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MODELING EXPERIMENTS IN BIOMECHANICAL BEHAVIOR OF DENTAL IMPLANTS

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Abstract. *The large use of computational approximated methods in the solution of continuum mechanics problems particularly as it occurs in solid mechanics, has driven its application to involve a diversity of areas such as biomechanics. Such is the case of the stress analysis, by finite element method, around endosseous dental implants. The present work shows 3-D Finite Element Analysis (FEA) of a BIOFORM vertical dental implant placed in the left pre-molar region of a mandible which had its model obtained from a computerized tomography. Some different models results, in term of principal stresses, are shown when one uses a reduced region around the local were the implant is placed, when we vary the boundary conditions imposed to the mandibular body and when the positioning level of the implant is modified.*

1 INTRODUCTION

Finite Element Method (FEM) has been widely used to study the biomechanical behavior around dental implants and besides the great number of uncertainties that still exist about the mechanic characterization of this type of problem, this tool is becoming each day more present in this area.

Among these uncertainties, involving the computational modeling of this kind of problem, one can mention the establishment of the elastic properties of the bone structure involved, the way how boundary conditions are imposed and even about the suitability of two or three-dimensional analysis.

In a recent paper Geng et all[1] presented a extensive survey over the literature about the utilization of FEM applied to biomechanics problem in implant-dentistry area referring to the work of Weinstein[2] in 1976 as the first to use this tool in this particular area. It points as one key factor to the success or failure of dental implants, the way in which applied loads are transferred to the surrounding bone, stating its dependency on the loading types, on the bone-implant surface, on the prosthesis type and of the quantity and quality of the surrounding bone. About this last aspect Akagawa et all,[3] Wadamoto et all[4] and Sahin et all[5] based on experimental data noticed that it is unrealistic to assume the implant totally surrounded by bone, claiming for further studies to clarify and define the real three dimensional bone structure after long-term loading. About the global modeling aspects the initial analysis taken in effect used only 2-D models being worth to mention that Siegele & Soltész[6] analysed several axisymmetric implants using an identical mandible volume around these implants. Some authors like Borchers & Reichart[7] and Lozada et all,[8] besides using 3-D models consider only a slice of the whole mandibular body imposing in its boundary conditions far from reality. Recently Tortamano[9] considered in his studies a simplified 3-D model of a mandible in equilibrium by the action of the Masseter muscles. Previous works[10–12] used three-dimensional analysis to calculate stress distribution around BIOFORM vertical dental implants employing the methodology proposed by Inou[13] . In this work we present three comparative analysis when the boundary conditions of the mandibular body is modified, when we alter the implant level positioning and when we consider only part of the mandible around the place where the implant is fixed. The comparisons are shown in terms of the minimum principal stresses in the bone near the implant and a discussion is made about the influence of this three models over these stresses. A linear elastic behavior is assumed for the constitutive material of the implant (pure titanium) and for the two kinds of bone: cortical and trabecular. The 3-D model developed for the mandible was based on a reconstruction from a computerized tomography, the loading simulating the masticatory actions were reduced to a 100 N axial force applied on the central point of the abutment, in equilibrium by a set of muscles actions, and supported in the TMJ region.

2 COMPUTATIONAL MODELS

We begin with the main characteristics of the computational models used in the analysis here presented. The computational geometry model used for the mandibular body was obtained from a computerized tomography that furnishes radiographical images of transverse sections placed along the mandible axis separated $3mm$ from each other. Only half of the bone structure was digitalized being the other half obtained by a reflection around the sagital plane thus generating a symmetric model with respect to this plane. A detailed description of the adopted procedure in constructing the complete modeling can be found in the previous cited references.[10–12]

To achieve high precision in the proposed analyses the muscles forces acting in the mandible during oclusion were considered as depicted in Figure 1, where it is shown the action of the muscles Masseter(M), Medial Pterigoyd (P_m), Lateral Pterigoyd (P_l) and Temporal (T).

Following the procedure described by Inou[13] applied to the present geometry, the mandible was supported by the condiles allowing a rotation around an axis connecting these two points.

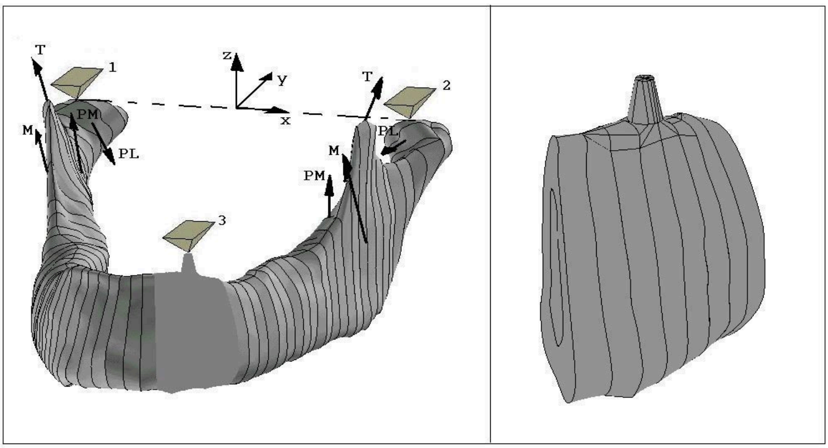


Figure 1: Domains (original and simplified), boundary conditions and loads considered.

To assess the influence of the previous cited parameters a few analyses were done, and are here presented in a comparative way, taking one of them as reference. For the main reference model supports were introduced according to Inou's proposal. Then, for boundary condition of this model, a supporting system is considered in which both condyles can turn in any direction like pivots and the condyle at one side can also move freely along the direction joining these points. These conditions are shown in Figure 1 where displacements were restrained in x, y and z directions for point 1 and in y and z for point 2. For point 3 the only displacement restrained was in the axial direction. The moments around the condyles produced by the muscular and the biting forces should be balanced. The muscular actions, proportional to its cross sections, were calculated in such a way that the force in the support point 3 (biting force) equals 100N.

The first issue verified was the influence of modeling the whole mandible, since other three-dimensional works can be found[7,8] using only partial models without considering muscles forces in the equilibrium. It was then considered an approximated model where the analysed domain were restricted to a distance of $24mm$, from the implant central line, measured along the mandible long axis as depicted in Figure 1. As boundary conditions for this simplified model all displacements in the cuting edges were restrained.

Secondly, a modified model was considedred by changing the boundary conditions in point 2 which had its x displacement restrained.

A third issue considered was the positioning of the implant, although one can not found any discussion of this aspect in the literature. The implant was then displaced $1mm$ downward in direction of its axis, as depicted in Figure 2.

To avoid results modification, the discretization was maintained unchanged, varying only, as a consequence of the new geometry, when the placement of implant was altered, as shown in Figure 2. The mesh of the reference model was composed by 45609 quadratic isoparametric thetrahedron elements, refined in bone-implant interface due to the complex geometry in this region and because this is the main interest region in the analysis where one expects greatest stress gradients.

3 NUMERICAL RESULTS

In the Figure 3 it is shown the global mandible deformation of the reference model.

Results, in terms of minimum principal stress (S3), are shown for those situations described in the last section. For each of them, curves representing this stress distribution along the bone interface with the implant were traced along three lines as depicted in Figure 4. The first is a closed curve, obtained by the intersection of the exterior surface of the cortical bone layer with the implant-bone interface surface. The other two are the intersections of this latter surface with the mesial-distal (tangent to mandible axis) and buccal-lingual (normal to mandible axis) planes.

In Figures 5,6 and 7, respectively, it can be observed the influence of the simplified domain, of the boundary conditions modification and of the two different positioning levels of the implant in the mandibular body. To ease quantitative comparisons, the results of

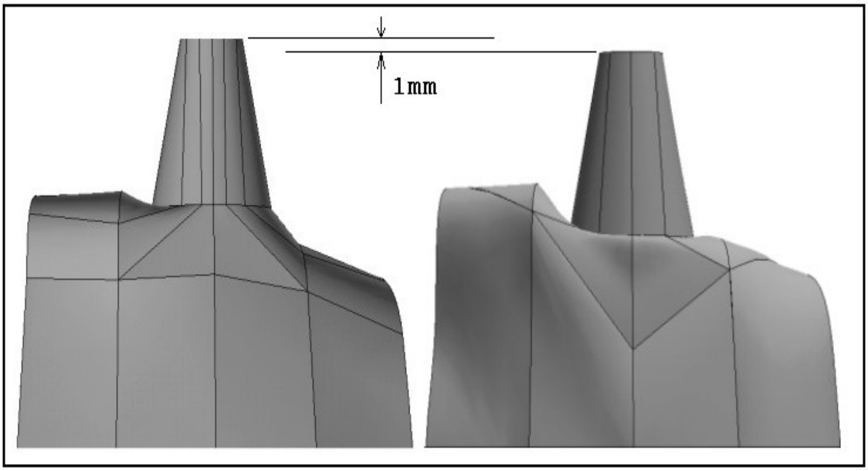


Figure 2: Different implant positioning - reference model in the left.

the reference model were plotted in all figures as solid lines.

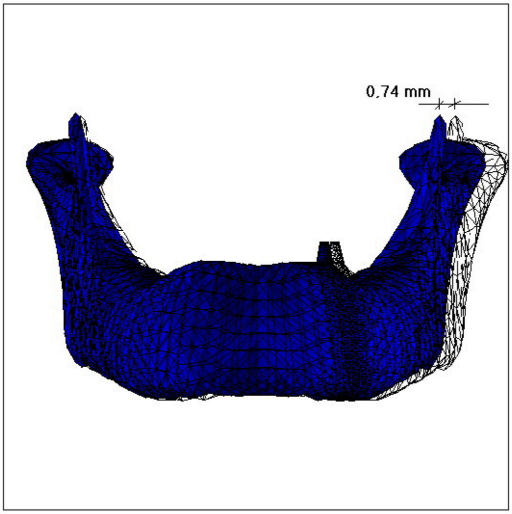


Figure 3: Global deformation of reference model.

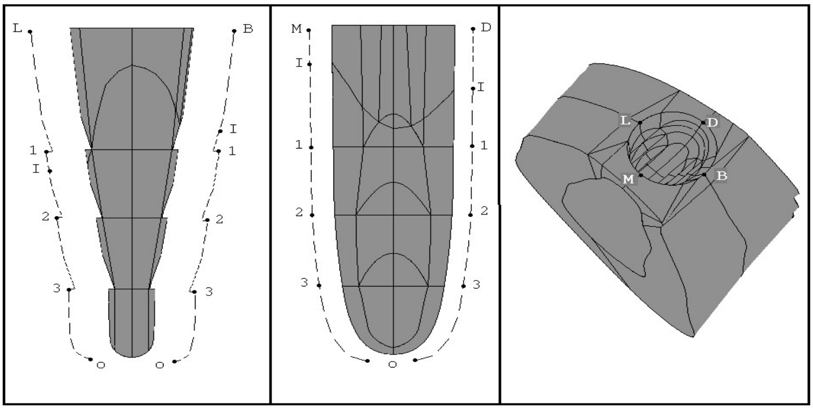
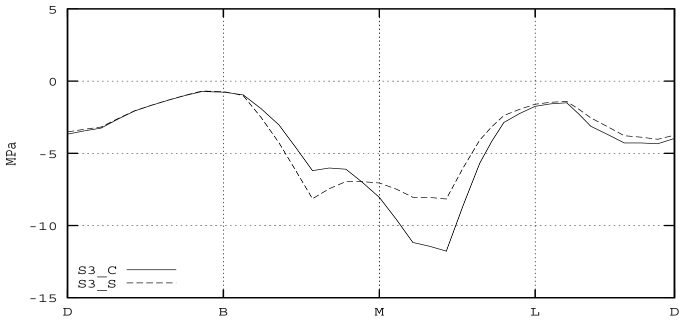
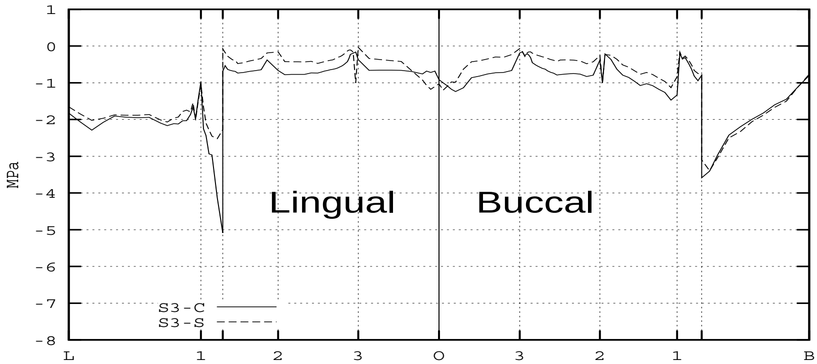


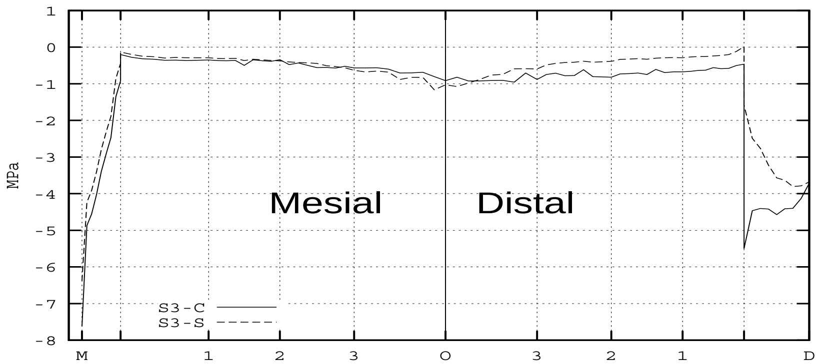
Figure 4: Lines for stress plotting.



(a) Top line.

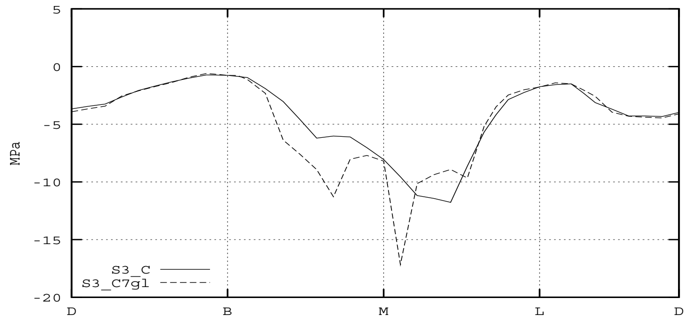


(b) Buccal-lingual line.

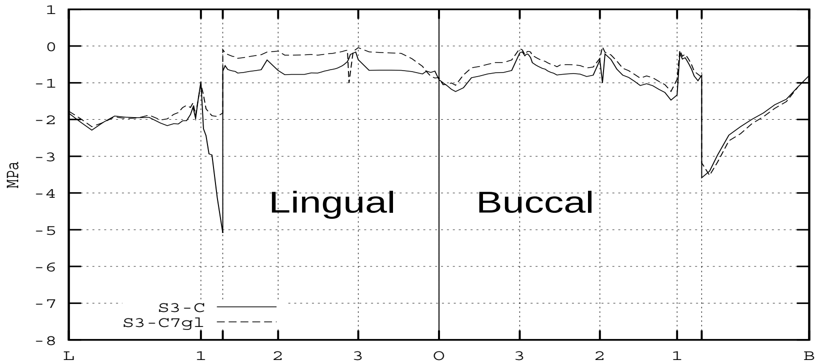


(c) Mesial-distal line.

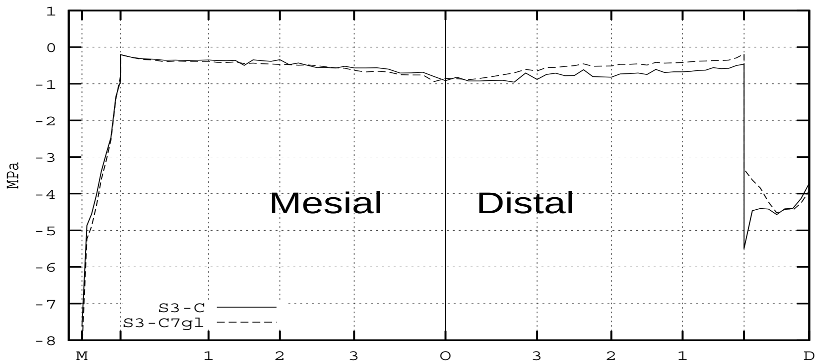
Figure 5: Comparisons between complete and simplified model.



(a) Top line.

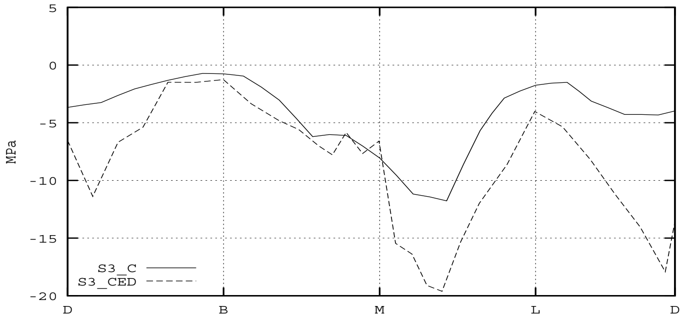


(b) Buccal-lingual line.

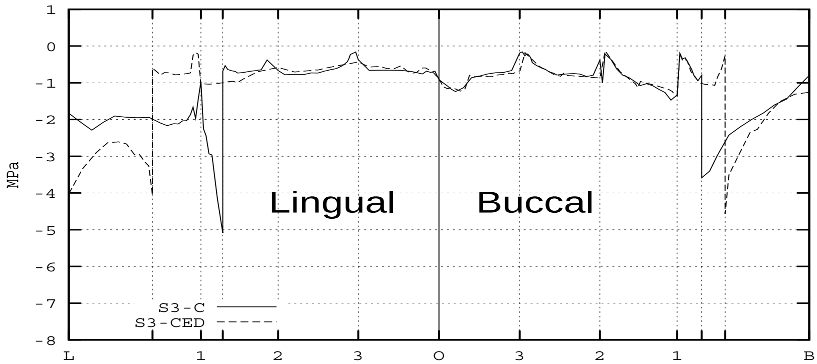


(c) Mesial-distal line.

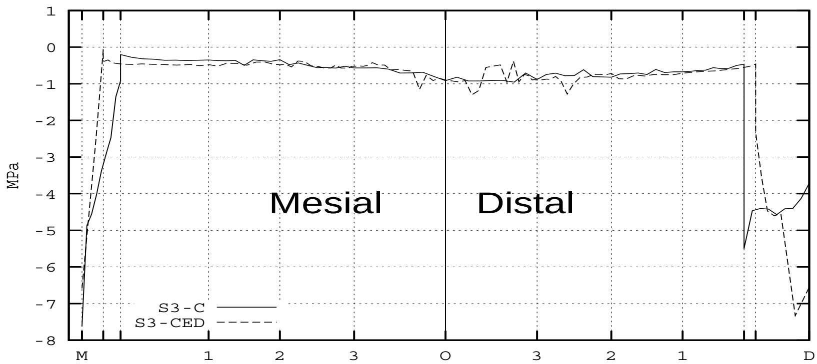
Figure 6: Comparisons between different boundary conditions.



(a) Top line.



(b) Buccal-lingual line.



(c) Mesial-distal line.

Figure 7: Comparisons between different implant positioning.

4 CONCLUSIONS

It is possible to conclude by the variation of the first parameter, the domain of the analysis, that its restriction to the neighborhood of the implant site, including unrealistic boundary conditions, although presenting results of the same magnitude, it reaches point-wise results 30% smaller (in top line between mesial and lingual lines) than those obtained with the complete model. Nevertheless the absolute values of developed stresses are not significant, such a relative variation of results can be relevant if we want to make correlations between the stress state in the neighborhood of the implant and bone ressorption.

Boundary condition variation in the full model, restricting the relative displacement of the nodes through which the mandible is attached to the TMJ, perpendicularly to sagital plane, caused relevant point-wise differences, showing the influence of this parameter and sugesting that more adequate modeling of the TMJ is a key factor in the precision of such results around implants.

The last analysed parameter, the placement of the implant, leads to the greatest differences in the achieved stresses, revealing its importance. It is interesting to note that the present authors have not found any reference to this aspect in the literature.

All the above observations points in the direction that to establish, even qualitative comparisons between two or more implant shapes, it is imperative to maintain the adopted model unchanged, including geometrical aspects, boundary conditions and discretization refinement.

By the influences of the different varied parameters in the analyses presented we can conclude that considering the 3D character of the problem and the availability of personal computers that can solve problems of this size, simplified two-dimensional analyses like those made a few years ago can not be justified anymore.

Results achieved in the present work will stand as reference to future comparisons of the biomechanical performance, in terms of stresses, between Bioform and the standard Branemark root form implant.

4.1 Acknowledgments

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