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Osseointegration in dental implant

A Project Submitted to
The College of Dentistry, University of Baghdad, Department of prosthodontics in Partial Fulfillment for the Bachelor of Dental Surgery

By

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Dedication

This project is wholeheartedly dedicated to my beloved parents, who have been my source of inspiration and gave me strength when we thought of giving up. To my brother, sister, relatives, mentor, friends, and classmates who shared their words of advice and encouragement to finish this study. And finally, l dedicated this project to the almighty god, thank you for the guidance, strength, power of mind, protection and skills.

Alaa Abdali

Certification of the supervisor

I certify that this project entitled "osseointegration in dental implant" was prepared by the fifth-year students **Alaa Abdali Hassan** under my supervision at the College of Dentistry/University of Baghdad in partial fulfilment of the graduation requirements for the Bachelor Degree in Dentistry.

Dr. Ghazwan Adnan Al-Kinani.

Acknowledgment

In the beginning, I thank “God” who gave me opportunity, ability, energy, spirit and patience to complete this project work .

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Introduction

The goal of modern dentistry is to restore the patient to normal contour, function, comfort, esthetics, speech, and health by removing a disease process from a tooth or replacing teeth with a prosthesis. What makes implant dentistry unique is the ability to achieve this goal, regardless of the atrophy, disease, or injury of the stomatognathic system.However, the more teeth a patient is missing, the more challenging this task becomes. As a result of continued research, diagnostic tools, treatment planning, implant designs, advanced materials, and techniques, predictable success is now a reality for the rehabilitation of many challenging clinical situations **(randolph. etal.,2021).**

Dental implants are inert, alloplastic materials embedded in the maxilla and/or mandible for the management of tooth loss and to aid replacement of lost orofacial structures as a result of trauma, neoplasia and congenital defects. The most common type of dental implant is endosseous compris-ing a discrete, single implant unit (screw- or cylinder-shaped are the most typical forms) placed within a drilled space within dentoalveolar or basal bone. Commercially pure titanium or titanium alloy are the common constituents of dental implants. However, alternative materials include ceramics such as aluminium oxide and other alloys (gold and nickelechromeevanadium). **(Erica Dorigatti. et al, 2014).**

The success of dental implants depends on the maintenance of osseointegration that is defined as a direct bone-to-implant contact without interposition of any other tissue. Simultaneously, in order to preserve osseointegration around dental implants it is desirable to have no relationship between the maxillary and mandibular or parafunctional We forces, malaligned forces of stress, peri-implantitis, absence of systemic diseases, e.g., diabetes mellitus , and to consider the host immune-inflammatory response to the bacterial challenge. Despite the relatively high success rates of dental implant survival, reported to be higher than 90% for both partially or completely edentulous patients in longitudinal studies. **(Erica Dorigatti. et al, 2014).**

Aims of Review

This review focussed on the osseointegration of dental implant and the factors that enhance it.

Review of literature

Modern dental implantology began almost half a century ago. A review current literature shows great evolution not only on implant design and surgical techniques, but also on the classification of clinical success, failure and different surface treatments **(Bartlett et al,2007).**

Brånemark coined the term 'osseointegration', which defines success and failure of dental implants. Osseointegration was originally defined at the light microscopic level as "a direct structural and functional connection between ordered, living bone and the surface of a load-carrying implant"(**Brånemark Pi et al,1977).**

Later, a more clinicallyoriented definition was devised for osseointegration as a process in which clinically asymptomatic rigid fixation of alloplastic materials is achieved and maintained in bone during functional loading. According to this revised definition, "clinical osseointegration implies histologic osseointegration, it is necessary there is a contiguous contact between the alveolar bone and the implant surface" **(Brånemark PI et al,1983).**

The conventional protocol proposed by Bränemark for treatment with dental implants establishes that implant procedures should be carried out in two phases. In the first, the 'surgical phase', the alveolus is prepared and the implant is installed. Furthermore, during the 'prosthetic phase', the prosthesis is molded, prepared and inserted. A 3-month interval between the surgical and prosthetic phase is recommended to allow proper healing of mandibular implants, whereas a 6-month interval is required for maxillary implants. **(Brånemark PI et al, 1985).**

Figure 1: example of commercially available dental implant design

1-1- osseointegration of dental implant

Defined as a direct structural and functional connection between ordered, living bone and the surface of a load-carrying implant, is critical for implant stability, and is considered a prerequisite for implant loading and long-term clinical success of endosseous dental implants. Osseointegration of titanium implant surfaces is dependent upon both physical and chemical properties **(Sul et al., 2005)**. This structural and functional union of the implant with living bone is strongly influenced by the surface properties of the titanium implant. As titanium and its alloys cannot directly bond with living bone, modification of the implant surface has been proposed as a method for enhancing osseointegration. Scientific research works to assess the influence of implant surface properties on bone healing have identified several factors which are important for osseointegration. The surface characteristics of implant which influence the speed and strength of osseointegration include surface chemistry, topography, wettability, charge, surface energy, crystal structureand crystallinity, roughness, chemical potential, strain hardening, the presence of impurities, thickness of titanium oxide layer, and the presence of metal and non-metal composites. Among these, wettability and free surface energy of an implant surface are considered to be very crucial. The influence of physical properties such as surface topography and roughness on osseointegration have translated to shorter healing times from implant placement to restoration **(Cochran et al., 2002).** The biologic basis underlying these clinical improvements continues to be explored **(Kim et al., 2005).**

Osseointegration can occur only if the cells adhere to the bio- material surface. At this phase, reorganization of the cytoskeleton and information exchange between cells and the extracellular matrix at the cell–biomaterial interface occur, generating gene activation and specific tissue remodeling. Both the morphology and roughness of the biomaterial's surface have an influence on cell proliferation and differentiation, extracellular matrix synthesis, local factor production and even cell morphology. Adhesion of osteoblasts onto implant surfaces is not enough to ensure osseointegration; it is necessary for cells to receive signals inducing them to proliferate. For example, coating the titanium surface with bone morphogenic protein-2 induces osteoblastic cell division after adhesion. The presence of fibronectin during the interaction between these cells and the implant surface, or the presence of protein, increases the cell division of human osteoblasts. **(Carlos Nelson Elias and Luiz Meirelles., 2010).**

Silva and Menezes cited that the success in the integration of biomaterial implants depends on responses such as cell attachment and cell adhesion (**Silva FC& Menezes GC et al.,2014).**

1-1-1_Interaction between cells and the surface of the dental implants

Since surface properties of biomaterials are important parameters influencing cellular reactions towards artificial materials, the properties of dental implant surfaces are extremely important in influencing the healing process leading to osseointegration and ultimate clinical success of the implant. Surface morphology modulates the response of cells to a dental implant, and surfaces with defined microstructures may be useful for enhancement of the stable anchorage (**Elias and Meirelles, 2010).** Surface chemistry involves adhesion of proteins, bacteria, and cells on implants. Wettability and surface energy influence the adsorption of proteins, and increase adhesion of osteoblasts on the implant surface. The cell behaviour on hydrophilic surface is completely different from that on a hydrophobic one. A hydrophilic surface is better for blood coagulation Not than a hydrophobic surface. The expressions of bone-specific differentiation factors for osteoblasts are higher on hydrophilic surfaces. Consequently, dental implants manufacturers have developed high hydrophilic and rough implant surfaces which in turn exhibited better osseointegration than implants with smooth surfaces. (**Boyan BD et al, 1996).**

Wound healing involves a highly orchestrated sequence of events which is triggered by tissue injury involving soluble mediators, blood cells, extracellular matrix and parenchymal cells. Ultimately, it culminates in either partial or complete regeneration or repair. Fracture healing in bone occurs in four phases which include inflammation, soft and hard callus formation, and remodelling. Following a fracture, blood coagulation and hematoma formation takes place. This is followed by inflammation. Various chemical mediators such as thrombin and growth factors released by activated leukocytes and platelets in the hematoma serve as chemotactic signals to many cell types which play an important role in bone healing. Unlike soft tissue healing, bone healing does not lead to scarring. Instead it leads to restoration of the bony tissue. During successful implantation, insertion of metal implants into cortical bone eventually leads to complete healing. Following implant placement, unlike in fracture healing, implants extend into and persist in the marrow spaces and this may have a bearing on the healing process. Although implant healing must to some extent adjust to the presence of the implant, ultimately, sound bony tissues will be completely restored during wound healing. This adjustment involves imbedding the implant surface in a layer of bone, continuous with the original bone.Wound healing around a dental implant placed into a prepared osteotomy follows three stages of repair- Initial formation of a blood clot occurs through a biochemical activation followed by a cellular activation and finally a cellular response (**Stanford and Schneider, 2004).**

1-1-2- Factor affect osseointegration

Albrektsson & Brånemark highlighted six factors that are especially important for the establishment of reliable osseointegration:

(Albrektsson T. et al., 1981).

1-1-2-1-implant material

The elemental metal titanium was first discovered in England by William Gregor in 1790, but in 1795 Klaproth gave it the name of titanium.
Combination of low density, high strength to weight ratio, good biocompatibility and improved corrosion resistance with good plasticity and mechanical properties determines the application of titanium and its alloys in such industries as aviation, automotive, power and shipbuilding

industries or architecture as well as medicine and sports equipment. Increased use of titanium and its alloys as biomaterials comes from their superior biocompatibility and excellent corrosion resistance because of the thin surface oxide layer, and good mechanical properties, as a certain elastic modulus and low density that make that these metals present a mechanical behaviour close to those of bones. Light, strong and totally biocompatible, titanium is one of the few materials that naturally match the requirements for implantation in the human body. Among all titanium and its alloys, the mainly used materials in biomedical field are the commercially pure titanium (cp Ti, grade 2) and Ti-6Al-4V (grade 5) alloy. They are widely used as hard tissue replacements in artificial bones, joints and dental implants. As a hard tissue replacement, the low elastic modulus of titanium and its alloys is generally viewed as a biomechanical advantage because the smaller elastic modulus can result in smaller stress shielding.Other property that makes titanium and its alloys the most promising biomaterials for implants is that titanium-based materials in general rely on the formation of an extremely thin, adherent, protective titanium oxide film. The presence of this oxide film that forms spontaneously in the passivation or repassivation process is a major criterion for the excellent biocompatibility and corrosion resistance of titanium and its alloys.The fundamental drawback of titanium and its alloys which limits wider use of these materials include their poor fretting fatigue resistance and poor tribological properties , because of its low hardness. Their poor tribological behavior is characterized by high coefficient of friction, severe adhesive wear with a strong tendency to seizing and low abrasion resistance. Titanium tends to undergo severe wear when it is rubbed between itself or between other materials. Titanium has tendency for moving or sliding parts to gall and eventually seize all metals and alloys are subjected to corrosion when in contact with body fluid as the body environment is very aggressive owing to the presence of chloride ions and proteins. A variety of chemical reactions occur on the surface of a surgically implanted alloy. The metallic components of the alloy are oxidized to their ionic forms and dissolved oxygen is reduced to hydroxide ions. (**Virginia Sáenz de Viteri and Elena Fuentes, 2013).**

1-1–2-2-implant design

Implant design refers to the three-dimensional structure of an implantwith all the components and features that characterize it. It has been reported that the implant design is a vital parameter for attaining primary stability Studies have demonstrated a relationship between implant design and osseointegration. Tapered implants were later introduced to enhance aesthetics and assist implant placement between adjacent natural teeth. The hypothesis behind using tapered implants was to provide a degree of compression of the cortical bone in an implant site with inadequate bone Cylindrical wide body implants increase the risk of labial bone perforation especially in thin alveolar ridges due to presence of buccal concavities, whereas the decrease in diameter of the tapered implants toward the apical region accommodates for the labial concavity. However, according to Chong et al. , if bone quality and quantity are optimal, then they may Implant surface characteristics and diameter have also been shown to influence primary stability. Rough implant surfaces present a larger surface area and allow a firmer mechanical link to the surrounding tissues. In vitro studies. have shown that sandblasted implant surfaces promote peri-implant osteogenesis by enhancing the growth and metabolic activity of osteoblasts. Studies have shown that surface topography and roughness positively influence the healing process by promoting favorable cellular responses and cell surface interactions.

It has been claimed that the introduction of microthreads or “retention grooves” at the neck of the implant may assist in reducing distributing stress and reducing the extent of bone loss following the implant installation. (**Fawad Javed., et al).**

1-1-2-3-surface morphology

Doubts exist about the optimal procedure for obtaining the best biological response to dental implants. When the importance the implant surface properties have for osseointegration is analyzed, one should separate the influence of implant design and the morphology of surface.Analysis of implant design involves dimensions (length, diameter and wall thickness), shape (cylindrical, conical and hybrid), screw thread type (triangular, squared, trapezoidal, rounded, microscrew and grooved), paths of screw threads, angle of screw threads and type of prosthesis connection (e.g., external hexagonal, internal hexagonal connection, Morse cone and star grip). Some of those parameters influence on the insertion force, primary stability and mechanical strength of the implant **(Dos Santos et al,2009).** With regard to the surface morphology, one should analyze the macro-, micro-, and nano-structures, as well as the surface homogeneity, chemical and physical properties, type of oxide and its crystal structure.

1-1-2-4-status of the bone

The significance of bone density and its association with implantdentistry has existed for more than two decades. Bone quality is often referred to as the amount (and their topographic relationship) of cortical and cancellous bone in which the recipient site is drilled. A poor bone quantity and quality have been indicated as the main risk factors for implant failure as it may be associated with excessive bone resorption and impairment in the healing process compared with higher density bone [Jaffin RA, Berman CLand and Herrmann I, Lekholm U, Holm S, Kultje C.]Clinical studies have reported dental implants in the mandible to have higher survival rates compared to those in the maxilla, especially for the posterior maxilla. In the posterior maxilla, there is commonly thinner cortical bone combined with thicker trabecular bone compared to the mandible. (**Turkyilmaz et al).** reported the bone quality around the implant to be superior in the mandible compared to the maxilla. Results by (**Miyamoto et al).** demonstrated that dental implant stability is positively associated with the thickness of cortical bone thickness. In contrast to the previous studies, additional studies in the posterior mandible showed high failure rates due to the poor bone quality as well as other additional factors.. surgical techniques, such as bone condensing, undersizing the osteotomy, improve the bone density and increase the primary (mechanical) stability. **(Fawad Javed., et al)** Misch Bone Density Classification (**Misch CE et al,1999)**

D1: Dense cortical bone.

D2: Thick dense to porous cortical bone on crest & coarse trabecular bone within.

D3: Thin porous cortical bone on the crest and fine trabecular bone within.

D4: Fine trabecular bone

D5: Immature, non-mineralized bone.

Studies of the Branemark System over the last 20 years have shown a 10% higher implant failure rate in soft maxillary bone in comparison to the dense bone of the mandible. (**Rasmussen et al,1992).**

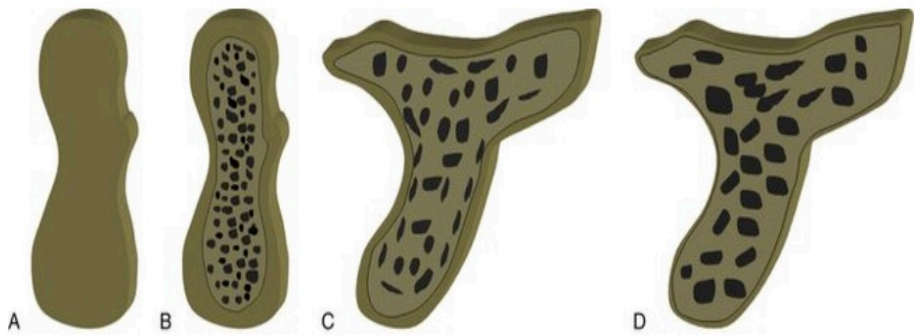

Figure 2: Diagrammatic presentation of the four bone density types described by Carl E Misch. (A) D1 bone is dense cortical bone and is the highest in the density, (B) D2 bone is coarse trabecular bone surrounded by thick porous cortical bone, (C) D3 bone is fine trabecular bone surrounded by thin porous cortical bone, and (D) D4 bone is fine trabecular bone with almost no cortical bone.

1-1-2-5-surgical technique

Minimal tissue violence at surgery is essential for osseointegration. This objective depends on continuous and careful cooling while surgical drilling is performed at low speed.If too violent a surgical technique is used, frictional heat will cause a temperature rise in the bone and the cells that should be responsible for bone repair will be destroyed. However, the critical time/temperature relationship for bone tissue necrosis is around 47 °C applied for 1 min.

1-1-2-6implant loading conditions

The primary factor for success at the time of placement is achieving primary stability. Any micromotion during initial phases of bone healing will cause a lack of integration. Failure is most often caused by overloading due to transmucosal forces of removable appliance over the implant site.

Any attempt to keep a patient functioning with fixed provisional restoration during the healing phases of treatment, will allow for easier patient management.If immediate loading at the time of final definitive implant placement is to be considered, not only should the initial stability be extremely tight, but control of the occlusion on the provisional interim restoration must be adjusted and monitored carefully through the initial healing period**.(S. Parithimarkalaignan and T. V. Padmanabhan)**

1-1-2-7-implant Bed

Implant bed a healthy implant host site is required. However, in the clinical reality; the host bed may have suffered from previous irradiation and osteoporosis, to mention some undesirable states for implantation. Previous irradiation need not be an absolute contraindication for the insertion of oral implants. However, it is preferable that some delay is allowed before an implant is inserted into a previously irradiated bed.

Furthermore, some 10–15 % poorer clinical results must be anticipated after a therapeutically dose of irradiation. Because of vascular damage, at least in part. One attempt to increase the healing conditions in a previously irradiated bed is by using hyperbaric oxygen, as a low oxygen tension definitely has negative effects on tissue repair. Smoking has been reported to yield significantly lower success rates with oral implants. The mechanism behind this lowered success is unknown, but vasoconstriction may play a role. Other common clinical host bed problems involve osteoporosis and resorbed alveolar ridges. Such clinical states may constitute an indication for ridge augmentation with bone grafts. In jaws with insufficient bone volume for implant installation, a grafting technique has been recommended in order to increase the amount of hard tissues. To create more alveolar bone without grafting, a new surgical technique was tested, relying on the biologic principle of guided tissue regeneration. It is of great value in situations with insufficient alveolar bone volume.

1-1-3-Enhancement of osseointegration

Several techniques to enhance the implant surface have been proposed to improve the success rate of oral rehabilitation with osseointegrated implants **(Elias CN et al, 2008).**

However, osseointegration in many cases can occur between 3-6 months But to shorter this healing period roughness and coating technique can made on dental implant **(Cochran et al., 2002)** , Initially, one could expect that increasing the surface area of the implant should result in more sites for cell attachment, facilitating tissue growth and improving mechanical stability. However, this is not a general rule and may vary depending on the cell type. Fibroblasts avoid rough surfaces and accumulate on smooth ones. On the other hand, macrophages exhibit rugophilia, that is, they prefer rough surfaces, whereas epithelial cells are more attracted to rough surfaces than to smooth ones. Osteoblastic cells adhere to rough surfaces more easily, a finding also observed in commercially available implants with chemically treated surfaces (**Thull R et al,2002)(Leduc P et al,2006)**.Chemical composition of the surface has an influence on the secondary stability and reactivity of the implant. Schneider et al. reported the effect of surface chemistry on the cell behavior of osteoblasts using a variety of cell cultures and animal models (**Schneider GB et al,2004)**.Recently, many works have been carried out on surface treated commercial titanium implants to enhance the osseointegration function By increasing the surface roughness, an increase in the osseointegration rate and the biomechanical fixation of titanium implants have been observed. The implant modifications can be achieved either by additive or subtractive methods. The additive methods employed the treatment in which other materials are added to the surface, either superficial or integrated, categorized into coating and impregnation, respectively. While impregnation implies that the material/chemical agent is fully integrated into the titanium core, such as calcium phosphate crystals within TiO_2 layer or incorporation of fluoride ions to surface, the coating on the other hand is addition of material/agent of various thicknesses superficially on the surface of core material. The coating techniques can include titanium plasma spraying (TPS), plasma sprayed hydroxyapatite (HA) coating, alumina coating, and biomimetic calcium phosphate (CaP) coating.(**Seunghan Oh,2015).**

1-1-3-1-Modification of Microtopography (mechanical surface treatment)

Microtopography is linked to microroughness on a micrometer scale (1–100 μm) and is modified by manufacturing techniques like machining, acid-etching, anodization, sandblasting, grit-blasting, and different coating procedures. Commonly used scientific parameters to describe the surface roughness are the 2-dimensional (profile roughness average) and the 3-dimensional (area roughness average).The majority of dental implants on the market have a moderate rough surface of 1-2 μm. According to Albrektsson and Wennerberg , by this range seems to provide an optimal degree of roughness to promote osseointegration. Pits, grooves, and protrusions characterize the microtopography and set the stage for biological responses at the bone-to-implant interface. The modifications of microtopography contribute to an increase in surface area. **(Shinji Kuroda.,2016).**

1-1-3-1-1-Plasma spray treatment

A titanium plasma-spraying (TPS) method has been used for producing rough implant surfaces (Fig.3) This method consists in injecting titanium powders into a plasma torch at high temperature. The titanium particles are projected on to the surface of the implants where they condense and fuse together, forming a film about 30m thick. The thickness must reach 40–50 m to be uniform. The resulting TPS coat- ing has an average roughness of around 7 m, which increases the surface area of the implant. It has been shown that this three-dimensional topography increased the tensile strength at the bone/implant interface. In this pre-clinical study using minipigs, the bone/implant interface formed faster with a TPS surface than with smooth surface implants presenting an average roughness of 0.2 m. However, particles of titanium have sometimes been found in the bone adjacent to these implants. The presence of metallic wear particles from endosseous implants in the liver, spleen, small aggregates of macrophages and even in the para-aortic lymph nodes have also been reported. Metal ions released from implants may be the product of dissolution, fretting and wear, and may be a source of concern due to their potentially harmful local and systemic carcinogenic effects. However, the local and systemic adverse effects of the release of titanium ions have not been universally recognized. In a clinical study comparing SLA and TPS implant surfaces, no clinical difference was observed between these two surfaces. In a pre-clinical model, the percentage of bone/implant contact was found to be inferior for the TPS surface than for plasma-sprayed hydroxyapatite-coated implants. Nowadays, there is a consensus on the clinical advantages of implanting moderately rough surfaced implants (in the micrometric range) rather than using rough plasma-sprayed implant surfaces. **(Pierre Layrolle et al, 2007).**

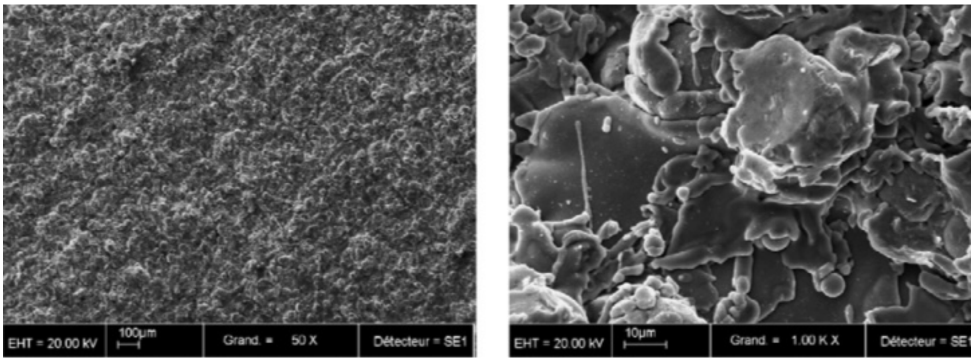

Figure 3: SEM micrographs of a titanium plasma-sprayed (TPS) surface (Courtesy of Cam Implants BV, The Netherlands).

1-1-3-1-2-Laser ablasion

The process of selectively remove material fromsurface of dental implant by irradiating it with laser ablastion the main problem of surface treatment is the contamination of the surface during the roughening procedure. Using laser techniques for roughening the implants surface, contamination is avoided, because the laser enables implant surface treatment without direct contact, and an easier control of the micro-topography is achieved.

Laser irradiation has here been demonstrated to be a suitable, clean and easy method to improve bon response. A tendency to more bone formation was found for the laser treated implants compared t control implants. It can be due to the formation of TiN on the surface that improves biocompatibility. (**M Marticorena 2007,et al).**

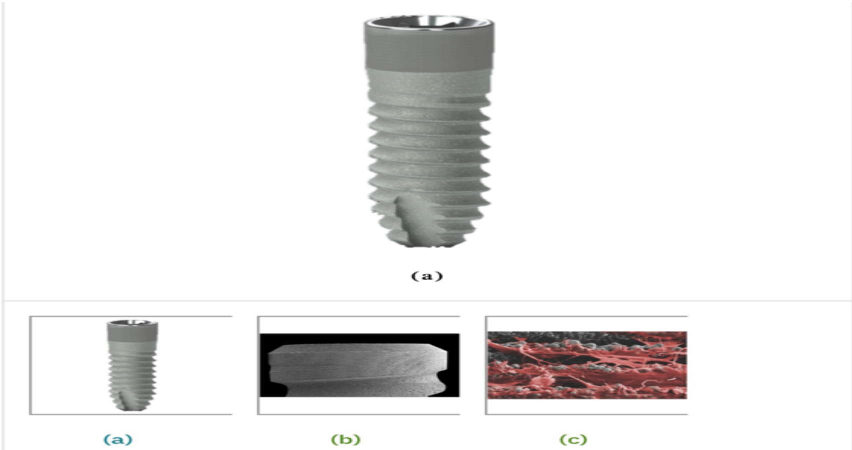

Figure 4: Laser-Lok implant (BioHorizons, Birmingham, AL, USA).

A pattern of microchannels around the implant collar (b) is created by laser ablation. These cell-sized microchannels have been shown to act as a biological seal around the implant by fostering the attachment of connective tissue (c). Courtesy of BioHorizons IPH Inc.

1-1-3-1-3-Acid Etching

In acid etching, the use of acids on metal surfaces is not only to clean the surface but also to modify the roughness. A strong acid like hydrofluoric (HF), nitric (HNO3), and sulphuric (H2SO4) or a combination of these acids is commonly used in this technique. Acid etched surfaces had increased cell adhesion and bone formation, thus enhancing the Mosseointegration **[J. I. Rosales-Leal, et al 2010].** Due to its dissolution ability HF has been used for etching restorative ceramic materials in order to increase the bonding surface for luting agents. The significance of this technique also renders the substrate with homogeneous roughening regardless of the sizes and shapes **[C. Y. Guo, et al 2012].** The roughness of titanium is one of the of the factors that helps in determining the stability of bone formation and resorption at the interface of bone implants. Alla et al. reported that a nanotopography that allows bone ingrowth via acid etching on an implant may improve the roughness. Previous study has reported that the rate of etching depends on the type and concentration of the acid us, However, the suitability of these acids in etching was not determined as they required further tests particularly on the bone implant contact and torque removal. Titanium samples etched by H_2SO_4 with differentconcentrations demonstrated an increase in surface roughness **(Y. Iwaya,et al 2008).**

Concentrated H_2SO_4 has been proven as an effective solution to roughen the surfaces particularly for biological applications.

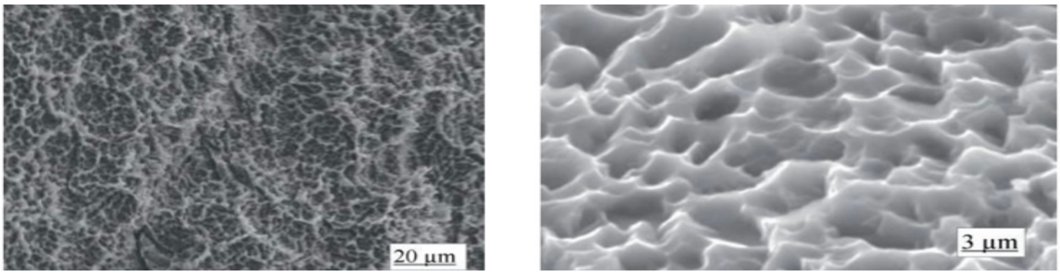

Figure 5: Typical dental implant surface morphologies with acid etching treatment

1-1-3-1-4-Blasting ceramic particles

Another approach for roughening the Titanium surface consists in blasting (also called grit-blasting or sand- blasting) the implants with hard ceramic particles. The highly roughened implants have been shown to favor mechanical anchorage and primary fixation to bone. The abrasive ceramic particles are projected against the target material under high pressure. Thus, for the blasting of biomedical materials, the particles should be chemically stable, biocompatible, and should not hamper the osseointegration of the Titanium implants. Usually, Alumina (Al_2O_3), Titania (TiO_2), or hydroxyapatite particles are applied for blasting treatments. The desired roughness can be set up by the particle size.

1. Alumina is frequently used as a blasting material and produces surface roughness varying with the granulometry of the blasting media. However, the blasting material is often embedded into the implant surface and residue remains even after ultrasonic cleaning, acid passivation, and sterilization. Alumina is insoluble in acid and is thus hard to remove from

the Titanium surface. In some cases, these particles have been released into the surrounding tissues and have interfered with the osseointegration of the implants. Moreover, this chemical heterogeneity of the implant surface may decrease the excellent corrosion resistance of Titanium in a physiological environment.

2. Titanium oxide is also used for blasting Titanium dental implants. An experimental study using microimplants in humans has shown a significant improvement for bone-to- implant contact (BIC) for the TiO2 blasted in comparison with machined surface implants. Other experimental studies confirmed the increase in BIC for Titanium-blasted surfaces. Furthermore, some authors have reported high clinical success rates for Titanium-blasted implants, up to 10 years after implantation. Comparative clinical studies gave higher marginal bone levels and survival rates for TiO2-blasted implants than for turned implants.

Other studies have shown that the torque force increased with the surface roughness of the implants while comparable values in bone apposition were observed, thus corroborating that roughening increases the mechanical fixation of Titanium dental implants to bone.

3. A third possibility for roughening Titanium dental implants consists in using a biocompatible, osteoconductive, and resorbable blasting material. Calcium phosphates such as hydroxyapatite, ß-tricalcium phosphate, and mixtures have been considered useful blasting materials. These materials are resorbable, leading to a clean, textured, pure Titanium surface. Experimental studies have demonstrated a higher bone-to-implant contact with these surfaces, when compared to machined surfaces and a BIC contact similar to that observed with other blasting surfaces when osseointegration is achieved.

Sub-micro and nano-porous surfaces, preferred to highly roughened one, can be produced by Etching and Anodization. These surfaces promote protein adsorbtion, osteoblastic cell adhesion, and the rate of bone tissue healing in the peri-implant region. (**Askeland DRP et al,2006)**

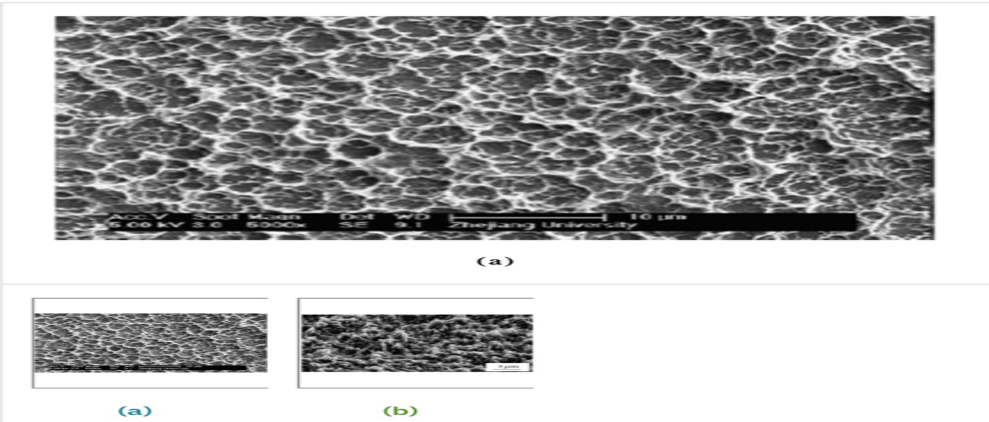

Figure 6: The surface morphology of (a) sandblasted and treated Ti6Al4V alloy implants with DAE (HCl and H2SO4) [57] and (b) sandblasted and etched Ti implant with warm HCl.

1-1-3-2-coating surface treatment

1-1-3-2-1-hydroxyapatite coating material

HA is one of the most biocompatible material ,HA enhance bone healing adjacent to the implant and a popular surface modification on dental implants. HA coatings have the advantage of increasing surface area, decreasing corrosion rates, and accelerating bone formation via faster osteoblast differentiation. Other advantages of HA include the more organized bone pattern and higher degree of mineralization at the interface, as well as increased bone penetration (which improves fixation). The bone bonding capabilities of HA make ita very desirable surface and probably the most reliable surface up to date. Due to their brittle nature,HA and fluorapatite cannot be used as implants in load-bearing applications. Therefore, load-bearing implants have been coated with HA and fluorapatite. The objectives of employing apatitic coatings are to cause an earlier stabilization of the implants in the surrounding bone and to eliminate the use of polymethylmethacrylate bone cement around hip prostheses.Numerous methods of depositing HA on metallic implants have been reported. The current deposition process for commercial dental and orthopedic implants is plasma spraying or arc plasma spraying. Plasma spraying of HA usually takes place under normal atmospheric conditions, as opposed to the plasma spraying of some metallic powders during which a vacuum or an inert atmosphere is used to minimize oxidation. It has been reported that plasma spraying of HA results in coatings with a thickness greater than 30 µm. This is a thermal spraying process that utilizes a gas stream to carry HA powders, which are then passed through an electrical plasma produced by a low-voltage, high-current electrical discharge. The composition of the carrier gas may be pure argon or a hotter plasma that is produced by a small addition of hydrogen or other gases. With all other coating parameters remaining unchanged, a gas composition of 90% argon and 10% hydrogen results in a significantly hotter plasma than the use of 100% argon. The semi-molten HA powders are sprayed onto the titanium substrate, where they solidify. Advantages of plasma spraying include a rapid deposition rate and sufficiently low cost.63 However, problems cited with the plasma-sprayed coatings include variation in bond strength between the coatings and the metallic substrates, alterations in HA structure due to the coating process, and poor adhesion between the coatings and metallic substrates. As in the case of the adhesion between the plasma-sprayed coatings and the metallic substrates, the nature of the substrate plays an important role. The bonding of the plasma-sprayed HA coatings appears to be entirely mechanical in nature. Evidence has been presented that a highly roughed substrate surface exhibits a higher bond strength when compared with a smooth substrate surface. (**Joo L Ong and Daniel Chan,2000).**

1-1-3-2-2-Carbon coatings:

carbon coatings as a type of implant coating material.Thin car bon film with a chemical composition of Ti0.500.3C0.2 has been used to coat Ti implants.[1]5,16 Carbon-coated implants were reported to give a good and stable chemical inertia between the carbon coating and the etching agent used. The carbon coatings were also found to be hemocompatible, histocompatible, bio stable, and chemically stable in vitro and in vivo. The corrosion resistance of the carbon coating could be

improved by plasma immersion ion implantation and deposition or by direct carbon bonding. The surface properties together with the biologic properties were found to be improved by carbon plasma immersion ion implantation and deposition.**[Oshida Y, et al**]The direct carbon bonding actually allows for osteoblast adhesion and proliferation at the surface of the nickel-titanium (NiTi) shape memory alloy.[1]8 Even though this seems to be a promising form of implant coating, not much long-term data could be found and most studies focused on other more innovative materials.

1-1-3-2-3- Bioactive glass and bioactive ceramics.

Bioactive glasses and ceramics also have been proposed as good, innovative surface coatings for dental implants due to their glass properties, which would help obtain better implant osseointegration and reduced prosthetic corrosion in the body fluids.The thermal expansion coefficients of the bioactive glass es and ceramics are usually much larger than those of Ti oxide. This thermal expansion can be reducedby increasing the silicon dioxide (SiO_2) content of the bioglass. On the other hand if the SiO_2 content is increased the bioactivity of the glass coating is reduced significantly. The main disadvantage of these coatings is the limitation of use in load-bearing areas. Bioactive glass is actually a family of glass compositions that allow bonding to the peri-implant tissues within a short span of time. In a recent study, a reactive plasma spray bioactive glass coating was used to demonstrate the behavior of this type of surface coat ing in load-bearing situations. It was concluded that a coating material can only be considered functional if it satisfies the following two criteria:

(1) Able to with stand the load-bearing forces imposed on them while

(2) Maintaining a strong bond with the implant surface to be totally functional. In vitro results showed that the bioactive glass satisfied both criteria even after a couple of months of load-bearing analyses. It was also demonstrated that the silicate glasses have to have a weight percentage higher than 60% so as to be able to withstand corrosion and thermal expansion of the coating. 9 Silica contents above 60% weight would delaminate and crack. This can be circumvented by partial substitutions of calcium oxide (CaO) by magnesium oxide (MgO) and Na_2O by potassium oxide (K_2O) in the bioglass composition to match the thermal expansion between the coatings and that of Ti-based alloys [Lobez - estbana S et al,2003] bioactive glasses were applied as a coating on Ti dental implants by an enameling technique with HA coatings acting as a control. Overall results showed that the bioactive glass coatings were as equally successful as HA coatings in achieving osseointegration and bioactivity.**(Maria xuereb, etal.,2015).**

1-1-3-3-Technique of coating

3-3-1- plasma spattering technique:

Plasma-spraying. This is the most widely used technique for the commercial application of HA coatings to prosthetic implants. Even though it is the most widely used technique due to the tight adhesion between the implant surface and the coating, studies have shown that the coating is prone to adhesion failure and cracking.Others have evaluated the elevated temperatures required during the coating process, which can cause detrimental effects on the prosthesis, including an alteration in the crystalline structure, the formation of a highly crystalline HA surface, and an eventual debonding of the coating." Plasma sprayed HA coating, which results in a minimal phase decomposition and high crystallinity without affecting the adhesive bond strength of the coating material, has been proposed. It was also found that disintegration of the surface coating occurred; this was mainly due to the excessive dissolution of the HA layer with amorphous Ca,(PO4)2 formation and cracking of the coating. The modulus of elasticity, stress, and strain; bonding strength; and microstructural analysis of such a coated implant were investigated in the presence of Hank's salt solution and also without being immersed in solution. It was concluded that all of the factors investigated deteriorated on insertion into the solution. This was mainly caused by the degraded co- hesive bonding in the coating material due to an in creased porosity. From this, one may conclude that even though HA gives a promising bond with the Ti implant, the long-term properties of the material can alter from the initial ideal bonding to the eventual degradation of the cohesion.(**Nikolia.etal.,2015).**

3-3-2-Hydrocoating techniques:

This is another way to coat Ti implants with an HA layer. Several hydro coating techniques have been proposed. These in clude cathode electrolysis, electrophoresis, and the thermal substrate technique. Because the latter two are single-step coating techniques, the HA is applied directly to the surface from solution. Hydroprocessing is used to coat complex-shaped substrates. This is used in such cases where high temperatures cannot be used but at the same time the collagen content and mass has to be studied closely.(**Jossete camilleri.etal.,2015).**

3-3-3-Nanoscale technology:

In a study by Jiang et al, 51 HA particles were charged as they were expelled from a powder spray gun while being exposed to an electrostatic field. The latter guided the charged particles toward the Ti to form a uniform coating. The coated Ti was then sintered in a microwave furnace. Nanoscale technology was found to give several benefits, include ing improved adhesion with decreased chances of delamination, increased surface areas for osseointegration, and improved implant-tissue integration to gether with a resulting chemistry mimicking that of natural osseous tissue.This showed that this inno vative technology can overcome the problems arising with other mentioned coating methods, thus improv ing the properties of the prosthesis.(**Attard.etal.,2015).**

3-3-4-Two process stage technique:

Two-stage process. This process involves micro arc oxidation of Ti forming Ti films followed by UV light illumination of the films in simulated body fluids. This technique was then further developed and im-proved into the sol-gel technique.4[9] This more innovative method resulted in a coating having a good homogenous composition, low crystallization temperature, and fine grain size.49,50 HA and fluor-HA films were deposited on a Ti substrate using the sol-gel technique. Various fluoride concentrations were in corporated into the HA structure during the sol phase preparation. The coating rate of dissolution decreased with increasing fluoride concentrations. As expected, pure Ti implants gave less expression levels when compared to the activity present between the alkaline phosphatase and the apatite coatings.

4- Failure of osseointegration

Osseointegration may be failed due infection or over loading of implant. In case of infection, Infections within 3 months are considered as early postoperative infection, while delayed (or subacute) infection occurs after 3–24 months and late infection more than 24 months later (**Montanaro et al., 2011; Zimmerli, 2014).** Early infection is usually caused by pathogens such as Staphylococcus aureus at the surgical site (**Trampuz and Widmer, 2006**). After operation, patients need systemic antibiotic treatment to prevent infections, but the rising antibiotic resistance of bacteria can make the existing antibiotics noneffective **(Park et al., 2019).** Also, the concentration of antibiotics in the focus site is insufficient, resulting in the rapid proliferation and secretion of extracellular polymers to form a biofilm after some pathogens gather and adhere to the implant surface **(Gristina and Costerton, 1985**). Exopolysaccharides of the biofilm can hinder and delay the penetration of antibiotics, and the quorum sensing of bacteria in the biofilm regulates the development of the biofilm to resist the host immune defense, thus making the biofilm a barrier to antibiotics **(Kaestner, 2016).** Therefore, the ideal antibacterial coating is supposed to remove or kill the pathogens once the primary contact occurs, thus preventing the formation of the biofilm. In case of over loading ,Numerous studies have all concluded that the strength of an osseointegrated implant is far greater than that of a fibrous encapsulated implant. Also, the strength of the interface between bone and implant increases soon after implant placement (0–12 weeks). This strength may in fact be related to the amount of bone surrounding the implant surfaces. Other factor that may affect the strength of the interface is biophysical stimulation and time allowed for healing. Studies have shown that measurable increases in bone implant interactions take place for at least 3 years. Revised criteria for implant success **(Gross KA et al, 1997).**

1. Individual unattached implant is immobile when tested clinically.
2. No evidence of peri implant radiolucency is present as assessed on an undistorted radiograph.
3. Mean vertical bone loss is less than 0.2 mm after 1st year of service.
4. No persistent pain, discomfort or infection.
5. A success rate of 85% at the end of a 5-year observation period and 80% at the end of a 10-year period are minimum levels of success.

Conclusion

I.Osseointegration" is a multifactorial entity. It is because of the attention to training, research & clinical studies that osseointegration has now become an accepted part of the treatment regime in many countries worldwide and no longer regarded as the last resort when all else has failed but often as a treatment of choice.

II. Various processes exist to treat the surface of commercially available implants. Most of these surfaces have been analyzed by in vivo and in vitro studies, showing high clinical success rates. However, the methodologies used to prepare these surfaces are mostly empirical, requiring a great number of assays. Moreover, the tests are not standardized and this makes it difficult to compare the results.

III. The dental implant surface treatment influences the way cells adhere to the surface, which influences differentiation, proliferation and formation of extracellular matrix

IV. Topographic characteristics, roughness, energy and chemical composition modify
cell growth and change cell function at the initial stages of osseointegration.

V. Further studies are needed to improve and describe the interaction between cells and implant surfaces, as well as to assess the influence of different parameters involved, such as proteins, bone formation stimuli and individual therapy, for compromised
patients.

References

A

Albrektsson T, Brånemark PI, Hansson HA, Lindstrom J. (1981) Osseointegrated titanium implants. Requirements for ensuring a long-lasting, direct bone-to- implant anchorage in man. Acta Orthop. Scand. 52(2), 155–170.

Anselme K, Bigerelle M. (2005) Topography effects of pure titanium substrates on human osteoblast long-term adhesion. Acta Biomater. 1(2), 211–222.

A. B. Novaes Jr., S. L. S. de Souza, R. R. M. de Barros, K. K. Y. Pereira, G. Iezzi, and A. Piattelli, "Influence of implant surfaces on osseointegration," Brazilian Dental Journal, vol. 21, no. 6, pp. 471–481, 2010.

Albrektsson, T.; Sennerby, L. State of the art in oral implants. J. Clin. Periodontol. 1991, 18, 474–481.

B

Brånemark, R. Adell, U. Breine, B. O. Hansson, J. Lindström, and A. Ohlsson, "Intra-osseous anchorage of dental prostheses: I. Experimental studies," Scandinavian Journal of Plastic and Reconstructive Surgery, vol. 3, no. 2, pp. 81–100, 1969.

Brånemark, R. Adell, T. Albrektsson, U. Lekholm, S. Lundkvist, and B. Rockler, "Osseointegrated titanium fixtures in the treatment of edentulousness," Biomaterials, vol. 4, no. 1, pp. 25–28, 1983.

Brånemark PI, Zarb GA, Albrektsson T. (1985), Tissue-integrated prostheses: Osseointegration in clinical dentistry. Quintessence, Chicago, IL, USA.

Buser D, Broggini N, Wieland M et al(2004), Enhanced bone apposition to a chemically modified SLA titanium surface. J. Dent. Res. 83(7), 529–533.

Beer A, Gahleitner A, Holm A, Tschabitscher M, Homolka P. Correlation of insertion torques with bone mineral density from dental quantitative CT in the mandible. Clin Oral Implants Res. 2003 Oct;14(5):616–620.

C

C. Knabe, F. Klar, R. Fitzner, R. J. Radlanski, and U. Gross, "In vitro investigation of titanium and hydroxyapatite dental implant surfaces using a rat bone marrow stromal cell culture system," Biomaterials, vol. 23, no. 15, pp. 3235–3245, 2002.

C. Y. Guo, A. T. H. Tang, and J. P. Matinlinna, "Insights into surface treatment methods of titanium dental implants," Journal of Adhesion Science and Technology, vol. 26, no. 1–3, pp. 189–205, 2012.

C. Y. Guo, J. P. Matinlinna, and A. T. H. Tang, "Effects of surface charges on dental implants: past, present, and future," International Journal of Biomaterials, vol. 2012, Article ID 381535, 5 pages, 2012.

D

Davies JE. Mechanisms of endosseous integration. Int J Prosthodont. 1998 Sep-Oct;11(5):391–401.

E

Elias CN, Oshida Y, Lima JH, Muller CA. (2008), Relationship between surface properties (roughness, wettability and morphology) of titanium and dental implant removal torque. J. Mech. Behav. Biomed. Mater. 1(3), 234–242. endosseous implants. J Prosthet Dent; 62(5): 567-572.

F

Faeda RS, Tavares HS, Sartori R, Guastaldi AC, Marcantonio E Jr. (2009), Biological performance of chemical hydroxyapatite coating associated with implant surface modification by laser beam: biomechanical study in rabbit tibias. J. Oral Maxillofac. Surg. 67(8), 1706–1715.

H

H. Nakae, M. Yoshida, and M. Yokota, “Effects of roughness pitch of surfaces on their wettability,” Journal of Materials Science, vol. 40, no. 9-10, pp. 2287–2293, 2005.

J

J. I. Rosales-Leal, M. A. Rodríguez-Valverde, G. Mazzaglia et al., “Effect of roughness, wettability and morphology of engineered titanium surfaces on osteoblast-like cell adhesion,” Colloids and Surfaces A: Physicochemical and Engineering Aspects, vol. 365, no. 1–3, pp. 222–229, 2010.

Javed F, Romanos GE. Impact of diabetes mellitus and glycemic control on the osseointegration of dental implants: a systematic literature review. J Periodontol. 2009 Nov;80(11):1719–1730. doi: 10.1902/jop.2009.090283.

Javed F, Almas K. Osseointegration of dental implants in patients undergoing bisphosphonate treatment: a literature review. J Periodontol. 2010 Apr;81(4):479–484. doi: 10.1902/jop.2009.090587.

J. I. Rosales-Leal, M. A. Rodríguez-Valverde, G. Mazzaglia et al., “Effect of roughness, wettability and morphology of engineered titanium surfaces on osteoblast-like cell adhesion,” Colloids and Surfaces A: Physicochemical and Engineering Aspects, vol. 365, no. 1–3, pp. 222–229, 2010.

Junker, R., Dimakis, A., Thoneick, M. &. Jansen, J.A. Effects of implant surface coatings and composition on bone integration: a systematic review. Clinical Oral Implants Research 2009;20 185-206

K

Kim, H.J., Kim, S.H., Kim, M.S., LeeJ, E.J., Oh, H.G., Oh, W.M., et al. Varying Ti-6Al-4V surface roughness induces different early morphologic and molecular responses in MG63 osteoblast-like cells. Journal of Biomedical Materials Research 2005,74A 366-373.

L

L. Ponsonnet, K. Reybier, N. Jaffrezic et al., “Relationship between surface properties (roughness, wettability) of titanium and titanium alloys and cell behaviour,” Materials Science and Engineering C, vol. 23, no. 4, pp. 551–560, 2003.

-L. Le Guéhennec, A. Soueidan, P. Layrolle, and Y. Amouriq, “Surface treatments of titanium dental implants for rapid osseointegration,” Dental Materials, vol. 23, no. 7, pp. 844–854, 2007.

M

M. Esposito, Y. Ardebili, and H. V. Worthington, “Interventions for replacing missing teeth: different types of dental implants,” The Cochrane Database of Systematic Reviews, vol. 7, Article ID CD003815, 2014.

N

N. Goyal and R. K. Priyanka, “Effect of various implant surface treatments on osseointegration—a literature review,” Indian Journal of Dental Sciences, vol. 4, pp. 154–157, 2012.

P

Peñarrocha M, Boronat A, Garcia B. Immediate loading of immediate mandibular implants with a full-arch fixed prosthesis: a preliminary study. J Oral Maxillofac Surg. 2009 Jun;67(6):1286–1293. doi: 10.1016/j.joms.2008.12.024.

R

R. Junker, A. Dimakis, M. Thoneick, and J. A. Jansen, "Effects of implant surface coatings and composition on bone integration: a systematic review," Clinical Oral Implants Research, vol. 20, supplement 4, pp. 185–206, 2009.

Roos, J.; Sennerby, L.; Albrektsson, T. An update on the clinical documentation on currently used bone anchored endosseous oral implants. Dent. Update 1997, 24, 194–200.

Romanos GE. Treatment of advanced periodontal destruction with immediately loaded implants and simultaneous bone augmentation: a case report. J Periodontol. 2003 Feb;74(2):255–261.

Romanos GE, Johansson CB. Immediate loading with complete implant-supported restorations in an edentulous heavy smoker: histologic and histomorphometric analyses. Int J Oral Maxillofac Implants. 2005 Mar-Apr;20(2):282–290.

Romanos GE, Testori T, Degidi M, Piattelli A. Histologic and histomorphometric findings from retrieved, immediately occlusally loaded implants in humans. J Periodontol. 2005 Nov;76(11):1823–1832

Romanos GE. Bone quality and the immediate loading of implants – critical aspects based on literature, research, and clinical experience. Implant Dent. 2009 Jun;18(3):203–209. doi: 10.1097/ID.0b013e3181991248.

S

Stanford, C.M.; Brand, R.A. Toward an understanding of implant occlusion and strain adaptive bone modeling and remodeling. J. Prosth. Dent. 1999, 81, 553–561.

Schwarz F, Ferrari D, Herten M et al. (2007), Effects of surface hydrophilicity and microtopography on early stages of soft and hard tissue integration at non- submerged titanium implants: an immunohistochemical study in dogs. J. Periodontol. 78(11), 2171–2184.

Silva FC, Menezes GC. (2004) Osteoblasts attachment and adhesion: how bone cells fit fibronectin-coated surfaces. Mat. Sci. Eng. C-Bio. S. 24(5), 637–641.

Smith DE, Zarb A, George and Dale. (1989), Criteria for success of osseointegrated

Sul YT, Johansson CB, Jeong Y, Wennerberg A, Albrektsson T. (2002), Resonance frequency and removal torque analysis of implants with turned and anodized surface oxides. Clin. Oral Implants Res. 13(3), 252–259.

Sun L, Berndt CC, Gross KA, Kucuk A. (2001), Material fundamentals and clinical performance of plasma-sprayed hydroxyapatite coatings: a review. J. Biomed. Mater. Res. 58(5), 570–592.

Souza, A. T. P., Bezerra, B. L. S., Oliveira, F. S., Freitas, G. P., Bighetti Trevisan, R. L., Oliveira, P. T., et al. (2018). Effect of Bone Morphogenetic Protein 9 on Osteoblast Differentiation of Cells Grown on Titanium with Nanotopography. J. Cell Biochem. 119 (10), 8441–8449. doi:10.1002/jcb.27060.

Steckbeck, J. D., Deslouches, B., and Montelaro, R. C. (2014). Antimicrobial Peptides: New Drugs for Bad Bugs? Expert Opin. Biol. Ther. 14 (1), 11–14. doi:10.1517/14712598.2013.844227.

Su, K., Tan, L., Liu, X., Cui, Z., Zheng, Y., Li, B., et al. (2020). Rapid Photo-Sonotherapy for Clinical Treatment of Bacterial Infected Bone Implants by Creating Oxygen Deficiency Using Sulfur Doping.

T

T. Kokubo, "Bioactive glass ceramics: properties and applications," Biomaterials, vol. 12, no. 2, pp. 155–163, 1991.

Timperley AJ, Nusem I, Wilson K, Whitehouse SL, Buma P, Crawford RW. (2010), A modified cementing technique using BoneSource to augment fixation of the acetabulum in a sheep model. Acta Orthopaedica;81(4):503-507

V

V. Sollazzo, F. Pezzetti, A. Scarano et al., "Zirconium oxide coating improves implant osseointegration in vivo," Dental Materials, vol. 24, no. 3, pp. 357–361, 2008.

Vlacic-Zischke, J., Hamlet, S.M., Friis, T., Tonetti, M.S. & Ivanovski, S. The influence of surface microroughness and hydrophilicity of titanium on the up-regulation of TGFb/BMP signalling in osteoblasts. Biomaterials 2011;32 665-671.

X

Xu B, Zhang J, Brewer E, Tu Q, Yu L, Tang J, Krebsbach P, Wieland M, Chen J. (2009), Osterix Enhances BMSC associated osseointegration of implants. J Dent Res;88(11):1003- 100

Z

Zarb CA, Albrektsson T. Nature of implant attachments. In: Branemark P-I, Zarb C, Albrektsson T, editors. Tissue-integrated prostheses osseointegration in clinical dentistry. Chicago: Quintessence Publishing Co.; 1985. pp. 88–98.

Zarb GA, Albrektsson T. Osseointegration: a requiem for periodontal ligament? Int J Periodontal Restor Dent. 1991;11:88–91.

Zhao G, Schwartz Z, Wieland M et al. (2005), High surface energy enhances cell response to titanium substrate microstructure. J. Biomed. Mater. Res. A 74(1), 49– 58.

Zollner A, Ganeles J, Korostoff J, Guerra F, Krafft T, Bragger U. Immediate and early non-occlusal loading of Straumann implants with a chemically modified surface (SLActive) in the posterior mandible and maxilla: Interim results from a prospective multicenter randomized-controlled study. Clin. Oral Implants Res.