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Design and optimization of a dental implant

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The basis of this process is to design a dental implant and different associated prosthetic components, with the principal objective of creating an innovative dental implant model which allows a better final integration in the patient. Additionally, the model should be compatible with other dental components currently available in the market and able to be made using a good manufacturing process. Firstly, the state of the art is researched by analyzing the main manufacturers in the sector, the main techniques of dental implantology, the medical treatments and the associated medical framework. Secondly, a study is made of the design and functionality of the prosthetic components, which form part of the different surgical stages in the insertion of the implant, as well as their prior manufacture. Finally, as a consequence of these previous steps, a new more creative design is developed. This design improves the integration in the bone (osseointegration), increases stability and allows for adjustment to the majority of other components in the current market.

Keywords: Dental implant; Design Methodology; industrial feasibility; CAE

Diseño y optimización de un implante dental

Se establece el proceso de diseño de un implante dental y de los diferentes componentes proteicos asociados. Como principal objetivo se plantea el diseñar un modelo de implante dental innovador que permita conseguir una mejor integración final en el paciente, que sea compatible con el resto de componentes dentales presentes en el mercado, y que permita un buen proceso de fabricación. En primer lugar, se investiga el estado de la técnica analizando los principales fabricantes del sector, las principales técnicas de implantología dental, los tratamientos médicos y el marco medico asociado. En segundo lugar, se estudia el diseño y funcionalidad de los componentes proteicos que forman parte de las diferentes etapas quirúrgicas durante la inserción del implante, así como la fabricación previa de esta. Y finalmente, como consecuencia de los apartados anteriores, se elabora una nueva propuesta más creativa que mejora la integración ósea (osteointegración), la estabilidad, y posibilita la adaptación con la mayoría de los otros componentes presentes en el mercado actual.

Palabras clave: Implante dental; Metodología de diseño; Viabilidad industrial; CAE

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1. Introduction

According to the National Institute of Dental and Craniofacial Research (2017), adults in the range of 20 to 64 years old, have an average of 24.92 percent of remaining teeth, rather than 32 in a normal adult mouth. The main causes of tooth loss are poor or inexistent dental care, dental hygiene neglection, gum disease, smoking, diabetes, high blood pressure, rheumatoid arthritis among others.

Dental implants are surgical components, which interface with the bone of the jaw or skull providing support to dental prosthesis, being a quasi-permanent solution for the replacement of lost teeth. Endosseous implants are usually made of biocompatible materials such as titanium and feature a threaded external shape, which allows a good grafting in the bone. Currently, a great variety of dental implants can be used depending on the patient's needs, as well as a series of prosthetic components to be connected to the implant during the different surgical phases.

2. Objective

The main purpose of this work is to analyse the design and manufacturing process of endosseous implants in pursuance of creating an innovative dental implant, which improves assimilation into the patient's body, besides seeking compatibleness with the prosthetic components already available in the market.

3. Dental Implants

Dental implants are surgical devices conceived for replacing lost teeth (acting as artificial roots) which are capable of a total healthy and organic integration with the rest of oral tissues.

Those implants will support the crown or dental prosthesis, which will be as similar as possible to a real tooth

The prosthesis consists of:

- Dental implant: the part remaining under the gum line.
- Abutment: the part that comes out of the gum line.
- Custom-made crown or prosthesis: covers the abutment, it is the only visible part.



Figure 1: Dental implants

From a biomedical perspective, the main features of a dental implant are:

- **Osseointegration and biointegration**: These are the two interfaces considered direct interfaces. Osseointegration is the direct structural and functional connection between the living bone and the implant surface, which has to withstand functional loads. Biointegration is the chemical bond formed on a layer between the implant and the bone. This layer is made of chemical compounds such as the hydroxyapatite (a bioactive material for the bone tissue) which form favourable tissue connections that allow the creation of direct bonds with the bone.
- **Stability:** refers the implant capacity to withstand axial and lateral loads and rotations.
- Able to prevent peri-implant diseases: in means of minimizing the risk of suffering associated to the teeth and the implants such as peri-implant mucositis and peri-implantitis.
- **Suitable for the different types of bone** (quantity and quality): The type of bone is a critical factor in treatment planning.

Different biomaterials and surface treatments have been analysed to reach the best solution. Therefore, the selected biomaterial must meet the following requirements (Breme & Biehl, 1998), (Ratner, 2004):

- Biocompatibility: must perform its function without causing a rejection in the patient
- Inertness. Non-toxic for the patient and not biologically active.
- Osseointegration promoter.
- Corrosion resistance.
- Processability.
- Availability.

Materials compatible with these requirements are pure titanium, silicon nitride, cobalt-chrome alloys, and PEEK (polyether ketone).

Desirable secondary features are: a high mechanical resistance, consistency, dimensional stability after sterilization, long-term biocompatibility, allowing for an easy checking once in place, osteoprogenitor cells attractant, hydrophilicity, and disinfectant properties... etc.

Regarding the surface treatment, a rugged surface is preferable. Also, that the treatment should improve the chemical and biological properties of the material with a view to increasing biointegration and osseointegration.

4. Threaded Endosseous Dental Implants

Dental implants have three main parts:

• Apex: the tip where the placement of the implant begins.

- Body: the central part which contains the thread and has an important effect on the implant final stability.
- Crest module (also collar or neck): the upper part where the higher tensions between the implant and the bone accumulate.

Other parts to consider:

Connection: provides a mechanical link between implant and abutment. This feature is used to distinguish and identify the different leading brands. Currently the internal connection is the most widely used, since it grants better results in terms of abutment-implant stability, bacterial sealing and microgap (Quiñones, 2010).

Figure 2: Dental implants connections



Prosthetic platform: it refers to the maximum diameter of the implant's surface in contact with the abutment.

Figure 3: Prosthetic platform (source: Nobel Replace)

Platform switching: the diameter of the abutment tapers regarding the diameter of the prosthetic platform.

Figure 4: Platform Switching

Shape: most common shapes are parallel or cylindrical walls as well as conical.

Figure 5: Shape

It is also desirable that the implant-abutment connection features an anti-rotation geometry, for example a hexagonal one, preventing relative spinning between the prosthesis and the implant.

5. Design and Selection Factors for Dental Implants

A single design cannot provide a solution for each patient. Implant requirements are patientspecific and a successful implant treatment does not depend solely on osseointegration and on the implant's design but on the whole prosthetic system. Hence, there are 8 basic needs to be taken in consideration when choosing and designing an implant system. These criteria are based on scientific evidence regarding to avoid the causes of failure and benefit the patient.

5.1. Selecting the implant-abutment connection

There are as many types of connection as manufacturers, and this is the feature that defines the main leading brands. The connection should be chosen from a range that is easy to use,

and as compatible as possible with the main leading brands regarding complications avoidance ensuring the quality of the final result.

Among these complications, one of the most important is the peri-implant bone loss, which is caused by the gap created in the implant-abutment union, known as microgap. When microgap takes place, bacterial leakage is created in this area, which directly affects the peri-implant bone morphology (Weng et al., 2008). Hence, biomechanically stable connections with bacterial seal that maximize bacterial growth inhibition must be chosen to prevent bone damage (Piatelli et al., 2003), (Jiang, 2002).

Another key factor to take into consideration is mechanical overload (Gay-Escoda & Sanchez-Garcés, 2004) (Uribe, 2004) for bone formation in this union, and apparently the Morse type connection gives better assurance (Weng et al., 2008), (Steinebrunner et al., 2008), (Zipprich & Weigl & Lange, 2007).

Loosening of the threaded union over time (Brånemark et al., 1969) is another possible complication, very inconvenient both for professionals and patients. To avoid this problem frictional system implants are used. These implants have no threaded unions, and create a totally watertight cold weld (Urdaneta et al., 2008), (Soliva Garriga & Catalán Bajuelo, 2006).

Regarding the rest of conventional factors, the adjustments between components and salivary contamination during the loading (Theohaidou, 2009), may be singled out for special mention.

It can be said that internal connections are more stable than the flat topped hexagonal external connections (Theohaidou, 2009), (Weiss & Kozak & Gross, 2000).

5.2. Macro design

The dental implant external shape is sometimes underestimated, but it is of crucial importance to assure a good transmission of forces to the bone, and to achieve a good implant insertion (Gay-Escoda & Sanchez-Garcés, 2004). The conical profile has been selected, since it grants better results in most patients.

The threaded profile tapers along the implant in regards of avoiding an equally aggressive attachment across the whole implant length. A double thread has been selected to increase the thread pitch, consequently reducing the insertion time.

The overall geometry selected will condition the increase of the primary stability, the adaptation to existing anatomical defects, and peripheral bone structure preservation or resorption.

After the first curing time of the implant is over, the macro design is no longer important, and the micro design plays a prominent role.

5.3. Micro design

Micro design refers to the implant design in the micro and nano scales. It is necessary to differentiate the topography (which provides the initial attachment) and the chemical characteristics (which define the surface interactions previous to the chemical bond union) (Weiss & Kozak & Gross, 2000).

The most noteworthy among the many parameters that define these surfaces are the average rigidity, and the difference in height between the peaks and valleys of the implant surface. Implants with smooth surfaces (Ra <0,2 μ m) are not used due to poor integration with the tissue, since without unevenness there is no resistance against mechanical loads in the bone-implant interface (Bollen et al.,1996).

Regarding the surface chemistry, the selected material as well as the different surface treatments, have proved to be critical.

Figure 6: Microscopic detail of the rough surface of an implant

5.4. Prosthetic versatility

The objective of implantology focuses on the prosthesis. Therefore, the prosthesis-implant system should be chosen in accordance to the restorative capacity offered.

A stable connection is required so machined abutments capable of working screwed on will be the optimal choice. In the same way, the implant-abutment connection should also be a machined part to keep the strict fitting tolerances needed.

Systems that offer a variety of anchoring and locking elements to be used in different clinical cases will be required too. Finally, the prosthesis-implant system does not have to be complicated; on the contrary, maximum simplicity is preferred.

Figure 7: Prosthetic versatility

5.5. Adaptation to Anatomical Defects and Post-extraction Alveoli

Several geometries have been developed to adapt in a more physiological way to the postextraction alveoli and to preexisting or caused anatomical defects after an atrophic process. It has been shown that the post-extraction alveolus may suffer vertical bone reductions of 3 to 4 mm in the 6 months following the extraction unless regeneration techniques are performed. To perform an immediate implantation, it is mandatory to use geometries that adapt to the alveoli and thus minimize the gap with the adjacent bone. This will facilitate contact osteogenesis and the decrease peri-implant bone healing time (Clemens et al., 1997).

A minimum bone thickness of 1.5 mm around the implant is considered necessary for a correct peri-implant bone regeneration. The use of designs with straight or slightly conical profiles that fit in the alveolus allow the preservation of this bone thickness (Brunsky & Puleo & Nancy, 1999). Bone thicknesses lower than 1.5 mm in the implant vestibular area will contribute to bone resorption.

Figure 8: Adaptation to Anatomical

5.6. Aiming for the Biological Seal

The gingival biological seal consists of the attachment of the gingival mucosa to the crest module of the dental implant in a similar way as it attaches to a natural tooth. This union is a key factor to ensure a successful and durable implant, since it creates a barrier around it that prevents destructing agents (such as bacterial toxins, food remains drinks and other destructive agents) form entering the bone, which would cause the progressive destruction of the bone, and therefore the gradual loss of the implant support.

It is a proven fact that in some cases the biological seal may cause the loss of surrounding bone crest. In case of an existing mucosa thickness <3 mm, the soft tissue resorbs the bone until it attains this thickness and thus develops the biological seal. When this occurs, there is an undesired bone loss regardless of the implant design.

To anticipate this problem two different approaches can be taken:

- Use completely polished neck (abutment) designs, expecting that the soft tissue adapts to this area when resorption occurs.
- Modify the surgical protocol by submerging the implant a little longer so that the bone crest is at the platform level when the mucosa level increases.

In means of facilitating the biological seal, the ideal rugosity and thickness of the abutment or transmucosal necks has been studied, always avoiding a rugosity high enough to lead to bacterial contamination.

It has been observed that rugged abutments contain 25 more bacteria than smooth surface abutments (Bollen et al., 1996).

Figure 9: Biological Seal

5.7. Avoiding Bacterial Invasion of the Microgap

One hypothesis proposes that the implant-abutment interface and the possibility of a bacterial invasion caused by the microgap are responsible for the bone crest resorption.

Supporting this theory, there is evidence that in systems using a conical internal connection there is a microgap reduction with lower bacterial colonization than in systems with an external connection (Cooper, 2000).

Figure 10: Avoiding bacterial invasion

5.8. Reactions to Biomechanical Loading

It is broadly accepted that load transfer is a major factor in success of the bone-implant interface. Both bone an implant are subjected to a certain amount of stresses within the equilibrium range (Geng & Tan & Liu,2001), (Rieger & Adams & Kinzel, 1990).

In the case of the implant, stresses must be such that they avoid material fatigue. Regarding the bone, it is known that overstrain can cause bone resorption while low stresses may result in atrophy from disuse and consequent bone loss (Schwarz, 2000).

Under normal conditions the forces that originate from occlusion conditionate the physiological adaptation of periodontal tissues, and if their adaptive capacity is exceeded injury and trauma may occur (Saffar & Lasfargues & Cherruau, 2000).

Moreover, due to the loss of periodontal tissue during insertion, the occurrence of trauma in the bone-implant interface generates adverse forces that cause mechanical complications in the implant, such as the loss of the thread profile and stress fracture (Schwarz, 2000).

The formation of the bone-implant interface depends on an adequate initial stability. Immediate loading can produce micro movements that stimulate the creation of fibrous tissue (Puleo, 1999). These micro movements are normal in natural teeth (Saffar & Lasfargues & Cherruau, 2000). However micro movements above 100 μ m are sufficient to put at risk osseointegration process.

Figure 11: Reactions to biomechanical loading

6. Original Design

From all the different platforms and lengths available for the range of implants of interest, only the design for the platform RP \emptyset 4.1 and length 11.5 mm will be developed.

6.1. Final Connection

The most beneficial advantage that can be brought to this implant is the modification of the final connection. This will be its most salient feature and it will allow to create a distinctive and innovative design that stands out from the competition. For this reason, a design that emphasizes the combination of good mechanical properties with the maximum compatibility and adaptability to the prosthetic components of the main current brands has been the choice made.

On one hand, it is considered of utmost importance that the connection provides the best conditions for optimal tightening torque, stress concentration, compaction, and seal between the components. For this reason, along with the tri-lobe easy positioning, the Torx® connection has been included.

On the other hand, an adaptation to the prosthetic parts that use an internal hex connection has been seeked. This compatibility will help dentists choose beyond prosthesis range of interest, and to include components form other dental companies. This strategy will allow to gradually introduce this implant model.

For these purposes, the 3Hexular connection has been created. It combines 3 lobes and 3 hexagonal vertexes that allow to obtain good positioning, antirotation, and a perfect seal, as well as enabling the use of prosthetic components from other brands.

Figure 12: 3Hexular connection

More specifically, the vertexes are located matching the dimensions of the Zimmer Dental (6/c, 2.43 mm) connection, and the three lobes match the dimensions of the Tri-lobe Replaces (Nobel Biocare) connection.

The selected anti-rotational system minimizes microgaps and bacterial colonization. The best shape to do so is the conical one with a 9° slope with which "Morse" effect is obtained that allows an optimal force distribution, minimizing micro movements, and creates an airtight sealing, that reduces the loosening rate and bone resorption.

Figure 13: 3Hexular implant

6.2. External Profile

First of all, the crest module will have a polished surface with a Ø3.75 gradually widening to Ø4.1 in a section of less than 1 mm in length. This polished area is designed to sit above the bone crest helping to obtain a perfect adhesion with peri-implant soft tissues as well as biological sealing.

The fact that the crest module closes in the occlusal area - where the union with the abutment is located – will allow for more bone space at the bone crest and will keep the implant-tooth distance needed to preserve the bone in this level.

Next to the polished area, the crest module will have a micro-grooved rugged section beginning at the bone crest level that will increase the implant-bone contact and promote primary stability. These micro grooves will also help decrease stress in the crestal bone level, preventing bone resorption and the accumulation of infectious bacteria.

Regarding the implant body, it has been chosen to adapt it to a conical profile beginning with a small 1.5° slope that will evolve to a sudden 7.5° change before ending at the apex. This facilitates the insertion and gives a very high primary stability.

The thread is double-start, trapezoidal and deep, which enables a very high primary stability. It also offers the advantage of inserting the implant in less than three turns, making the task of the maxillofacial surgeon significantly simpler.

The design of the thread features variable shape and thickness with different profiles for the apical and middle areas. In the apical area, the profile is V-shaped while in the middle area it has a 45° trapezoidal shape. Both this shape and its dimensions have been specially conceived to increase the contact surface with the bone and minimize the invasive process. This makes for the middle thread compacting the bone fragments expelled by the apical thread, favoring total stability

Finally, the apex thread has a rounded profile with a small flat area on the tip to facilitate manufacturing as well as preventing periodontal tissue damage. It will also have two channels that begin at Ø1.8 and will extend helically over a quarter turn up to the middle of the implant body. This double apical channel improves the self-tapping properties, minimizes preparation of the implant surgical bed, and helps store bone fragments generated during insertion.

The chosen material is grade 4 Ti4 titanium according to ISO 5832-2, subsequently applying three surface treatments included in the BONITex® treatment: a mechanical one (peening or abrasive blasting with hydroxyapatite), a chemical one (double acid etching) and very thin calcium phosphate coating.

This treatment results in a high primary stability, rapid appositional bone growth and the creation of a functional layer that shortens the patient's recovery time.

Figure 14: 3Hexular implant

BONITex® treatment

Section with micro grooves increase the contact between the implant and the bones and increase primary and contributes to a general stress decrease in the crestal area.

Double-start thread that contributes to a great primary stability and makes insertion easier due to the thread penetration

Thread design with different shape and thickness in the mid and apical areas. This double profile increases the contact surface with the bone favoring the implant initial insertion

Two self-tapering helical channels to collect bone residue and improve the general self-taper capacity

Polished section that allows for the biological sealing and for a perfect adhesion of peri-implantar tissue. The slope inclination towards the occlusal area promotes bone conservation.

Conical profile body beginning with a small 1.5° slope that evolves to a 7.5° change before ending at the apex. This conic shape facilitates the insertion and gives a very high primary stability

Rounded profile at the apex with a small flat area on the tip to facilitate manufacturing as well as preventing periodontal tissue damage.

7. Conclusions

The design and production of dental implants dental requires a continuous review of the engineering expertise with a view to fulfilling the patient's biomedical needs in order to obtain a satisfactory result.

A dental implant compatible with the components of the main brands in the market has been successfully, featuring a profile that provides a quick and easy final integration into the patient, minimizing the risk of infection and bone resorption, and increasing primary stability.

And finally, it has been confirmed that it is possible to innovate while the sector of implants is a very mature industry.

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