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A new approach to modelling and designing mono-block dental implants

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ABSTRACT

Purpose: of this paper is present a new approach to modelling and design the low cost mono-block dental implants based on the integration of the computer aided techniques. This approach provides the automation of the design process of the mono-block dental implants.
Design/methodology/approach: The approach used to develop the modelling and design of the mono-block dental implants are based on the parametrization of the main geometric features of the implants. This approach allows to generate several designs of the implant with different configurations respect to the dimensions, forms and tolerances.
Findings: The findings are focused on two main topics. The first one is the minimization of the manufacturing cost and time based on the manufacture process automation. The second one is the integration, in the same informatics platform, of the design, analysis and manufacturing environment.
Research limitations/implications: The implications are focused on the development of a new design of mono-block dental implants. One of the main features of this design is associated to the reduction of the surgical stage and their simplification respect to other commercial implants.
Practical implications: The main outcomes and implications of this research is the design of a low cost dental implant. This solution is implemented to assist the social programs of oral health.
Originality/value: The originality of this research is the design of a new model of mono-block dental implant. The structure of this implant improves the mechanical properties; reduce the manufacturing cost and the surgical complications.
Keywords: Automation engineering process; CAD systems; CAM systems; Mono-block dental implant

1. Introduction

At present, the technique of oral rehabilitation used in patients with lack of either partial or total jag pieces uses a group of titanium implants at bony level as supporting structure for setting restorations of crown or bridge type. These devices perform the function of establishing a restoration root, and of granting stability, resistance and capacity of load transmission to the implants. The regenerative physiologic phenomenon, that allows the fixation of the implants to the patient bone, is denominated bone integration. It was discovered and defined by Branemark in the sixties, when using titanium cameras for live studies. The bone integration, from a biomechanic point of view, is defined as the absence of progressive and relative movement among the implants and the surrounding bony structure facing physiologic loads or any other load that can emerge during the patient life.

The bone integrating process is determined by six main factors: 1) the biocompatibility, which is the level of acceptance that presents the guest organism to the production material of the implant; 2) the design, which involves the geometry and the manufacturing features of the implant; 3) the implant surface, involving the level of superficial roughness and the contact surface between the implant and the receptor's bone; 4) the quality or level of the receptor's bone, dealing with the level of solidity that the bone gives to the substrate of the implant; 5) the insert technique, which is the clinical process for setting the implant, the surgery and the conditions of the surgery, and 6) the load conditions applied once the implant has been placed.

From their discovery and until today, the material used for the production of the implants is the titanium, specifically the Pure Titanium Degree ISO 4 [1], which is a material that presents up to now the best biocompatible conditions. As for the constructive type of the implants, it has been established that both, the conical and the threaded configurations, present a better bone integration level and a reduction of the bony retraction which results in a smaller number of rejection or nuisances compared to the flat-cylindrical ones [1-2].

The design, analysis and production methods of the implants are subjected to the use of CAX (Computer Aided eXperiences) techniques, specifically CAD, CAE, CAM and CAL. Due to the nature of the implants, the pattern of tolerances has been proposed by Hunter for the definition of the inspection process [3]. At present, the different makers of dental implants have incorporated physical-chemical post-treatment procedures to the traditional process of production in order to increase the superficial roughness of the implants and to consequently improve even more the bone integrating capacity of the titanium.

Although the current methods of elaboration and post-treatment have proved their clinical effectiveness, conventional and not conventional methods of production are still in use [4-6]. On the other hand, the inclusion of chemical processes implies an increase in the production costs that are inevitably passed over to the patient.

The use of virtual design approaches to model the manufacturing of ceramic implants have been intended [7]. However, at the present time, the titanium implants represent the most efficient and effective form of fixing prosthesis and restoration structures to the patient's mouth.

At present time, the entirety of the implants that are traded possesses two structures: 1) the Implant, or basic supporting structure, and 2) the Pillar, interface or joining structure between the implant and the restoration element. Although this configuration of two elements presents clear advantages regarding the versatility of the implants, it generates areas of stress concentration in the union of the two parts, and it constitutes one of the points with more probability of failures in the implants. On the other hand, the construction of this type of implants implies the application of production processes of great complexity that increase the costs of production of the implants.

This work presents a new approach for the modelling of a mono-block dental implant. For the development of this model, the concept of concurrent engineering applied to the design, analysis and manufacturing of the dental implant has been used. The design parameterization and connectivity among the CAD, CAE and CAM systems is especially sought to optimize the design and automation of the processes related to the development of the implants, and to diminish this way the costs of massifying the solution generated.

2. Description of the approach developed

2.1. Implant description

The design of the implants has been divided in three schematic sections, 1) Area of Integration, 2) Exposed or Neck Area, and 3) Pillar or Area of Restoration. The Area of Integration corresponds to the surface of the implant in direct contact with the bone, which is determined by the tip of the implant or apical area (Figure 1). This area is characterized by a cylindrical form in the middle of its length and a conical form at 1/3 of the total length of this area. The neck, or exposed area, maintains the same height or length for all the implants, only modifying the magnitude of the curvature (Figure 1). The restoration area is the same for all of the implants and it allows the installation of any of them. Besides, this area is the reception surface of the piece or restoration element.

The measures of the implant length are defined by the longitude of the Area of Integration and they correspond to the values of 6, 8, 10 and 12 mm, due to the fact that they are the most used at the present time. The diameter of the implant is defined by the diameter of the cylindrical part of the Integration Area not considering the diameter of the thread. It corresponds to the values of 2.2, 2.8, 3.5 and 4.2 mm, based on the tools for the preparation of channel of the ITI-Straumman system. The Figure 1 shows the design of dental implant developed. The Figure 1 shows the design of dental implant developed.

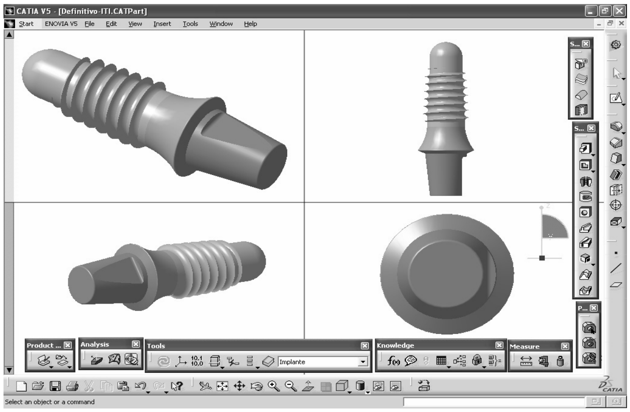

Fig. 1. Implant design

2.2. Parametric implant design

Through the application of techniques of design automation, a basic model is parameterized facilitating the immediate generation of an infinity of models that are subordinated to the diameter and longitude of the implant as well as to the pillar length. The time associated to the design work are notoriously diminished which causes an important cost benefit. By using a computer interface integrated to the software CATIA V5 R14 it is possible to redesing each of the models generated for the environments CAE and CAM for the validation of the pattern and the generation of the codes used in the production of the implants.

The longitudes used to define the Integration Area, which includes the apical area, have been adopted based on the most common lengths used by some of the most relevant companies within this field, such as

ITI-Straumann and Nobel Biocare. Four length and 4 different diameters have been adopted which generate 16 available models, together with the inclusion of 3 different pillar length, in order to satisfy a great variety of clinical requirements.

The lengths are considered from the tip of the apical area until the beginning of the neck. The diameters, as it was mentioned, are measured within the cylindrical area of the implant without considering the external diameter of the threads.

The elaboration of the automated pattern of the dental implants has used a design bases (dimensions: 2.2 mm of diameter and 6 mm length and 7 mm pillar length), in which the relationships and parametrization functions were generated. The Figure 2 shows the process of definition of functions to the design of the one it implants.

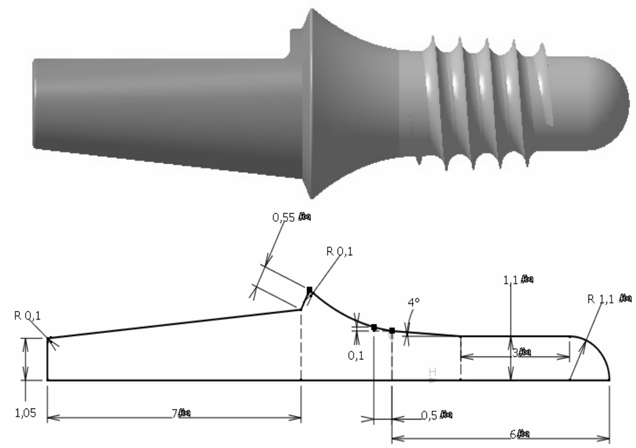

Fig. 2. Function definition for the geometric features

2.3. Description of the implant geometry relationship and functions

The definition of the necessary functions for the automation and redesign of the implant model are presented in this section. In order to achieve the redesign of the implant model, a group of basis parameters that allows the definition of a new implant in an automatic way have been defined.

- IS relationships (Solid Implant): Relationships used in the parameterized base sketch for the generation of the basic solid structure of the pattern. Eight relationships belong to this group.
- GB relationships (Geometric Basic): Relationships used to modify the parameters of the basic geometric elements which are predecessor of the solid thread. These relationships govern the step, longitude and tapering of the wire thread. Six relationships belong to this group.
- EC relationships (CAM Elements): Relationships used to modify the parameters that define the material, its bases and the profiles used for the generation of the factory program. One relationship belongs to this group.

The design is governed by two parameters and 14 relationships. Through these functions, they can be generated in way automatic 16 models different from you implant, geometrically similar.

3. FEM implant analysis

The research developed in this field has been establish the numerical simulation on the biomechanical interactions of dental implants under several forces, load and boundary conditions [8-13].

Taking in consideration the internal and external condition of the FEM analysis the materials bone condition adopted are type 4 according to the classification of Leckhol y Zarb [14]. This type of bone is the worst support for the dental implant, because they have poor mechanical conditions.

The design of the boundary conditions has been defined according to prismatic model of the bone and the relation between cortical and marrow bone is 1:9. The cortical bone is the better and extern layer of the bone. This layer shows a high density microestructure and offers the better mechanical properties for the implant. The marrow bone is the inner part of the bone and present a bad quality because present a low density microstructure. The features of the different tissue are shows in the Table 1.

Table 1.
Materials properties

Parameter	Cortical	Marrow	Titanium
Young Module (GPa)	17	0.69	102
Poisson	0.3	0.25	0.34

The cases analyzed correspond to the implant proponed in this research (CA1), cylindrical non threaded (CA2), cylindrical threaded (CA3), conical non threaded (CA4), conical threaded (CA5) and finally a non threaded implant (CA6). The discretization developed has uses a combination of brick and parabolic tetrahedral elements. The load applied to the analysis has been defined in 100 Newton axial compressions and 50 Newton radial [2]. The models uses for the six cases and the FEM statics are shows in the Figure 3.

The other models has been compared in a similar way, taking in consideration the volumetric different not pass the 5% in comparison with the implant proposed in this paper.

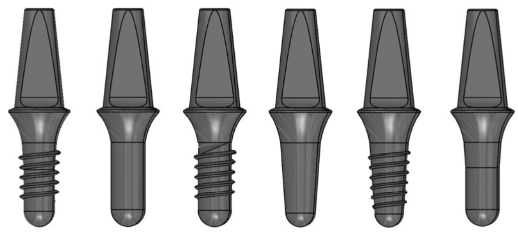

Fig. 3. Cases of the study

The results of the graphics analysis and the numerical results shows the reduction of the strain and stress for the thread implant versus non thread implants. By the other side, the design implant proposed in this paper shows one of the better strain generated at the bone level. The reduction of the strain in the bone interface improves the integration and the healing process of the bone [15-16]. The Figure 4 shows the results of the FEM analysis. The analysis has been developed considering one type of quality bones, type 4 (Cortical and Marrow bone). The design of the dental implant proposed in this research have the best results in strain/stress distribution (CA1 = 0.92 KPa).

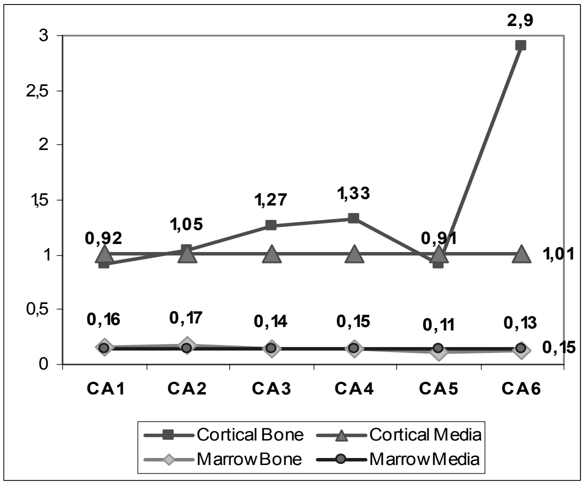

Fig. 4. Results of the FEM Analysis to the dental implant

4. Conclusions

A new design of mono-block dental implant has been proposed in this paper. The main implications of this research are focused in the automation of the implant design and the reduction of the manufacturing cost.

The automation of the design implant has been developed establishing a group of relationships and functions that allow to define a structure of parametric parameters associated to the geometry, dimensions and tolerances. Taking in consideration features one design it has allowed generate 16 different designs of the implant.

The three-dimensional graphic visualization of the mono-block implants provides a realistic definition respect to the geometries and dimensions of the implants, bringing near the designer to the final product. This feature allows the possibility to carry out modifications in real time of the geometric structure of the implants, with the objective of satisfying new requirements of design this product.

The use of automation entities for the design has allowed to define the operations and parameters to automate a base model. This automation allows to generate "on line" the machining lathe tool path, according to the geometry information of the implants.

The use of computer aided techniques in the development of an implants has allowed the direct cooperation between the designer and the dentist, the virtual representation of the implant let the dentist possesses a realistic understanding of the design. The analysis phase has allowed validate the design of the mono-block dental implant respect other commercial solutions. The analysis has been developed considering the worst and the real conditions possible and join the mechanical approaches of resistance, and on the other hand, the clinical approaches of the dentist..

References

[1] C. Johansson, On tissue reactions to metal implants, PhD Thesis, Goteborg: Biomaterials, Handicap Research, Universidad de Goteborg, 1991.

[2] S. Tada et al., Influence of implant design and bone quality on stress/strain distribution in bone around implants: A 3 Dimensional finite element analysis, International Journal of Oral & Maxillofacial Implants 18 (2003) 357-368.

[3] R. Hunter, M. Guzman, J. Möller, J. Perez, Implementation of a tolerance model in a computer aided design and inspection system, Journal of Achievements in Materials and Manufacturing Engineering, 17 (2006) 345-348.

[4] T. Laoui, N. Konstantinovich, A. Sergeevich Artushkevich, L. Froyen, Bone osseointegration tests performed on titanium dental root implants made by laser processing, International Journal of Product Development 1 (2004) 165-171.

[5] N. Moszner, S. Klapdohr, Nanotechnology for dental composites, International Journal of Nanotechnology 1 (2004) 130-156.

[6] R. Hunter, F. Alister, J. Alister, R. Bolomey, J.C. Millar, Integration and automation of CAx techniques for the design and manufacture the low cost dental implant, Chilean Conference of Mechanical Engineering, COCIM 2007, Talca – Chile, 2006 (in Spanish).

[7] T. Ito, T. Sato, Custom-made production of porous ceramics implants towards e-manufacturing, International Journal of Manufacturing Technology and Management 10 (2007) 419-428.

[8] C. Lin, J. Wang, Y. Kuo, Numerical simulation on the biomechanical interactions of tooth/implant supported system under various occlusal forces with rigid/non-rigid connections, Journal of Biomechanics 39 (2006) 453-463.

[9] C. Lin, C. Chang, C. Cheng, C. Wang, H. Lee, Automated finite element mesh generation for maxillary second premolar. Computer Methods and Programs in Biomedicine 59 (1999) 187-195.

[10] B. Rangert, D. Sullivan, Mechanical aspects of a Branemark implant connected to a natural tooth: an in vitro study. The International Journal of Oral & Maxillofacial Implants 6 (1991) 177-186.

[11] C. Lin, J. Wang, Nonlinear finite element analysis of a splinted implant with various connectors and occlusal forces. International Journal of Oral & Maxillofacial Implants 18 (2003) 331-340.

[12] C. Provatidis, A comparative FEM-study of tooth mobility using isotropic and anisotropic models of the periodontal ligament. Finite element method. Medical Engineering & Physics 22 (2000) 359-370.

[13] R. Villaverde, J. Vilán, X. Baltar, FEM analysis of a threaded dental implant, Journal of Achievements in Materials and Manufacturing Engineering 9 (2000).

[14] U. Lekholm, G. Zarb, Patient selection, In: Tissue integrated prostheses. Osseointegration in clinical dentistry, Quintessence Books, Chicago, USA, 1985.

[15] P. Branemark, et al., The osseointegration book, from calvarium to calcaneus, First Edition, Quintessence Boocks, Berlin, Germany, 2005.

[16] J. Lindhe, Clinical periodontology and implant dentistry, 4ª Edition, Blackwell Munksgaard, Oxford, England, 2003.