Universidad Europea

TRABAJO DE FIN DE GRADO

Grado en Odontología

ZIRCONIA IMPLANTS
VS
TITANIUM IMPLANTS

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Número identificativo **150**

RESUMEN

Introducción: Los implantes de titanio están liderando el campo de la implantología durante años, pero están siendo criticados por la aparición de reacciones de hipersensibilidad, toxicidad y posible decoloración gris antiestética. Con la creciente demanda estética de los pacientes y, ocasionalmente, la necesidad de restauraciones no metálica, se cree que la aparición del material cerámico, el circonio, supera estas deficiencias y es de interés como alternativa al titanio.

Objetivos: Revisar las principales características del circonio y del titanio para establecer sus diferencias, indicaciones, contraindicaciones y la posibilidad por el zirconio de ser admitido como material valioso en implantología.

Materiales y métodos: Una búsqueda bibliográfica de artículos en inglés publicados hace menos de 10 años utilizando bases de datos como PubMed y Mendeley. Los artículos se seleccionan según su relevancia científica favoreciendo la metanálisis y la revisión científica. Se utilizaron los siguientes palabras clave: “circonio”, “titanio”, “implante”, “osteointegración”, “biocompatibilidad”,…

Resultados y discusión: Muchos estudios compararon titanio y circonio y permitieron resaltar su diferencia. De hecho, ambos materiales presentan excelentes propiedades mecánicas, fuerte biocompatibilidad y osteointegración. Sin embargo, el titanio destaca por su mejor resistencia en el tiempo y a las fracturas, lo que está avalado por numerosos estudios. Al contrario, los estudios a largo plazo son más escasos con respecto al circonio. Sin embargo, además de sus propiedades físicas, este material destaca por su color natural, su hipo alergénico y su baja afinidad por la placa dental.

Conclusión: Durante años, el titanio fue establecido como material de referencia en implantología, pero cada vez mas, vemos la aparición del circonio para superar sus carencias. Por lo tanto, se utiliza principalmente hoy en día para sectores anteriores en el caso de biotipo delgado e hipersensibilidad al titanio del paciente. Se espera más estudios e investigaciones sobre el desarrollo de implantes de circonio.

ABSTRACT

Introduction: Titanium implants are leading the implantology field for years but are being criticized regarding their onset of hyper sensibility reactions, toxicity, and potential unesthetic grey discoloration. With the increase in esthetic demand from patients and occasionally the need for non-metallic restoration, the emergence of the ceramic material, the zirconium is believed to overcome these defects and is valuable as an alternative to titanium.

Objectives: Review the main characteristics of zirconia and titanium to establish their differences, indications, contraindications, and the possibility for zirconium to be admitted as a valuable material in implantology.

Materials and Methods: A literature search for English articles published less than 10 years ago using database as PubMed and Mendeley. Articles are selected according to their scientific relevance favoring meta-analysis & scientific review. Following keywords were used: “zirconium”, “titanium”, “implant”, “osseointegration”, “biocompatibility”, …

Results and Discussion: Many studies compared titanium and zirconia and allowed to highlight their difference. Indeed, the two materials present excellent mechanical properties, strong biocompatibility, and osseointegration. However, titanium stands out for its better resistance over time and to fractures, which is supported by numerous studies on this subject. On the contrary, long-term studies are scarcer regarding zirconium. However, in addition to its physical properties, this material stands out for its natural color, hypoallergenic, and low affinity for dental plaque.

Conclusion: Over the years, titanium was established as the reference material in implantology, but we are increasingly seeing the emergence of zirconium to overcome its

shortcomings. It is thus mainly used today for anterior sectors in the case of thin biotype and titanium hypersensitivity of the patient. More studies and research are expected to continue the development of zirconium implants.

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I. INTRODUCTION

The absence of one or several teeth can not only trigger some dental problems such as bone resorption, extrusions, or teeth displacements but it can also be the cause of countless functional problems as lack of aesthetics, difficulty in mastication, phonation complications, or speech. Therefore, there is a need for the replacement of missing teeth. (1)

Since the end of the 20th century, implantology in dentistry is in constant development. With the work of Branemark, Titanium has become the leading material used for the replacement of the tooth with an implant. (1)(2) However, despite its very good mechanical and physical properties, Titanium also presents few disadvantages, especially aesthetics and allergenic. But today, the aesthetic demand had increased exponentially, and some new materials are used to fulfill those needs. (2)

Zirconium appears as the material of choice as being already used in dentistry and very appreciated for its good mechanical, physical, and optical properties. Therefore, the development of Zirconium for use in implantology is very interesting in order to improve the aesthetic demand. But is Zirconium a good alternative to Titanium? (2)(3)

1.1 CONCEPT OF AN IMPLANT

1.1.1 Definition of an implant

A dental implant is a prosthetic device used in the treatment of a partial or completely edentulous patients and allowed the replacement of any missing teeth that have been lost or extracted due to periodontal disease, caries, or trauma. (4)They can be the support for crowns that replace a single tooth, bridge for several teeth, and can even be used in support for full denture in an edentulous patient. (5)

In order to replace a tooth, the implant must be manufactured in a biocompatible material that will mimic the natural tooth in its physical and chemical properties without inducing any deleterious reaction or immunological effect from the host. (1) Those materials should present the following criteria: toughness, strength, corrosion resistance, wear, and resistance. (2) Nowadays, thanks to clinical studies and experiences, dental implants are a safe approach to replace missing teeth with a natural outcome. (6)

The dental implants are composed of several elements: the body of the implant with the shape of a screw or cylinder between 4mm and 16mm in length, is the part inserted into the prepared socket in the bone. (4) On top of the body, is attached the abutment part which is forming the connection with the prosthetic element (crown, bridge, dentures,). (4)

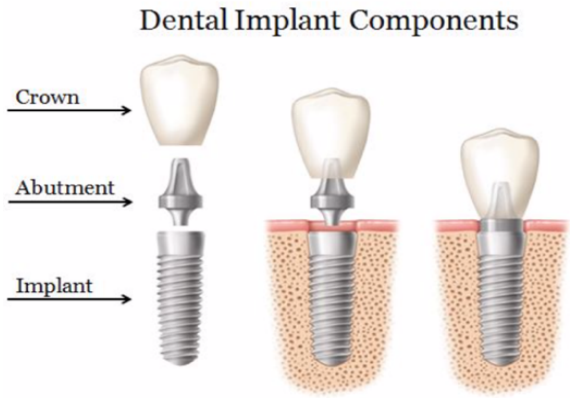

Figure 1: Different part of an implant

From: http://www.southjerseyperiodontics.com/dental-implants.html

Two different systems exist regarding the relation to the abutment and the implant. In the one-piece system, the abutment is the extension of the implant and both parts are one. (6) In the two-piece system, the abutment and the implant are separated and can present two different structures of attachment: first was developed the external hexagonal one. (6)(3) Those types of implants showed screw loosening, so they were generally used for the replacement of splinted numerous pieces in a partially edentulous patient. (4) Therefore, were developed a new interface, the internal hexagonal structure where the mechanism of attachment is used for the replacement of unique implant restoration as it presents better antirotating capacities. (4)

Regarding the shape of an implant, initially were developed cylindrical form with a flat surface but over the years, it becomes more relevant to create a root shape, more conical at the level of the artificial apex to mimic the natural tooth as much as possible. (4)(6) Likewise, the surface has undergone changes and became rough in order to increase the healing process and provide early, primary stability of the implant. (6)

All those modifications in the surface and the shape were developed to increase the physical and mechanical properties of the implant as well as to enhance the biological responses of the tissues. (5)

1.1.2 Development of titanium implants

The titanium implants were introduced by a Swedish orthopedic surgeon, Branemark, who discovered the concept of osseointegration out of serendipity. (1) In 1908 while performing researches about the healing and regeneration process of the bone, Branemark placed titanium into the femur of a rabbit which got ankylosed. (7) Later he described this relation of osseointegration as " a direct structural and functional connection between ordered, living bone, and the surface of a load-carrying implant". (1)(8).

A few decades later, after numerous studies and investigations on animals and humans to perfect this concept of osseointegration between bone and titanium and to prove its stability, Branemark introduced the titanium implant for oral rehabilitation. (8) Over the years, Titanium implants have undergone a lot of modifications regarding their shape, structure, and manufacturing methods in order to improve their mechanical and physical properties. (2) Indeed, the first titanium implant on the market was the CP Ti (commercially pure titanium), and following some researches to improve the material, some titanium alloys were introduced particularly the Ti 6Al 4V. (3)(6) Nowadays concerning the systems, the most commonly used one is the two pieces system with a screwed abutment that presents the better properties and characteristics. (2)(6)

These, combined with the excellent biocompatibility of titanium, make titanium implants the favorite material for dental implants. (2) Quickly, titanium implants became the golden standard in implantology thanks to their remarkable biocompatibility, strength, stability, and survival rate. (6) Nevertheless, the aesthetics remaining its Achilles heel due to the dark color of the metal, new approaches are sought and in particular the "Metal-free implants". (7)

1.1.3 Introduction of ceramics implants

The ceramic implants were developed especially in order to answer the aesthetic problems produced by the greyish color of the titanium implant and for the patients asking for non-metallic restorations as an alternative. (9) Indeed, due to its tooth-like color and good mechanical properties, ceramic implants appeared as an adequate option. (2)

The first ceramic material used for implants was aluminum oxide, however, despite showing great osseointegration capacities, aluminum oxide implants were removed from circulation due to the insufficiency of their mechanical properties as fracture toughness. (9) Another material was afterward introduced based on good mechanical properties, biocompatibility, and aesthetic outcomes, the Zirconium. (9)(10)

Zirconium is the name given to the zirconium dioxide of chemical formula ZrO_2 discovered by a German chemist, Martin Heinrich Klaproth in 1789. In order to be used in dentistry as a ceramic material, it is necessary to separate the impurities by the mean of heat and to obtain a pure zirconium dioxide powder. (10) The material obtained, although being a ceramic material, does not have a vitreous phase, it is polycrystalline, which gives it superior resistance to fracture. (2)

Initially, the zirconium is observed in three crystalline phases (monoclinic, tetragonal, and cubic) depending on the temperature. Indeed, the monoclinic form is predominant and stable at ambient temperature but changes to tetragonal and cubic while increasing temperature, at 1170°. The cubic form is present at a temperature above 2370°C. (3)(9) However, while cooling from tetragonal to monoclinic form, the change in the crystalline structure creates a volume expansion of 4%. This will create micro-fractures when reaching the ambient temperature again which will result in low mechanical strength. (9)(6)

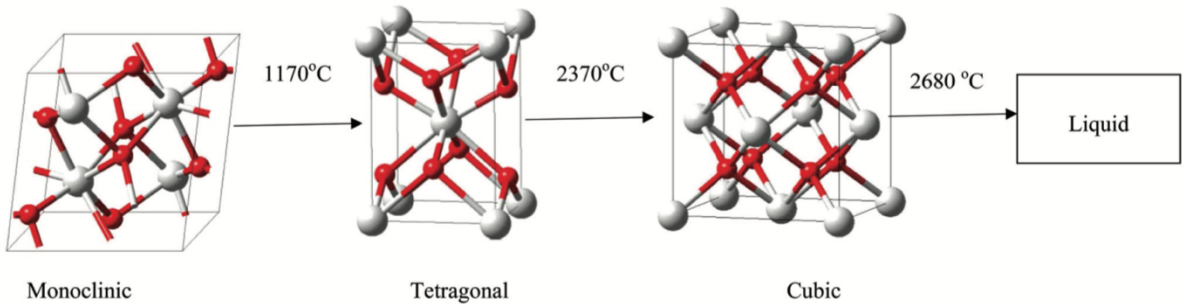

Figure 2: Transition phase of Zirconium

From: Gautam C, Joyner J, Gautam A, Rao J, Vajtai R. Zirconia based dental ceramics: structure, mechanical properties, biocompatibility and applications. Dalton Trans. 2016 Dec;45(48):19194–215.

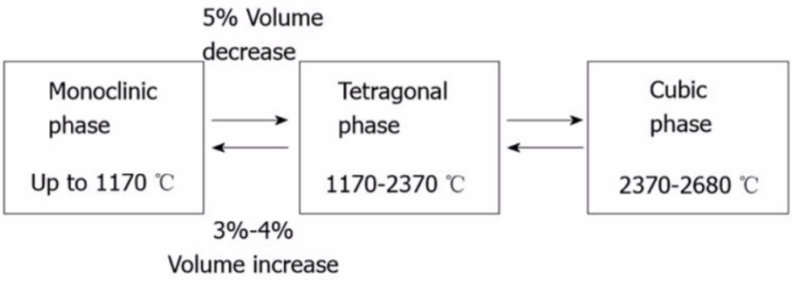

Figure 3: Transformation phase of Zirconium according to temperature (3)(9)

Therefore, Zirconium has been the subject of much researches in order to obtain a stable form in which the mechanical and physical capacities are optimal. (9) Various stabilizing agents are used to avoid this phenomenon and steady the tetragonal or cubic phase. Among them, magnesia (MgO), Limestone (CaO), or Yttria (Y_2O_3) are the most common. (7)(2)

In 1977, the Y-TZP (Yttria Stabilized Tetragonal Zirconia Polycrystalline) became the most promising material. Indeed, due to a phenomenon called phase transformation toughening, the Y-TZP presents a remarkable resistance to fracture compared to other ceramic materials. (3) It consists of the material ability, when subjects to stress or energetic input, to adopt a tetragonal structure at ambient temperature and therefore to increase its volume. This capacity of volume compression decreases the propagation of the fracture and gives Y-TZP a high resistance. (2)(9)

Nevertheless, regarding the fracture strength, the Y-TZP presents the disadvantage of having a low temperature degradation, also called aging. (6) In contact with water, the tetragonal phase is irreversibly slowly turning into the monoclinic phase from the outer surface and proceed inward. (11) The phase transformation toughening is then compromised due to the water penetration which can cause cracks as well as progressive wear of the material, surface deterioration, and a decreased resistance. (6)(9)(2)

Initially used for ball head in artificial hip surgery, Y-TZP quickly turns out to be the most used ceramic material in dentistry and implantology thanks to its aesthetic white aspect and its highest mechanical properties. (3) Currently, the most common ceramic implant on the market is the monobloc one-piece Y-TZP implants but further studies are performed in order to develop a two pieces system of zirconium implant. (2)(6)

1.2 HEALING PATTERN AROUND AN IMPLANT

1.2.1 Bone formation and osseointegration

In order to successfully place an implant, a proper connection and therefore stability in between the implant and the bone is required. The bone is a vascular tissue that allows high capacities of regeneration and remodeling which is in constant modification. (5) This bone tissue can be classified into two types: the trabecular bone (spongy) and the cortical bone (compact). (12) Each different structure appears in specific and distinct locations and will develop a different pattern of the healing process. Indeed, the trabecular bone as being present close to the marrow of the bone is a highly vascularized area with a faster healing pattern than the cortical bone, which is more compact with less vascularization. (12)

The healing process of the peri-implant tissues obeys a three steps process very similar in both cortical and trabecular bone: the osteoinduction phase, the de novo bone phase, and the bone remodeling phase.

- Osteoinduction: while placing an implant, we must first drill a hole into the bone which will induce an injury of the bone tissues and the blood vessels. Therefore, a hematoma or blood clot is produced and will initiate the cellular cascade of peri-implant healing. The blood is mostly composed of erythrocytes and platelets. Those platelets are activating several growth factors that will act as regulators of the healing cascade by stimulating and inducing the proliferation of various bone marrow-derived cells, the osteogenic cells. (12)(13)
- De novo bone: Once migrated on the surface of the implant, the osteogenic cells convert into osteoblasts and will start the bone formation. The osteoblasts are then

creating a bone matrix that will be the starting point of the development of new bone. As the matrix is created by the osteoblasts, the bone will grow by apposition thanks to the polarity of the osteoblasts. (12)

- Bone remodeling: the matrix produced by the osteoblasts starts to mineralize and the de novo bone formation is then followed by the modeling of the peri-implant bone. (12)

The quality of the bone is one of the factors influencing the bone formation and osseointegration. According to the type of bone, the vascularization and therefore the angiogenesis in the new bone will change. (12) Lekholm and Zarb classified the bone density into four classes based on radiographic studies to assess the ratio of compact and trabecular bone. (14) As expressed in figure 4, cortical bone is predominant in class I while the trabecular bone is the main component in class IV. The two types of bone and their characteristics induced the classification of the bone in dentistry with class 1 being predominantly cortical and class 4 being trabecular. (14)

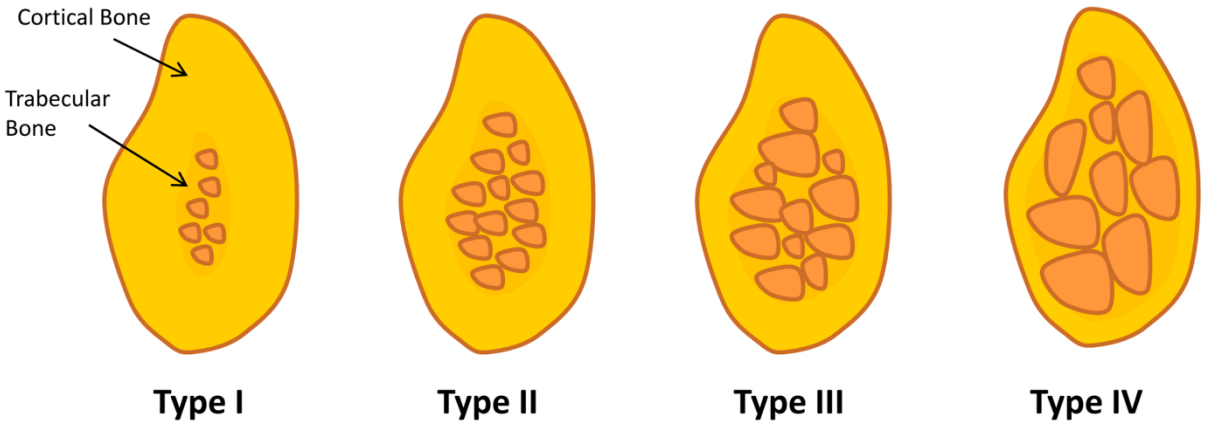

Figure 4: Classification of bone according to its density

From: Warreth A, Ibieyou N, O'Leary R, Cremonese M, Abdulrahim M. Dental implants: An overview. Dent Update. 2017;44:596–620.

Therefore, while placing an implant the type of bone has its importance for the healing pattern as well as the material used for the implant. Indeed, the reaction of the bone is also dependent on the physicochemical properties of the material used. (12)(13)

The osseointegration is a principle discovered while studying titanium. It represents the ability of the material to bond to the bone without cartilaginous or ligamentous tissue in between. (15) The titanium possesses the ability to bond with bone naturally thanks to its high surface energy that allows good angiogenesis, one of the first steps of a suitable bone formation. Other materials, as Zirconium, need surface modifications in order to perform correct osseointegration. The formation of new bone around zirconium is following the same pattern as titanium, by creating a surface favorable to the cellular adhesion thanks to the material properties (wettability, roughness,…). (12) The zirconium is a material presenting adequate bioinert characteristics, good cell adhesion, and biological response. Indeed, some studies on the osteoconductivity of the zirconium explained the close relationship between new bone and the implant surface. (3)(16) A few weeks after the implant placement, a high degree of bone apposition is perceived due to this ability of zirconia to create close contact with the newly formed bone. (2)(9)

The osseointegration is mainly evaluated using the BIC, the bone-implant contact. It is expressed as a percentage that is measured by histomorphology. (16)

1.2.2 Surface modification of an implant

Although zirconium and titanium, both used in dentistry for implants, present good mechanical properties, biocompatibility, and survival rate, it is possible to increase those capacities by modifying the surface of the implant. (3) Indeed, a proper modification technique can improve the interaction between the implant and the bone by increasing the wettability, the osseointegration process and the cell proliferation, and growth around the implant. (3)(13)

Before performing any surface modification, a pre-treatment is required to ensure the absence of any contamination on the surface. Depending on the technique developed below, a different method will be performed: grit blasting before plasma spray, preheat before coating, polishing before acid etching, … (17)

Along with the research, various methods were developed for the surface modification of the implant.

Among these methods, the mains ones are:

- Plasma sprayed coating: due to its low cost and high efficiency, it is the most widely used method. This method makes it possible to create a porous surface while controlling the thickness. The particles of material are heated before being injected into the implant where they will condense and form the coating. The main material used for this technique is hydroxyapatite (HA) due to its capacity to form a strong bond between the bone and the implant thanks to its composition of calcium and phosphate. Nevertheless, hydroxyapatite may present some long-term survival issues

due to its dissolution into the tissues. Titanium is also a possible material for plasma sprayed coating. (8)(13)(17)(18)(19)

- Laser: this method uses a laser in order to melt the material on the surface of the implant causing changes in the microstructure and creating a grooved surface promoting the cells attachment. Then is applied a gas jet to remove the excess material and cool the surface. This technique is very efficient and allows a controlled accuracy and topology of the implant surface creating a regular pattern. It allows better interaction with the bone for healing by enhancing the osteoblasts migration, the proteins adsorption, and the osseointegration. (13)(18)(19)(20)
- Sol-Gel: the sol-gel technique (solution-gelation) is based on the use of a hybrid material to create a coating with a defined microstructure by controlling the annealing temperature. This induces a hydrolytic or polymerization reaction of the material used. This method is easy, inexpensive, and allows the coating of a large complex implant. (13)(20)
- Sandblast and acid etching (SLA): this technique in two steps consists of the sandblasting of the surface of the implant using titanium dioxide or aluminum oxide. As the surface is left rough and irregular after the sandblasting, a chemical erosion using a strong acid like sulfuric acid (H_2SO_4) or hydrochloric acid (HCl) is performed in order to create the micro pit and obtain a more uniform surface. (8)(13)(18)(19)(20)
- UV light treatment: this technique has proved to enhance the healing process in the early stage around the implant. Indeed, the treatment by UV light allows an important increase of the wettability of the surface that turns into an ultra-hydrophilic state. This allows a better interaction between the surface of the implant and the cells and

proteins of the bone and therefore, enhances the healing, cellular migration, and attachment to the implant as well as the bone-implant contact (BIC). (18)(19)

- Machined: the machined implant surface refers to the manufacturing process of the implant that can be then polished or milled. Machined implants show an improvement in the osseointegration as well as a lower inflammation of the tissue and lower bacterial activity. (19)

2 OBJECTIVES

General:

- To realize a bibliographic revue of the main features of Zirconium and Titanium.

Specifics:

- Establish the principal differences between Titanium and Zirconium.
- Determine the indications and contraindications for Titanium and Zirconium.
- Value Zirconium as the possible future replacement of Titanium implant.

3 MATERIALS AND METHODS

In order to develop this study, several tools were used.

The search for articles was performed on databases like PubMed and Mendeley to avoid any non-scientific sources. Were also used, the database of the Universidad Europea de Madrid's library, the Crai Dulce Chacón. Another method was to search the bibliography of previously used articles for relevant analysis, articles, or furthers data.

The articles were selected according to the following criteria:

Criteria for inclusion:

- Recent article (not more than 10 years old)
- Literature review, Clinical trial, Books, Journal, Meta-analysis, …
- Article with title or abstract of valuable content

Criteria for exclusion:

- Articles out of the range 2010-2020
- Articles without the full text available
- Any articles from non-scientific origin
- Articles without a keyword in the title
- Although the appealing title, articles without relevant information for this work

Despite those criteria of inclusion, four articles (12),(21),(22)(23) were used. As being about a concept developed and understood years ago and also be frequently found as one of the first references in many recent articles. It was judged possible to use a more than 10 years old article to help the understanding.

The articles were then organized through the Mendeley Library that was merged with the Word program to facilitate their access and referencing.

The bibliography of this study is then listed in Vancouver style at the end of the document.

The various keywords used for the research in this study were: “implants”, “zirconia implant”, “titanium implants”, “osseointegration”, “implant toxicity”, “properties zirconia implant”, “properties titanium implant”, “healing dental implant”, “surface modification implant”, “evolution dental implant”, “implant biocompatibility”, “dental implant”, …

4 RESULTS

OSSEOINTEGRATION AND SURVIVAL RATE

In implantology, osseointegration has a very important role which allows in particular to judge the success or the failure of the implant. (15) Described by Branemark as " a direct structural and functional connection between ordered, living bone, and the surface of a load-carrying implant" (1)(8), different methods are developed in order to evaluate it. The first and main method we will focus on is histomorphometry, which allows us to define the Bone to Implant Contact (BIC). The BIC is expressed by a percentage, the proportion of the surface of the bone in contact with the surface of the implant. (2)(15)

Many studies have been made to compare the osseointegration of Zirconium and Titanium, these have been analyzed through meta-analysis. For example in their study, Manzano and al (24) compared the values of BIC obtained in 16 studies performed on animals with titanium and zirconium implants. The results show no significant differences between the two materials as a similar quality of osseointegration is observed. This study was performed regardless of any surface modifications on the implant. (24)

Likewise, in their systematic review, Nishihara and al (11) studied 42 preclinical studies in order to compare the BIC of zirconium and titanium implants. They obtained values between 25 to 88% and between 24 to 85% for titanium and zirconium respectively. They also concluded that there were no significant differences, without considering the surface modifications. (11)

Regarding the surface modifications, Pawel and al (15) compared the osseointegration of zirconium implant with different surface modifications to the one of the titanium implant. By comparing the BIC of each type of implant obtained showed in the table below, they conclude for similar osseointegration in between those different implants. (15)

IMPLANTS	Zirconia with blasted surface	Zirconia with etched surface	Zirconia with blasted and etched surface	Zirconia implants	Titanium with sandblast and etched surface
BIC	46 %	61 %	56 %	58 %	64 %

Figure 5: Table of the average of BIC % according to histomorphometry (18)

Regarding the implant osseointegration relative to time, Hoffmann and al (2) compared the osseointegration of zirconium and titanium at two weeks and four weeks. After two weeks, zirconium presents slightly higher osseointegration (54-55%) compared to titanium (42-52%). However, at four weeks, the titanium BIC is higher (68-91%) than the zirconium (62-80%). (2)

Finally, in their meta-analysis, Andreiotelli and al (21) compared various studies regarding the survival rate of the implant. After 21 months of observation, the survival rate of the titanium implant was 98% in the maxilla and 97% in the mandible while the survival rate of the zirconium implant was 84% in the maxilla and 98% in the mandible. (21)

The osseointegration of the implant can also be measured using the Removal Torque (RT) which depends on the biological strength in between the implant and the bone. (11)Nishihara and al, in their studies, obtained an RT from 7 to 74 N for titanium implant and from 9 to 78 N for zirconium implant. Therefore no significant differences were observed. (11)

MECHANICAL AND PHYSICAL PROPERTIES

The physical and mechanical properties of the materials generate a fair amount of studies due to their importance in predicting the material behavior and adapting their uses. (6) Various types of titanium materials can be used in implantology, thereby, only the two main types will be analyzed: Ti (CP Ti) grade 2 and Ti 6Al 4V alloy as well as Y-TZP, the most used ceramic material for implants. (11)

The ceramic material, zirconium, is a very strong material with a Vickers hardness of 1200 HV against 150 – 170 HV and 270 - 320 HV for CP Ti and Ti 6Al 4V respectively. (3)(11)
However, unlike a natural tooth, the dental implant does not present a periodontal ligament in order to absorb the occlusal forces and this role must be fulfilled by the material and its attitude to do so is represented by the Young Modulus. The zirconium presents a very high value of 210 GPa whereas titanium has one comprised of between 100 and 110 GPa. (3)(6)

Fracture toughness is the ability of a material to resist fracture and cracks. In the case of the zirconium, it is from 8 to 10 MPa/m which is very high for a ceramic material but remains lower than the titanium value with 66 MPa for CP Ti and 50 MPa for Ti 6AL 4V. (2)(3)

Regarding the bending strength, the ability to resist deformation under a load, the zirconium presents a higher value of 900 - 1200 MPa against 400 MPa for CP Ti and 950 MPa for Ti 6Al 4V. (3)(25)

Finally, the zirconium shows greater resistance to corrosion than titanium. (6) This ability is linked to the thermic conductivity of the material which in the case of the zirconium obtains a value of 1.9 W/m.K while for the CP Ti it reaches 22 W/m.K and 7 W/m.K for the Ti 6Al 4V. (3)(6)

	Y-TZP	**Ti (CP Ti) grade 2**	**Ti 6Al 4V alloy**
Vickers Hardness (HV)	1200	150 - 170	270 - 320
Bend Strength (MPa)	900 - 1200	400	950
Fracture toughness (MPa/m)	8 - 10	66	50
Young modulus (GPa)	210	100	110
Thermic conductivity (W/m.K)	1.9	22.0	7
Corrosion	Lower	Higher	Higher

Figure 6: Summaries of zirconium and titanium materials properties (2)(10)(20)(22)

FRACTURE PROBLEMS

Regarding the resistance to fracture, many studies associate the material as well as the type of connection used to the incidence of fracture of implants. (26)

Indeed, the titanium implant fracture is not a common event and presents the lowest rate of fracture with an incidence from 0% to 6%. (6)

On the contrary, as previously saw, the zirconium implant presents the disadvantage of aging also called the Low Temperature Degradation (LTD), which influences the mechanical properties of the material and therefore the fracture strength. (2) Some studies established this decrease of fracture strength of zirconium to be only observable when more than 50% of

the zirconia on the surface of the implant reaches the monoclinic phase. (11) In order to reduce this effect, many authors analyzed the different causal factors and advise against the use of zirconium implant with a diameter inferior at 3.25µm but recommend the use of zirconium with a grain size superior at 1µm. (2)(11)

One of the possible factors of fracture is the design of the implant, Andreiotelli and al studied the resistance to fracture of implant and established the higher resistance for the two pieces screwed titanium implant. (11) Kohal and al studies the resistance to fracture in zirconia implants and concluded for a lower fracture strength in the case of the loaded implant than unloaded, no matter of the system (one or two pieces). (2) Furthermore, others authors concluded for a higher fracture rate in the case of unloaded one-piece zirconium implant than in loaded zirconium implants. (2)

RELATION WITH PERI IMPLANT TISSUES

A good relationship between the implant surface and the peri-implant tissues is necessary in order to optimize the success of an implant. (3) A similar tissue adhesion for both zirconium and titanium implants is demonstrated in many studies. For example, Koch and al studied the soft tissues relation with those implants and observed the same biological space formation with the same components around the implant than around natural teeth. (27) Other studies analyzed the adhesion of connective tissues and demonstrate that the titanium implants and those in zirconium are following the same adhesion pattern, which is a parallel and parallel oblique orientation of the collagen fibers regarding the axis of the implant. (2)(3)(9)(27)

In their analysis, Thoma et al observed the soft tissue dimensions in between zirconium and titanium implants, they established there were no significant differences between both materials regarding the junctional epithelium and the height of the implant mucosa. (28)
Some reports also expressed a similar probing depth in between zirconium and titanium implant. (3)

Finally, many studies observed a short length in between the peri-implant mucosa and the apical termination of the sulcular epithelium in zirconium implants than in titanium implants. (2)(3)

BACTERIAL ADHESION

The relationship between the formation of dental plaque and different materials used in implantology has also been reviewed. In their in vitro study, Roehling and al (29) compared experimental disk out of titanium and zirconium with different surface modifications and observed a superior bacterial layer thickness in the case of a titanium implant than in the case of a zirconium implant. They also find a significantly higher number of bacterial species in the case of titanium. (29) The same observation is made by Sanchez et all (30) who compared the thickness of the bacterial biofilm after 12, 48, and 72 hours of cultures in an in vitro environment.

SAMPLE	12H		48H		72H	
	Ti surface	Zr surface	Ti surface	Zr surface	Ti surface	Zr surface
BIOFILM THICKNESS	10.2µm	7.4µm	16.1µm	8.9µm	23.2µm	11.5µm

Figure 7: observed changes in biofilm thickness (27)

Scarano and al (22) also demonstrated a lower attraction for zirconium surface in vivo. After 24 hours of incubation, 12.1% of a zirconium surface is covered with bacteria against 19.3% on a titanium surface. (22)

AESTHETICS

Regarding the aesthetic, the zirconium implants were mainly developed in order to increase the aesthetic demand of the patient. Indeed, the titanium implant, due to the grey color of the material may present some secondary esthetics effects manifested by the greyish color visible through the peri-implant mucosa. (10) On the contrary, the zirconium implants, thanks to their good optical properties (opacity, translucency…) and white color shows a better natural and aesthetic result. (7)

In 2007, Jung and al performed a study to evaluate the effect of different materials including titanium and zirconium on the mucosa. They establish a relation between the use of titanium and a visible mucosal discoloration until 2 mm of gingival thickness. On the other hand, the zirconium doesn't show any discoloration until 1.5 mm of gingival thickness. (23)

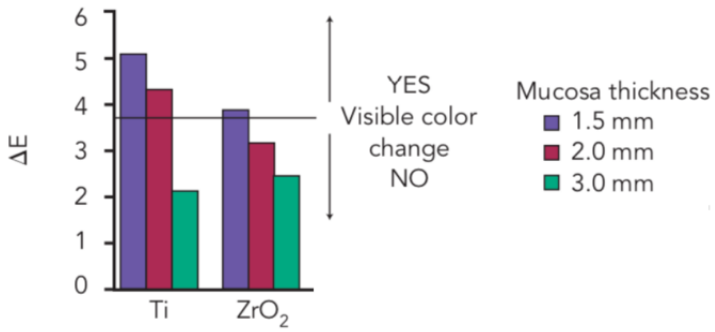

Figure 8: Visible changes regarding the gingival thickness

From: Roehling S, Astasov-Frauenhoffer M, Hauser-Gerspach I, Braissant O, Woelfler H, Waltimo T, et al. In Vitro Biofilm Formation on Titanium and Zirconia Implant Surfaces. J Periodontol. 2017 Mar;88(3):298–307.

Therefore, especially on a thin gingival biotype or with gingival recession, the zirconium appears to show better results than the titanium regarding the aesthetic. (10) Those results can be enhanced combined with an all-ceramic crown to ensure optimal aesthetic results. (7)

TOXICITY AND ALLERGIES

Although being an excellent biocompatible material with good properties, report failure of titanium implant remains possible especially due to hypersensitivity reaction. (31) Indeed, like any metallic material, and despite being biocompatible, titanium can be subject to corrosion and wear which leads to the release of ionized particles in the tissues around the implant. (31) This phenomenon, in some people, has the consequence of creating a hypersensitivity reaction which will manifest itself by pain, eczema, urticaria, swelling, rashes, fatigue, discomfort, and even sometimes, rejection of the implant. (32)

Due to corrosion, the presence of titanium particles in the peri-implant tissues, in particular macrophages, can not only cause hypersensitivity but also a type IV allergenic reaction (T cell-mediated) which therefore manifests itself several hours or even days after the exposure to the allergen. (31) The degradation of titanium and its spread in the peri-implant tissues can also cause mucositis and in more severe cases periimplantitis and failure of the implant. (32)(10) Some studies demonstrate the role of environmental factors, the corrosion phenomenon would be greater in an environment with a low pH as well as a high concentration of fluoride. (32)

In the case of the suspicion of an implant failure due to titanium hypersensitivity, the removal of the implant is usually enough for the withdrawal of the symptoms. (31) Nevertheless, titanium remains the biocompatible metallic material with fewer hypersensitivity reactions with a prevalence of 0.6%. (32) As being a non-metallic material, the zirconium has the advantage of avoiding any allergic reaction or hypersensitivity. However, there is a lack of data regarding this material, especially in long-term studies. (32)

5 DISCUSSION

Generally speaking, zirconium appears to be similar to titanium in many aspects.

Regarding the osseointegration, the authors agree to conclude for a similar process and quality. (11) However, in order to compete with the titanium capacity of osseointegration which is superior, the zirconium needs to undergo surface modifications to enhance its abilities. (19) Indeed, such a process allows for a rougher surface and capacity to interact with the surrounding soft tissues, increasing the relation and apposition of bone to the implant. (20) Titanium itself presents remarkable osseointegration properties that can be enhanced by surface modifications as well. (17) Therefore, if focusing on the osseointegration of the material, both surface-modified zirconium and titanium are a suitable choice. The main surface modifications used are plasma sprayed coating, acid etching, and SLA (sandblast and acid etching) are the most commonly used techniques even if no universal method has been determined. (3)(11)(17)(20)

If the osseointegration is well studied and established, the survival rate of both materials isn't. Indeed, there is a lack of scientific data regarding zirconium in long-term survival. (6)(16) It is well proved that in a few years of placement, zirconium and titanium present a similar rate. (15) However, in a range of ten years, the titanium had proven to still have a proper function while the zirconium is still missing some data and further studies are needed to ensure a proper survival rate. (16)(15)

According to the mechanical properties of both materials, they are presenting similar characteristics. (11) The zirconium is particularly showing a very important resistance to the

masticatory forces and high bending strength. However, it is recommended the use of a zirconium implant with a diameter superior to 3.25µm in order to reduce the risk of fracture of the material. (2)(3) On the other hand, titanium presents a higher fracture toughness and a very low risk of fracture compared to zirconium. Despite the promising results, there is a lack of data regarding the use of zirconium in the posterior sector and even if this material is promising regarding the anterior sector, titanium remains a preferable choice. (2)(6)(25)

Those mechanical properties are linked to the system of implant used, one-piece or two pieces. Indeed, a titanium implant in two pieces with a screw abutment is the reference choice for implant rehabilitation as presenting the best fracture resistance, axis control, and masticatory forces resistance. (11)(25) In the case of zirconium implant, the monobloc one-piece implant is the most common for now despite showing less favorable resistance than the titanium implant. The two pieces screwed implant system with screw-retained abutment is the most favorable choice for zirconium as well, therefore, furthers investigations are expected. (3)(11)(26)

The relation between the soft tissues and the implants is similar for both materials. But another interesting factor is the relation of the material to the formation of plaque. According to the studies, zirconium presents a lower attraction for plaque and bacteria than titanium. (29) Therefore, it may be recommended in the case of a patient susceptible to bacteremia or a patient with a high risk of infection to reduce those risks by placing a zirconium implant. (29)(30)

One of the main interesting characteristics of zirconium is its hypoallergic status. While in some rare cases, the titanium can present hypersensitivity reactions from the host or being toxic, the zirconium, being a ceramic material is cleared from such events. (10)(31) Therefore, in the case of a patient with a history of titanium hypersensitivity or allergic reaction to titanium, zirconium is the material of choice in the case of implant rehabilitation to ensure avoiding any further manifestations. (6)(32)

Finally, regarding the aesthetic factors, zirconium as being a white material presents a higher natural and aesthetic finish than titanium. According to the studies, the aesthetic of the patient can be compromised if using titanium implants in the case of gingiva thinner than 2mm. (7)(23) Therefore, if the patient presents an aesthetic demand, especially if it is for rehabilitation in the anterior sector, or possesses a thin biotype, the use of zirconium is preferable to ensure a natural aspect of the gingiva. (3)(9)

The main characteristics and differences between Zirconium and Titanium are studied, it allows us a better understanding of the main use and indications of both materials. The two pieces system with a screwed abutment titanium implant is the golden standard, with proven success and ability for rehabilitation in implantology. (4)(11)

However, the zirconium implants have proven to be a perfect alternative regarding the aesthetics demand and toxicity issues of the titanium. Indeed, zirconium is mostly recommended in the case of anterior sector rehabilitation to avoid the possible greyish discoloration of the titanium, especially in the case of a thin biotype (<2mm). (23) Also, as

being an inert and hypoallergenic material, zirconium is to use when hypersensitivity or toxic reactions to titanium are observed. (31) It is also the material of choice when the patient is asking for a non-metallic missing tooth rehabilitation. Finally, due to its lower affinity for bacteria plaque, zirconium is recommended in the case of sensitive patients. (29)

Regarding the type of zirconium implant, long-term data about two pieces system are scarce therefore monobloc one-piece implants are the most commonly used, and those showing the better properties. (11)(15) Nevertheless, furthers studies are performed in order to improve disadvantages of the zirconium implant including the fracture resistance and the low temperature degradation of the material. (2)(6)

6 CONCLUSION

For many years, Titanium has dominated the field of dental implantology. Indeed, supported by numerous long-term studies and solid data, it is established as the golden standard material recommended for any circumstances. It is proven to offer some high physical and mechanical properties as well as good osseointegration, survival rate, and biocompatibility regarding the soft tissues. (2)(3)

But since a few years, the introduction to the ceramic zirconium implant is, according to the many studies analyzed comparing both materials, accepted as a valuable alternative to Titanium. (9) Indeed, the ceramic material, zirconium, exhibits properties similar to titanium regarding the physical mechanical properties, good biocompatibility, and osseointegration. More importantly, it allows overcoming the main disadvantages of titanium, the aesthetics aspect, and toxicity. (11)

According to the previous study, zirconium implants are nowadays mainly used in the following specific case:

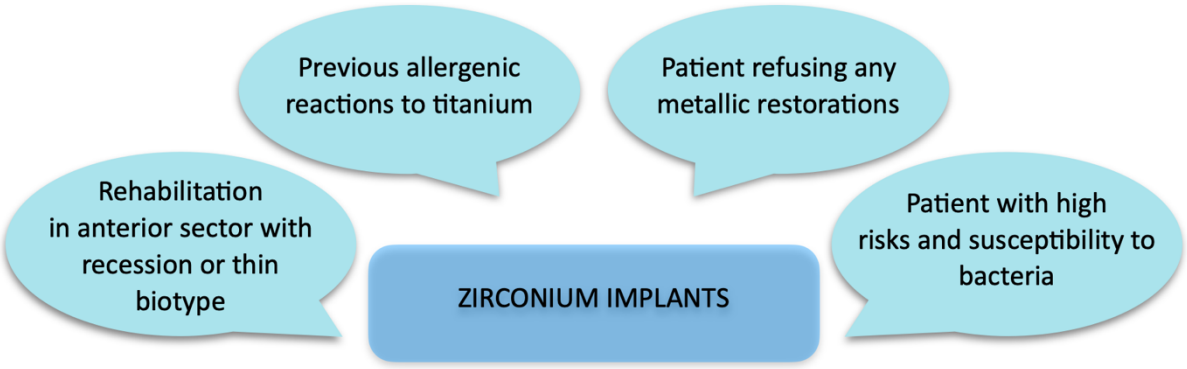

Figure 9: Main indications of zirconium implant placement

However, the zirconium still presents some disadvantages, especially regarding the fracture strength, the low temperature degradation, and the lack of perspective. (6)

Therefore, even if furthers studies especially in the long term are needed to ensure reliability and to improve the zirconium, it remains a fine alternative to titanium and is a promising material for the future of implantology. (9)

SOCIAL RESPONSABILITY

Our society is constantly evolving, in a permanent quest for productivity, efficiency, and performance. In the field of health, and particularly dentistry, the importance of an excellent understanding of human biology is primordial. Indeed, current research is moving more and more towards a conservative approach that seeks to imitate as well as possible the natural structures of the human body. Regarding implantology, the material mainly used for implants has been titanium for several years. However, this material presents some imperfections which can prove to be deleterious, thus, research pushes to discover and obtain a new material allowing to replace biological tissues in the most similar way possible without repercussion on the remaining tissues. The objective of this research is to offer to the patients the most effective alternative possible, both biologically, and economically and allowing adequate sustainability.

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8 FIGURES

9 ANEXES

Fundamentals and history of implant dentistry

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ABSTRACT

The practice of implant dentistry was not there a few decades ago It has its long historical retrospectives. The quest for rehabilitation of edentulous ridge has intrigued mankind since ancient times. The period from the time of Egyptian and Mayan civilizations to 1930s was unique when clinicians attempted to replace a missing tooth utilizing various materials. The spark of inquiry began from mid-1930s with the advent of an alloy named "vitallium;" attempts have been made to utilize this new material as an implant. Thereafter, in early 1950s, a good deal of fundamental and clinical research started taking place. These research data had given a boost to the tremendous growth of the practice of using dental implants made of vitallium that practically exploded to reach every general practitioner's clinic across the globe. Critical understanding of bone physiology, drilling protocol, implant design and surface texture, initial implant stability, single-stage implant surgery, and immediate loading of implants are the few factors based on which modern implant practice has become a predictable treatment modality for the replacement of missing teeth.

Key words: Fibrous encapsulation, HA-coating, immediate loading, osseointegration

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INTRODUCTION

Loss of teeth leads to many edentulous situations. This creates many problems like loss of aesthetic look, deterioration of chewing efficiency, and problem of speech. All these three problems lead to handicapping situations. As a result, replacement of lost teeth becomes a necessity. Attempts have been made since the time of Egyptians and Mayan civilizations to reproduce a tooth-like object that can be inserted into the jaw bone.[1] Newer innovations have led to biologically compatible materials.

HISTORICAL PERSPECTIVES

The dental implantology can be traced back to earlier civilizations [Table 1].[2,3] It can, thus, be divided into seven eras [Table 2]. The year 1937 - a remarkable period known as the "dawn of the modern era" - can be credited to Venable *et al*.[4] for his role in the invention of an alloy material named vitallium, a mixture of cobalt, chromium, and molybdenum. Thereafter, in 1939, Strock[5] did animal experimentations using this unique metal alloy and confirmed its biocompatibility. This was a wonderful material of choice and practically dominated the world of implantology in both dental and medical fields for decades. The earlier popular form or design of the dental implant was flat or blade-like. Blade form design was introduced to utilize the narrow alveolar ridge which was undergoing resorption as this narrow ridge does not support the placement of root form implant. From 1960s till the early parts of 1980s the popularity of these dental implants reached its zenith. The significant and major contribution during this period was from a German dentist Leonard I. Linkow who earned fame for his unilateral subperiosteal implants to start with and subsequently, for his invention of blade-vent implants in 1967.[3]

RECOGNITION OF IMPLANT DENTISTRY

The research data on dental implants were practically nonexistent in 1972.[2-6] The American Dental Association

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Review

Is zirconia a viable alternative to titanium for oral implant? A critical review

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ABSTRACT

Purpose: Titanium based implant systems, though considered as the gold standard for rehabilitation of edentulous spaces, have been criticized for many inherent flaws. The onset of hypersensitivity reactions, biocompatibility issues, and an unaesthetic gray hue have raised demands for more aesthetic and tissue compatible material for implant fabrication. Zirconia is emerging as a promising alternative to conventional Titanium based implant systems for oral rehabilitation with superior biological, aesthetics, mechanical and optical properties. This review aims to critically analyze and review the credibility of Zirconia implants as an alternative to Titanium for prosthetic rehabilitation.
Study selection: The literature search for articles written in the English language in PubMed and Cochrane Library database from 1990 till December 2016. The following search terms were utilized for data search: "zirconia implants" NOT "abutment", "zirconia implants" AND "titanium implants" AND "osseointegration", "zirconia implants" AND compatibility.
Results: The number of potential relevant articles selected were 47. All the human in vivo clinical, in vitro, animals' studies were included and discussed under the following subheadings: Chemical composition, structure and phases; Physical and mechanical properties; Aesthetic and optical properties; Osseointegration and biocompatibility; Surface modifications; Peri-implant tissue compatibility, inflammation and soft tissue healing, and long-term prognosis.
Conclusions: Zirconia implants are a promising alternative to titanium with a superior soft-tissue response, biocompatibility, and aesthetics with comparable osseointegration. However, further long-term longitudinal and comparative clinical trials are required to validate zirconia as a viable alternative to the titanium implant.

1. Introduction

The rehabilitation of edentulous spaces in patients with an osseointegrated dental implant is a scientifically accepted and well-documented treatment modality. Branemark in 1908, first discovered the concept of osseointegration as a serendipity when blocks of titanium placed into the femur of rabbit got ankylosed with the surrounding bone and could not be retrieved. Since then, numerous investigations and clinical studies have established titanium as a reliable biomaterial for oral rehabilitation and reconstruction. Various modifications in the structure, composition, and design of titanium implants have been made since then to enhance its physical, mechanical and optical properties [1–4]. However, the development of undesirable allergic reactions, cellular sensitization, galvanic current formation and aesthetics gray hue have raised demands for more aesthetic and biocompatible implant material [5–9]. Zirconia is emerging as a promising alternative to conventional Titanium based implant system for oral rehabilitation with superior biological, aesthetic, mechanical and optical properties. Zirconia implant is made from a lustrous, grey-white, strong transition metal named Zirconium (Symbol Zr). Zirconia is the oxide form of zirconium. Jons Jakob Berzelius in 1824 was the first to isolate zirconium in an impure form. Initially, zirconia was used in various orthopedic surgical procedures for manufacturing ball heads for total hip replacements, artificial hips, finger and acoustic implants prosthesis. Later it was introduced in dentistry for fabrication of endodontic posts, crown/bridge, restorations, esthetic orthodontic brackets and implant abutments

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Review

Zirconia *versus* titanium in dentistry: A review

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This review scientifically compares the properties of zirconia and titanium, but does not identify the best among them as an implant material. Surface treatment and modification to improve tissue bonding and inhibit bacterial adhesion are not considered in this review. The mechanical properties of titanium are superior to those of zirconia; some studies have shown that zirconia can be used as a dental implant, especially as an abutment. Extensive surface treatment research is ongoing to inhibit bacterial adhesion and improve osseointegration and soft tissue adhesion phenomena which make it difficult to evaluate properties of the materials themselves without surface treatment. Osseointegration of titanium is superior to that of zirconia itself without surface treatment; after surface treatment, both materials show comparable osseointegration. The surface morphology is more important for osseointegration than the surface composition. To inhibit bacterial adhesion, zirconia is superior to titanium, and hence, more suitable for abutments. Both materials show similar capability for soft tissue adhesion.

Keywords: Zirconia, Titanium, Bacterial adhesion, Osseointegration, Soft tissue adhesion

INTRODUCTION

Metal-free treatment is now popular in dentistry due to the esthetic problem of metal restoratives. Metals have long been used for dental restoratives. In dentistry, esthetics is among the predominant goals. Therefore, even if the mechanical properties of a material are insufficient, its esthetics is sometimes preferred. Metals or metallic materials are defined as "materials consisting of metallic bonds." One of the characteristics of metals is metallic luster due to these metallic bonds. This disadvantage of metals has led to their substitution by ceramics and polymers in dentistry. There are always discussions and debates on material selection among dentists, manufacturers, and dental materials researchers. However, these discussions, debates may not always be based on scientific viewpoints such as materials science and engineering. Among the causes for debates is the propaganda from manufacturers which only highlight the merits of products that is believed by most of dentists and some of researchers. An interesting theme of recent debates is the selection of zirconia or titanium as dental implants. Comparing zirconia to titanium is almost equivalent to comparing ceramics with metals. The advantages of ceramics are high-temperature resistance, wear resistance, chemical stability, and importantly, white color for dentistry, while the disadvantages include low fracture toughness or brittleness. On the other hand, the advantages of metals are high fracture toughness based on high strength and elongation and good balance between rigidity and stiffness, while the disadvantages include corrosion and fatigue. As is well known, all materials have advantages and disadvantages; there is no material that shows only advantages. In this review, a scientific comparison of the properties of zirconia and titanium is attempted, but the best among them as an implant material is not judged. Surface treatment and modification to improve tissue compatibility and inhibit bacterial adhesion are not considered in this review; nevertheless, recent research on tissue compatibility has focused on evaluation after surface treatment involving the surface morphology. In this review, the terms "zirconia" and "titanium" are used for general and comprehensive material names, while ZrO_2 and Ti are used when the compositions are clear.

OVERVIEW OF ZIRCONIA AND TITANIUM

Zirconia

Zirconia was originally discovered as a mineral in 1892[1], and has been widely used as a refractory material for applications such as the outer wall of space shuttles owing to its high melting point of 2,715°C. The most stable phase at ambient temperature is monoclinic, which, upon heating, transforms into tetragonal and cubic phases[2]. However, when sintered zirconia is cooled to ambient temperature, cracks are formed in zirconia due to the volume increase from the tetragonal phase to the monoclinic phase, which decreases the mechanical strength of zirconia[3]. The history of zirconia and its application to medicine and dentistry are summarized in Table 1.

Many researchers have found that small amounts of calcia (CaO), magnesia (MgO), ceria (CeO_2), and yttria (Y_2O_3) in a solid solution of ZrO_2 can stabilize the tetragonal or cubic phase of ZrO_2 at ambient temperature, depending on the amount of oxide added. Fully stabilized zirconia (FSZ), consisting of only the cubic phase, shows the greatest ion conductivity and has been used in solid oxide fuel cells and oxygen sensors. On the other hand, partially stabilized zirconia (PSZ) contains the monoclinic or tetragonal phase in addition to the cubic phase. Classical theory shows that the strain energy of the surrounding material allows the

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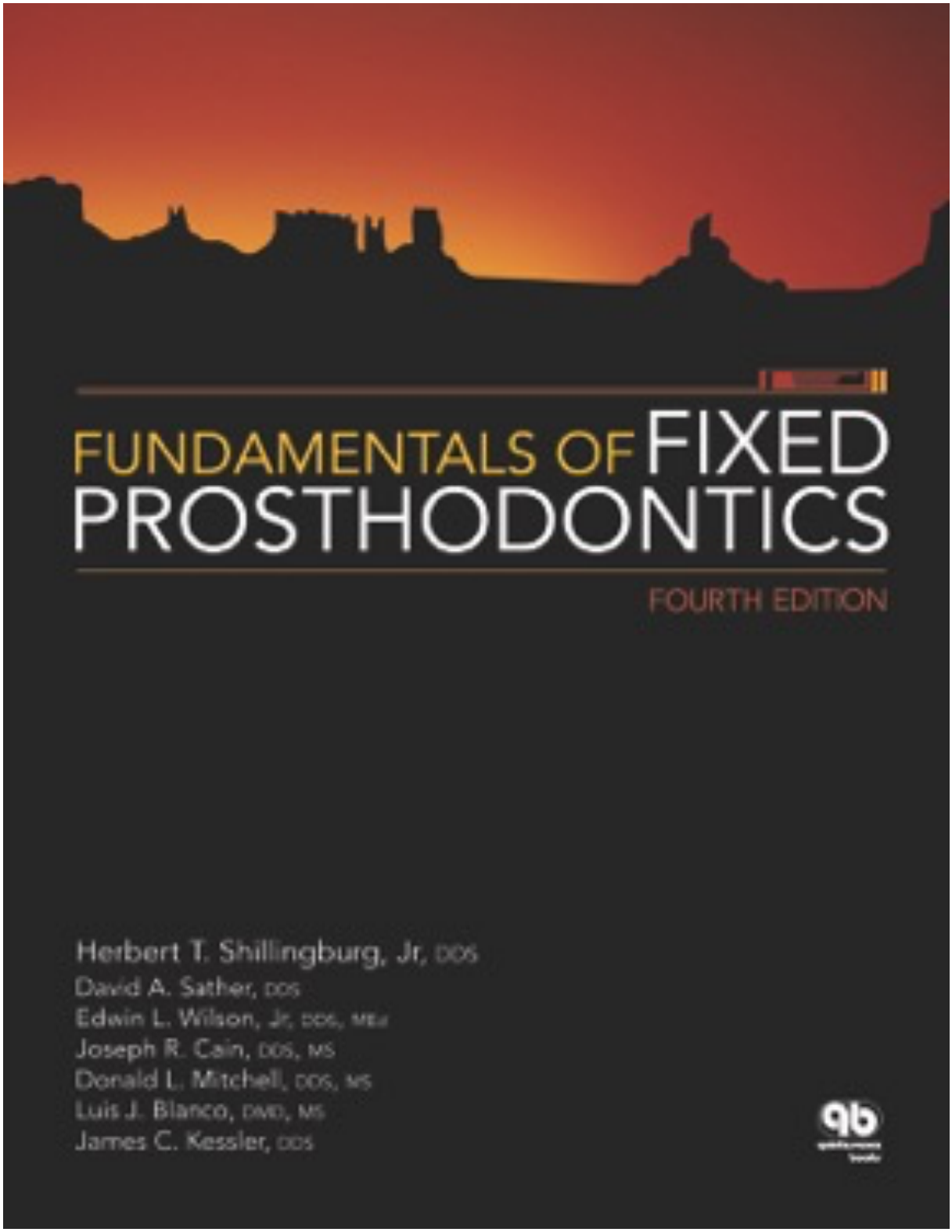
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WILEY

REVIEW

On osseointegration in relation to implant surfaces

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Abstract

Background: The understanding of mechanisms of osseointegration as well as applied knowledge about oral implant surfaces are of paramount importance for successful clinical results.

Purpose: The aim of the present article is to present an overview of osseointegration mechanisms and an introduction to surface innovations with relevance for osseointegration that will be published in the same supplement of *Clinical Implant Dentistry and Related Research*.

Materials and Methods: The present article is a narrative review of some osseointegration and implant surface-related details.

Results and Conclusions: Osseointegration has a changed definition since it is realized today that oral implants are but foreign bodies and that this fact explains osseointegration as a protection mechanism of the tissues. Given adequate stability, bone tissue is formed around titanium implants to shield them from the tissues. Oral implant surfaces may be characterized by microroughness and nanoroughness, by surface chemical composition and by physical and mechanical parameters. An isotropic, moderately rough implant surface such as seen on the TiUnite device has displayed improved clinical results compared to previously used minimally rough or rough surfaces. However, there is a lack of clinical evidence supporting any particular type of nanoroughness pattern that, at best, is documented with results from animal studies. It is possible, but as yet unproven, that clinical results may be supported by a certain chemical composition of the implant surface. The same can be said with respect to hydrophilicity of implant surfaces; positive animal data may suggest some promise, but there is a lack of clinical evidence that hydrophilic implants result in improved clinical outcome of more hydrophobic surfaces. With respect to mechanical properties, it seems obvious that those must be encompassing the loading of oral implants, but we need more research on the mechanically ideal implant surface from a clinical aspect.

KEYWORDS
implant surface, osseointegration, titanium

1 | ON OSSEOINTEGRATION

Direct bone anchorage of metallic implants was discovered by Brånemark in 1962 and after some animal experiments was applied clinically for oral implants in 1965. The development of directly bone-anchored implants has meant a breakthrough in possibilities to treat partially or totally edentulous individuals. The term osseointegration was coined by Brånemark in 1976 and then defined as a direct contact between implants and bone at the resolution level of the light microscope.[1]

Initially, incorporation of titanium implants was seen as a simple wound healing phenomenon which was regarded as possible due to the assumed benign tissue reactions to the material, possibly even encompassing some sort of chemical attachments of the implants.[2] However, based on findings from later research, these initial ideas about titanium as a unique material have been questioned. Firstly, it was demonstrated that other metals, such as titanium alloys, tantalum and niobium as well as various ceramic materials, were likewise capable of osseointegration.[3] Secondly the notion of titanium being bioinert without any adverse tissue reactions was questioned.[4] Donath and colleagues[4] described that titanium was far from bioinert, but instead capable of eliciting immune responses when placed in tissues. Donath and colleagues concluded that osseointegration was but a foreign body reaction where the tissues aimed at embedding the titanium material in bone as a mode of protection for nearby tissues. They claimed that any foreign material placed in bone will be rejected, dissolved, resorbed, or demarcated with a dense layer of bone to protect nearby tissues (Figure 1). What is seen as osseointegrated materials is the latter body defense of demarcation, which develops on the

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Review

A Critical Review of Dental Implant Materials with an Emphasis on Titanium *versus* Zirconia

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Abstract: The goal of the current publication is to provide a comprehensive literature review on the topic of dental implant materials. The following paper focuses on conventional titanium implants and more recently introduced and increasingly popular zirconia implants. Major subtopics include the material science and the clinical considerations involving both implant materials and the influence of their physical properties on the treatment outcome. Titanium remains the gold standard for the fabrication of oral implants, even though sensitivity does occur, though its clinical relevance is not yet clear. Zirconia implants may prove to be promising in the future; however, further *in vitro* and well-designed *in vivo* clinical studies are needed before such a recommendation can be made. Special considerations and technical experience are needed when dealing with zirconia implants to minimize the incidence of mechanical failure.

Keywords: zirconia; titanium; dental implants; oral implants; implant materials

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Ceramic Dental Implants: A Literature Review

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Abstract

Background: Titanium, also known as conventional implant is the gold standard material for dental implant. The reason behind this is their outstanding biocompatibility, adequate mechanical properties and beneficial results. When exposed to air, titanium instantly develops a stable oxide layer, which forms the basis of its biocompatibility leading to a better Osseointegration [1-3]. Zirconia (ZrO2) is a ceramic material with sufficient mechanical properties for manufacturing of medical devices [2] Zirconia-based implants were introduced into dental implantology as a substitute to titanium implants. Zirconia seems like an appropriate candidate for implant material due to its tooth-like color, its biocompatibility and its mechanical properties and low plaque affinity [1,4] The major drawback of titanium is its gray color. In various situations, there could be an unaesthetic display of the metal components due to lack of soft tissue height over the implant level this can also take place following soft tissue recession and marginal bone loss [4,5]. Zirconia opacity is very helpful in unfavorable clinical situations. Radio-Opacity can aid evaluation during radiographic controls. Frameworks of Zirconia are made using computer-aided design/manufacturing (CAD/CAM) technology [5].

Aims of this Study: The aim of this study is to review clinical and research articles conducted on zirconia dental implants, observe their success rate with a minimum follow up of 5years & compare them with titanium dental implants.

Materials and Methods: A literature search was performed of the Pub Med database using the following key words: 'zirconia,' 'zirconia implant,' 'zirconia versus titanium. The searches were limited to articles in English published from 2003 to 2016.

Results: A total of 4 articles matched the criteria of a minimum 5year follow up study. A cumulative success rate of 92.2% was observed.

Conclusion: Literature search showed that the success and longevity of dental implants strongly depend on surface characteristics and adequate osseointegration. And that the use of right size, shape, length and diameter of the implant in optimal loading conditions would increase the chances of successful implant placement. Although it also highly depends on that the right technique is being followed by the operator. Some of the properties of zirconia seem to be suitable for making it an ideal dental implant, such as biocompatibility, osseointegration, favorable soft tissue response and aesthetics due to light transmission and its color. Zirconia can prove a feasible alternative in replacing titanium. A need for more clinical trials concerning resistance to failure in long-term is of high importance.

Key words: Zirconia; Zirconia implant; Zirconia versus titanium

Introduction

Dentists and dental specialists use significant clinical skills in an attempt to deal with the consequences of complete and/or partial edentulism [6]. The therapy of completely and partially edentulous patients with dental implants is an accepted and eminent treatment modality [2]. Zirconia is one of the most capable restorative biomaterial, due to its highly positive mechanical and chemical properties appropriate for medical application. Zirconia ceramics (ZrO2) are becoming a widespread biomaterial in dentistry and dental implantology [2]. Titanium has been the preference for dental implants for the past many years. Its properties and characteristics have been found to be most fitting for the success of implant treatment. But lately, zirconia is gradually rising as one of the materials to reinstate the gold standard of dental implant, i.e., titanium [1]. Dental implants are biocompatible metal anchors surgically placed in the jaw bone beneath the gums to hold an artificial crown where natural teeth are missing.

Using the root form implants which are the nearest in shape and size to the natural tooth root, the non-union bone healing stage generally varies from three months to six or more. During this period, osseointegration occurs. The strong sustainability of the implant is due to the bone growing in and around it, to which a superstructure will be attached later on by either cementation or screw-tightening retaining technique [7,8]. Since the material composition and the surface topography of the implants play a fundamental part in osseointegration, various chemical and physical surface modifications have been developed in order to decrease the

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A Brief Historical Perspective on Dental Implants, Their Surface Coatings and Treatments

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Abstract: This review highlights a brief, chronological sequence of the history of dental implants. This historical perspective begins with ancient civilizations and spotlights predominant dentists and their contributions to implant development through time. The physical, chemical and biologic properties of various dental implant surfaces and coatings are discussed, and specific surface treatments include an overview of machined implants, etched implants, and sand-blasted implants. Dental implant coatings such as hydroxyapatite, fluoride, and statin usage are further reviewed.

Keywords: Dental history, implant surface, implants, surface coating.

A BRIEF HISTORY OF DENTAL IMPLANTS

"There's Gold (Ivory and Stone) in them thar (Implants)"!

The history of the evolution of dental implants is a rich and fascinating travelogue through time. Since the beginning of mankind, humans have used dental implants in one form or another to replace missing teeth. In approximately 2500 BC, the ancient Egyptians tried to stabilize teeth that were periodontally involved with the use of ligature wire made of gold. Their manuscripts and texts allude to several interesting references to toothaches. About 500 BC, the Etruscans customized soldered gold bands from animals to restore oral function in humans; they also fashioned replacements for teeth from oxen bones. At about the same period, the Phoenicians used gold wire to stabilize teeth that were periodontally involved; around 300 AD, these innovative peoples used teeth creatively carved out of ivory which were then stabilized by gold wire to create a fixed bridge. The first evidence of dental implants is attributed to the Mayan population roughly around 600 AD where they excelled in utilizing pieces of shells as implants as a replacement for mandibular teeth. Radiographs taken in the 1970's of Mayan mandibles show compact bone formation around the implants-bone that amazingly looks very much like that seen around blade implants! Moreover, around 800 AD, a stone implant was first prepared and placed in the mandible in the early Honduran culture [1].

From Rocks to Roosters- Early Implants Emerge

In the middle of the 1600's periodontally compromised teeth were stabilized in Europe with various substances. From the 1500's to about the 1800's, teeth in Europe were collected from the underprivileged or from cadavers for the use of allotransplantation. During this period, Dr. John Hunter came on to the scene; for many years he worked with "resurrectionists"-people who acquired corpses underhandedly through the robbing of graves. By doing so, he was able to observe and document with great detail the anatomy of the mouth and jaw. In the 1700's, Dr. Hunter suggested transplanting teeth from one human to another; his experiment involved the implantation of an incompletely developed tooth into the comb of a rooster. He observed an extraordinary and astonishing event: the tooth became firmly embedded in the comb of the rooster and the blood vessels of the rooster grew straight into the pulp of the tooth [1, 2]. In 1809, J. Maggiolo inserted a gold implant tube into a fresh extraction site. This site was allowed to heal and then a crown was later added; unfortunately, there was extensive inflammation of the gingiva which followed the procedure [1, 3]. Innumerable substances during this time period were used as implants; these included silver capsules, corrugated porcelain, and iridium tubes [1, 3].

Brothers Strock to Building Spirals

Dr. EJ Greenfield, in 1913, placed a "24-gauge hollow latticed cylinder of iridio-platinum soldered with 24-karat gold" as an artificial root to "fit exactly the circular incision made for it in the jaw-bone of the patient "[4]. In the 1930's, two brothers, Drs. Alvin and Moses Strock, experimented with orthopedic screw fixtures made of Vitallium (chromium-cobalt alloy). They carefully observed how physicians successfully placed implants in the hip bone, so they implanted them in both humans and dogs to restore individual teeth. The Vitallium screw provided anchorage and support for replacement of the missing tooth. These brothers were acknowledged for their work in selecting a biocompatible metal to be used in the human dentition [5]. The Strock brothers were also thought to be the first to place the first

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Zirconia dental implants: where are we now, and where are we heading?

NORBERT CIONCA, DENA HASHIM & ANDREA MOMBELLI

The notion of an alternative to titanium implants has been growing for almost 40 years. As shown in other chapters of this volume of *Periodontology 2000*, titanium dental implants demonstrate excellent biocompatibility and offer numerous treatment possibilities to improve patients' quality of life. Nevertheless, questions regarding sensitivity to titanium have been arising in recent years. One study (61) indicated that some patients could develop clinical signs of hypersensitivity to titanium, and the inadequacy of conventional epicutaneous patch tests in detecting such allergies has been established. An optimized version of the lymphocyte transformation test, also called the memory lymphocyte immunostimulation assay (MELISA®), seems to be more reliable than patch tests for detecting sensitivity to titanium (99). The prevalence of titanium allergy was estimated at 0.6% using this method (91). An animal study (107), in which titanium implants with a titanium plasma-sprayed coating were examined, showed accumulation of titanium particles in regional lymph nodes and other organs, notably the lungs and bones, after implant placement in the jaws. Moreover, a corrosion process was demonstrated when titanium was placed in contact with fluoride or metal alloys in the saliva (104). It has also been suggested that bacterial biofilms could induce oxidation on the surface of titanium implants in an acidic environment (97). Higher concentrations of corrosion products have been associated with the length of time that the implants are in place (8). However, the clinical relevance of these observations remains unclear (56). Furthermore, none of these studies revealed histological signs of inflammation in association with titanium deposits. Another drawback of titanium is its grey color. When placed in esthetic areas with a thin gingival biotype, the dark shadow of titanium may be visible through the peri-implant tissues, thus impairing the esthetic outcome (105). The high esthetic standards demanded nowadays, accompanied by fears of sensitivity to titanium, has led to the growing demand for metal-free restorations. Consequently, ceramic materials were proposed as potential surrogates.

Implant material and design

Evolution of the material

The first generation of ceramic implants was made of aluminum oxide (82, 106). Several systems of aluminum oxide implants were produced, such as Cerasand (Incermed, Lausanne, Switzerland) and Tübingen implant (Frialit I; Friadent, Mannheim, Germany). Single-crystal alumina implants, such as Bioceram (Kyocera, Kyoto, Japan), have also been fabricated. Aluminum oxide implants can be osseointegrated but their biomechanical properties, as reflected by fracture toughness, are unsatisfactory. Clinical studies on these implants have shown long-term survival rates of between 65% and 92% (22, 26, 50, 98, 110). However, the heterogeneity of the results prevented clear recommendations for routine use. Consequently, aluminum oxide implants were withdrawn from the market in the early 1990s.

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REVIEW

Zirconia ceramics in metal-free implant dentistry

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ABSTRACT

Because of their outstanding mechanical properties, chemical stability, and biocompatibility, 3-mol % yttria-stabilised tetragonal zirconia polycrystals (3Y-TZP), known as zirconia ceramics in dentistry, are an important choice for various types of prosthesis. In addition to extensive use for crown and bridge construction, considerable interest has been generated for applications in implant dentistry, including full-contour zirconia crowns as supra-constructions, zirconia abutments, and novel zirconia implants. However, their use among dentist and researchers is controversial, especially compared with the well-established implants made of titanium alloys. As a latecomer, the merits and limitations of 3Y-TZP are awaiting careful investigation. Design, manufacturing, and clinical operation guidelines are urgently needed. The aim of this review was to address the present status of the application of zirconia ceramics related to implant dentistry by analysing the published data from both *in vitro* and *in vivo* studies. Suggestions are provided for potential improvements and suitable applications of zirconia ceramics in metal-free implant dentistry.

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Introduction

Since Branemark et al. [1] inserted the first titanium screw implant in a patient in 1965, titanium has been established as the preferred metal for dental implants. In the past 50 years, the use of titanium dental implants has been well-documented, with high survival and success rates. Titanium dental implants consist of roughly 97% of the total dental implant material market. Combined with titanium implants, metal abutments, and metal ceramic crowns are also applied to implant restoration. However, with more and more applications of this kind of implant system, concerns have been raised in relation to the use of metals.

Titanium hypersensitivity [2–5] is a growing concern. Sicilia et al. [6] reported that the prevalence of titanium allergy in 1500 dental implant patients was about 0.6%, which may induce implant failure by inhibiting implant integration. Although titanium allergy is uncommon, the appearance of significant complications in particularly sensitive patients cannot be disregarded [7]. The accumulation of metal ions in the vicinity of dental and in regional lymph nodes has been verified, despite the excellent corrosion resistance of titanium. Poor aesthetic results are another problem of titanium implants and abutments (Figure 1). The metallic colour cannot be fully hidden by the soft tissue peri-implant, which induces a greyish appearance, especially for patients with thin soft tissue [8–10]. It has been demonstrated that over 60% of cases showed a colour mismatch between single implant restoration and natural tooth gingiva [11]. After gingiva recession, the titanium implant becomes exposed [11,12]. Moreover, the release of metal ions could induce discolouration of gingiva after implantation in a slow and continuous way, leading to dissatisfaction with the long-term aesthetic results.

Although an appearance matching that of standard gingiva can be achieved by a bone-level titanium implant with a ceramic abutment, a metal-free implant system in which all parts are made from ceramics, without the potential hypersensitivity risk and using a material very similar to bone, is of particular interest. The 3 mol % yttria partially stabilised tetragonal zirconia (3Y-TZP), known as zirconia in dental applications, is the strongest and toughest material in the field of dental ceramics. It has high flexural strength ranging from 900 to 1200 MPa and fracture toughness of about 8–10 MPa $m^{1/2}$. These properties suggest that zirconia has great potential for applications in implant dentistry [13], although many doubts have been raised concerning the feasibility of its clinical application. In this paper, we systematically review the published literature on zirconia ceramics related to their application as implants, abutments, and restorations. It is hoped

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Review

Current status of zirconia implants in dentistry: preclinical tests

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ABSTRACT

Purpose: This systematic review aimed to provide an overview of zirconia implants as well as regarding the outcome of the implant-restorative complex in preclinical studies.
Study selection: An electronic search of the literature prior to July 2017 was performed to identify all articles related to preclinical research on zirconia implants. The search was conducted using MEDLINE (National Library of Medicine) and PubMed without restrictions concerning the date of publication. The search terminology included: zirconia implant, osseointegration, bone-to-implant contact, soft tissue, histology, histomorphometry, surface modification, surface roughness, surface characteristics, and restoration (connecting multiple keywords with AND, OR).
Results: Fifty-seven studies were finally selected from an initial yield of 654 titles, and the data were extracted. The identified preclinical studies focused on several aspects related to zirconia implants, namely biocompatibility, mechanical properties, implant design, osseointegration capacity, soft tissue response, and restorative options. Due to heterogeneity of the studies, a meta-analysis was not possible. The most frequently used zirconia material for the fabrication of implants is yttria-stabilized tetragonal zirconia polycrystal. The resistance-to-fracture for zirconia implants ranged between 516–2044 N. The mostly investigated parameter was osseointegration, which is compared to that of titanium. A lack of evidence was found with other parameters.
Conclusions: Due to its good biocompatibility as well as favorable physical and mechanical properties, zirconia implants are a potential alternative to titanium implants. However, knowledge regarding the implant-restorative complex and related aspects is still immature to recommend its application for daily practice.

1. Introduction

Since the introduction of dental implants for clinical application, titanium has been considered the standard material of choice. The selection of titanium is based on its excellent biocompatibility, good physical and mechanical properties, and versatility for fabrication of dental implants and components. Clinical studies have clearly validated the long-term success of titanium dental implants for the treatment of edentulous and partially edentulous jaws [1,2]. Although titanium has been in use for more than 40 years, a number of criticisms regarding its clinical application have been raised [3,4]. Basically, there are two types of titanium implant designs available: one- and two-piece implant designs. A one-piece titanium implant denotes that the transmucosal portion of the implant is manufactured together with the implant body as a single unit [5,6]. On the other hand, a two-piece implant necessitates the use of an abutment as a foundation for the prosthetic rehabilitation [7]. One-piece implants have been suggested to offer several advantages over two-piece implants from biologic, clinical and technological point of view [8]. However, the literature does not provide evidence that favors a specific implant design in terms of long-term clinical performance [6,7]. Regardless of the design, it is well known that titanium implants may lead to a dull greyish background of the soft tissue in cases with a thin peri-implant mucosa or recession. This discoloration may become an esthetic disadvantage in the anterior visible region, especially with a high lip line [9]. A further concern relates to possible adverse reactions against the metal titanium. Although convincing evidence remains to be introduced, a number of reports concluded that exposure to titanium could lead to hypersensitivity [10–13]. Additionally, discussions about the existence of titanium in a wet organic milieu, i.e., bone and soft tissue, suggested that the material's resistance to corrosion degrades over time [14–16]. With such disadvantages, and in

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Understanding Peri-Implant Endosseous Healing

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Treatments for enhancing the biocompatibility of titanium implants

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Titanium surface treatment is a crucial process for achieving sufficient osseointegration of an implant into the bone. If the implant does not heal sufficiently, serious complications may occur, e.g. infection, inflammation, aseptic loosening of the implant, or the stress-shielding effect, as a result of which the implant may need to be reoperated. After a titanium graft has been implanted, several interactions are crucial in order to create a strong bone-implant connection. It is essential that cells adhere to the surface of the implant. Surface roughness has a significant influence on cell adhesion, and also on improving and accelerating osseointegration. Other highly important factors are biocompatibility and resistance to bacterial contamination. Bio-inertness of titanium is ensured by the protective film of titanium oxides that forms spontaneously on its surface. This film prevents the penetration of metal compounds, and it is well-adhesive for calcium and phosphate ions, which are necessary for the formation of the mineralized bone structure. Since the presence of the film alone is not sufficient for the biocompatibility of titanium, a suitable surface finish is required to create a firm bone-implant connection. In this review, we explain and compare the most widely-used methods for modulating the surface roughness of titanium implants in order to enhance cell adhesion on the surface of the implant, e.g. plasma spraying, sandblasting, acid etching, laser treatment, sol-gel etc., The methods are divided into three overlapping groups, according to the type of modification.

Key words: titanium treatment, osseointegration, biocompatibility, surface modification

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INTRODUCTION

Bone is the second most commonly transplanted tissue[1,2]. For present-day treatment of degenerative diseases, such as arthritis and traumatic bone damage, the replacement of bone tissue by an implant is an option when conservative treatment has already failed. Bone tissue is characterized by excellent regenerative and remodelling capabilities. There are several methods for treating bone diseases and injuries. In the case of small-scale tissue damage, the bone is self-regenerating. For larger-scale injuries, it is necessary to use optimal bone replacement therapy[3]. However, many traumatic and also non-traumatic bone injuries require treatment with bone substitutes or with grafts, depending on the extent of the defect and the loss of bone volume[1,2].

One approach for the treatment of traumatic bone damage is to transplant a bone graft, which may be of autologous, allogeneic or xenogeneic origin[4]. This method is necessary to maintain the patient's quality of life, and it is mainly used for treating disorders accompanied by a bone volume loss, e.g. due to non-union as a result of bone fractures, removal of bone neoplasm, osteomyelitis, osteonecrosis, cyst formation, etc[5]. An *os ilium* bone graft has been considered as the "gold standard", but the use of bone tissue from an allogeneic donor is ten times more common than the use of an autologous graft[6]. These classical operations are often associated with graft problems, donor morbidity, low graft availability, and, in the case of allogeneic grafts, with the risk of disease transmission and an undesirable immunological response of the organism[5,6].

Synthetic grafts and implants, made of a variety of metallic, ceramic and polymer-based materials, are currently successfully used, but they also have limitations that lead to implant failure and to the need to reoperate[5,7]. Biomaterials used for bone implantation should meet high requirements, such as long-term material durability, biocompatibility, corrosion and wear resistance, and biomechanical compatibility[8]. Implants for replacing missing or damaged bones, or for interconnecting bone fragments, must not only be mechanically resistant, but must also quickly integrate with the host organism and must perform their functions as soon as possible and for as long as possible[2].

A biomaterial is defined as any organic or inorganic material used in medical devices interacting with biological systems in order to treat, enhance or replace any tissue, organ or function of the human body. Several materials are used for implantation into the human body, namely various types of metals (non-corrosive steel, cobalt alloys, titanium alloys), ceramics (alumina, zirconium, calcium phosphate), and natural or synthetic polymers[9].

After a biomaterial has been implanted into the patient's body, there are mutual interactions of the two sys-

Abdulhadi Warreth

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Dental Implants: An Overview

Abstract: Dental implants are widely used and are considered to be one of several treatment options that can be used to replace missing teeth. A number of implant-supported treatment options have been used successfully to replace a single tooth and multiple teeth, as well as a completely edentulous jaw. However, as the number of patients who have dental implants is increasing, dental personnel are more likely to see patients with implant-supported restorations or prostheses. Nevertheless, dental implants may fail as a result of mechanical complications, such as screw loosening or due to biological causes like peri-implant diseases. As a result, dental personnel should be able to recognize these complications and the factors that have negative effects on the success of such implant-supported restorations or prostheses. Therefore, a basic knowledge of dental implants is necessary for every dental student, hygienist and dentist.

CPD/Clinical Relevance: Maintenance of implant-supported restorations and prostheses requires long-term follow-ups. It is the responsibility of the patient to maintain good oral hygiene and also of the dental personnel who look after the patient to ensure a durable restoration and prosthesis.

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Dental implants (also known as oral or endosseous implants) have been used to replace missing teeth for more than half a century. They are considered to be an important contribution to dentistry as they have revolutionized the way by which missing teeth are replaced with a high success rate.[1-3] This success depends on the ability of the implant material to integrate with the surrounding tissue. However, this integration is influenced by several factors, such as implant material, bone quality and quantity, and the implant loading condition.[2,3]

As the use of dental implants has become much more common, dental personnel are more likely to see patients who have implant–supported/retained restorations. Nevertheless, dental implants are affected by diseases in a similar manner to teeth and may also fail after several months or years in service.[4-6] Therefore, it is not unreasonable to suggest that the implant and the peri-implant tissue should be examined on a routine basis in a similar manner to that which is carried out for periodontal examination.[7] So, when a deviation from the norm is found, the treatment may be carried out in practice or by a specialist, depending on the severity of the condition. Accordingly, the dentist should be equipped with basic knowledge of dental implants. Hence, it is the aim of this article to provide this basic information which is needed by every dental student and dentist alike.

Implant-soft tissue interface

The tissue that surrounds implants is known as peri-implant tissue and is comprised of soft (mucosa) and hard (bone) tissues. The peri-implant soft tissue has similar features to the soft tissue that surrounds teeth.[7-10] It consists of a junctional epithelium and connective tissue. The junctional epithelium is attached to the implant and/or abutment surface through a hemi-desmosomal attachment. Connective tissue is present apical to the junctional epithelium and coronal to the crest of alveolar bone.[10] Connective tissue fibres are found to be positioned close to the implant surface but not attached to it, and predominantly arranged in a circular manner. Connective tissue fibres also arise from the crest of alveolar bone and from the periosteum and are oriented parallel to the implant/abutment surface and extend towards the oral epithelium. Thus, the junctional epithelium and connective tissue form a protective seal between the oral environment and the peri-implant bone which plays a vital role in the success of the implant treatment outcome. The junctional epithelium and the connective tissue are collectively known as the biologic width, which is comparable to that found around teeth.[11]

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Osseointegration of zirconia implants with 3 varying surface textures and a titanium implant: A histological and micro-CT study

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Abstract

Background. Zirconium – a bioinert metal – in comparison with titanium implants, offers a variety of potential advantages for use in the esthetic area of dentistry due to its tooth-like color. Zirconium dental implants are considered to be an alternative method of treatment to conventional titanium dental implants for patients with a thin gingival biotype.

Objectives. This study was designed to study the bone tissue response to new zirconia implants with modified surfaces in comparison with commercially available titanium dental implants and commercially available zirconia implants.

Material and methods. The study was carried out on a group of 12 16-month-old minipigs. New zirconia implants with 3 different surfaces were used: M1 – blasted surface, M2 – etched surface and M3 – blasted and etched surface (Maxon Motor GmbH, Sexau, Germany) and compared to conventional titanium implants with an sandblasted and acid etched (SLA) surface (Straumann GmbH, Freiburg, Germany) and commercially available zirconia implants (Ziterion GmbH, Uffenheim, Germany). Histological and micro-computed tomopgraphy (micro-CT) evaluation was performed.

Results. In the micro-CT assessment, the average bone-implant contact (BIC) of the zirconia experimental implants was 41.44%. In particular, the BIC% for M1 was 39.72%, for M2 it was 43.97%, and for M3 – 40.63%; in the control group it was 49.63% and 27.77% for ceramic and titanium control implants, respectively. The intra-group analysis showed no statistically important differences between the BIC values for implants in any group. However, the analysis of BIC for different regions of the same implant showed statistically significant differences in all of the groups between the results of the threaded region and the neck and the apex.

Conclusions. The results of our study suggest that zirconia implants with modified surfaces display features of osseointegration similar to those of titanium implants. These results are promising in using zirconia implants for dental applications in the future.

Key words: dental implants, osseointegration, micro-computed tomography, histomorphometry, zirconia implant

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Research

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Osseointegration of zirconia implants compared with titanium: an *in vivo* study

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Abstract

Background: Titanium and titanium alloys are widely used for fabrication of dental implants. Since the material composition and the surface topography of a biomaterial play a fundamental role in osseointegration, various chemical and physical surface modifications have been developed to improve osseous healing. Zirconia-based implants were introduced into dental implantology as an altenative to titanium implants. Zirconia seems to be a suitable implant material because of its tooth-like colour, its mechanical properties and its biocompatibility. As the osseointegration of zirconia implants has not been extensively investigated, the aim of this study was to compare the osseous healing of zirconia implants with titanium implants which have a roughened surface but otherwise similar implant geometries.

Methods: Forty-eight zirconia and titanium implants were introduced into the tibia of 12 minipigs. After 1, 4 or 12 weeks, animals were sacrificed and specimens containing the implants were examined in terms of histological and ultrastructural techniques.

Results: Histological results showed direct bone contact on the zirconia and titanium surfaces. Bone implant contact as measured by histomorphometry was slightly better on titanium than on zirconia surfaces. However, a statistically significant difference between the two groups was not observed.

Conclusion: The results demonstrated that zirconia implants with modified surfaces result in an osseointegration which is comparable with that of titanium implants.

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Review Article

Surface Modifications and Their Effects on Titanium Dental Implants

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This review covers several basic methodologies of surface treatment and their effects on titanium (Ti) implants. The importance of each treatment and its effects will be discussed in detail in order to compare their effectiveness in promoting osseointegration. Published literature for the last 18 years was selected with the use of keywords like titanium dental implant, surface roughness, coating, and osseointegration. Significant surface roughness played an important role in providing effective surface for bone implant contact, cell proliferation, and removal torque, despite having good mechanical properties. Overall, published studies indicated that an acid etched surface-modified and a coating application on commercial pure titanium implant was most preferable in producing the good surface roughness. Thus, a combination of a good surface roughness and mechanical properties of titanium could lead to successful dental implants.

1. Introduction

Surface treatments are normally carried out to modify yet maintain desirable properties of the substrate materials especially in the dental implant industry. The surface area can be increased remarkably by using proper modification techniques, either by addition or subtraction procedures [1, 2]. A surface treatment can also be classified into mechanical, chemical, and physical methods. In dental implant, the surface treatment is used to modify the surface topography and surface energy, resulting in an improved wettability [3–5], increased cell proliferation and growth [3], and accelerated osseointegration process [6]. The quality of dental implant depends on the properties of the surface. In order to have good interaction of the tissue and osseointegration, materials' biocompatibility and roughness of the surface played an important role. Goyal and coworkers [7] observed that the increased roughness can simultaneously increase the surface area of the implant, improve cell migration and attachment to implant, and enhance osseointegration process. Past literature has revealed most of the surface treatments able to brings a good effect to the dental implants [3–6]. Coating is proved to increase the surface area of the implants substantially [8]. The surface treated with plasma sprayed titanium exhibits the highest value of the surface roughness ($3.43 \pm 0.63\,\mu$m) compared to machined surface ($0.15 \pm 0.04\,\mu$m) [9]. The healing period was enhanced with hydroxyapatite (HA) coating compared to untreated one [10]. The behavior of modified surface on cells culture studies has revealed that an acid etched zirconia implant surface shows a significant improvement in cell proliferation, except for bone attachment and adhesion on the first day of culture [11–13]. In the study by Parsikia et al. [14], the commercially pure titanium surface was blasted followed by two-step chemical treatment (acid-alkali) resulting in optimized surface topography. The cell bioactivity was improved and expected to have good osseointegration at early stage. Furthermore, a rougher titanium surface promotes shorter healing process [15] than the

Review Article

Surface Modification Techniques for Zirconia-Based Bioceramics: A Review

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ABSTRACT

Zirconia is gaining interest as a ceramic biomaterial for implant applications due to its biocompatibility and desirable mechanical properties. At present, zirconia-based bioceramics is often seen in the applications of hip replacement and dental implants. This article briefly reviews different surface modification techniques that have been applied to zirconia such as polishing, sandblasting, acid etching, biofunctionalization, coating, laser treatment, and ultraviolet light treatment. The potential of surface modification to make zirconia a successful implant material in the future is highly dependent on the establishment of successful *in vitro* and *in vivo* studies. Hence, further effort should be made in order to deepen the understanding of tissue response to implant and tissue regeneration process.

KEYWORDS: *Biofunctionalization, electrophoretic deposition, laser treatment, sandblasting, selective infiltration etching, self-assembly, ultraviolet treatment, yttria-tetragonal zirconia polycrystal*

INTRODUCTION

Zirconia is rapidly gaining interest as a ceramic biomaterial for implant applications. Zirconia has three different crystalline phases: a monoclinic phase, a cubic phase, and a tetragonal phase. The latter is the one that is clinically used. Yttrium, the chemical element with symbol Y and atomic number 39, is added for aging resistance and so the Yttria Tetragonal Zirconia Polycrystal (YTZP) is formed. This is a bioinert material and is six times harder than stainless steel. Moreover, YTZP has some other eloquent characteristics: (1) electrically neutral, (2) low thermal conductivity, (3) high resistance to high temperature, (4) high thermal shock resistance, (5) chemical stability, (6) color similar to tooth structure, (7) high strength, (8) fracture toughness, (9) biocompatibility, (10) high affinity for bone tissue, (11) noncarcinogenic property, (12) absence of an oncogenic effect, (13) exhibiting minimal ion release compared with metallic implants, and (14) zirconia grain serves as a nucleation site for development of calcium-based minerals.

A material surface is known to be uniquely reactive, with properties different from the bulk. The purpose of surface modification is to alter these surface properties to enhance the biological performance of the surface, without changing the bulk properties of the material. Many approaches have been made to improve surface properties of an implant material. Two key approaches are (1) optimization of roughness and (2) application of bioactive coating. The aim of this article is to discuss various surface modification techniques for zirconia-based implant bioceramics.

SANDBLASTING

Sandblasting, also known as airborne particle abrasion, produces a surface with micro-roughness. Several parameters affect the roughness on the implant surface—size, shape, kinetic energy of the particles, etc. During the sandblasting process, compressed air pressure creates impulse to eject the particles. Thus the kinetic energy obtained by the particles depends on the density, volume, and velocity of the particles. The main advantage of sandblasting is we get a homogenous and gentle

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Zirconia surface modifications for implant dentistry

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Abstract

Background: Zirconia has emerged as a versatile dental material due to its excellent aesthetic outcomes such as color and opacity, unique mechanical properties that can mimic the appearance of natural teeth and decrease peri-implant inflammatory reactions.

Objective: The aim of this review was to critically explore the state of art of zirconia surface treatment to enhance its biological and osseointegration behavior in implant dentistry.

Materials and Methods: An electronic search in PubMed database was carried out until May 2018 using the following combination of key words and MeSH terms without time periods: “zirconia surface treatment” or “zirconia surface modification” or “zirconia coating” and “osseointegration” or “biological properties” or “bioactivity” or “functionally graded properties”.

Results: Previous studies have reported the influence of zirconia-based implant surface on the adhesion, proliferation, and differentiation of osteoblast and fibroblasts at the implant to bone interface during the osseointegration process. A large number of physicochemical methods have been used to change the implant surfaces to improve the early and late bone-to-implant integration, namely: acid etching, gritblasting, laser treatment, UV light, CVD, and PVD. The development of coatings composed of silica, magnesium, graphene, dopamine, and bioactive molecules has been assessed although the development of a functionally graded material for implants has shown encouraging mechanical and biological behavior.

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coatings

MDPI

Review

Surface Modification of Biomedical Titanium Alloy: Micromorphology, Microstructure Evolution and Biomedical Applications

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Abstract: With the increasing demand for bone implant therapy, titanium alloy has been widely used in the biomedical field. However, various potential applications of titanium alloy implants are easily hampered by their biological inertia. In fact, the interaction of the implant with tissue is critical to the success of the implant. Thus, the implant surface is modified before implantation frequently, which can not only improve the mechanical properties of the implant, but also polish up bioactivity and osseoconductivity on a cellular level. This paper aims at reviewing titanium surface modification techniques for biomedical applications. Additionally, several other significant aspects are described in detail in this article, for example, micromorphology, microstructure evolution that determines mechanical properties, as well as a number of issues concerning about practical application of biomedical implants.

Keywords: titanium alloy; surface modification; biomedical application

1. Introduction

In the past few decades, resulting from the aging of the population and the change of people's lifestyle, tens of thousands of people have been plagued by orthopedic, oral and maxillofacial diseases [1]. Thus, solving these problems enables patients to return to a high-quality life, and the demand for medical implants increases dramatically with the growing maturity of implant technology [2]. As scientists have predicted, more people will suffer from orthopedic diseases in the future and the annual economic costs will be particularly huge [3].

Today, as biomaterials are developing rapidly, biomedical materials can be mainly divided into metals, ceramics, bioactive glass, plastics and their combinations [4]. Among all biomedical materials, metal materials are the earliest applications and the most widely used in clinical practice [5]. Titanium alloy especially, compared with other metal alloys, has great advantages in mechanical properties, such as elasticity modulus, tensile strength, toughness, and fatigue resistance [6,7]. At the same time, titanium alloy has excellent corrosion resistance to physiological fluids and excellent biocompatibility, due to its oxidation film passivation stability [8,9]. In addition, biological responses of titanium alloy implants, such as bioactivity and osseointegration, are positive for clinical application [10]. Thus, it is not only widely used in dental implants, artificial joints and bone wounds, but also has become an important material for human body hard tissue substitutes. Moreover, with the continuous improvement and perfection of medical titanium alloys, the exploration of novel medical titanium alloys and the diversification of production technology will further expand their applications [11,12].

Although titanium-based alloys have excellent mechanical properties, the exposed surface of titanium-based implants is easily affected by the environment and may cause complications. Therefore,

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Are ceramic implants a viable alternative to titanium implants? A systematic literature review

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The authors declare no conflicts of interest.

Key words: alumina, oral implants, systematic review, zirconia, zirconium dioxide

Abstract

Aim: The aim of this systematic review was to screen the literature in order to locate animal and clinical data on bone–implant contact (BIC) and clinical survival/success that would help to answer the question 'Are ceramic implants a viable alternative to titanium implants?'

Material and methods: A literature search was performed in the following databases: (1) the Cochrane Oral Health Group's Trials Register, (2) the Cochrane Central Register of Controlled Trials (CENTRAL), (3) MEDLINE (Ovid), and (4) PubMed. To evaluate biocompatibility, animal investigations were scrutinized regarding the amount of BIC and to assess implant longevity clinical data were evaluated.

Results: The PubMed search yielded 349 titles and the Cochrane/MEDLINE search yielded 881 titles. Based upon abstract screening and discarding duplicates from both searches, 100 full-text articles were obtained and subjected to additional evaluation. A further publication was included based on the manual search. The selection process resulted in the final sample of 25 studies. No (randomized) controlled clinical trials regarding the outcome of zirconia and alumina ceramic implants could be found.

The systematic review identified histological animal studies showing similar BIC between alumina, zirconia and titanium. Clinical investigations using different alumina oral implants up to 10 years showed survival/success rates in the range of 23 to 98% for different indications. The included zirconia implant studies presented a survival rate from 84% after 21 months to 98% after 1 year.

Conclusions: No difference was found in the rate of osseointegration between the different implant materials in animal experiments. Only cohort investigations were located with questionable scientific value. Alumina implants did not perform satisfactorily and therefore, based on this review, are not a viable alternative to titanium implants. Currently, the scientific clinical data for ceramic implants in general and for zirconia implants in particular are not sufficient to recommend ceramic implants for routine clinical use. Zirconia, however, may have the potential to be a successful implant material, although this is as yet unsupported by clinical investigations.

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Oral implants improve the quality of life for many of our patients (Kuboki et al. 1999; Heydecke et al. 2003, 2005). They were introduced some 30–40 years ago (Brånemark et al. 1969, 1977, 1984; Adell et al. 1970; Schroeder et al. 1976, 1978, 1981; Schulte & Heimke 1976; Schulte et al. 1978a; Adell et al. 1981; Albrektsson 1983). The material of choice for oral endosseous implants has been and still is commercially pure titanium. Ceramics have however been proposed as an alter-

Bacterial Adhesion on Commercially Pure Titanium and Zirconium Oxide Disks: An In Vivo Human Study

Antonio Scarano,* Maurizio Piattelli,* Sergio Caputi,* Gian Antonio Favero,† and Adriano Piattelli‡

Background: Little is known about the mechanisms of bacterial interaction with implant materials in the oral cavity. A correlation between plaque accumulation and progressive bone loss around implants has been reported. Bacterial adhesion shows a direct positive correlation with surface roughness. Other surface characteristics also seem to be extremely important with regard to plaque formation. Different adhesion affinities of bacteria have been reported for different materials. The aim of this study was to characterize the percentage of surface covered by bacteria on commercially pure titanium and zirconium oxide disks.

Methods: Ten patients participated in this study. A removable acrylic device was adapted to the molar-premolar region, and commercially pure titanium (control) and zirconium oxide (test) disks were glued to the buccal aspect of each device. The surface roughness of titanium and test specimens was similar. After 24 hours, all disks were removed and processed for scanning electron microscopy, for the evaluation of the portion of surface covered by bacteria.

Results: In control specimens, the area covered by bacteria was 19.3% ± 2.9; in test specimens, the area was 12.1% ± 1.96. The disk surface covered by bacteria on test specimens was significantly lower than that of control specimens ($P = 0.0001$).

Conclusion: Our results demonstrate that zirconium oxide may be a suitable material for manufacturing implant abutments with a low colonization potential. *J Periodontol 2004;75:292-296.*

KEY WORDS

Bacterial adhesion; dental abutments; dental implants; zirconium oxide.

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Little is known about the mechanisms of bacterial interactions with implant materials in the oral cavity.[1] The microflora around dental implants appear to be similar to that found around natural teeth and, thus, microbial pathogens associated with periodontitis may also contribute to implant failures.[2,3] A correlation between plaque accumulation and progressive bone loss around implants has been reported in experimental and clinical studies.[4] Plaque accumulation on implant surfaces or abutments induces an inflammatory reaction in the gingiva and alveolar mucosa just as around teeth.[5-7] In fact, bacterial infection has been reported to be one of the reasons for implant failure.[8-11]

The longevity of oral implants can be jeopardized by either peri-implantitis or occlusal overload.[4,12] In the partially edentulous patient, in whom pockets around teeth act as a reservoir for the colonization of the pockets around implants, the risk for inflammatory reactions of the peri-implant soft tissues seems higher than in the fully edentulous patient.[13] Bacterial adhesion shows a direct positive relationship with surface roughness.[14-21] It must, however, be borne in mind that surface roughness is only one of the parameters involved in plaque formation. Moreover, it has been clearly shown that the initial colonization of an intraoral hard surface starts from the surface irregularities (cracks, grooves, or abrasion defects) and subsequently spreads out.[21] The surface with a low Ra value strongly inhibits accumulation and maturation of plaque within 24 hours.[16]

In Vitro Color Changes of Soft Tissues Caused by Restorative Materials

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A crucial factor influencing implant esthetics is the color of the peri-implant mucosa. This in vitro study analyzed the effect of titanium and zirconia with and without veneering ceramic on the color of mucosa of three different thicknesses. Ten pig maxillae were used, and the palatal area was chosen as the test region. To simulate different mucosa thicknesses, connective tissue grafts, 0.5 mm and 1.0 mm thick, were harvested from three additional jaws. Defined mucosa thicknesses were created by placing the grafts under a palatal mucosa flap. Four different test specimens (titanium, titanium veneered with feldspathic ceramic, zirconia, and zirconia veneered with feldspathic ceramic) were placed under the mucosa, and the color of the tissue was evaluated with a spectrophotometer for three different soft tissue thicknesses (1.5, 2.0, and 3.0 mm). The color was compared to mucosa without test specimens, and the color difference (ΔE) was calculated. All restorative materials induced overall color changes (ΔE), which diminished with increases in soft tissue thickness. Titanium induced the most prominent color change. Zirconia did not induce visible color changes in 2.0-mm-thick and 3.0-mm-thick mucosa, regardless of whether it was veneered. However, with a mucosa thickness of 3.0 mm, no change in color could be distinguished by the human eye on any specimen. Mucosa thickness is a crucial factor in terms of discoloration caused by different restorative materials. In patients with thinner mucosa, zirconia will show the least color change. (Int J Periodontics Restorative Dent 2007;27:251–257.)

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In implant dentistry, a large variety of materials are available for restoring single or multiple implants. Decision making in implant prosthetics is often based on the question of which restorative material will meet the physical and esthetic requirements of a given patient situation. The most frequently used abutment materials for implant reconstructions include gold, titanium, veneering ceramic, alumina (Al_2O_3), and zirconia (ZrO_2). The choice of material depends on a number of criteria, including long-term stability, compatibility with oral tissues, esthetics, and costs. Several clinical studies have documented good long-term stability with titanium and zirconia abutments for the restoration of single-tooth implants for 3 to 5 years.[1–3] In addition, experimental studies have shown that both titanium and zirconia have excellent biocompatibility and are able to establish a soft tissue attachment when used for transmucosal healing.[4,5] Whereas zirconia and titanium have similar properties regarding long-term stability and biocompatibility, differences might be expected with respect to esthetics.

Comparison of Clinical Performance of Zirconia Implants and Titanium Implants in Animal Models: A Systematic Review

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Purpose: *This study aimed to compare the values of removal torque (RT) and bone-implant contact (BIC) reported in different animal studies for zirconia and titanium implants.* ***Materials and Methods:*** *A systematic review of the literature was performed to analyze BIC and RT of animal studies in which both zirconia and titanium dental implants were used. To identify the studies to include in this systematic review, an exhaustive search of PubMed was performed of animal studies published in English with reports on the quantification of the osseointegration of both titanium and zirconia implants by means of BIC and/or RT. The results were aggregated and analyzed within each of the animal models (pig, rabbit, rat, monkey, dog, and sheep).* ***Results:*** *The selection process resulted in a final sample of 16 studies. In general, no significant differences were found between titanium and zirconia. The significant differences in terms of BIC and RT reported by the authors were attributable to the different surface treatments and microporosities of the implant surfaces studied, not to the materials themselves. Only two articles reported significantly lower BIC for modified zirconia implants as compared to modified titanium implants. Four authors described statistically significant differences in terms of RT between zirconia and titanium implants in the different animal models, regardless of the surface treatment received by the implants.* ***Conclusions:*** *Within the limitations of this study, the values for the BIC and RT of zirconia implants in most of the studies analyzed did not show statistical differences compared with titanium implants. Modified-surface zirconia may have potential as a candidate for a successful implant material, although further clinical studies are necessary.* Int J Oral Maxillofac Implants 2014;29:311–320. doi: 10.11607/jomi.2817

Key words: *dental implants, titanium, zirconia*

The replacement of teeth with dental implants in partially or completely edentulous patients is a widely accepted and documented treatment modality.[1–5] The materials most commonly used for this purpose are commercially pure titanium and titanium alloys because of their biocompatibility and excellent mechanical properties.[1–3] Commercially pure titanium has different degrees of purity (grades 1 to 4), as characterized by oxygen, iron, and carbon content.[6] Most implants are made of grade 4 titanium, since it is stronger than the other grades.[6] Titanium alloys are typically titanium-aluminum-vanadium (Ti-6Al-4V) (grade 5 titanium alloy), which has greater strength and fatigue resistance than pure titanium.[6]

Since the introduction by Brånemark et al[1,2] of the biologic concept of osseointegration, defined as a direct structural and functional connection between ordered living bone and the surface of a load-carrying implant, titanium has been considered the gold standard material used for dental implants.[1–5] Ten-year survival rates above 95% and 15-year survival rates above 90% have been reported[3,5,7] for machined titanium implants.

Zirconia has been proposed as an alternative to titanium as an implant material primarily for esthetic reasons.[8] When titanium implants are used, especially in anterior sites in the mouth, they can produce poor esthetics; the greyish color of the implant body is exposed after soft tissue recession or if a thin gingival biotype is present. The material of zirconia implants is yttria-stabilized zirconia ceramic (Y-TZP), which

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Use of Zirconia in Dentistry: An Overview

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Abstract: Due to an increasing interest in esthetics and concerns about toxic and allergic reactions to certain alloys, zirconia was proposed as a new ceramic material in the later part of 20th century. It has become a popular alternative to alumina as biomaterial and is being used in dental applications for fabricating endodontic posts, crown and bridge restorations and implant abutments. It has also been applied for the fabrication of esthetic orthodontic brackets. This article presents a brief history, dental applications and new methods for fabrication of zirconia improving its mechanical properties. Additionally, the bonding between zirconia and resin cements as well as conventional cementation has been discussed. The methods of the improvement of the bonding strength have also been highlighted.

Keywords: Zirconia, dentistry, alumina-zirconia nanocomposites, CAD/CAM, functionally graded concept, interfacial adhesive.

1. INTRODUCTION

Zircon has been known as a gem since ancient times. The name zirconium comes from the Arabic "*Zargun*" (golden in color) which in turn comes from the two Persian words "*Zar*" (Gold) and "*Gun*" (Color) [1]. Zirconia is a crystalline dioxide of zirconium. Zirconium oxide was first used for medical purposes in 1969 for orthopedic application. It was proposed as a new material for hip head replacement instead of titanium or alumina prostheses [2].

Due to an increasing interest in esthetics and concerns about toxic and allergic reactions to certain alloys, patients and dentists have been looking for metal-free tooth-colored restorations. Therefore, the development of new high strength dental ceramics, which appear to be less brittle, less limited in their tensile strength, and less subject to time dependent stress failure, has dominated in the later part of 20th century. These capabilities are highly attractive in prosthetic dentistry, where strength and esthetics are paramount [3-5].

It has become a popular alternative to alumina as biomaterial and is used in dental applications for fabricating endodontic posts, crown and bridge restorations and implant abutments. It has also been applied for the fabrication of esthetic orthodontic brackets [6]. The mechanical properties of commercial yttria stabilized zirconia are given in Table **1** [1].

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Table 1. Mechanical Properties of Zirconia

Mechanical Properties	Amount
Density	6.05 g/cm^3
Hardness	1200 HV
Bend strength	900-1200 MPa
Compressive strength	2000 MPa
Fracture toughness	7-10 MPam^{½}
Young's modulus	210 GPa
Thermal expansion coefficient	11x10^{-6} 1/K

Zirconia is organized in three different patterns: monoclinic (M), tetragonal (T), and cubic (C). Pure zirconia is monoclinic at room temperature and remains stable up to 1170°C. Above this temperature, it transforms into tetragonal and then into cubic phase that exists up to the melting point at 2370°C. During cooling, the tetragonal phase transforms back to monoclinic in a temperature ranging from 100°C to 1070°C [1].

2. DENTAL APPLICATION OF ZIRCONIA

Although many types of zirconia-containing ceramic systems are currently available [7], only three are used to date in dentistry. These are yttrium cation-doped tetragonal zirconia polycrystals (3Y-TZP), magnesium cation-doped partially stabilized zirconia (Mg-PSZ) and zirconia-toughened alumina (ZTA).

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In vitro performance of zirconia and titanium implant/abutment systems for anterior application

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ABSTRACT

Objectives: To investigate the type of failure and fracture resistance behaviour of different zirconia and titanium implant/abutment systems for anterior application.

Methods: Eight groups of implant–abutment combinations (n = 8/system) were restored with identical full-contour zirconia crowns. The systems represented one-piece and multi-piece zirconia (Z) or titanium (T) implants/abutments with different types of connection (screwed = S, bonded = B). The following combinations (implant–abutment-connection) were investigated: ZZS, ZZB, ZZZB (three-piece), ZTS, TTS, TTS reference, and Z (one-piece, 2×). To simulate clinical anterior loading situations the specimens were mounted into the chewing simulator at an angle of 135° and subjected to thermal cycling (2 × 3000 × 5°/55 °C) and mechanical loading (1.2 × 10^6 × 50 N; 1.6 Hz). Fracture resistance and maximum bending stress were determined for all specimens that survived ageing. Data were statistically analyzed with the Kolmogorov–Smirnov-test and one-way ANOVA (α = 0.05). Survival performance was calculated with the Kaplan–Meier Log-Rank test.

Results: Independent of the material combinations screwed systems showed partly failures of the screws during simulation (ZZS: 3×, ZTS: 8×, TTS: 3×). Screw failures were combined with implant/abutment fractures of zirconia systems. Zirconia one-piece implants and the reference system did not show any failures, and only one specimen of the systems with a bonded connection (ZZZB) fractured. Mean (±standard deviation) fracture forces and maximum bending stresses differed significantly (p = 0.000) between 187.4 ± 42.0 N/250.0 ± 56.0 N/mm^2 (ZZZB) and 524.3 ± 43.1 N/753.0 ± 61.0 N/mm^2 (Z).

Conclusions: Both material (zirconia or titanium) and the type of connection influenced failure resistance during fatigue testing, fracture force, and maximum bending stress.

Clinical significance: Different material combinations for implants and abutments as well as different types of connection achieved acceptable or even good failure and fracture resistance that may be satisfactory for anterior clinical application.

1. Introduction

Yttria-stabilized zirconia (Y-TZP) ceramics have proven their suitability for many clinical applications in dentistry. Zirconia has high potential to be successfully used for fixed partial dentures, root posts, and implant abutments.[1,2] However, the few scientific data on the performance of zirconia implants available mainly consist of case reports and are restricted to

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Soft Tissue Healing at One-Piece Zirconia Implants Compared to Titanium and PEEK Implants of Identical Design: A Histomorphometric Study in the Dog

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This study aimed to histomorphometrically evaluate the soft tissue reactions of one-piece zirconia implants versus titanium implants in regard to their insertion depth. Four one-piece implants of identical geometry were inserted on each side of six mongrel dogs: an uncoated zirconia implant, a zirconia implant coated with a calcium liberating titanium oxide, a titanium implant, and an experimental implant made of a synthetic material. Using a split-mouth design, they were inserted in both submerged and nonsubmerged healing modes. After 4 months, dissected blocks were stained with toluidine blue to histologically assess the marginal portion of the implant mucosa, apical extension of the barrier epithelium, and margin level of bone-to-implant contact. The inflammation status at the crestal part of the implant was assessed as well. The histomorphology presented the typical soft tissue configuration of barrier epithelium and connective tissue near the bone-to-implant contact. Histomorphometrically, the length of the barrier epithelium did not differ significantly concerning material type or healing modality. Furthermore, the inflammation signs were higher with nonsubmerged implants. The submerged uncoated zirconia implants, however, showed few signs of inflammation. Within the limits of this study, it is concluded that uncoated and coated zirconia implants are capable of establishing sufficient soft tissue configurations that are comparable to those of titanium implants. (Int J Periodontics Restorative Dent 2013;33:669–677. doi: 10.11607/prd.1043)

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Dental implants made from ceramic materials have been used since 1969, when Sandhaus presented the first aluminum oxide (Al_2O_3) implant. In 1974, the Tübingen implant was introduced and investigated by clinical studies. Although the biologic material characteristics provided sufficient osseointegration, the frequent fracture incidence led to the substitution of Al_2O_3 by titanium.[1] Zirconia, however, has material characteristics more similar to those of titanium.[2] Several in vivo animal studies have examined the bone response to zirconia implants.[3–6] Recently, the authors have shown similar osseointegration properties of zirconia implants compared with titanium implants.[7]

The long-term success of implants, however, requires not only osseous integration but also the establishment of a mucosal barrier around the implant to generate a sufficient seal between the oral cavity and the bone margin. After implant placement, soft tissue formation is characterized by the gradual shift from a coagulum to granulation tissue followed by the formation of a barrier epithelium

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Histological analysis of loaded zirconia and titanium dental implants: an experimental study in the dog mandible

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Abstract

Objective: To assess whether or not peri-implant soft tissue dimensions and hard tissue integration of loaded zirconia implants are similar to those of a titanium implant.

Materials and methods: In six dogs, two one-piece zirconia implants (VC, ZD), a two-piece zirconia implant (BPI) and a control one-piece titanium implant (STM) were randomly placed. CAD/CAM crowns were cemented at 6 months. Six months later, animals were killed and histomorphometric analyses were performed, including: the level of the mucosal margin, the extent of the peri-implant mucosa, the marginal bone loss and the bone-to-implant contact (BIC). Means of outcomes variables were calculated together with their corresponding 95% confidence intervals.

Results: In general, the mucosal margin was located coronally to the implant shoulder. The buccal peri-implant mucosa ranged between 2.64 ± 0.70 mm (VC) and 3.03 ± 1.71 mm (ZD) (for all median comparisons $p > 0.05$). The relative marginal bone loss ranged between 0.65 ± 0.61 mm (BPI) and 1.73 ± 1.68 mm (ZD) (buccal side), and between 0.55 ± 0.37 mm (VC) and 1.69 ± 1.56 mm (ZD) (lingual side) ($p > 0.05$). The mean BIC ranged between 78.6% ± 17.3% (ZD) and 87.9% ± 13.6% (STM) without statistically significant differences between the groups ($p > 0.05$).

Conclusions: One- and two-piece zirconia rendered similar peri-implant soft tissue dimensions and osseointegration compared to titanium implants that were placed at 6 months of loading. Zirconia implants, however, exhibited a relatively high fracture rate.

Key words: bone; crowns *(all Mesh terms)*; dental implants; histology; titanium; zirconium oxide

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Conflict of interest and source of funding statement

The authors do not report to have any conflict of interest to any products related to this study.

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Dental implants made of titanium and titanium alloys are considered as the gold standard and have successfully been used for a variety of indications including the support of removable prostheses, fixed single tooth reconstructions and fixed dental prostheses (Jung et al. 2012, Pjetursson et al. 2012, Roccuzzo et al. 2012). Hard and soft tissue integra-

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In Vitro Biofilm Formation On Titanium And Zirconia Implant Surfaces

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Background: It has been hypothesized that zirconia might have a reduced bacterial adhesion compared to titanium; however, results from experimental studies are rather controversial. The aim of the present study was to compare biofilm formation on zirconia and titanium implant surfaces using an in vitro 3-species biofilm and human plaque samples.

Methods: Experimental disks made of titanium (Ti-M, Ti-SLA) or zirconia (ZrO_2-M, ZrO_2-ZLA) with a machined or a sandblasted and acid-etched surface topography were produced. Applying an in vitro 3-species biofilm or human plaque samples for bacterial adhesion to each type of disk after 72 hours of incubation was assessed using an anaerobic flow chamber model.

Results: Zirconia showed statistically significant reduction in 3-species biofilm thickness compared to titanium (ZrO_2-M: 8.41µm; ZrO_2-ZLA: 17.47µm; Ti-M: 13.12µm; Ti-SLA: 21.97µm); however, no differences were found regarding 3-species-biofilm mass and metabolism. Human plaque analysis showed optical density values of 0.06 and 0.08 for ZrO_2-M and ZrO_2-ZLA, and values of 0.1 and 0.13 for Ti-M and Ti-SLA, respectively; indicating statistically significant reduction in human biofilm mass on zirconia compared to titanium. Additionally, zirconia revealed statistically significant reduction in human plaque thickness (ZrO_2-M: 9.04µm; ZrO_2-ZLA: 13.83µm; Ti-M: 13.42µm; Ti-SLA: 21.3µm) but a similar human plaque metabolism compared to titanium.

Conclusion: Zirconia implant surfaces showed statistically significant reduction in human plaque biofilm formation after 72 hours of incubation in an experimental anaerobic flow chamber model compared to titanium implant surfaces.

KEY WORDS:

Zirconium oxide, Titanium, Biofilms, Bacterial Adhesion, Dental Materials, Dental Implants.

Peri-implant infections are among the main reasons for early and late implant failures.[1] With regard to infections of successfully osseointegrated and functionally loaded implants, a reversible inflammatory reaction in the peri-implant soft tissues, termed peri-implant mucositis, has to be distinguished from inflammatory reactions that are associated with peri-implant pocket formation and bone loss, named peri-implantitis.[2-4] With regard to the etiology of peri-implant infections, microbial colonization is very important.[5-7] In detail, on teeth and implant surfaces, bacteria live in mixed and structured communities that are irreversibly attached to each other and to the surface of the substrate. These bacterial communities are termed as biofilm and lead to plaque accumulation over time.[8] Similar to teeth, it has been

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An *in vitro* biofilm model associated to dental implants: Structural and quantitative analysis of *in vitro* biofilm formation on different dental implant surfaces

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ABSTRACT

Objectives. The impact of implant surfaces in dental biofilm development is presently unknown. The aim of this investigation was to assess *in vitro* the development of a complex biofilm model on titanium and zirconium implant surfaces, and to compare it with the same biofilm formed on hydroxyapatite surface.

Methods. Six standard reference strains were used to develop an *in vitro* biofilm over sterile titanium, zirconium and hydroxyapatite discs, coated with saliva within the wells of pre-sterilized polystyrene tissue culture plates. The selected species used represent initial (*Streptococcus oralis* and *Actinomyces naeslundii*), early (*Veillonella parvula*), secondary (*Fusobacterium nucleatum*) and late colonizers (*Porphyromonas gingivalis* and *Aggregatibacter actinomycetemcomitans*). The developed biofilms (growth time 1 to 120 h) were studied with confocal laser scanning microscopy using a vital fluorescence technique and with low-temperature scanning electron microscopy. The number (colony forming units/biofilm) and kinetics of the bacteria within the biofilm were studied with quantitative PCR (qPCR). As outcome variables, the biofilm thickness, the percentage of cell vitality and the number of bacteria were compared using the analysis of variance.

Results. The bacteria adhered and matured within the biofilm over the three surfaces with similar dynamics. Different surfaces, however, demonstrated differences both in the thickness, deposition of the extracellular polysaccharide matrix as well as in the organization of the bacterial cells.

Significance. While the formation and dynamics of an *in vitro* biofilm model was similar irrespective of the surface of inoculation (hydroxyapatite, titanium or zirconium), there were significant differences in regards to the biofilm thickness and three-dimensional structure.

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CLINICAL ORAL IMPLANTS RESEARCH

Review

Titanium allergy: could it affect dental implant integration?

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Key words: biomaterials, patient centered outcomes, structural biology, tissue physiology

Abstract

Purpose: Degradation products of metallic biomaterials including titanium may result in metal hypersensitivity reaction. Hypersensitivity to biomaterials is often described in terms of vague pain, skin rashes, fatigue and malaise and in some cases implant loss. Recently, titanium hypersensitivity has been suggested as one of the factors responsible for implant failure. Although titanium hypersensitivity is a growing concern, epidemiological data on incidence of titanium-related allergic reactions are still lacking.

Materials and methods: A computer search of electronic databases primarily MEDLINE and PUBMED was performed with the following key words: 'titanium hypersensitivity', 'titanium allergy', 'titanium release' without any language restriction. Manual searches of the bibliographies of all the retrieved articles were also performed. In addition, a complementary hand search was also conducted to identify recent articles and case reports.

Results: Most of the literature comprised case reports and prospective *in vivo*/*in vitro* trials. One hundred and twenty-seven publications were selected for full text reading. The bulk of the literature originated from the orthopaedic discipline, reporting wear debris following knee/hip arthroplasties. The rest comprised osteosynthesis (plates/screws), oral implant/dental materials, dermatology/cardiac-pacemaker, pathology/cancer, biomaterials and general reports.

Conclusion: This review of the literature indicates that titanium can induce hypersensitivity in susceptible patients and could play a critical role in implant failure. Furthermore, this review supports the need for long-term clinical and radiographic follow-up of all implant patients who are sensitive to metals. At present, we know little about titanium hypersensitivity, but it cannot be excluded as a reason for implant failure.

Osseointegration has been described as 'a process in which a clinically asymptomatic rigid fixation of alloplastic material is achieved and maintained in bone during functional loading' (Zarb & Albrektsson 1991). The implication of this discovery has been the use of titanium oral implants by clinicians to replace missing teeth; today such implants have become an essential and predictable treatment for the oral rehabilitation of patients with tooth loss. Although success rates are high, failed implant treatment still presents a significant clinical, psycho-social and financial challenge for clinicians and patient alike (Mardinger et al. 2008). Implant failure during the initial healing period and after osseointegration has been extensively reviewed in the literature (Friberg et al. 1991; van Steenberghe & Quirynen 1993; Esposito et al. 1998a, 1998b; Montes et al. 2007; Alvim-Pereira et al. 2008). Factors including surgical trauma, impaired healing ability, bone characteristics, systemic reasons and implant-related factors have been implicated.

In the main, successful osseointegration has been ascribed to the use of dental implants manufactured from titanium. Titanium has long been regarded as a biocompatible material with high corrosion resistance due to its thin protective oxide (TiO_2 or titania) layer, which spontaneously develops on its surface when exposed to air. Titanium is a non-essential element – no enzymatic pathway has been elucidated that requires titanium as a cofactor. Moreover, there does not appear to be any physiological mechanism for the homeostatic control of titanium (Luckey & Veugapal 1979). Since the 1960s, titanium has developed into a popular metallic biomaterial because of its properties, with many biomechanical applications including arthroplasty, osteosynthesis, pace-maker cases, oral reconstructive procedures, anchorage of bone conductive hearing aids and epistheses as well as jewellery for body piercing. It should be noted, however, that no material can be considered universally biocompatible and this does include titanium (Williams 1994).

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REVIEW Open Access

General review of titanium toxicity

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Abstract

Background: Titanium is a commonly used inert bio-implant material within the medical and dental fields. Although the use of titanium is thought to be safe with a high success rate, in some cases, there are rare reports of problems caused by titanium. In most of these problematic reports, only individual reports are dominant and comprehensive reporting has not been performed. This comprehensive article has been prepared to review the toxicity of titanium materials within the medical and dental fields.

Methods: We used online searching tools including MEDLINE (PubMed), Embase, Cochrane Library, and Google Scholar by combining keywords such as "titanium implant toxicity," "titanium implant corrosion," "titanium implant allergy," and "yellow nail syndrome." Recently updated data has been collected and compiled into one of four categories: "the toxicity of titanium," "the toxicity of titanium alloys," "the toxicity of titanium implants," and "diseases related to titanium."

Results: Recent studies with regard to titanium toxicity have been increasing and have now expanded to the medical field in addition to the fields of environmental research and basic science. Problems that may arise in titanium-based dental implants include the generation of titanium and titanium alloy particles and ions deposited into surrounding tissues due to the corrosion and wear of implants, resulting in bone loss due to inflammatory reactions, which may lead to osseointegration failure of the dental implant. These titanium ions and particles are systemically deposited and can lead to toxic reactions in other tissues such as yellow nail syndrome. Additionally, implant failure and allergic reactions can occur due to hypersensitivity reactions. Zirconia implants can be considered as an alternative; however, limitations still exist due to a lack of long-term clinical data.

Conclusions: Clinicians should pay attention to the use of titanium dental implants and need to be aware of the problems that may arise from the use of titanium implants and should be able to diagnose them, in spite of very rare occurrence. Within the limitation of this study, it was suggested that we should be aware the rare problems of titanium toxicity.

Keywords: Titanium toxicity, Titanium dental implant toxicity, Titanium allergy, Titanium corrosion, Yellow nail syndrome

Background

Titanium is one of the most widely used materials for dental implants due to its mechanical strength, biocompatibility, and a long history of use [1, 2]. Current titanium dental implants possess a high success rate; however, failures are still being reported [3–5]. Cause of these implant failures can be poor oral hygiene, uncontrolled deposition of plaque, and calculus around the implant which cause peri-implantitis or occlusal problems. In the light of new investigations in biological and mechanical aspects, the allergy response to dental implant materials and toxicity of the particle released from implant system are reported to have a role in implant failure [6, 7]. There are also a variety studies on titanium and its alloys as well as implant surface treatment materials to determine their toxicity behavior and its mechanism [8, 9]. Typical examples include bone loss due to inflammation reactions due to implant corrosion [10–12], hypersensitivity to titanium and allergic reactions [13–16], and yellow nail syndrome [17–20].

Titanium is also used commonly in industrial applications such as coatings for pharmaceuticals, processing

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