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Develop mono-block tooth implants using automate design and FEM analysis

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ABSTRACT

Purpose: 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

MATERIALS MANUFACTURING AND PROCESSING

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 biomechanics 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 [1].

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 [2], 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 [2-3].

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 CAI. Due to the nature of the implants, the pattern of tolerances has been proposed by Hunter for the definition of the inspection process [4]. 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 [5-7]. On the other hand, the inclusion of chemical processes implies an increase in the production costs that are inevitably passed to the patient.

The use of virtual design approach to model the manufacturing of ceramic implants has been intended [8]. 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. This configuration derives from the fact that the absence of loads on implants, immediately after the surgery and in the short postoperative term, favours the bony integrative process, and increases the primary stability of the inter-phase implant-bone [9-11].

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 production costs of the implants [12].

The positioning of dental implants of immediate load based on the Novum protocol is settling down as a new methodology of oral rehabilitation. It has been demonstrated that the level of rejection or failure of the implants being installed increases only in 1%, and, in the long term, there are no noticeable differences between the level of bony integration of two-stages implants and implants of immediate load [13].

On the other hand, in spite of the impulse that the implant techniques positioning for immediate load are taking, not yet solutions have been developed nor mono-block or integrated pillar-implants have been massively proved. The advantages that these types of construction give are basically a greater resistance for smaller diameters in comparison to solutions of two stages, as well as more simplicity in construction procedure. This implies a smaller cost for the patient and the decrease of instruments required for the positioning when using geometrically similar pillars or when diminishing the number of parts of the implant-pillar solution. Along with this, the use of restorations of pure ceramics fixed by cementation to the pillar of the implant makes the use of screws unnecessary. Therefore, it simplifies even more the manufacture of implants [12].

In spite of the great competition established world-wide in the implanting area, the costs associated to oral rehabilitation devices, or dental implants, are high, and the value of the rehabilitation treatments is not less. The use of mono-block implants or of integrated pillar facilitates the manufacture process and diminishes the costs associated to the machining of complex structures. Besides, the application and integration of the modern technologies of design and manufactures (CAD/CAE/CAM) makes it possible the generation of an economic and viable oral rehabilitation solution, which facilitates the emerging of special governmental plans of oral health.

This work presents a new approach for modelling 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 morphology

Actually, the full procedures to establish an implant solution use two structures and at least two surgical stages. This derivates from the fact that an implant requires the use of an inter-phase for the positioning the definitive tooth. This fact implies to carry out two surgical interventions; one for the positioning of the implant, which will need a time for the soft muscle tissues to heal and to acquire a certain degree of integration, and a second intervention for the positioning of the inter-phase and the tooth. One of the main reasons of this configuration is based on the Branemark protocol, a referee in implant methods. This protocol defines a condition of zero loads on the implant during the first months after the positioning; that is to say, implants must be isolated of any stress or possible force condition, in order to take to a good end the integration process and prevent the contamination of the implant bone interface.

However, the actual tendency in oral rehabilitation is to use a two stages implant, like a mono-block implant, because this methods allow to allocating an implant with a false crown in the earlier stage of the rehabilitation process. This method provides an aesthetics solution to the patient and a fast response to the functionality of the dental system.

The tooth implant functionality resides in the versatility of the functions that the implants carry out. For example different geometrical forms of the implant are used to replace a dental piece in any position of the jaw or establish a physical connection to repair maxillary zone with lack of bone. An example of the commercial implants is illustrated on the Figure 1. In this figure is able to see one base implant (a) and two interchange pillars (b-c) with different geometric configurations.

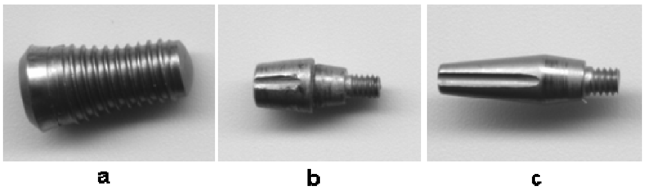


Fig. 1. Geometric features of the two stages implants

The advantage of this kind of implants is the fact that a same base is used for diverse conditions of dental absence. It is even possible the use of pillars of inclined column for frontal pieces or, instead, to use pillars of different length for a same implant. Nevertheless, this constructive type presents a disadvantage. This refers to the fact that the zone of implants that receives the (screwed) inter-phase presents wall thicknesses of the order of tenth of millimetres becoming a zone of stress concentration which causes most of the failures in this kind of implants.

The implant structure responds to a mono-block configuration, that is, the implants and the pillars are integrated in a single device oriented to the positioning of cemented crowns.

Although the mono-block structure does not have the versatility of not integrated implants, and its use is restricted to certain patient clinical conditions, it presents several favourable features. Mainly, it simplifies the number of tools required for its positioning, diminishes the number of surgeries and increases the implant mechanical strength in the neck zone. On the other hand, by not having additional constituent elements the implant itself avoids the formation of bacterial colonies or the deposition of dirt in the joint zones as it happens in traditional implants [12].

Different studies have established the convenience of a threaded form instead of a smooth form. Based on FEM tools and clinical studies, the greater capacity of distribution of load presented by a threaded form compared to a cylindrical form has been demonstrated. This implies a smaller stress in the implant surrounding zone that favours both, the curative process and, as a consequence, the bony integration. On the other hand, through clinical studies, and analysis of removed implants, a smaller index of bony retraction in threading implants compared to smooth implants has been identified. Therefore, it is not by chance that the smooth cylindrical implants are the ones presenting the greater number of failures, translated in deficient bony integration or simply in rejection [3].

Other studies have established that in implants of similar dimensions of a same company (ITI-Straumman), the threaded form determined greater torque of extraction and a greater percentage of bony contact compared to its similar of smooth shape. This reinforces the fact that the threaded structures present a better bony integration condition.

As for the morphology properly so, both, a hemispheric form for the apical zone, and a combination of cylinder and cone for the integration zone has been established. In a first portion of the implant, the smooth cylindrical configuration allows an easy adjustment to the axis of insertion of the bed, and the conical zone provides a progressive adjustment so much of pres-fit as of the height of emergency of the implant. The present tendency shows an inclination for the inclusion of a thread into a large extent of the integration zone, which allows a better adjustment, retention and distribution of stresses on the bony substrate respect to the smooth implants [12].

Both, the neck of the implant and the pillar are based on the ITI-Straumann profile. This is due to the level of massification reached by it and to the effectiveness in the formation of a gum neck. In addition, the pillar forms the element through which the implant is placed. Thanks to the geometric similarity of the 3 types of defined pillars, it is necessary only a unique tool for the positioning of the implants.

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 2). 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 2). 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.

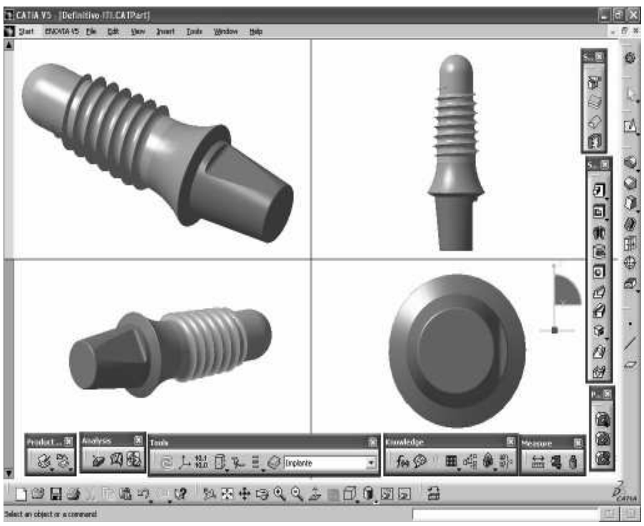


Fig. 2. Implant design

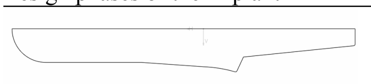
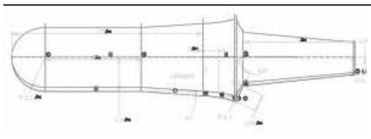
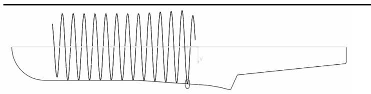
The measures of the implant length are defined by the length of the Area of Integration and they correspond to the values of 6, 8, 10 and 12 mm, due to the fact that they are the most used at the present time. The diameter of the implant is defined by the diameter of the cylindrical part of the Integration 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 2 shows the design of dental implant developed.

2.2. Parametric implant design

Through the application of techniques of design automation, a basic model is parameterized facilitating the immediate generation of infinity models that are subordinated to the diameter and length 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 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 numerical control codes used in the production of the implants.

The design phases defined to develop the parametrization of the implant are shows in the Table 1. The design phases have been structured in six steps. The first one presents the sketch generation in two dimensions. The second step shows the parametrization of the geometric features. These features provide a framework to establish the automation of the implant design. The third step shows the generation of the 3 dimensional geometry of the implant. The fourth step shows the pocket definition in the pillar part of the implant. The fifth and sixth step shows the threads generation of the implants.

Table 1.
Design phases of the implant

	2D Sketch generation of the implant. Definition of the geometric entities.
	Generation of the solid body throughout the shaft operator. Definition of the parameters and formulas to the geometric entities
	Solid body of the implant based on *Pocket* and *Fillet* operators. (Neck area)
	Definition of the base pillar entity based on *Pocket* and *Fillet* operators. (restoration area)
	Definition of the implants threads.
	Generation of the solid part of the thread implant (integration area) based on *Rib* operator.

The length 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.

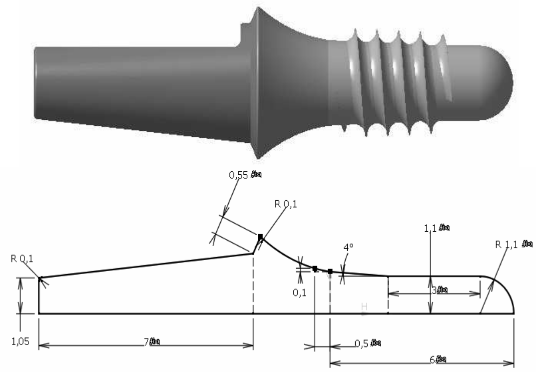


Fig. 3. Function definition for the geometric features

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 3 shows the process of definition of functions to the design of the implants.

2.3. Description of the implant geometry relationships 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 pitch, length and tapering of the wire thread. Four 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.

2.4. Description of the solid body relationships (IS)

This section presents a detailed description of relationship defined to develop the automation of the dimensions and geometric forms of the implants. The main goal of the implants design automation is the definition of several models of the implant. These models have been results of one parametric design of the implants. The Figure 4 shows a description of the relationships defined for the implant design.

Fig. 4. Description of the implant design relations

- IS-1: The IS-1 relation establishes a virtual connection between the "Implant length" and the dimension "Length 210". This relation allows to define the length properties of Length 210 parameter to implant length. The dimension value of the length 210 parameter corresponds to total length of the integration area.
- IS-2: The IS-2 relation establishes a relationship between the implant diameter and the radial apical zone named "Radius 216". The Radius 216 defines the length of the radius of the implant tip.
- IS-3: The IS-3 relation defines the function to determine the length of the implant cylindrical zone, named "Length 256", based on the total integration length of the implant (Length 210). We are establishes that the cylindrical length is the half of the total length of the integration zone.
- IS-4: The IS-4 relation defines a relationship between the implant radius (Radius 216) and the top edge of the implant neck.
- IS-5: The IS-5 relation defines a relationship between the implant diameter parameter and the radius of the cylindrical zone of the implant, named "Length 305". This parameter defines the length between the extern edge of the cylindrical zone and the rotation axis.
- IS-6: The IS-6 relation defines the horizontal position of the spline central point. This relation allows to determine the bend feature of the neck implant. The "Length Implant" is a constraint defined for this relation.
- IS-7: The IS-7 relation defines the relationship between the length of the pocket (defined in the pillar zone) and the length of the pillar zone.
- IS-8: The IS-8 relation modifies the extension of the pillar in 3 dimensions respect to the Length Pillar parameter. This parameter represents a main modification of the geometric features in the implant.

2.5. Description of the geometric Basic relationships (GB)

The geometric basic relationships are used to modify the parameters of the geometric entities. This relationship establishes the main elements to define the length and pitch parameters of the implant thread. The Figure 5 shows the description of the relationship defined to automate the implant design.

Fig. 5. Description of the geometric basic relations

- GB-1: The GB-1 relation corresponds to the angle of the helix parameter. This parameter determines the basic element to define the thread of the conic zone of the implant (Taper Angle). The value of this parameter has been defined in 4 grades.
- GB-2: The GB-2 relation defines the length of the thread, parallel to the rotation axis. This parameter has been defined taking in consideration the projection line that defines the conical zone of the implant.
- GB-3: The GB-3 relation defines a relationship between the pitch of the cylindrical zone (Pitch_2) and the pitch of the conical zone (Pitch_2). Taking in consideration this relation the values of the pitch_1 and pitch_2 are the same.
- GB-4: The GB-4 relation defines the length of the thread in the cylindrical zone.

Finally, the entire design is governed by a group of parameters and 12 relationships. Through these relationships, they can be generated in a automatic way 16 models different to the basic implant design, geometrically similar but with different sizes and forms. The Figure 6 shows the manufactured implant taking in consideration one of the 16 models obtained.

Fig. 6. Manufactured mono-block tooth implant

3. FEM implant analysis

The research developed in this field has been establishing the numerical simulation on the biomechanical interactions of dental implants under several forces, load and boundary conditions [14-19].

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 and Zarb [20]. 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 2 [3].

Table 2.
Materials properties

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

The values obtained in the static FEM analysis are presented in the Table 3. The security factor defined to the FEM analysis has been taking in consideration the yields point and the Von Mises values.

Table 3.
Static stress results

Yield point	Von Mises	Security factor
7.200 Kg/cm2	4.000 Kg/cm2	1.8

The Figure 7 shows the analyze sequence, taking in consideration the application of the boundaring conditions and the loads applied in the static case.

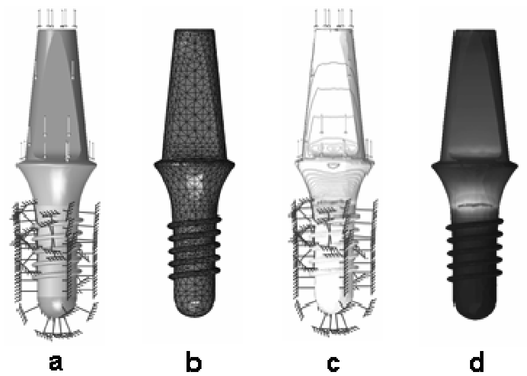


Fig. 7. Analyze sequence of the static case

The previous figure shows that the last models (c and d), the concentration of the strains are located in the neck of the implant, over the bone profile. In this sense, taking in consideration the configuration of the implant, this zone is a critical part of the implant. However, the geometry of the implant proposed, in this research, reduce the problems presented in this zone respect other commercial implants. The main value of this advantage is the increase of the implant stiffness, providing a greater stability of the implant.

By the other side, a comparison between the models proposed in this research with other implants has been presented. The cases analyzed correspond to the implant proposed 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 static are shows in the Figure 8.

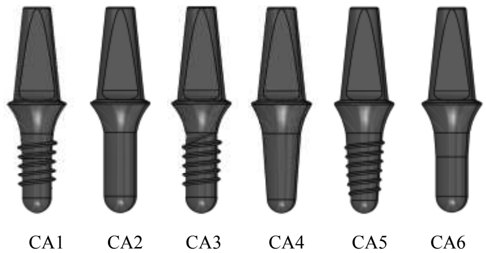


Fig. 8. Cases of the study

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.

The detailed analyses provided a better result of the mono-block implant capacities. In this sense, the comparison developed has been establish, in the case of the smooth implant, the best results are presented in the smooth patter. On the other hand, the implant design proposed in this paper present one of the best results only led by conical thread implant.

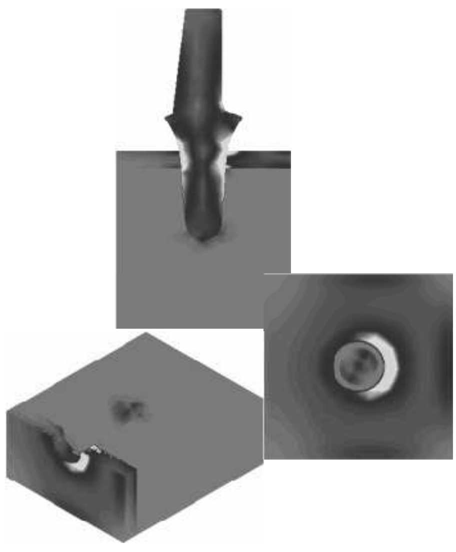


Fig. 9. FEM analysis of the new mono-block implant

Taking in consideration the graphical results, the cortical bone is the most important structure of the implant assembly, because the cortical bone presents the better material properties.

On the other side, 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 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 [12, 21]. The Figure 9 and 10 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).

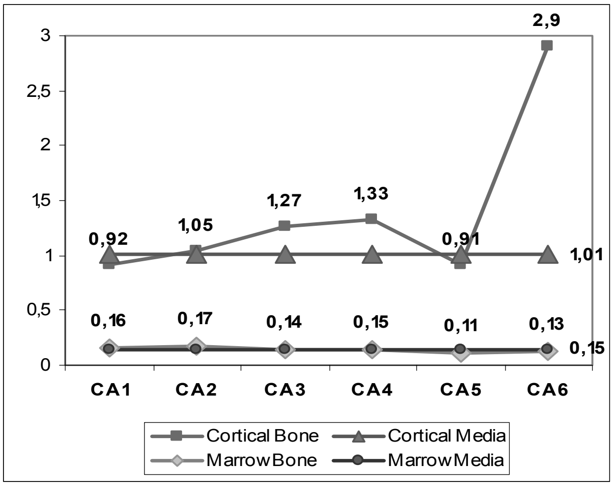


Fig. 10. Results of the FEM Analysis to the dental implant

Fig. 11. Prosthesis and tooth implant prototype

The configuration adopted in our solution present some advantages described in the previous sections. One of the most important features of the mono-block implant design is the reduction of the forces generated on the bone during the bite. Other features of the implant proposed in this paper are presented on the preparation facility and allocation of the implant in the bone.

Finally, the last phase of this research is the study of the materials behaviour assembly. In this case, the research group are develop a prosthesis that simulate the bone features (cortical and morrow bone) with the goal to realize the mechanical test of compression using vertical and angular forces. The Figure 11 shows the preparation probes to develop the compression test. The mechanical test is one of the final stages of this research.

4. Conclusions

A prototype of a new design of mono-block dental implant has been proposed in this paper. This prototype has been manufactured and assembly in a maxillary prosthesis. 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 the geometrical features of 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 joins the mechanical approaches of resistance, and on the other hand, the clinical approaches of the dentist.

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