THE EFFECT OF ULTRAVIOLET PHOTOFUNCTIONALIZATION ON TITANIUM IMPLANT SURFACE AND ITS RELATED CLINICAL PERFORMANCE

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by

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BIC	Bone Implant Contact
CBCT	Cone Beam Computer Tomography
CT	Computerized Tomography
ECM	Extracellular Matrix
FOV	Field of Vision
HU	Hounsfield Unit
ISQ	Implant Stability Quotient
MBL	Marginal Bone Loss
OSI	Osseointegration Speed Index
RFA	Resonance Frequency Analysis
SEM	Scanning Electron Microscopy
SL1	Streptococcus Sanguinis
SLA	Sandblasted and Acid-Etched
Ti	Titanium
TI-6AL-4 V	Titanium Aluminium Vanadium Alloy
TiO_2	Titanium Dioxide
UV	Ultraviolet
UVA	Ultraviolet A
UVC	Ultraviolet C
XPS	X- Ray Photoelectron Spectroscopy

KESAN FUNGSIONALISASI CAHAYA ULTRAVIOLET PADA SURFACE IMPLANT TITANIUM DAN KAITANNYA DENGAN PRESTASI KLINIKAL

ABSTRAK

Implan titanium komersil sangat reaktif dan ianya akhirnya mendegredasi seiring dengan masa kerana pengumpulan permukaan hidrokarbon daripada persekitaran berdekatan yang akhirnya mengurangkan lekatan selular dan formasi tulang ke atas permukaan implant. Hidrokarbon di permukaan boleh dikurangkan melalui nyahradiasi implant dengan sinaran ultraungu sebelum menggunakannya yang dikenali sebagai fungsionalisasi cahaya. Tujuan kajian ini adalah untuk mengenalpasti jarak gelombang ultraungu (UV) yang sesuai bagi mencetus kesan positif maksimum ke atas permukaan implant dan membandingkannya dengan implan ultraungu nyahradiasi. Objektif utama kajian ini adalah untuk menilai perubahan ukurlilit pori-pori dan juga tahap hidrokarbon permukaan implant titanium yang disaluti dengan SLA di makmal selepas nyahradiasi UV dengan kepelbagaian jarak gelombang. Dari sudut klinikal kajian ini, perubahan dalam kehilangan tulang marginal (MBL), kepadatan tulang dan kestabilan dalam tulang alveiolar yang merangkumi implan titanium dinilai dan dibuat perbandingan. Bahagian makmal kajian ini dilakukan ke atas Sembilan Dio UFII dengan rawatan permukaan bagas pasir hybrid dan beretsa asid yang dibahagikan kepada tiga kumpulan yang sekata. Implan dalam kumpulan kawalan A tidak dinyahradiasi manakala sampel kumpulan B dan C masing-masing diberi nyahradias UVA (382 nm, 25 mWcm2) dan UVC (260 nm, 15 mWcm2). Nisbah atom karbon, titanium, oksigen dan perubahan-perubahan dalam diameter pori di atas permukaan implant dianalisa dan dibandingkan di antara kumpulan tersebut. Dalam bahagian klinikal kajian ini, enam puluh enam implant diletakkan dalam peserta yang sihat secara sistematik. Perawakan ringkas dilakukan untuk meletakkan pesakit dalam tiga kunpulan. Kumpulan UVC juga menunjukkan peningkatan ketara dalam saiz pori berbanding dengan kumpulan UVA dan kawalan. Kandungan karbon agak berkurangan dan peratusan titanium dan oksigen untuk kumpulan C bertambah berbanding dengan kumpulan lain. Dalam bahagian klinikal kajian ini, Kedua-dua kumpulan yang dirawat dengan UVA dan UVC menunjukkan MBL yang minimum. Sementara itu, kumpulan UVC menunjukkan peningkatan kepadatan tulang yang signifikan di antara minggu ke-8 dan ke-26. Kestabilan implan juga dinilai pada masa penempatan lekapan implant (hari 0) dan selepas minggu ke-8 sebelum muatan fungsional. Implan yang dinyahradiasi dengan UVA mempunyai kesan signifikan tahap ISQ berbanding dengan kumpulan kawalan dan UVC. Kesimpulannya, nyahradiasi UVC mempunyai potensi untuk mengawal MBL dan mempercepatkan formasi tulang dengan mengurangkan hidrokarbon permukaan dan meningkatkan saiz pori ke atas permukaan implant.

THE EFFECT OF ULTRAVIOLET PHOTOFUNCTIONALIZATION ON TITANIUM IMPLANT SURFACE AND ITS RELATED CLINICAL PERFORMANCE

ABSTRACT

Commercial titanium implants are highly reactive, and it eventually degrades with time due to accumulation of surface hydrocarbons from surrounding environment, which ultimately decreases the cellular attachment and bone formation on implant surface. The surface hydrocarbons can be reduced through ultraviolet (UV) irradiation of implants also known as photofunctionalization. The aim of the present study was that which wavelength of ultraviolet (UV) radiation is suitable to induce maximum positive effects on implant surface and compare it with non-UV irradiated implants. The main objective of this study was to assess the changes in pore diameter as well as changes in hydrocarbon levels on the surface of SLA coated titanium implants in laboratory study following UV irradiation with varying wavelengths. In the clinical part of the study, changes in marginal bone loss (MBL), bone density and implant stability in the alveolar bone surrounding the titanium implants were assessed and compared. The laboratory part of the study was conducted on nine Dio UFII implants with hybrid sandblasted and acid-etched (SLA) surface treatments, divided equally among three groups. Implants in control group A were not irradiated, while groups B and C samples were given UVA (382 nm, 25 $mWcm^2$) and UVC (260 nm, 15 $mWcm^2$) irradiation, respectively. Changes in pore diameter and the atomic ratio of carbon, titanium, oxygen and on implant surfaces were analysed and compared among the groups. In the clinical part of the study, sixty-six implants were placed in systemically healthy participants. Simple randomization was employed to allocate patients into three groups. In group A (control group), patients received implants as it is without any intervention, while patients in group B (UVA group) and C (UVC group) received photofunctionalized implants. The MBL and bone density in the surrounding bone was evaluated through Cone Beam Computed Tomography (CBCT) at 8^{th} and 26^{th} week and comparisons were done among the three groups. It was observed in laboratory part of the study that UVC group showed more pronounced increase in pore diameter compared to UVA and control group. The surface carbon content was also considerably reduced, whereas percentages of titanium and oxygen were enhanced for group C compared to other groups. Meanwhile in the clinical part of the study, both UVA and UVC treated groups showed minimal MBL compared to control group. UVC group showed significant improvement in bone density between 8^{th} and 26^{th} week time. Implant stability was also evaluated at time of placement of implant fixture (day 0) and after 8^{th} week before functional loading. Implants irradiated with UVA had relatively significant effect on ISQ level as compared to control and UVC group. In conclusion, UVC irradiation has the potential to increase the pore diameter and reduce the surface hydrocarbons, thus inducing more bone formation around the implant surfaces.

CHAPTER 1

INTRODUCTION

Implants have been used to support dental prostheses for many decades (Ogawa, 2014; Rupp et al., 2018). They are the nearest equivalent replacement to the natural tooth, and are therefore a useful addition in the management of patients who have missing teeth secondary to trauma or developmental anomalies (Ananth et al., 2015; Guillaume, 2016; Huber et al., 2012). The implant mimics the root of a tooth in function (Vela & Rodríguez, 2019). It is not only biocompatible (Gosavi et al., 2013), but actually fuses to bone by osseointegration (John et al., 2016). Osseointegrated implants symbolizes one of the most significant breakthroughs in current dental practice in the oral rehabilitation of partially or fully edentulous patients (Buser et al., 2017). Osseointegration is a direct structural and functional union between living bone and surface of the load carrying implant (Smeets et al., 2016). The concept of osseointegration or functional ankylosis was first proposed by Branemark and his team through their revolutionary research work (Branemark et al., 1977).

Previously, the implants were used just as a replacement for the missing teeth. Nowadays, the clinical indications of dental implants have increased considerably, whereas the demands of the patients have increased in terms of improvement in mastication and higher aesthetic expectations. Patients desire for quicker healing and minimal treatment time due to their fast-paced lifestyle. It is also their right to request for safe and reliable dental solutions with fewer complications like implant failures.

However, the increased demand of the implants has made dentists look for implant systems with more simple surgical procedures, shorter osseointegration time, clinical flexibility and, lastly, a variety of prosthetic components to meet varying needs. With sufficient funds invested in research by companies and academic institutes, the advancement of manufacturing technologies and the collaboration between clinicians and experts of dental material, there has been tremendous improvement in the quality of dental implants (Alghamdi, 2018; Rupp et al., 2018; Smeets et al., 2016). One of the methods which recently gained interest is the improvement of physiochemical and biological properties effects of titanium implant surfaces through ultraviolet (UV) irradiation also known as photofunctionalization (Att & Takahiro, 2012; Flanagan, 2016; Roy et al., 2016).

Ultraviolet (UV) light–mediated photofunctionalization of titanium has gained considerable attention as a means to improve the bioactivity and osteoconductivity of titanium implants (Iwasa et al., 2010; Minamikawa et al., 2014) because it restores their superhydrophilicity, reducing surface carbon and optimizing surface electrostatic charges (Flanagan, 2016; Smeets et al., 2016). These biologic and physicochemical features are collectively known as photofunctionalization (Flanagan, 2016).

To our knowledge, very few in vitro studies have been done to compare the effects of UVA and UVC irradiation in improving the hydrophilicity on various surface modifications like zirconia, PEEK, grit blasted acid etched, anatase coating and MAO coated titanium implants (Al Qahtani et al., 2015; Gao et al., 2013). However, different surface modifications showed varying responses in increasing the hydrophilicity and reducing surface hydrocarbons. But there is a general concept that UVC irradiation shows promising results due to the generation of more hydrophilicity and greater surface energy, thus, inclining towards a fact that UVC is better than UVA irradiation (Aita et al., 2009; Gao et al., 2013; Miyauchi et al., 2010; Son et al., 2009; Uchiyama et al., 2014). Furthermore, in vitro studies conducted on different commercial titanium dental implants irradiated specifically with ultraviolet-C (UVC) concluded that the implants turned superhydrophilic without causing any changes or compromising the surface topography of the implants (Kim, 2016; Park et al., 2013; Roy et al., 2016).

Animal studies and clinical trials have also shown positive results following the insertion of photofunctionalized titanium implants. In the earliest known clinical cross-sectional retrospective analysis, photofunctionalized titanium implants were inserted in compromised bones with immediate loading protocol resulting in rapid healing time and improved implant stability (Suzuki et al., 2013). Chances of implant failure was significantly lowered by reducing the healing time and promoting osseointegration even if primary stability from host was good enough at time of placement (Funato et al., 2013; Hirota et al., 2018; Kitajima & Ogawa, 2016). Titanium implants along with titanium mesh were photofunctionalized in aesthetic zone area which ultimately showed promising results in radiographs of bone growth around the implant (Funato et al., 2014). However, there is lack of evidence as to which wavelength of ultraviolet radiation was used.

To date, studies on the effect of photofunctionalization of titanium dental in humans, especially randomized controlled trials, are yet to be reported (Razali et al., 2020). Currently, only retrospective case controls (Hirota et al., 2016) and case series (Funato & Ogawa, 2013; Funato et al., 2013) have been reported. Such extended work has seldom been conducted in vitro and rarely in vivo on SLA coated titanium dental implants. So, there was a dire need of randomized control trial to assess and compare the changes in surface hydrocarbons, changes in surface pore diameter after both UVA and UVC irradiation, as well as changes in surrounding bone around titanium implants in clinical patients. SLA coated implants are one of the most commonly used commercial implant system in Pakistan. So naturally it was important to conduct research on these implants to find that which wavelength of UV radiation is suitable to be used to benefit mankind.

This study is an extension and modification of previous studies by using novel idea of using sandblasted acid etched titanium implant which will be exposed to UVA and UVC irradiation through lamps. Elaborated laboratory and clinical study were conducted on more sample size to achieve objectives of this study. This will give an insight about the specific wavelength which will enhance the properties of the implant itself and at the same time reduce the healing.

1.1 Rationale of the study

- To study the effects of photofunctionalization on SLA coated titanium dental implants.
- There is a need to study the positive role of photofunctionalization of commercially available dental implants.
- It is also not clear that which of the two wavelengths i.e. UVA and UVC irradiation is more beneficial in human clinical trial.

1.2 Objectives

1.2.1 General objectives

To study the changes in surface morphology and carbon contents of UV irradiated titanium implants, and its role in osseointegration in human clinical trial.

1.2.2 Specific objectives

1. In laboratory of the study

    a) To access the changes in pore diameter on the surface of SLA coated titanium implants following UVA and UVC irradiation and to compare it with non-irradiated implants.

    b) To evaluate the changes in carbon to titanium ratio on surfaces of SLA coated titanium implants after UVA and UVC irradiation and to compare it with non-irradiated implants.

2. In the clinical part of the study

    a) To assess the marginal bone loss of alveolar bone around UVA and UVC irradiated titanium implants and to compare it with the patients in control group using non-irradiated implants.

    b) To assess bone density around UVA and UVC irradiated titanium implants and to compare it with the patients in control group using non-irradiated implants.

    c) To evaluate and compare the implant stability around the non-irradiated, UVA irradiated and UVC irradiated titanium implants.

1.3 Working hypothesis

1. There is no difference in the pore diameter on surface of titanium implants with or without UV irradiation at various wavelengths.
2. There is a difference in the carbon to titanium ratio of titanium implants with or without UV irradiation, with UVC radiations showing promising results.
3. There is a difference in the marginal bone loss of alveolar bone around implants in the control group and UV irradiated titanium implants, with UVC radiations showing promising results.
4. There is a difference in the bone mineral density around implants in the control group and UV irradiated titanium implants titanium implants, with UVC radiations showing promising results.
5. There is a difference in implant stability and OSI among the control group and UV irradiated titanium implants.

1.4 Research question

1. Is there any difference in pore diameter of SLA coated titanium implants with or without UVA and UVC irradiation?
2. Is there any difference in carbon to titanium ratio of titanium surfaces with or without UVA and UVC pre-treatment?
3. Is there any difference in the marginal bone loss of alveolar bone around UVA and UVC irradiated titanium implants while comparing it with the control group?
4. Is there any difference in the bone density around the non-irradiated, UVA and UVC irradiated titanium implants?
5. Is there any difference in implant stability and OSI around the control group, UVA and UVC irradiated titanium implants?

CHAPTER 2

LITERATURE REVIEW

2.1 Dental implants

One of the major aims of modern dentistry is to re-establish patient dentition to usual function and health, as well as preserving aesthetics. Restorative dentistry and social awareness of the importance of oral health have contributed significantly in the progress of the overall oral health of the population worldwide in the last decades, but still, although tooth decay indices have considerably dropped, a major portion of a dentist's job still comprises dealing with replacement of missing teeth. The increase in people's life expectancy, the increasing frequency of periodontal infection in the ageing populace, conventional fixed prostheses failure, poor performance of conventional removable prostheses as well as psychological affects of tooth loss have all played a part in the need to find a more dependable, everlasting and aesthetically acceptable alternative for replacing missing teeth.

Conventional fixed bridges are one of the one the solutions of replacing the missing teeth, but they can only be used in cases with limited number of missing teeth. On the other hand, conventional removable prostheses have a really low rate of acceptance by the patients, who are usually complaining of not being able to eat or speak properly with them and, while in the past they were used a lot, nowadays they are used primarily when there are anatomical or financial constraints that limits the dentist from providing the patient with a fixed prostheses. Dental implants, on the other hand, provide a very good alternate for treating missing teeth, aiding as both abutments for fixed crowns or bridges as well as abutments to secure, if not “lock”, removable prostheses to their position, making the latter ones smaller in size and a lot easier to function with. This explains why implants have currently become a standard treatment choice for the most of edentulous cases.

2.1.1 Types of dental implant

Historically, dental implants have been classified according to their design. This design was in turn based on the way in which they are surgically implanted. The three types of implants commonly used for the past 40 years are the endosteal implant, subperiosteal implant and the transosteal implant (Sakaguchi & Powers, 2012).

Endosteal implants

An endosteal implant is an alloplastic material surgically placed into a residual bony ridge, mainly as a prosthodontics base (Laney, 2017). The prefix endo comes from Greek and means “within”, and osteal means “bone”. The terminology endosseous implant is also used in the text and the term “osseous” specifies bone. Once the implant is successfully integrated with the bone, it can support physical loads for decades without failure (Misch, 2008; Qassadi et al., 2018). Common dental implants used in clinical practice nowadays are root form implants which are later connected to a prosthodontics abutment, which will support the prosthodontic restorations. These implants include screw types (threaded), cylinder types (smooth) or bladed types (Misch, 2008).

Subperiosteal implants

Subperiosteals were primarily used to hold dentures in place in patients with insufficient bone height (Sakaguchi & Powers, 2012). These implants are prefabricated along with pliable, work-hardened material. A short projection extends from on surface of plate and defines an aperture which receives post supporting an artificial tooth structure. The prefabricated implant is inserted through lateral incision in gum tissue, is then modelled to the bone. Post is installed on support plate. Placed on the jawbone within the gum tissue, with the metal implant post exposed to hold the restoration, subperiosteals are rarely if ever used today.

Transosteal implants

A design used only in the anterior mandible in which posts extend completely through the mandible and gingiva to provide prosthesis anchorage**.** A staple bone implant penetrates both cortical plate and passes through entire thickness of alveolar bone. These implants are not much used because they necessitate an extraoral surgical approach (Stellingsma et al., 2004; Sakaguchi & Powers, 2012).

In addition to prosthodontics uses, implants have also been introduced in the orthodontic practices and have provided a valuable solution to anchorage control problems (Nosouhian et al., 2015). Their clinical behaviour as rigid fixation points has significantly contributed in the effective management of asymmetry, mutilated dentition, craniofacial deformity and severe malocclusion (Agrawal et al., 2015). Currently, mini-implants have become part of the everyday training of clinical orthodontics (Smith, 2013).

Dental implants vary in length, diameter, thread design and surface characteristics and specific clinical considerations are usually used to justify the use of the different types. The growing demand for their use and the so far acceptable research findings has led to a market of hundreds of different types of implants which are easily accessible, yet most of them are not well-documented.

The purpose of this review is to present current concept about surface topography, change in carbon content, marginal bone loss, bone density and implant stability around non-irradiated dental implants. In addition, review on ultraviolet irradiation of UVA and UVC were also included. This review will help us to improve further knowledge in this area of research. The author will start with the background on basic factors responsible for success and failure of dental implants and then discuss the role of photofunctionalization in implant dentistry.

2.2 Osseointegration

Osseointegration is defined as a direct structural and functional connection between ordered, living bone and the surface of a load-carrying implant. Histologically the implant/bone interface contains no fibrous or soft tissue intervention hence known as functional ankylosis implant (Manea et al., 2019; Mavrogenis et al., 2009)

Although, implant placement till functional loading throughout is asymptomatic, functional relation is observed between bone and implant when osseointegration is established (Lindhe et al., 2003; Papaspyridakos et al., 2012). It involves a complex sequence of biological events which has similarity to direct healing after insult. The osteotomy is created by a surgical procedure of using implant drills resulting in a traumatic insult within the alveolar bone followed by healing phase. This process involves a hemostatic phase responsible for production of blood clot by laying down fibrin threads along with cellular initiation of angiogenesis, proliferation of osteoblast progenitor cells and lastly deposition of extracellular matrix. As implant fixture is engaged in the osteotomy or hole created, propagation of osteoblastic progenitor cells is initiated resulting in the development of osteoblasts. These cells in turn migrate along the implant fixture surface to lay down new bone towards the implant known as osteogenesis (Smeets et al., 2016).

The most commonly faced problem in implant therapy is incomplete or complete failure of implant to bone integration. This loss of osseointegration may be due to incomplete fixation or early/ late destructive changes at the bone-implant interface (Chuang et al., 2002; Olmedo-Gaya et al., 2016). The changes seen at bone/implant interface are highly dynamic. Initially, implant to alveolar bone interface is different which is altered after bone remodeling phase. The strength of alveolar bone and implant fixture is greater after healing period of twelve weeks of implant placement which may be related to amount of bone surrounding the implant fixture. The important feature that can play a part in affecting the strength of the interface is ample time for cellular stimulation and osseointegration during healing period (Albrektsson et al., 1986; Choi et al., 2019).

2.3 Factors affecting osseointegration

2.3.1 Surface topography

Implant surface plays a pivotal role for successful host tissue reaction. Surface topography is defined as small local deviation of a surface from a perfectly flat plane. Hence, surface topography of implants refers to the macroscopic and microscopic features of the implant surface. All commercially available implants are composed of pure titanium, but they vary in their surface textures and technique. Common goal of incorporating these features is to promote bone growth towards the implant, increase the surface area, removal of surface contaminants and prevention of wear and corrosion (Gupta et al., 2014).

The following three methods are typically employed to modify the implant surface: 1) Mechanical treatment to remove surface area by machining, polishing and grinding. 2) Chemical treatment which is widely used to alter surface roughness and enhance wettability/surface energy. Chemical treatment of implant surface includes treatment with acids or alkali, hydrogen peroxide treatment, sol-gel, chemical vapor deposition and anodization (Le Guéhennec et al., 2007). 3) Coating techniques which include plasma spraying, sputtering and ion deposition (Bagno & Di Bello, 2004; Jemat et al., 2015).

Implant fixture surface has some roughness on its surface to encourage the protein absorption, attachment of osteoblastic cell needed for bone formation between alveolar bone implant fixture interfaces (Albertini et al., 2015; Wennerberg & Albrektsson, 2009; Zareidoost et al., 2012). These studies suggest that more the irregularities more will be surface area to promote three dimensional bone growth around the implant fixture (Ananth et al., 2015; Coelho et al., 2009). The smaller grain size provides a suitable environment for protein absorption, cell attachment and proliferation which in turn uphill the higher surface energy (Ananth et al., 2015; Wennerberg & Albrektsson, 2009). This will also allow mechanical interlocking between implant and new bone formed. Subsequently, secondary implant stability will increase due to more bone to implant contact (Taniguchi et al., 2016). Over the last three decades, investigators have innovated new implant systems by incorporating surface roughness of varying orientation in coronal and radicular third of the implant. Surface modifications of different types have been used to achieve this feature (Saini, 2015; Wennerberg & Albrektsson, 2009). Moreover, on a nanometre scale, rise in roughness leads to an increase of surface energy and hence to enrichment of matrix protein adsorption, bone cell migration and proliferation and finally osseointegration.

On the other hand, chemical alteration of implant surfaces, such as adding calcium phosphate on the TiO_2 layer, might promote bone growth and increase mechanical interlocking between surface materials and matrix proteins (Coelho et al., 2009). Additionally, biochemical modification, such as incorporation of proteins, peptides or enzymes, can encourage specific cell and tissue responses. Although most procedures enhance either physical or chemical alteration, there are processes that can combine both. Likewise, electrochemical anodization of the titanium surface, which causes not only thickening of the TiO_2 layer, but also ion impregnation on the same layer, as well as porous structures (Kim & Ramaswamy, 2009).

Dio Implants (Dio UFII HSA implants, Haeundae-gu, Korea)

Currently, one of the most commonly used commercial implants are the SLA coated titanium implants, in which the titanium implants are first blasted by particles and then they are etched by acids. In short, the SLA process results in a combination of a macro-roughness, provided by the sandblasting process, and a micro-roughness, provided by the acid-etching process (Gupta et al., 2014; Mandracci et al., 2016). SLA coated titanium implants show good biocompatibility (Kim et al., 2008), enhanced proliferation of osteoblasts and bone formation due to presence of micro pits and sharp peaks on the surface (Li et al., 2002). These implants are considered to be far superior, due to more bone-to-implant contact (50-60%) as compared to other surface modifications like titanium plasma-sprayed (30-40%) or electropolished implants (20-25%) (Smeets et al., 2016).

Dental implant chosen based on the previous study which mention Dio Hybrid sandblasted and acid etched (HSA) implants (Dio UFII HSA implants, Haeundae-gu, Korea) were selected for this study (Abron et al, 2001; Hansson & Norton, 1999). This is due to the fact the coronal third portion of Dio UFII hybrid sandblasted acid etched implants has micro surface with Ra value: 0.5-1.0µm. It provides less friction around cortical bone which in turn reduces peri-implantitis. The body of the implant has macro plus micro surface with Ra value: 2.0-2.5µm which stimulates and promotes osseointegration quickly for long term stability (Fig. 2.1). The depth and diameter of 1.5µm and 3-5µm respectively of the hemisphere pit is ideal for perfect roughness. Micro scale roughness of 1-10µm stimulates attachment of osteoblast. It accelerates building of extracellular matrix (ECM) and mineralization on implant surface which helps to create faster osseointegration reaction. Thus rough surface increases the coherence between surface of implant and mineralized bone (Abron et al., 2001). The fixture and abutment interface confirms hermetic sealing. This distributes the load to the fixture evenly having more tapered connection 11º which minimizes bone loss. Open thread fixture minimizes resistance, so possibility of placing it deep without drilling prevails. The platform switching design of this implant is incorporated with 30º to minimize the marginal bone loss (Fig. 2.2).

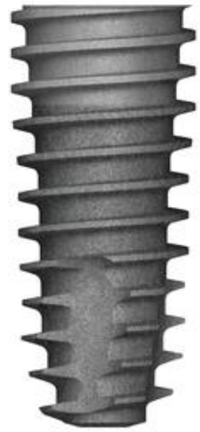

Figure.2.1: Illustration of Dio Implants (Dio UFII HSA implants, Haeundae-gu, Korea)

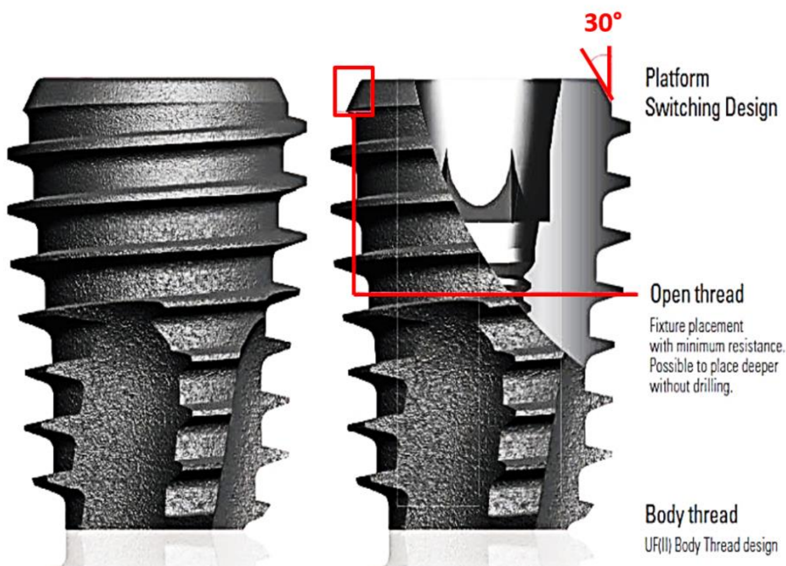

Figure.2.2: Illustration of Dio Implants (Dio UFII HSA implants, Haeundae-gu, Korea) showing the platform switching design with 30º incorporated

2.3.2 Physiochemical changes on surfaces of titanium implants

Titanium implants are best commercial products used to replace the lost teeth in oral cavity. It is one the best fixed prosthodontic replacements for edentulous patients (Dong et al., 2019; Jayasinghe et al., 2017). It is greatly biocompatible due to its matchless properties like corrosion resistance, no inflammatory response to peri-implant tissues and it is non-toxic to inflammatory cells like fibroblasts and macrophages (Amengual-Peñafiel et al., 2019; Silva-Bermudez & Rodil, 2013). It is considered to be biocompatible when it positively exists in a biological and physiochemical microenvironment with rarely any allergic reactions and discoloration in surrounding tissue (Albrektsson et al., 2018; Eliaz, 2019).

Titanium Passivation

Titanium is an extremely reactive metal that undergoes oxidation when exposed to air, water or natural environment (Gosavi et al., 2013). It forms a tenacious oxide layer of titanium dioxide (TiO_2) that contributes to titanium electrochemical passivity. TiO_2 layer has a protective function which provides resistance to corrosion (Bhola et al., 2011; Eliaz, 2019). Titanium dioxide (TiO_2) is the primary surface composition of dental implants after manufacturing (Rupp et al., 2018). After production, the elemental titanium on the surface undergoes passivation and it is oxidized to TiO_2 in a fraction of a second of time (Ahn et al., 2011). Implant surface requires a porous field so that ion exchange between bone and implant can take place and this oxide layer formed provides an active field for ion exchange giving it a hydrophilic characteristic (Gittens et al., 2013; Rupp et al., 2018). This ionic exchange is advantageous in attracting necessary proteins and cells for promoting three dimensionally bone formation around the implant thus enhancing load bearing ability (Gittens et al., 2014; Ogawa, 2014).

Theoretically, the proposed oxide layer formation starts with adsorbing oxygen on the surface of pure titanium to produce an oxide monolayer. Subsequently, an electron from the titanium will channel through the oxide layer to further adsorb oxygen, thereby producing oxygen ions (Fujishima et al., 2008). An oxygen with a valence of only two electrons is relatively electronegative and will readily bind with lightly held valence electrons of titanium to further thicken the oxide layers until the activation energy for ion transport increases and eventually limits further oxide formation (Akira Fujishima & Zhang, 2006). The passivation of the implant alters surface composition. These changes can be associated with the changes in surface energy (Kilpadi et al., 1998).

In dental implantology, a satisfactory biological response across the entire spectrum of interactions (water–proteins–cells), depending on the chemical and topographic properties of the surface, which determines the amount of bone that will come into contact with the biomaterials (John et al., 2016; Mustafa et al., 2001; Rupp et al., 2018). Moreover, the hydrophilic status of the material surfaces is a representative marker for surface energy and seems to affect the capacity to adsorb proteins and attract cells for interaction (Gittens et al., 2014; Massaro et al., 2002; Rupp et al., 2014). Osteoblast migration and proliferation occur during the initial stage of healing and critically affect the outcomes of bone–titanium integration. Up to the present time, various modifications for improving the physicochemical and topographic characteristics of dental implant surfaces have been investigated which is discussed later under current trends in surface characteristics.

Titanium Degradation

Biological aging or time-dependent degradation of titanium occurs due to surface contamination overtime under ambient conditions upon storage and transfer before reaching the end-users. The mechanism of the degradation process is unknown because of the stability of the oxide layer of titanium, however, progressive accumulation of hydrogen and carbon compounds occurs over time on the surface exposed to ambient temperature (Lee & Ogawa, 2012). When exposed to atmosphere, the TiO_2 surface can bind to hydrocarbons in the air through interactions with carboxyl and amine groups, regardless of the type of surface treatment (Roy et al., 2016). The deposition of hydrocarbons onto the titanium surface is inversely proportional with osteoblast activity (Hayashi et al., 2014). The first mechanism involves hydrocarbon compound contamination on the external layers of TiO_2. The second mechanism involves changes in surface energy that resulted from alterations in the electrostatic status of the titanium surface.

Titanium Surface Contamination

The presence of trace organic impurities or adventitious contaminants on the surface of an implant is unavoidable and is thought to affect the response to protein absorption and cells adjacent to the implant (Hayashi et al., 2014; Kamo et al., 2017). Even at small quantities, trace compounds such as polycarbonyls or hydrocarbons may alter the implant surface properties. The presence of impurities on the surface of an implant affects wettability as these impurities prevent the adhesion and adherence of water molecules (Kamo et al., 2017; Shi et al., 2016). The hydrocarbon contamination of titanium dental implants could occur during machining or surface modifications, sterilization, packaging, and storage prior to clinical use (Morra et al., 2003; Schwarz et al., 2009; Shi et al., 2016). Hydrocarbon contamination on the surface was found to alter the surface zeta potential of the titanium surface to become electronegative. This reaction led to the entrapment of air bubbles and the blocking of the protein receptor, thereby interfering with the interaction between the proteins and cells (Att & Takahiro, 2012; Gittens et al., 2014).

Following manufacture, sterilization is one of the final surface preparations performed before packaging to ensure that the implants prepared are free from bacterial contamination (Park et al., 2012). Interestingly, one further issue highlighted by studying cell–surface interactions is the fact that cleaning and sterilization methods may affect the surface energy of implants (Doundoulakis, 1987; Park et al., 2012). Effort to reduce bacterial contamination inevitably contributes to non-biological surface contamination of the titanium implants. Thus, autoclaving, ethanol or butanol sterilization creates organic contamination (Vezeau et al., 1996). Hence, sterilization via the hydrothermal method (Shi et al., 2016), gamma ray, or intense UV light exposure (Park et al., 2012) is recommended to achieve titanium with high surface energy that can induce cell adhesion as well as improve cellular activity and osseointegration (Funato et al., 2013).

In addition to processing and cleaning, the surface properties of titanium implants are also affected by the storage medium used. To our knowledge, most commercially used titanium implants are provided in sterile, gas-permeable packaging so that they can be stored up to expiry dates of approximately four years following fabrication. Given the nature of the packaging, plastic casing, and absence of light, the chemisorbed hydroxyl groups on the titanium surface are replaced with oxygen and carbon from air (Choi et al., 2019; Kamo et al., 2017). However, the level of hydrocarbon, not hydrophilicity level, was found to be inversely correlated with protein adsorption and cell attachment (Hayashi et al., 2014). The hydrocarbon formation on the titanium surface can start as early as four weeks after the production (Ogawa, 2014; Roy et al., 2016). Therefore, the amount of hydrocarbon adsorbed on TiO_2 from the time of manufacture to the time of implantation is crucial in determining the initial affinity level for osteoblasts. The implant surface comprises of an average of 35% to 55% carbon and it can increase to up to 75% depending upon the age of the implant (Morra et al., 2003).

Titanium Surface Energy Changes or wettability

Wetting is the ability of a liquid to maintain contact with a solid surface, resulting from intermolecular interactions when the two are brought together (Bhushan, 2018). The degree of wetting (wettability or surface energy) is determined by a force balance between adhesive and cohesive forces. Adhesive forces between a liquid and solid cause a liquid drop to spread across the surface resulting in a contact angle of less than 90° (low contact angle). Cohesive forces within the liquid cause the drop to ball up and avoid contact with the surface resulting in contact angle greater than 90° (high contact angle). Low contact angle means that the wetting of the surface is very favorable, and the fluid will spread over a large area of the surface whereas high contact angle generally means that wetting of the surface is unfavorable, so the fluid will minimize contact with the surface and form a compact liquid droplet (Rupp et al., 2014). Consequently, implant surface energy or wettability is an important factor for regulating osteogenesis. In general, the implant surface becomes hydrophilic when the surface is positively charged; attracting some of the plasma proteins necessary for initiation of cascades of events during wound healing and osseointegration (Dezellus & Eustathopoulos, 2010; Schwarz et al., 2009). Studies suggest that osteoblasts cultured in chemically pure and hydrophilic surfaces express higher levels of differentiation markers such as alkaline phosphatase and osteocalcin when compared to hydrophobic surfaces (Lee et al., 2008). In fact the positive effects of hydrophilicity in improving bone implant contact (BIC) and bone anchorage have been proven both in animal (Dezellus & Eustathopoulos, 2010; Schwarz et al., 2009) and clinical studies (Oates et al., 2007; Smeets et al., 2016).

The passivation and thickening of TiO_2 layers occur when an electron from titanium adsorbs oxygen from the air and produces oxygen ions. The ions on the surface are relatively electronegative and continuously maintain electronegative charges in the presence of air (Gittens et al., 2014), the positively charged new titanium surface directly interacts with the negatively charged biological cells. This interaction between the new titanium surface and osteoblasts occurs through electrostatic forces without cell–protein interaction.

2.3.3 Marginal bone loss

One of the most important criteria for implant success is the evaluation of crestal or marginal bone loss around the implant. MBL is inevitable after tooth extraction and particularly after implant placement and loading but the amount of bone loss varies in different cases (Esposito et al., 2010; Lombardi et al., 2019). After extraction, highest rate of bone resorption occur both buccolingually and apicocoronally, eventually leading to thinning of the alveolar process to allow for implant placement (Sanivarapu et al., 2010).

MBL around an implant was first reported in a 15 year study of osseointegrated implants in the 1980s (Adell et al., 1981). The exact etiology of marginal bone loss is unknown but the most important factors are: trauma to the bone during osteotomy, bacterial infection leading to peri-implantitis, biomechanical overload and micro gaps existing between the implant/abutment have a direct effect on crestal or marginal bone loss (Albrektsson et al., 1986; Koller et al., 2016; Oh et al., 2002; Qian et al., 2012). There is a growing need to preserve the marginal bone level after implant placement in order to achieve long term success of the implant, thus it is important to routinely