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Research Article

Simulation of Bone Microstrain of a Bruxomanist Patient with a Dental Implant Finite Element Analysis

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Abstract

Introduction: The purpose of this investigation was to evaluate the bone microstrain in bruxomanist patient with dental implants through the finite element analysis (FEA).

Methods: It was modeled one (1) Tapered Screw-Vent® implant (ref. TSVB10 Zimmer Dental) with a length of 13 mm x 3.7 mm of diameter, with a platform of 3.5mm, a zirconium abutment, a screw, lutting agent, a monolithic ceramic crown of a central superior incisive, cortical and cancellous bone, using the CAD Software of Solid Works 2010 (SolidWorks Corp., Concord, MA, USA), and then it was processed and analyzed through the ANSYS Software 14th edition. Those were evaluated von Misses stress and µstrain, applying loads in transversal direction with magnitudes of 200N and 800N.

Results: Every one of the elements of the modeled structure (Crown, Abutment, Screw, Implant, Cortical and cancellous bone) submitted to the incremental loads, presented Von Misses and µstrain particular values with a lineal behavior. Submitting the modeled structure to loads of 200N and 800N, no one of the components suffered permanent deformations, it means, it was not exceeded the yield strength. Conclusion: According to the mechanic behavior of the modeled structure, in bruxomanist patients is suitable the use of a dental implant in a superior central incisive, because the parafunctional loads generated by the bruxism are not superior to the presented in the modeled structure, therefore those not generate permanent deformations or damage in the bone.

Conclusion: According to the mechanic behavior of the modeled structure, in bruxomanist patients is suitable the use of a dental implant in a superior central incisive, because the parafunctional loads generated by the bruxism are not superior to the presented in the modeled structure, therefore those not generate permanent deformations or damage in the bone.

Keywords: Bone Microstrain; Bruxism; Dental Implant; Finite Element Analysis

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Introduction

Oral implantology procedures in recent decades have experienced significant growth due to their mechanical and biological advantages over treatment options such as fixed partial dentures and removable partial dentures. Despite the high success rates of dental implants, failures still occur, among which are mechanical problems related to occlusal overloads and stress, as is the case with bruxism that is included in occlusal parafunctions [1]. Because bruxism is an important occlusal overload factor, different positions have been generated on the possibility of performing an implant-supported treatment in bruxomanic patients, ranging from contraindication [2], supported by the forces to which the patients are subjected Dental implants and their structures can cause an overload resulting in the loss of bone around the implants or even their failure [3], including wear, fractures or loosening of the fixation screws [4].

Other authors affirm that the parafunctional forces exerted by bruxism are not considered a critical factor in the success of the implant and therefore do not affect the rehabilitation treatment [5]. Kaptein., *et al.* show that the frequency of parafunction is very common and that therefore, the use of implants in patients with parafunctional habits is inevitable [6]. Brunski., *et al.* [7], in their *in vivo* research, concluded that during the planning of implant-supported rehabilitation treatments, bruxism should be considered as a risk factor, since that the consequences of parafunctional movements can endanger the longevity of dental implants, cause changes in the marginal bone and deterioration in osseointegration. Lobbezoo and Naeije [8], in their literature review concluded that there is still insufficient evidence to accept or reject a causal relationship between bruxism and implant failure, which suggests the need to design new studies to determine the possible cause-effect relationship between bruxism, implant failure and bone microdeformation.

Due to the lack of consensus in the literature on the possibility of rehabilitating bruxomaniac patients with implants, the interpretation of the evidence available in recent studies is difficult and also leads to a lack of clarity to the clinician when planning a treatment for this type of patients. There is a real need for well-designed studies to evaluate bone microdeformation in these patients and its possible relationship with a failure in the implant and/or in its osseointegration. Ramos, Albrektsson and Wennerberg suggest that implant overload may contribute to failure, therefore, the risks of implant therapy should be considered as a possible contraindication for treatment, although the evidence for this is generally based only on clinical experience. The obligation to anticipate the results is an essential part for the detection of the risk in the treatment, this includes recognizing occlusal and dental conditions, which will allow informed decisions and refine the treatment plan to optimize the results [1]. Klineberg., *et al.* in their article, they insist that the design of the restoration (the occlusal shape, the contacts, the diameter and the direction of the exerted forces) are factors of high relevance for bone remodeling and the minimization of healing time, in addition to which generate a decr Distribution of efforts in biological structures ease in tension around the restored implants [9].

Purpose of the Study

The purpose of this study is to analyze bone microdeformation with ZIMMER dental implants in a higher exchange in patients with and without bruxism, using as a simulation tool the analysis of finite elements to determine the level of bone deformation, and also, if this level of deformation represents a risk factor in rehabilitation with a dental implant.

Materials and Methods

A three-dimensional geometric model was designed using the Solid Works 2010 CAD Software (SolidWorks Corp., Concord, MA, USA). It was processed and analyzed through ANSYS Software version 14. As a product of these two operations, the following system components were modeled:

- One (1) Tapered Screw-Vent® implant (ref. TSVB10 Zimmer Dental, Carlsbad, CA, USA) 13mm long x 3.7mm in diameter with a 3.5 mm platform, internal hexagon with its respective fixing screw.
- One (1) Zimmer® pre-contoured, straight zirconium abutment with hexagonal internal connection, 4.5 mm emergency profile, 1.0 mm vestibular margin height Reference number: ZRA341S, Manufacturer: Zimmer® Dental 1900 Aston Avenue Carlsbad, CA 92008-7308 USA.
- RelyX™ Unicem 2 Automix resin cement.
- One (1) monolithic ceramic crown in lithium district (IPS E. Max Press), Manufacturer: Ivoclar Vivadent, Schaan; Liechtenstein.

Given the conditions of the modeling, an osseointegration of 100% was assumed. Once obtained, a comparative study was carried out in which the variables of maximum tensile maximum stresses (μstrain) for cortical bone and spongy bone were evaluated, and minimum compressive main stresses (von Mises) for the entire structure in loads of 200N and 800N, with an oblique force vector. This analysis allowed to assess the behavior of the different modeled structures and the effects generated in the bone-implant interface.

The choice of the implant for a superior central incisor, the type of surface, the diameter and the connection of the abutment correspond to that reported in the literature [10].

Three-dimensional geometric modeling

All structures were modeled individually from a design created that simulates an implant to replace a superior central incisor, simulating a DII type bone, according to the Lekholm and Zarb [11] classification; said bone section was reproduced from a sagittal section taken from a tomographic image of the upper jaw, which included the spongy bone and the cortex. When modeling, the gum was not taken into account because it was not important for the simulation of bone microdeformation.

Figure 1: *Rendered image of bone, implant, abutment, screw and crown.*

The isotropic properties for the implant, the abutment, the screw and the crown were evaluated in addition to taking into account the transversally isotropic properties for the cortical and spongy bone. In the bone models of the jaws, the values that represent their elastic properties were introduced. Ideally these should represent bone anisotropy, which is considered anisotropic because it shows different mechanical properties depending on the direction from which they are registered. However, due to the complexity of the modeling of a structure with these characteristics, an approximation may be applicable because the elastic modulus of the cortical bone in buco-lingual and supero-inferior directions is not significantly different, and also this module in the Bone is similar in buco-lingual and mesio-distal directions. With this approximation or transverse isotropy (orthotropic) that is composed of five independent elastic properties, bone anisotropy is best represented [12]. The mechanical properties of the materials used are shown in table 1.

For the analysis of the mechanical behavior of the structure a linear elastic analysis was performed where tetrahedral elements were used (elements that allow three degrees of translational and three rotational freedoms, per node) in order to obtain a better approximation of the geometries of the parts In this way a three-dimensional mesh of finite elements of the model components was obtained.

Material	Elastic Limit (MPa)			Poisson number			Yield stress (MPa)
	X	Y	Z	XX	XY	XZ	
Cortical Bone [8]	10.000	11.000	14.300	370	330	230	60 - 120
Spongy bone [8]	1148	210	1148	50	320	10	60 - 120
Titanium Implant [22,23]	110.000	110.000	110.000	330	330	330	800
Titanium Abutment Screw [24]	110.000	110.000	110.000	330	330	330	800
Pillar of Circona [25-27]	200.000	200.000	200.000	270	270	270	900
Resin Cement [28]	6600	6600	6600	200	300	300	48
Monolithic ceramic crown in lithium disilicate [29]	95. 000	95.000	95.000	23	23	23	350

Table 1: *Mechanical properties of structures and modeled materials.*

Description	Number of Nodes	Number of Elements
Implant	730514	501246
Pillar	1244044	896129
Screw	21270	11912
Crown	251476	71686
Cortical	1443978	1031854
Spongy	1051952	7746127

Table 2: *Details of the mesh of the models studied.*

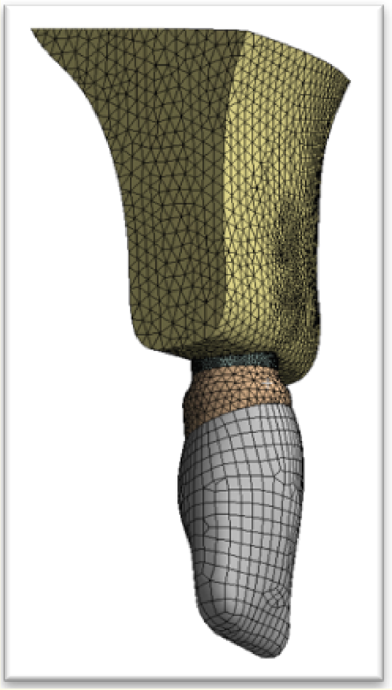


Figure 2: *Tetrahedral solid mesh of the structures.*

This model had a high number of elements because several components were modeled and because it was intended to have a good value of the average quality of the elements.

Load conditions

A screw preload condition was performed, using the following formula:

T=k*F*d

T: Torque; k:0.2; F: Axial Force; d: Screw Diameter.

The applied torque is 30 N cm as recommended by the manufacturer [13]. This axial force is related to the equations:

DL= (P*L) /(A*E)

DL= a*DT*L

Being

DL: Length change

P: Axial force

A: Screw area

E: Modulus of elasticity

a: Thermal expansion coefficient

DT: Temperature change.

This uniaxial thermal contraction serves as the preload on the screw and the resulting force is the equivalent applied by the torque, the static load was made by subjecting the model to a force of 45° at the level of the lingual wall (See figure 3).

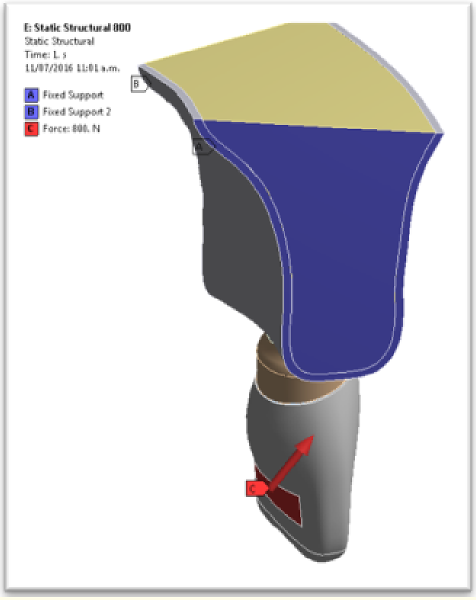
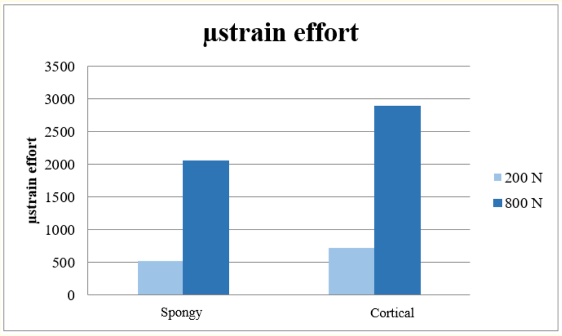


Figure 3: *Direction and location of loads (red areas) in the model.*

When validating the mesh, the adaptive method known as the H method was used, which consists in refining the mesh size in the places of greatest interest for the study.

Results

The report of the results was made descriptively and the graph corresponding to the von Mises stresses of the entire structure and µstrain for the cortical and spongy bone was added, in the comparative analysis of the stress distribution loads of 200N were evaluated and 800N. The following graphs show the stress values for each component.



Graph 1: *Comparisons of µstrain forces at 200N and 800N of cortical bone and spongy bone.*

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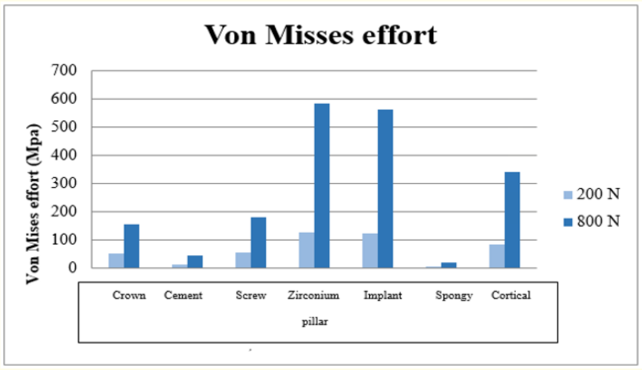

Graph 2: *Comparison of von Mises stresses at 200N and 800N of the model elements.*

Distribution of efforts in the crown

The von Mises effort for the crown increased linearly in a ratio of 1 to 3 by increasing the force from 200N to 800N, showing a maximum von Mises effort value of 156.7 MPa, a value that does not exceed the creep limit, therefore the element did not show permanent deformation. The concentration of efforts was found in the lingual and cervical area.

Distribution of efforts in the cement

The von Mises effort for cement increased linearly in a ratio of 1 to 3 by increasing the force from 200N to 800N, showing a maximum von Mises stress value of 42.8 MPa, a value that does not exceed the creep limit, therefore the element did not show permanent deformation. The concentration of efforts was found in the cervical portion.

Distribution of efforts in the pillar of zirconia

The von Mises effort for the zirconium abutment increased linearly in a ratio of 1 to 4.6 as the force increased from 200N to 800N, showing a maximum von Mises stress value of 584 MPa, although it was the component of the modeling that presented the highest von Mises value, the creep limit was not exceeded, therefore the element did not present a permanent deformation. The concentration of efforts was found in the cervical part of the pillar in its internal part.

Screw stress distribution

The von Mises effort for the screw increased linearly in a ratio of 1 to 3 by increasing the force from 200N to 800N, showing a maximum von Mises stress value of 181 MPa, a value that does not exceed the creep limit, therefore the element did not show permanent deformation; The stress concentration in the screw was located on the outer surface of the screw threads.

Distribution of efforts in the implant

The von Mises effort for the implant increased linearly in a ratio of 1 to 4.5 by increasing the force from 200N to 800N, showing a maximum von Mises stress value of 561 MPa, after the abutment, the implant is the second component of the structure that shows a greater von Mises value, however the value does not exceed the creep limit, therefore the element did not present a permanent deformation. The concentration of efforts was located in the upper area of the implant platform.

Distribution of efforts in biological structures

The µstrain value showed a linear increase for cortical bone in a 1 to 5 ratio by increasing the force from 200N to 800N, showing a maximum µstrain value of 2890, while the spongy bone showed a linear increase in a 1 to 4 when subjected to the same forces, registered a maximum value µstrain of 2050, the application of static loads yielded values that failed to exceed the elastic limits of these fabrics and did not cause permanent deformations.

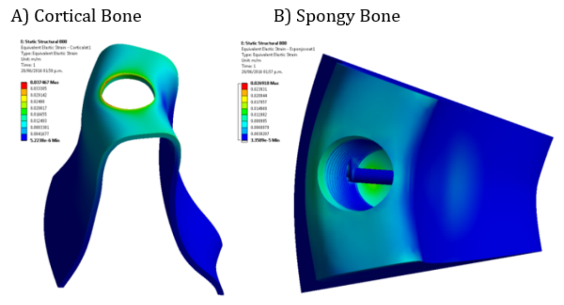

Figure 4: *Areas of concentration of the µstrain forces in the cortical bone (a) and spongy bone (b), under a load of 800N.*

The von Mises result for cortical bone increased linearly in a ratio of 1 to 4, increasing the force from 200N to 800N, showing a maximum von Mises stress value of 341 MPa; after the abutment and the implant, the cortical bone is the third component of the structure that shows a greater von Mises value. For the spongy bone, von Mises increased linearly in a ratio of 1 to 3.8 by increasing the force from 200N to 800N, thus showing a maximum von Mises stress value of 18.6 MPa, this being the lowest value recorded by All modeled structure.

Discussion

It has been suggested that bruxism generates an excessive occlusal load on dental implants and their superstructures, generating bone losses or even implant failures; although it is not possible to suggest that the placement of dental implants in bruxoman patients affects the survival rate therefore, it should be remembered that an uncontrolled load could lead to micro movements above the critical limit, which can lead to fibrointegration and not desired osseointegration [14].

The complex osseointegration process presents as a general rule predictable and positive results under induced loads, bone adaptation occurs in the presence of localized tensions or stress and in the presence of function and/or parafunction. Bone remodeling involves apposition and overflow, generating positive or negative consequences depending on the magnitude, frequency and type of load [9]. This is a process where there are changes in the internal microstructure, in the external morphology, in the size and bone shape to generate an adaptation to changing conditions; These specific surface effects also occur during growth or during healing [15]. At present, bruxism is considered a concern or even a contraindication for the treatment with dental implants [16,17]. Proprioception around dental implants is limited due to the absence of the periodontal ligament, which generates an altered perception, of forces, therefore, it is likely that the forces that are applied to the implants during bruxism are even greater than those generated during chewing, making them more prone to occlusal overload and subsequent failure. Although no information was presented regarding marginal bone loss in the comparison between bruxomaniacs and non-bruxomaniacs [1].

Wannfors and collaborators [18], reported a significant relationship between bruxism and implant failure after one year. Glauser and colleagues [19] found a higher percentage of implant loss in bruxomanic patients than in non-bruxomaniac patients after one year (41% vs. 12%). Bragger and collaborators [20] reported biomechanical problems in implants of bruxomanic patients in 60% of cases, compared with about 20% of problems in non-bruxomaniacs.

On the other hand, some studies do not report significant associations between bruxism and problems with dental implants. According to F Lobbezo [5,8] the evidence that justifies the contraindication of dental implants in bruxomanic patients, is based solely on clinical experience, since studies that establish a cause and effect relationship between bruxism and the failure of implants do not present conclusive or specific results.

For the present study a comparative analysis was carried out, in which the variables µstrain and stresses von Mises were evaluated in loads of 200N and 800N respectively, with an oblique force vector; the initial load of 200N corresponds to the normal occlusal load reported by the literature for the previous sector in an upper central incisor [21,22], likewise, in the modeling a maximum limit of 800N was established as a safety factor since according to the studies carried out to date, the maximum occlusal load recorded in bruxomaniac patients does not exceed (682N) [3], thus leaving a wide margin of error if this limit is exceeded.

According to the results obtained in this study, the cortical bone showed a greater von Mises value (341 MPa) due to its rigidity and less deformation with respect to the spongy bone tissue, while the spongy bone showed the lowest von Mises value (18.6 MPa) due to its low modulus of elasticity, which leads to resist compression and tension forces, as well as to absorb and transmit to the other structures the effects of repetitive loads [23]. This result is corroborated in the study of D Kurniawan., *et al*. [24], where they conclude that the lower the bone density, the greater the stress induced in the cortical bone and less effort is distributed in the spongy bone.

Taking into account the µstrain results and the microdeformation levels [µε] systematized by Frost [25] (See table 3), both the cortical bone and the spongy bone, under the 800N load of this study, presented a level of microdeformation called "ON LIGHT LOAD ", which means that it is possible that fatigue fractures are generated in the bone, but the tissue alone initiates a tissue repair, increasing bone volume to reduce stress [25]. The author further states that a certain amount of effort is required to maintain bone homeostasis. A very small stimulation results in atrophy of the bone with the induction of microfractures and loss of bone tissue. These results are similar to those found in the 15-year prospective study by Lindquist., *et al.* [26] where they concluded that the tightening is not significantly correlated with the loss of the marginal bone and which also did not lead to problems with the superstructures; In the study by Greenstein G., *et al*. [27] they report that if a load is below the destructive limit of bone, this may be a stimulus to induce apposition and increase bone density. Bone apposition is an important compensation mechanism when tension exceeds its physiological range, that is, stress and tension induce a reparative process, because the bone becomes stronger.

Bone inactivity	**Adaptation zone**	**Light overload**	**Pathological overload**	**Spontaneous fracture**
0 - 50	50 - 150	150 - 3000	3.000 - 10.000	10.000 - 20.000

Table 3: *Microdeformation Levels [µε] of Frost [26].*

The adaptive capacity of bone for dynamic growth (modeling) and remodeling has been well supported; it is shown that the interface between the bone and the implant is able to resist and also adapt to the variation of occlusal loads in function and function. This is an elementary key in the initial stability of the implant that varies with bone density in different regions of the mouth [9].

It can also be observed in this study, that the maximum von Misses efforts of the entire system, both in loads of 200N and 800N are mainly presented in the abutment and in the implant body, which are the elements with the modulus of higher elasticity. However, the values obtained did not exceed the material flow limit; this is consistent with what was found in studies such as that of Lekholm and Zarb [11], where they submitted a prosthetic structure to stress in conditions of a type II bone and the results showed a distribution of efforts mainly at the level of the screw and the implant were the elements that presented the greatest von Mises value during their study. Similar results were found by FM Roldán., *et al.* [10], where the abutment, the screw and the implant were the elements that presented the greatest von Mises value during their study.

Based on the results of the present study and considering the limitations associated with three-dimensional modeling with specific bone characteristics, a 100% osseointegration and a static force, it is considered that loads around 800N do not significantly affect the different types of bone, nor to the prosthetic components, these results coincide with those found by Jacobs and De Laat, where no direct cause was found between bruxism and a failure in the implant [22].

It should be considered that this study is a simulation, so its results are important information but caution should be taken when extrapolating to the clinical part and seeking its assessment with similar clinical studies [31-36].

Conclusions

- According to the mechanical behavior of the modeled structure, the use of a dental implant in an upper central incisor is appropriate for the 800N load, because the parafunctional forces generated by bruxism are not superior to those presented in the structure modeled, consequently they do not generate permanent deformations in the bone, as is derived from the results obtained.
- By subjecting the modeled structure to a force increase of 200N to 800N, each modeled component has particular Von Misses and µstrain values, indicating that each component reacts differently when loads are applied.
- According to the results and considering the microdeformation levels [µε], the one presented in the cortical and spongy bone, they correspond to a “Light Load Overload”, which does not represent a risk in the treatment according to this study in loads of 800N with a dental implant for a superior central.
- No pathological efforts were generated for any of the structures.

Conflict of Interest

The authors confirm that they have no conflict of interest in the development of this research.

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