Ultraviolet photofunctionalization: A review.

Debajyoti Datta[1], Ranjita Nandi[1], Preeti Goel[2], Samiran Das[2], Sayan Majumdar[2], Shubhabrata Roy[3].

[1]PGT, Department of Prosthodontics and Crown & Bridge, Guru Nanak Institute of Dental Sciences and Research, India.
[2]Professor, Department of Prosthodontics and Crown & Bridge, Guru Nanak Institute of Dental Sciences and Research, India.
[3]Reader, Department of Prosthodontics and Crown & Bridge, Guru Nanak Institute of Dental Sciences and Research, India.

Abstract

Objective: Greater biologic capabilities in implant surfaces are required to address the challenges and rising expectations in implant therapy.
Background: The results of current in vitro and in vivo investigations on titanium's ultraviolet (UV) photofunctionalization are compiled in this article.
Method: The term "UV photofunctionalization" describes a comprehensive phenomenon of surface alteration of titanium after exposure to UV light, encompassing modifications to physicochemical properties and enhancements to biological capacities. In an animal model, bone morphogenesis surrounding titanium implants exposed to UV light is significantly better than that surrounding untreated control implants, with nearly 100% bone-to-implant contact. UV irradiation dramatically enhanced the adhesion, retention, and following osteogenic cell cascades that are functioning and come from both humans as well as animals, according to a number of in vitro studies. Its surfaces are titanium.
Conclusion: For all types of titanium surface treatment studied, UV treatment has been shown to be efficient and inexpensive. According to these findings, UV photofunctionalization may be an efficient technique for enhancing implant therapy in the domain of dentistry. The goal of future study will be to confirm these results in clinical investigations.

Keywords: Bone–implant interface, dental implant, osseointegration, titanium, ultraviolet.

Address of correspondence: Dr. Debajyoti Datta, Department of Prosthodontics and Crown & Bridge, Gurunanak Institute of Dental Sciences and Research. Vill: Uttar Chatra, P.O: Dakshin Chatra, PIN: 743247,
Email address: - debajyotidattadj@gmail.com **Phone no:** 8910727320.
DOI: 10.5281/zenodo.11045896
Submitted: 21-Feb-2024 **Revised**: 09-Mar-2024 **Accepted:** 04-Apr-2024 **Published:** 26-Apr-2024
Bibliographic details: Journal of Orofacial Rehabilitation Vol. 4(1), Apr 2024, pp. 17-21.

Introduction

Dental implants are a well-recognized treatment for tooth replacement. Implant placement should begin as soon as possible because it shortens the time until dentition occurs and because early or immediate implant loading lessens the functional restrictions and psychological strain associated with dentition in the cosmetic area.[1]

Dental implants are becoming a more and more common restorative option due to their initial success rate, which can reach up to 98%. Over time, this success percentage decreases and, depending on the type of implant, reaches a range of 90.1% to 95.4% after 5 years. After 10 and 16 years, respectively, this success rate continues to decline, reaching a further 89% and 83% after the longest monitoring time yet recorded.[2]

It has recently been found that biological aging influences osseointegration. Biological aging is gradually shown as decreases in protein adsorption and hydrophilicity as a result of airborne carbon and nitrogen sticking to the titanium implant surface.[3,4] The surface of titanium loses its hydrophilicity when airborne carbohydrates adhere to it, which causes a shift in the surface electrical potential.[4] Research indicates that blood adhesion protein can be adsorbed. S—like fibronectin declines significantly when the surface becomes hydrophobic as opposed to when the surface becomes hydrophilic.[4] Early in the implant implantation process, these factors may have an effect on the bone-implant contact ratio (BIC).[5]

Hydrocarbons are inevitably present in the packaging of implants that are available for purchase; on average, their content varies from 17.9% to 76.5%. Implant failure is more likely when hydrophilicity is reduced due to increased carbon content.[4] To enhance the osseointegration of dental implants, Over the years, many surface treatment methods have been put forth and refined. Currently, sandblasting and acid-etching (SLA) is a common surface preparation technique for dental implants.[5]

Effects of UV photofunctionalization:

Surface Characteristics of Titanium Materials:

The first titanium surfaces had a contact angle greater than 90° and were hydrophobic. The degree of hydrophilia conversion, with a contact angle of less than 30 degrees, varies depending on the UV source, with the high-energy UVC (HUVC), proprietary UV (PUV) and vacuum UV (VUV) treatments, thus that for UVC, the resulting contact angles are 0^{o} and 30^{o}, respectively.[2,6] The acid-etched surface created superhydrophilicity more quickly. The machined surface needed 48 hours of UV treatment, but the acid-etched surface just needed one hour.[1] The acid-etched surface's superhydrophilic state was maintained for a longer amount of time following 48 hours of UV illumination, with the 0o contact angle of H2O being maintained for 7 days in the dark.[1]

Titanium's enhanced UV light-induced protein binding capacity:

Recent studies have shown that the surfaces of commercial implants are usually high in carbon. This implies that when UV light is exposed to implants, the hydrocarbons on their surface vanish, exposing the OH and oxygen radicals and creating a super-hydrophilic surface that draws in proteins, water molecules, and bone-forming cells.[7] Because of this, hydrophilicity is genuinely impacted by the carbon to oxygen ratio, declining as carbon concentration rises and vice versa.[2,8]

After a 24-hour incubation period, the amount of the proteins adsorbed on the untreated surfaces was lower than what was observed on UV-treated surfaces. The UV-treated surface still had increased protein absorption even four weeks later than the untreated surface.[9]

Albumin and fibronectin adsorption was sped up by UV exposure. For instance, albumin adsorption rates on titanium surfaces that had been exposed to UV light for 48 hours increased from 10% to 50-60% after 2 hours of incubation. For both proteins, the acid-etched surface had a stronger UV enhancing effect than the machined surface.[1]

Furthermore, it's possible that photofunctionalization did more than just break down carbohydrates; it also introduced a hydroxyl group to the surface, leading to a higher amount of protein adsorption while by eliminating the carbs in the titanium after it was exposed to UV light, hydrophilicity was obtained. This is due to the fact that protein binding in adsorption to the titanium surface is mediated by the hydroxyl group.[2]

UV dose-dependency of biological effects:

Protein adsorption and cell attachment capacities were both influenced differentially by UV dosage. Rapid albumin adsorption rate increases were followed by saturation after one hour of UV exposure. With an extension of the UV treatment period up to 48 hours, the rate of cell attachment increased dramatically again.[1]

Enhanced attachment of osteoblasts to UV-treated titanium:

For both machined and acid-etched surfaces, the number of osteoblast cells adhered to UV-treated surfaces was three to five times more than that of untreated surfaces. For a whole day, the UV-induced advantage in cell adhesion persisted.[1] At 72 hours the cell proliferation ability is significantly higher for UV treated titanium surface.[4] UV-treated machined surfaces show philopodia-like cell processes formed in various directions for osteoblasts.

On acid-etched surfaces exposed to UV light as opposed to untreated acid etched surfaces, cells are noticeably bigger and the cellular processes extended more.[1]

The surface of titanium displays improved osteoblastic differentiation, enhanced osteoblast proliferation, increased protein adsorption, increased osteoblast migration, increased osteoblast attachment, and facilitated osteoblast spread following UV light exposure.[1] These procedures shouldn't be viewed as being independent of one another, though. For example, greater protein adsorption may have encouraged osteoblastic attachment through improved protein-cellular integrin interaction. Due to increased cell-to-cell interaction, greater osteoblastic proliferation may have been the root of the accelerated differentiation.[5]

Bone morphogenesis around UV-treated implant:

More bone is formed all around the UV-treated implant. The degree to which soft tissue was involved was another obvious distinction. The soft tissue positioned between the implant and bone is related to certain bone tissues around untreated implants, despite the fact that this connection is rarely observed around UV-treated implant surfaces.[1] It has been shown that the hydrophilicity of the titanium surface due to UV photofunctionalization contributes to the adsorption of various cytokines and proteins, which has a higher BIC value and affects osseointegration.[4] Additionally, it causes a stiffer bone condition and denser cortical bone development.[5] Greater interaction between the surrounding bone and photofunctionalized implants is sufficient to lower mechanical stress around the implant neck by 50%, according to finite element analysis, it further indicates that stress concentration and distribution around the implant neck are significantly influenced by the degree of contact.[4]

Conclusions:

The potential of titanium surfaces to facilitate bone growth was markedly improved by pretreatment with ultraviolet (UV) radiation. After four weeks of recuperation, UV-treated implants showed significant new bone formation without compromising soft tissue, increasing bone-implant contact to nearly 100%.[1] The UV-treated surface created an osteoblast-affinity environment, as seen by enhanced osteoblast attachment, spread, proliferation, and differentiation in addition to increased protein adsorption.[10]

These findings suggest that because photofunctionalization increases the load-bearing capacity and positional stability of immediately loaded implants, the results are improved.[2,11, 12]
An innovative method and solution for the packaging of medical implants that works with photofunctionalization and displays quartz ampoules' exceptional UV permeability as an alternative to the commonly used sterile plastic or metal containers. So it is important to install specialized equipment in the dental clinic's disinfection room for implant surface treatment.[4,13]

Instead of triggering all the above mentioned early accelerating biologic changes, research indicates that after a 12-week healing time, the percentage of bone to implant contact did not differ between the titanium surfaces that underwent UV treatment and those that hadn't.[5]

References:

1. Hideki Aita, Norio Hori, Masato Takeuchi, Takeo Suzuki, Masahiro Yamada, MasakazuAnpo, Takahiro Ogawa. "The effect of ultraviolet functionalization of titanium on integration with bone", Biomaterials, 2009.
2. Pooya Soltanzadeh, Amirreza Ghassemi, Manabu Ishijima, Miyuki Tanaka, Wonhee Park, Chika Iwasaki, Makoto Hirota, TakahiroOgawa. "Success rate and strength of osseointegration of immediately loaded UV-photofunctionalized implants in a rat model",The Journal of Prosthetic Dentistry, 2017.
3. Oshikatsu Suzumura, Takanori Matsuura, Keiji Komatsu, Takahiro Ogawa." A Novel High-Energy Vacuum Ultraviolet Light Photofunctionalization Approach for Decomposing Organic Molecules around Titanium." International Journal of Molecular Sciences, 2023.
4. MIKI, Takahito, Tomonori MATSUNO, Yoshiya HASHIMOTO, Akiko MIYAKE, and Takafumi SATOMI. 2019. "In Vitro and In Vivo Evaluation of Titanium Surface Modification for Biological Aging by Electrolytic Reducing Ionic Water" Applied Sciences 9, no. 4: 713.
5. Choi B, Lee YC, Oh KC, Lee JH. Effects of photofunctionalization on early osseointegration of titanium dental implants in the maxillary posterior region: A randomized doubleblinded clinical trial. International Journal of Implant Dentistry. 2021 Dec;7:1-7.
6. Naauman Z, Rajion ZA, Maliha S, Hariy P, Muhammad QS, Noor HR. Ultraviolet A and Ultraviolet C light-induced reduction of surface hydrocarbons on titanium implants. European journal of dentistry.
7. Zaheer Naauman, Zainul Ahmad Bin Rajion, Shahbaz Maliha, Pauzi Hariy, Q.

Saeed Muhammad, H. A. Razak Noor. "Ultraviolet A and Ultraviolet C Light-Induced Reduction of Surface Hydrocarbons on Titanium Implants", European Journal of Dentistry, 2019.

8. Takahito MIKI, Tomonori MATSUNO, YoshiyaHASHIMOTO, Akiko MIYAKE, Takafumi SATOMI. "In Vitro and In Vivo Evaluation of Titanium Surface Modification for BiologicalAging by Electrolytic Reducing Ionic Water", Applied Sciences, 2019.

9. Takeshi Ueno, Takayuki Ikeda, Naoki Tsukimura, Manabu Ishijima et al. "Novel antioxidant capability of titanium induced by UV light treatment", Biomaterials, 2016.

10. Shi Qian, Yuqin Qiao, Xuanyong Liu. "Selectivebiofunctional modification of titanium implants for osteogenic and antibacterial applications", J. Mater. Chem. B, 2014.

11. Aita, H.. "The effect of ultraviolet functionalization of titanium on integrationwith bone", Biomaterials, 200902.
12. Won-Mi Bok, Seo-Young Kim, Sook-Jeong Lee, Gwi-Su Shin, Ju-Mi Park, Min-Ho Lee. "Surface characteristics and bioactivation of sandblasted and acid-etched (SLA) Ti-10Nb- 10Ta alloy for dental implant", International Journal of Precision Engineering and Manufacturing, 2015.

13. Takahiro Ogawa. "Ultraviolet Photofunctionalization of Titanium Implants", The International Journal of Oral & Maxillofacial Implants, 2014.