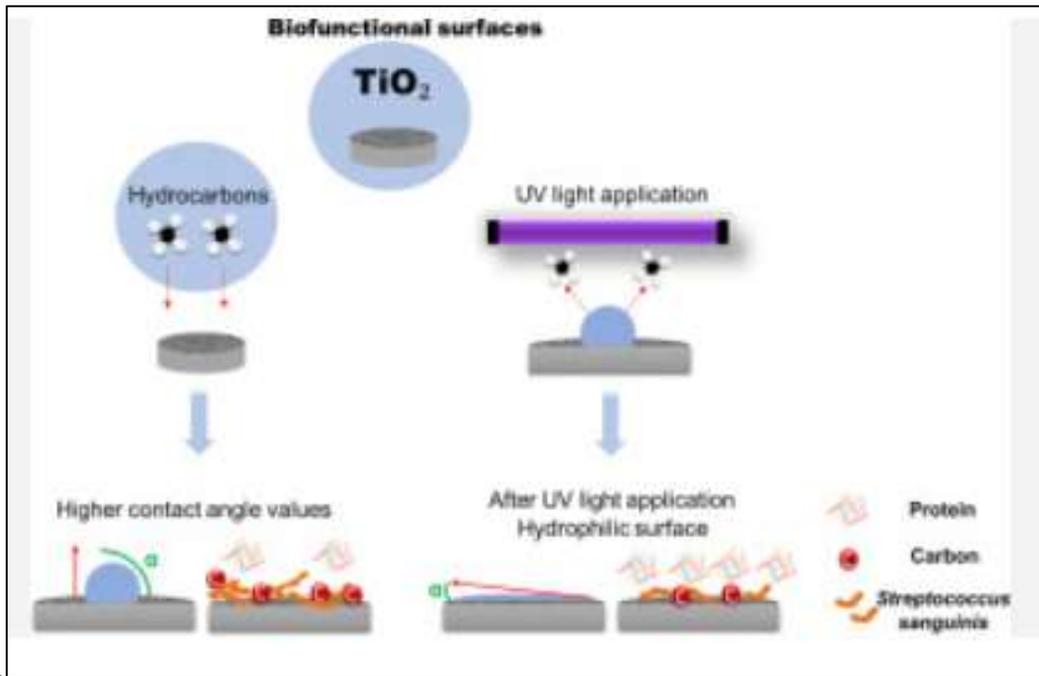
Different methods of surface treatments

Additionally, osseointegration may be impacted by the dental implant's surface wettability. In 1997, it was shown that ultraviolet (UV) radiation might generate superhydrophilicity in titanium dioxide (TiO<sub>2</sub>) due to the conversion of relevant Ti<sup>4+</sup> sites to Ti<sup>3+</sup> sites for increased water adsorption caused by surface oxygen vacancies at bridging sites. The idea was used to dental implant therapy in addition to antifogging and self-cleaning materials.

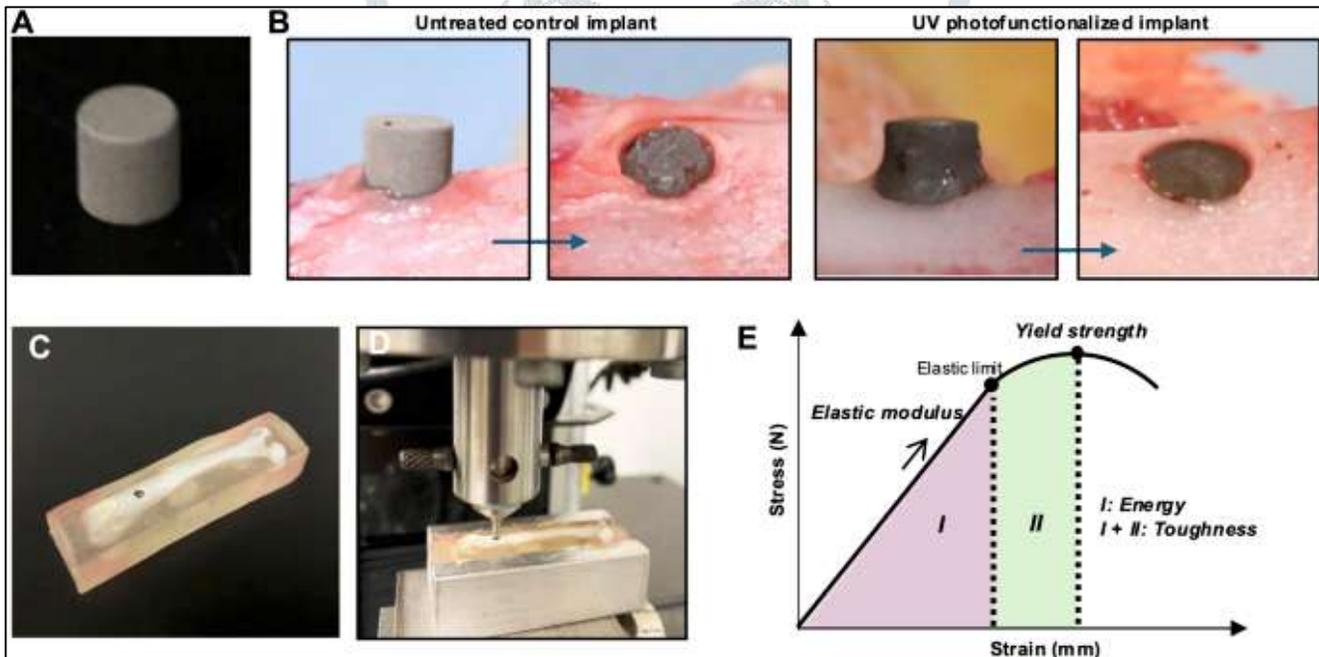
First reported in 2009, photofunctionalization (PhF) is an all-encompassing phenomenon of titanium surface change following UV irradiation, including both the improvement of biological capabilities and the modification of physicochemical characteristics [4,5].

Photofunctionalization (PhF), a technique pioneered by Takahiro Ogawa, employs ultraviolet (UV) light to modify the physical and chemical properties and improved biological characteristics of titanium surfaces. This method has been demonstrated to substantially increase BIC, achieving nearly 100% contact, a phenomenon termed “Superosseointegration.”

UVA (wavelength  $\lambda = 320\text{--}400\text{ nm}$ ), UVB ( $\lambda = 280\text{--}320\text{ nm}$ ), and UVC ( $\lambda = 200\text{--}280\text{ nm}$ ) are the three types of UV radiation. PhF has the effect of reversing the biological aging of the implant and changing its surface from hydrophobic to super-hydrophilic. Additionally, PhF may preserve the antimicrobial surface in vitro and reduce bacterial adhesion and accumulation. In 2013, the first report of PhF's clinical use included seven implants in four implant difficult cases that used PhF prior to implant placement.



A.



B.

A. and B. UV surface treatment on dental implants

UV treatment is said to increase the hydrophilicity of the implant surface and decrease surface hydrocarbon by increasing the recruitment, attachment, retention, proliferation, and overall phenotype of osteogenic cells, allowing for the rapid and complete establishment of bone-to-implant contact (BIC) and thus allowing a faster loading protocol without compromising implant success rate [14, 15]. PhF has been shown to enhance BIC by up to 98.2%, resulting in a threefold increase in bone-implant fusion

strength during early recovery. Furthermore, it has been shown that this increased BIC helps to the uniform distribution of mechanical stress in the peri-implant marginal bone, lowering stress levels. Because of these advantages, PhF is an effective and feasible surface treatment option [16], [17].

Among the new surface treatments, photofunctionalization, or the application of ultraviolet (UV) radiation to titanium, has shown great promise. This method enhances surface hydrophilicity and eliminates hydrocarbons, which improves protein adsorption and osteoblast adhesion. Following photofunctionalization, increased bone-to-implant contact and quicker integration, known as "superosseointegration," have been seen.[5] Simultaneously, low-magnitude, high-frequency (LMHF) mechanical vibration has developed as a noninvasive biophysical method for stimulating osteoblastic activity. By simulating physiological mechanical loads, LMHF vibration has showed promise to aid bone remodeling and repair, notably in orthopedic and dental applications.

Direct UV radiation can be damaging to dental implants after placement, whereas preimplantation PhF is a safer option that does not affect human cells. PhF was created to slow titanium's biological aging by increasing protein adsorption, adhesion, and bone-forming cell activity in laboratory trials.

Implant PhF considerably boosts the osteoconductive potential, allowing for a quicker loading approach while maintaining implant success rates. This leads to a speedy and complete installation of BIC. This approach reverses the bioactivity deterioration associated with titanium implant surfaces over time. After PhF, titanium surface modifications are seen to reduce bacterial adherence and biofilm formation.

## MECHANISM:

### 1. UV Irradiation of Titanium Surface

Titanium dental implants are naturally coated with a thin coating of titanium dioxide ( $\text{TiO}_2$ ). When the implant is exposed to UV light (typically UVC  $\sim 254$  nm), the  $\text{TiO}_2$  layer absorbs photon energy. This activates the surface and starts the photocatalytic activities.

UV photons excite electrons in  $\text{TiO}_2$ , creating electron-hole pairs that cause oxidation-reduction processes at the surface.

### 2. Photocatalytic Decomposition of Hydrocarbons

The accumulation of atmospheric hydrocarbon pollutants in titanium implants during storage is referred to as "biological aging of implants." These hydrocarbons decrease cell adhesion and prevent protein adsorption.

Reactive oxygen species (ROS), including superoxide ions and hydroxyl radicals, are produced when UV light activates  $\text{TiO}_2$ . Carbon-carbon and carbon-oxygen bonds are broken by these ROS, which causes oxidative degradation and the loss of hydrocarbons from the implant surface.

Resulting in increased biological responsiveness of the implant.

### 3. Formation of Oxygen Vacancies and $\text{Ti}^{3+}$ Sites:

The electrical structure of titanium dioxide is changed by UV radiation. On the surface, photocatalytic processes produce  $\text{Ti}^{3+}$  active sites and oxygen vacancies. These chemical alterations raise surface energy and produce biological molecules' active binding sites.

These recently created bonds support:

- a. Molecular adsorption of water
- b. Proteins being adsorbed
- c. Enhanced contacts between the cell and surface

#### **4. Conversion from Hydrophobic to Superhydrophilic Surface:**

Water and biological fluids are repelled by untreated titanium surfaces because they are hydrophobic.

Following photofunctionalization:

The water contact angle sharply drops.

Superhydrophilicity ( $\approx 0^\circ$  contact angle) occurs on the surface.

Blood and tissue fluids can spread quickly over the implant surface because to its hydrophilic surface.

Clinical significance:

- a. Quick blood soaking
- b. Enhanced development of fibrin networks
- c. Early attachment of cells

#### **5. Increased Surface Energy and Electrostatic Changes:**

Titanium's electrostatic characteristics are also altered by photofunctionalization. A positively charged surface may result from UV treatment, which also raises surface energy.

The implant surface is more attracted to negatively charged biological molecules including proteins and cell membranes as a result of this electrostatic shift.

Increased surface energy enhances:

Adsorption of proteins

adhesion of cells

Implant biological integration

#### **6. Enhanced Protein Adsorption:**

Blood proteins quickly adhere to the implant surface once it is inserted into the bone.

Surfaces with photofunctionalization exhibit enhanced adsorption of-

Albumin, Vitronectin, and Fibronectin and Growth Elements.

These proteins form a bioactive layer that serves as a cellular attachment scaffold.

## 7. Improved Osteoblast Attachment and Proliferation:

Mesenchymal stem cells and osteoblasts adhere to photofunctionalized surfaces more easily.

Research shows that titanium surfaces treated with UV light:

- Enhance the adhesion of osteoblasts
- Increase the spread of cells
- Promote the proliferation and development of osteogenic cells

## 8. Enhanced Bone Formation and Osseointegration:

Because of the enhanced cellular response, photofunctionalized implants exhibit:

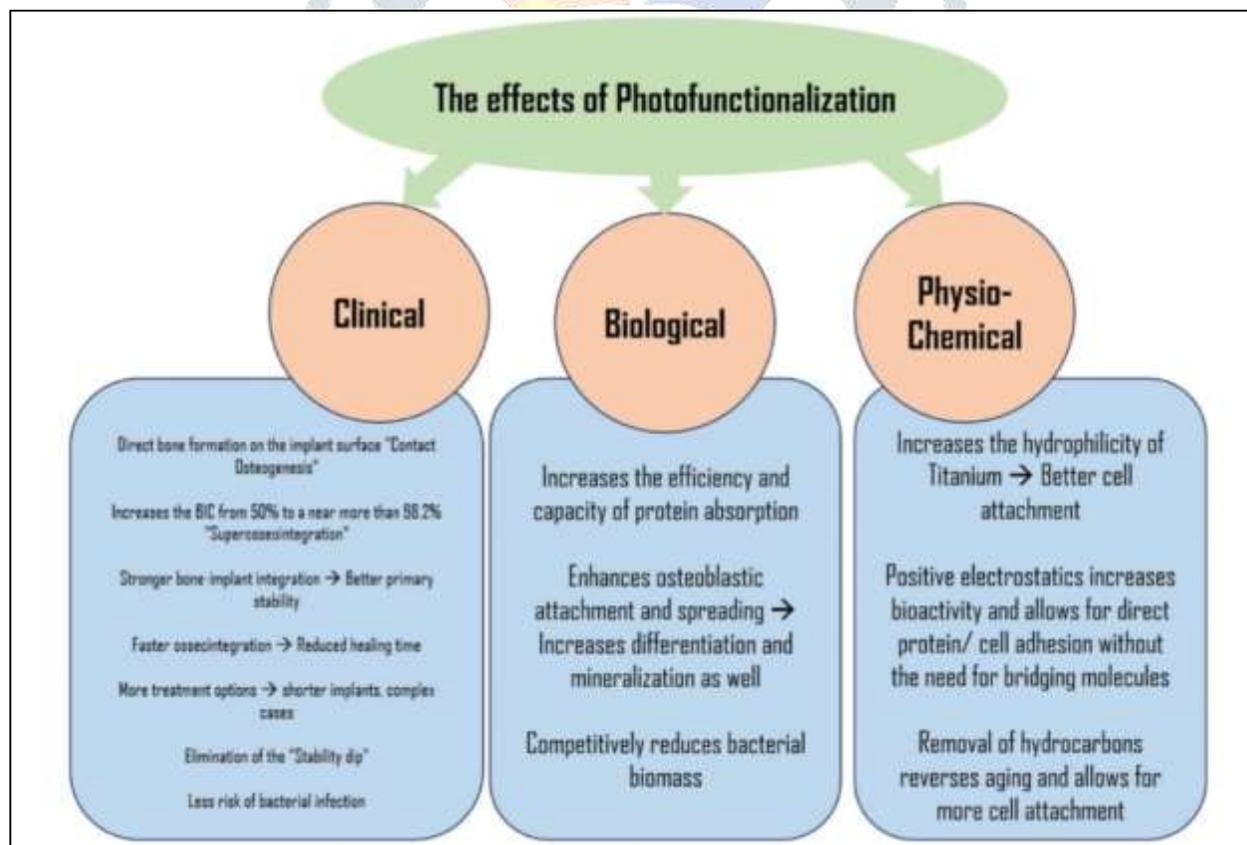
Bone-implant contact (BIC) has increased.

Quicker deposition of bone

More robust mechanical anchoring

## 9. Reduced Bacterial Adhesion:

Additionally, photofunctionalization may provide hydrophilic surfaces that lessen early bacterial colonization, increasing implant success and lowering the risk of peri-implant infection.



Effects of Photofunctionalization

**ADVANTAGES:****I. Enhanced Osseointegration-**

Stronger bone-implant contact and increased stability are the outcomes of photofunctionalization, which improves the interaction between the implant surface and bone.

**II. Elimination of Hydrocarbon Pollution-**

UV treatment restores the biological activity of titanium surfaces and eliminates organic impurities that have collected during storage.

**III. Enhanced Implant Surface Hydrophilicity-**

The procedure improves wettability and biological interaction with surrounding tissues by changing the implant surface from hydrophobic to superhydrophilic.

**IV. Improved Cell Attachment and Protein Adsorption-**

Better bone repair is facilitated by UV-treated surfaces, which draw proteins and encourage osteoblast adhesion, proliferation, and differentiation.

**V. Fast Healing and Early Loading-**

When compared to untreated implants, photofunctionalized implants exhibit quicker stability and permit earlier functional loading.

**VI. Enhanced Success Rate and Stability of Implants-**  
Research indicates that photofunctionalized implants have superior implant stability values and success rates of around 97–100%.

**VII. Improved Function in Conditions with Compromised Bones-**  
Even in difficult clinical situations like low bone quality, the method enhances osteogenesis and cell proliferation.

**DISADVANTAGES:**

**I. Absence of a Standard Procedure-**Clinical results vary because the ideal UV exposure duration and intensity are not completely defined.

**II. Specialized Equipment Needed-**A UV irradiation instrument is necessary for photofunctionalization, which raises the cost and demands more clinical setup.

**III. Restricted Infiltration via Sterile Packaging-**Because UV radiation cannot pass through implant packaging, the implant must be exposed prior to treatment, which makes the process less convenient.

**IV. Transient Surface Activation-**If implantation is postponed, the active surface eventually loses its improved hydrophilicity.

**V. Scarce Long-Term Clinical Data-**Long-term clinical investigations are necessary to demonstrate its efficacy in difficult clinical circumstances, despite the encouraging short-term results.

**CONCLUSION:**

To improve the biological performance of titanium dental implants, photofunctionalization is a potential development in implant surface modification. When implant surfaces are exposed to ultraviolet (UV) radiation, hydrocarbon impurities that have collected during storage are eliminated, surface energy is restored, and the implant surface changes from hydrophobic to superhydrophilic. By enhancing protein adsorption, osteoblast

adhesion, and cellular proliferation, these physicochemical modifications facilitate quicker and more robust bone-implant contact. Consequently, during the early healing phase, photofunctionalized implants show increased bone-implant contact, improved implant stability, and quicker osseointegration.

Photofunctionalization may enable earlier loading techniques and reduce healing times without sacrificing implant success rates, according to clinical and experimental research. By boosting osteogenic cell recruitment and accelerating implant stability, the method has also demonstrated potential advantages in compromised clinical scenarios, such as low bone quality or difficult implant locations.

Nevertheless, the available data is still few and sometimes contradictory despite these positive results. While some studies reveal little to no long-term changes between photofunctionalized and conventional implants, others claim notable increases in implant stability and osseointegration. Therefore, in order to provide standardized procedures and completely confirm the therapeutic benefits of photofunctionalization in regular implant therapy, more carefully planned randomized clinical trials and long-term research are needed.

To sum up, photofunctionalization is an easy, non-invasive, and physiologically efficient way to increase the bioactivity of the implant surface. It has the potential to develop into a significant supplementary tactic for enhancing the predictability and efficacy of contemporary dental implant therapy with more study and clinical confirmation.

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