STRESS, STRAIN AND DISPLACEMENT OF CONE-MORSE TYPE DENTAL IMPLANTS IN ALVEOLAR SOCKET – A 2D FINITE ELEMENT ANALYSIS

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Abstract. *Dental implants have been placed and loaded immediately after tooth extraction. This protocol has several advantages such as reduction of the treatment time and cost, fewer surgical procedures and optimal aesthetic results. Despite of this success, fails on this protocol can be related to biomechanical factors. Thus, the aim of this research is to analyze the stress/strain and displacement of dental implants in alveolar socket both before and after the implant osseointegration. The model of a socket of an upper medial incisor was obtained from computer tomography. The geometric model of a conical cone-morse type implant was inserted in a buccal position and exported to the finite element program. For immediate load analysis contact elements were used to simulate bone-implant interface. For osseointegrated implants the alveolar socket was closed and the bone-implant interface was simulated as perfect adhesion. All materials involved were considered isotropic, homogenous and linear elastic. The results showed more stress/strain and displacement for the immediate load implants situation comparing with osseointegrated simulation. However, both protocols simulated in this analysis were biomechanics compatible with the secure maintenance of the osseointegration.*

Keywords*: Biomechanics, dental implants, immediate load, finite element method.*

1. INTRODUCTION

In the last decade, promising results have been observed when non submerged dental implants are subjected to immediate functional loads (Ericsson *et al.*, 2000). This treatment protocol was proposed by the ITI (International Team for Oral Implantology - Waldernburg, Switzerland) to eliminate the 4 to 6 months period of undisturbed healing of the traditional approach (Brånemark *et al.*, 1977). From the clinical point of view, the immediate loading implants offer several benefits because both function and esthetic are immediately restored (Lederman, 1979). In some cases, the implants can be placed into fresh extraction sockets reducing the treatment time and cost, decreasing the surgical procedures and the patients morbidity, and optimizing the esthetic results (Schwartz-Arad & Chaushu, 1997). With the association of the immediate implant placement and loading, the traditional protocol has been preterit because of the important reduction in the time between the tooth extraction and the patient rehabilitation.

However, independently whether an implant is put in function following an undisturbed healing or immediately after placement, the predictability and long-term success of implant treatment is greatly influenced by the biomechanical environment. The intimate bone-implant contact in the interface allows the direct transmission of the loads applied over the implant of the surrounding bone. The stress and strain concentration can exceed bone's tolerance level, cause microdamage accumulation and induce bone resorption (Hoshaw *et al.*, 1994; Isidor, 1996; Duyck *et al.*, 2001; Mich *et al.*, 2005). Under certain conditions, this excessive occlusal loading may cause the implant failure, even in osseointegrated implants (Isidor, 1996, 1997). In immediate load protocol, the overall requirement is to control interfacial movement between the implant and the surrounding bone. Micromoviments that exceed 100µm can induce fibrous connective tissue formation instead of the desirable bone regeneration (Brunski, 1992; 1993). Otherwise, the bone supporting level is one of the most important factor on the determination of periimplant soft tissue position and, consequently, on the maintenance of periimplant esthetic harmony. Marginal bone resorption in the buccal or proximal aspects of the implant can lead to recession or absence of papilla, respectively (Bengazi *et al.*, 1996; Tarnow *et al.*, 1992).

In addition to load transmission at the bone-implant interface, long-term performance of dental implants is closely related to the stability of implant–abutment connection mechanism (Scacchi *et al.*, 2000). Screw complications, such as loosening and/or fracture had been encountered in particular in single tooth replacement scenarios (Geng *et al.*, 2001; Schwarz, 2000).

Several factors are recognized to influence the biomechanical environment which the implants are exposed to, such as: bone density in the insertion area, the nature of bone-implant interface, the materials' proprieties of the implants and prosthesis, the surface pattern of implant material (microinterlocking properties), the design of the implant (macrointerlocking properties), the occlusal condition, i.e., the magnitude, direction and frequency of the loading (Misch *et al.*, 2005; Geng *et al.*, 2001; Bozkaya *et al.*, 2004). Thus, a very important concern is to develop implants with shapes, dimensions, materials, surfaces and prosthetic connections with the capability to provide some degree of biomechanical stability, under masticatory standard loading (Hansson, 1999).

In this way, the ITI's implant system (Institute Straumann AG, Waldenburg, Switzerland) introduced a novel design of implant-abutment mating with an internal cone-morse joint which was supposed to offer a mechanically sound, stable, and self-locking interface (Sutter *et al.*, 1993; Merz *et al.*, 2000). These intents were supported later by many different researches. Recent studies reported insignificant episodes of abutment loosening (3.6–5.3%) or fracture for ITIs solid-screw morse-taper implants (Levine *et al.*, 1999; Schwarz *et al.*, 2000).

Moreover, Merz *et al.* (2000), comparing by experimental and finite element methods the stresses induced by off-axis loads on tapered and butt-joint connection, concluded that the tapered interface distributed the stresses more evenly when compared to the butt-joint connection. In another study, using an axisymmetric finite element analysis, Hansson (2003) observed that a morse-taper implant-abutment at the level of the marginal bone substantially decreased peak bone stresses and improved the distribution of stress in the supporting bone. Hansson also (2000) found that, with a 'flat to flat' implant–abutment interface at the level of the bone–connective tissue junction, the peak bone–implant interface shear stress was located at the very top of the marginal bone. With a conical interface, the peak bone–implant interface shear stress had a more apical location, what could avoid marginal bone resorption.

Experimental and clinical studies showing the success of the morse-taper implant–abutment encouraged the researchers and implant companies to focus on understanding and evaluating the mechanical properties of the tapered interface and others implant-abutments connections (Bozkaya *et al.,* 2005). Nevertheless, to our knowledge there are no studies on the influence of morse-taper implant-abutment type on the biomechanical environment of implants placed into dental sockets. Therefore, considering the expansion of implant indications and the importance of the biomechanical environment to implants' esthetical and functional predictability, the objective of the present study is to evaluate morse-taper connection in this clinical situation.

2. MATERIALS AND METHODS

2.1 Model Design

A computer tomography of an upper central incisor extraction socket was done. Then, the tomographic slices were regrouped in a 3D image by the software Vworks^{TM} 4.0 (CyberMed, Seoul, South Korea) and a bucco-palatal section of the bone structure of the alveolus' central portion was generated (Fig. 1). This section was worked in the Matlab (The MathWorks Inc., Natick, Massachusetts, USA) environment and a CAD (Computer Aid Designer) model of bone's structure was obtained. The CAD models of a conical 13-mm implant and implant-abutments were yield by an implant producer (Neodent, Curitiba, Brazil). For the positioning of the implant into the extraction socket, the contra-lateral upper central incisor was used as a reference. The model of the implant placed into the extraction socket was imported by the finite element software ANSYS^{TM} 10.0 (ANSYS Inc., Canonsburg, PA, USA). Figure 2 shows model's components and some dimensions. Second-order effects resulting from tightening of the abutment and the pre-load in the abutment screw were ignored in the present study, as well the effects resulting from the installation torque of the implant.

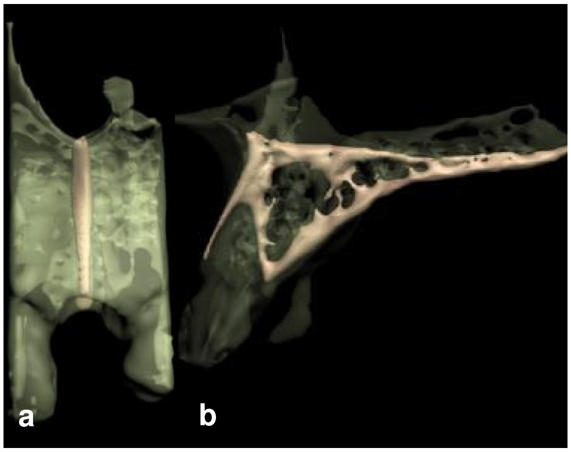

Figure 1. a. 3D image of the upper central incisor extraction socket computer tomography. b. Bucco-palatal section of the bone's structure of the alveolus' central portion.

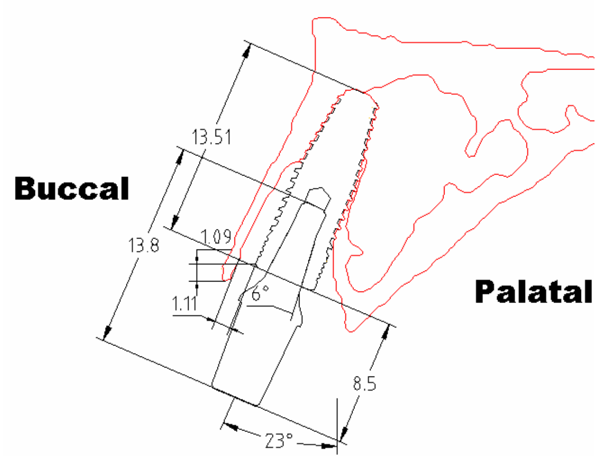

Figure 2. Model's components (dimension in mm).

2.2 Interface Condition

For simulating the stage before osseointegration (non-integrated model), non-linear frictional contact elements (Coulomb frictional interface), with a coefficient of 0.3 was assumed between the bone and the implant (Mellal *et al.*, 2004). This configuration allows minor displacements between the implant and the bone. Under these conditions, the contact zone transfers pressure and tangential forces (i.e. friction), but no tension. Also in this case, the bone-implant contact was restricted to the threads' flank and vertex (Berglundh et al. 2003).

For simulating the stage after osseointegration (integrated model), the bone-implant interface was assumed to be fully bonded and the whole implant's thread was in contact with the bone. In addition, a hard tissue bridge was modeled at the alveolar ridge region.

In all the models, the implant-abutment and implant interface were considered bonded.

2.3 Material Properties

All materials used in the models were considered to be isotropic, homogeneous, and linearly elastic. The mechanical parameters necessary for the characterization of the mechanical behavior of the elastic materials are the Young's modulus and Poisson ratio. The values of these parameters for the materials used in the present study can be easily found in the available literature (Geng *et al.*, 2001) and are listed in tab. 1. Note that models' bone structure were formed by cancellous and the cortical bone in different areas and with different proprieties.

Table 1: Mechanical properties of bone, implant and prosthetic materials.

Properties	**Materials**		
	Titanium	Cortical Bone	Cancellous Bone
Young's modulus (E) – MPa	110000	13700	1370
Poisson ratio (ν)	0.33	0.30	0.30

2.4 Elements and nodes

The finite element model was constructed using the six-nodes triangular element PLANE 2, with 2 degrees of freedom in each node, leading to 9860 elements and 20600 nodes for the non-osseointegrated model and 12075 elements and 25060 nodes for the integrated model.

Based on the nature of the materials, the problem of the contact was considered flexible-flexible. The contact pairs were assumed to be surface-to-surface. The implant was considered the target surface and was modeled with the TARGE 169 element, while the contact surface was the cortical and cancellous bones which were modeled with the CONTAT 172 element.

A structured mesh was used, formed by areas with different degrees of refinement. In the areas near the contact regions, the smaller elements used was about 0.009mm. Figures 3 and 4 show the mesh for each model.

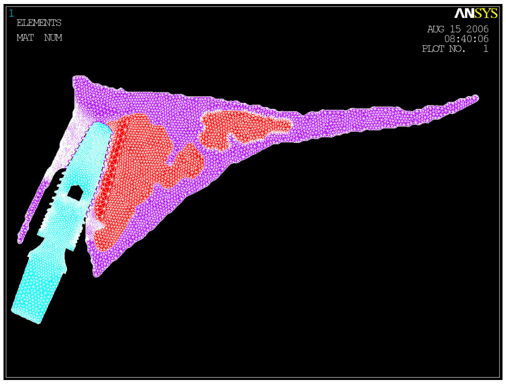

Figure 3. Non-integrated models' mesh.

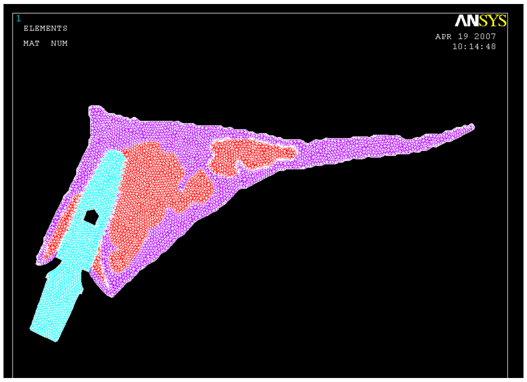

Figure 4. Integrated models' mesh.

2.5 Constraints and loads

Models were constrained in all direction at the nodes on the most external superior aspect of the cortical bone. For the non osseointegrated stage model, two static loads were applied in the same point on the top of the abutment: a 6,42 N intrusive force and a 7,66 N palato-buccal force. These two forces resulted in a 10 N force, with a 40° of inclination in relation to the alveolus long axis. For the osseointegrated stage model, a 12,84 N intrusive force and a 15.32 N palato-buccal load at the same point and direction was applied, resulting in a 20 N force. The forces applied on both models were calculated based on the average occlusal force in the incisor area (100N), and considering that the models are in 2D.

The analysis was performed for each model by means of the ANSYS software program. The Von Mises' (equivalent stress, abbreviated EQVstress), compressive, tensile and shear stresses, as well the Von Mises' strain (equivalent strain, abbreviated EQVstrain), were used to display the stress and strain in the bone and implant–abutment units. The relative displacement between the implant and the bone was also analyzed for the non-integrated model.

Stress and strain distributions along selected zones of the bone–implant interface were calculated (Fig. 5 and 6).

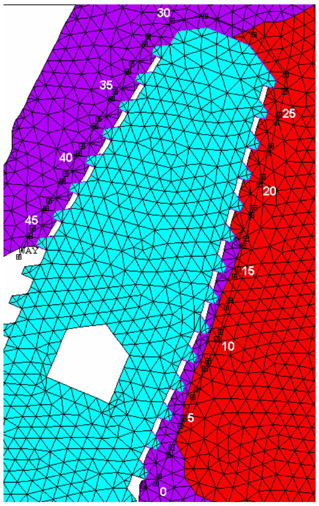

Figure 5. Selected points for stress and strain calculation in the non-integrated model.

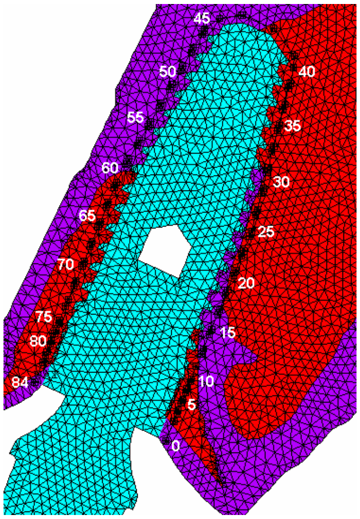

Figure 6. Selected points for stress and strain calculation in the integrated model.

3. RESULT

The solution was obtained by a computer equipped with an Intel® Core™ 2 Due (Intel, Santa Clara, CA, USA) processor and 1 Gb of DDS memory, in a mean period of 1 hour.

EQV stress patterns are shown as contour lines with different colors connecting equivalent stress points between certain ranges (Figs. 7-8).

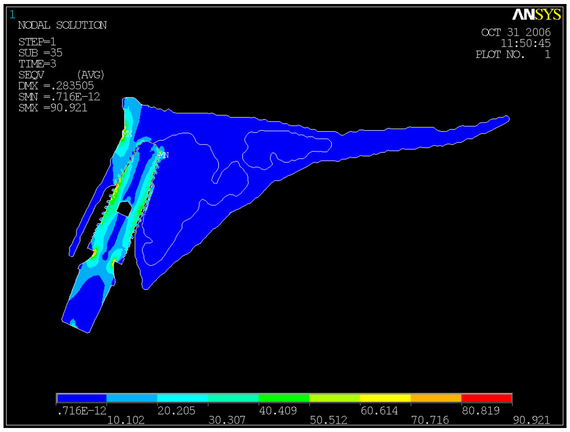

Figure 7. Equivalent stress distribution in non-integrated model (Stress in MPa).

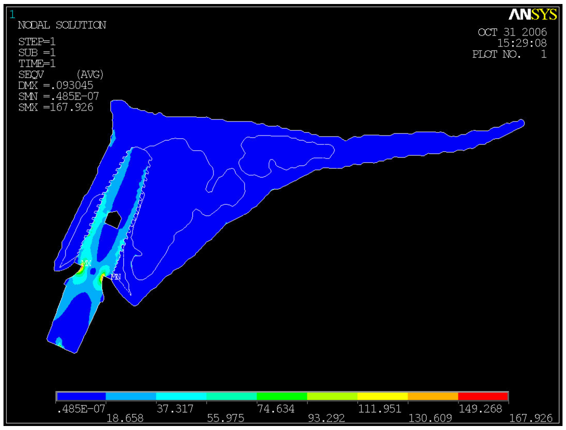

Figure 8. Equivalent stress distribution in integrated model (Stress in MPa).

The values of compressive, tensile, shear and EQV stresses and EQV strain in the selected regions of bone-implant interface for non-integrated model are shown in Figs. 9 and 10. Matching data for integrated model are shown in Figs. 11 and 12.

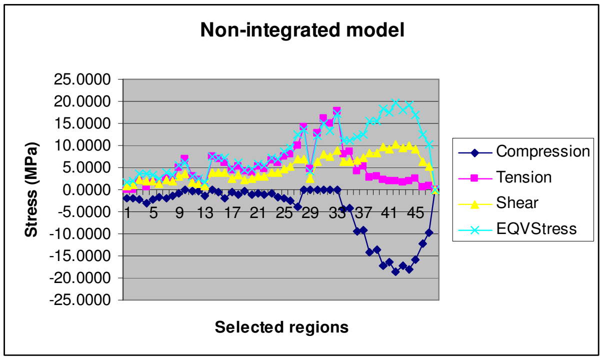

Figure 9. Compression, tension, shear and EQV stresses in the selected region of bone implant interface for non-integrated model.

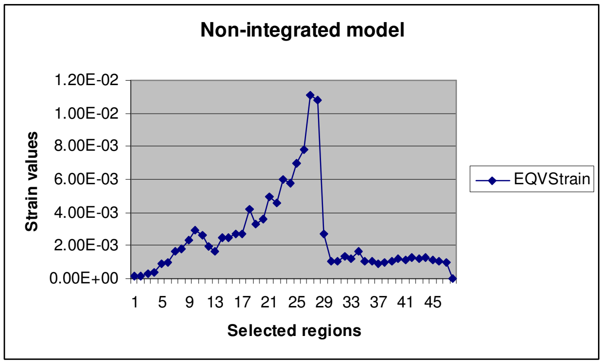

Figure 10. Strain generated in selected regions for non-integrated model.

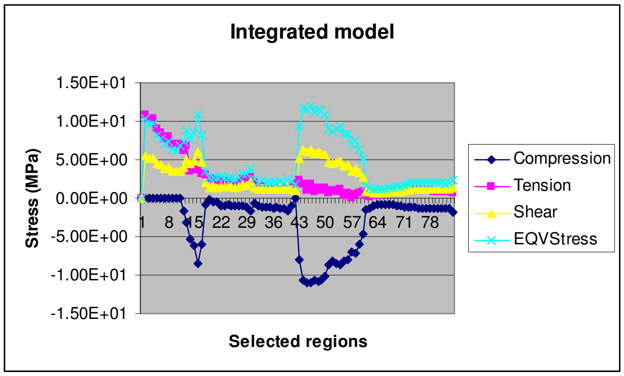

Figure 11. Compression, tension, shear and EQV stresses in the selected region of bone implant interface for integrated model.

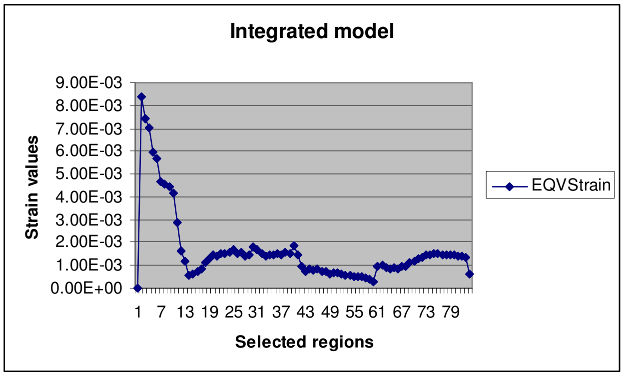

Figure 12. Strain generated in selected regions for integrated model

In both clinical situations (non-integrated and integrated implant), the highest stress in the bone at the implant vicinity was concentrated in the cortical bone. In the non-integrated model the compressive, shear and EQV stresses were concentrated near the region of the first buccal threads of the implant. However, the highest tensile stress was observed in the buccal apical bone at implant edge. On the other hand, in the integrated model the main compressive, shear and EQV stress concentration was located not at the marginal bone, but in a lower bone region between point 60 to 43. The highest tensile stress in this model was observed at the palatal marginal bone.

Also in both clinical situations, the highest stress in the implant complex was observed at the implant-abutment, near the implant shoulder.

Differently, in both clinical situations, the highest strain levels were observed in the cancellous bone. In the non-integrated model, the EQV Strain was concentrated in the cancellous bone of the apical-palatal region. In the integrated model, the highest EQV Strain was observed in the cancellous bone of the palatal marginal region.

The higher relative displacement between bone and the implant in the non-integrated model was of 144 µm. This higher displacement occurred at the marginal palatal region

4. DISCUSSION

The installation of implants in extraction sockets coupled with immediate functional loading has been presented as a predictable alternative for the conventional approach (Brånemark *et al.*, 1977; Becker *et al.*, 1998; Cooper *et al.*, 2002). This protocol is advocated as a means to reduce the number of surgical procedures; to preserve the dimensions of the alveolar ridge; and to reduce the interval between the removal of the tooth and the insertion of the implant supported restoration (Schwartz-Arad & Chaushu, 1997). However, due to the delicate interplay between bone resorption in contact regions and bone formation in contact-free areas in the vicinity of implants (Berglundh *et al.*, 2003), is crucial to implant survival and long-term success to obtain a high initial intraosseous stability and a safe biomechanical environment. Adverse forces on the implant-supported prostheses could not only cause mechanical failure of components of the implant-prosthesis-complex (Langer *et al.*, 1993; Morgan *et al.*, 1993; Kallus & Bessing 1994), but could also impair osseointegration (Quirynen *et al.*, 1992; Hoshaw *et al.*, 1994; Isidor, 1996; 1997).

The intricate design of the implants and their relationship with the supporting tissues and prosthetic restoration prevent the use of simple formulas to the evaluation of the effect of external loading on the internal stresses, strains and displacements. In this analysis type, the finite element method has provided valuable data, in a relatively low operational cost and time. Moreover, this method is able to offer some information unavailable for clinical or experimental studies (Geng *et al.*, 2001). In the Implantology, the finite element analysis (FEA) has been applied to predict the biomechanical behavior of different implants design (Hansson, 1999; 2000; 2003; Rieger, 1988; Rieger *et al.*, 1989; Siegele & Soltesz 1989; Rieger *et al.*, 1990; Holmgren *et al.*, 1998; Merz *et al.*, 2000), various clinical scenarios (Akca & Iplikcioglu, 2001; Iplikcioglu & Akca 2002; Van Oosterwyck *et al.*, 2002), and prosthesis design (Papavasiliou *et al.*, 1996; 1996; Stegaroiu *et al.*, 1998a,b). In this way, the stress and strain states of loaded implant in extraction socket were analyzed in the present study before and after osseointegration using finite element techniques.

Nevertheless, the results obtained in present FEA should be interpreted with some care. In fact, the models used deviated in many aspects from the real clinical situation.

Although the *in vivo* stress and strain state is a three-dimensional problem, a non-linear two-dimensional FEA was chosen because it led to a smaller number of nodes and, consequently, made feasible the modeling of important structures such as the implant threads, the implant-abutment details and the bone anatomy (Van Oosterwyck *et al.*, 1998). Besides, a plane model allowed the use of a refined mesh, with complex elements, which provided more precise results (Hart *et al.*, 1992).

In another simplification, the bone was assumed to be homogenous, isotropic and linearly elastic and, in reality, it is anisotropic, to some extent viscoelastic (Katz, 1971), and contains voids. It was also assumed that the interface between the implant-abutment and the implant was perfectly bonded, which is not the actual scenario for dental implants. As a result, if the purpose of the present study had been to evaluate the true biomechanical behavior of an implant placed into an extraction socket, the model would have been inadequate. However, even though the suppositions regarded to model geometry, mechanical proprieties and interface condition of some models' components were an important limitation for the analyses of the absolute values of the stress, strain and displacement of implants (Akagawa *et al.*, 2003), the relative values could still yield important information (Hansson, 2003; Meijer *et al.*, 1993).

In the present study, stress in bone concentrated mainly at the level of the first buccal thread for non-integrated simulation. On the other hand, in the integrated model the most important stress concentration was observed not in the marginal bone, but in a lower region. In Mechanical Engineering, it is stated that when two materials of different elastic module are placed together with no intervening material and one is loaded, a stress contour increase will be observed where the two materials first come into contact (Baumeister & Avallone, 1994). However, different implant-abutment designs imply that the functional load is distributed in different ways upon the implant. This will result in different stress patterns in the marginal bone when this reaches levels close to the implant crest (Hansson, 2000).

In this way, the results for integrated model are in accordance with the findings reported by Hansson (2000) who using a finite element model showed that the peak stress for a conical implant-abutment interface at the level of marginal bone was located at some depth in the marginal bone. In another study, Hansson (2003) observed that the highest peak bone stresses for a conical abutment at the level of the bone, in the majority of cases arose between the 5th and the 9th thread turns from the top.

Hansson also observed that when the conical implant-abutment interface was located 2mm more coronally, this beneficial effect disappeared and the peak stresses arose at the level of the first thread. This were also confirmed by the finding in other studies (Stoiber 1988, Mailath et al. 1989, Meijer et al. 1993, Hansson 1999) which showed that, in general, the peak bone stresses resulting from axial loads arise where the implant starts to become attached to the bone. In the present study similar results were observed for the non integrated models, probably because of the initial bone defect at the marginal region.

In the present numerical results, in both non-integrated and integrated models, the locations of the peak von Mises' strain do not coincided with the locations of the peak von Mises' stress. These observations have to be interpreted with some attention. In a superficial analysis, these results are not in accordance with authors like Bidez & Misch (1992), whom stated that the amount of strain in a material is directly related to the amount of stress applied. Also Duyck *et al.* (2002), investigating the bone response under dynamic loading conditions, demonstrated by a FEA that the maximum

EQV strains occurred at the side where large pressure forces were being transferred from the implant to the marginal bone. At the opposite (non-pressure) side, only small strains were encountered. However, these authors plotted theirs results in a simple model with only one material (Bidez & Misch, 1992) or isolated the cortical bone (Duyck *et al.*, 2002). In the current FEA, the result was plotted for the composite model. Observing Hooke´s law ($\sigma = E \times \varepsilon$), it can be concluded that the high strain level should be observed at the area with the lowest Elastic Module, since the value of stress are of the same order. In this case, the cortical bone's Elastic Module is ten times higher than the cancellous bone's Elastic Module. Hence, the highest EQV Strain levels in both model coincides with the highest EQV stress levels in the cancellous bone, which were responsible for absorbing some of the models' energy.

Another interesting observation is the fact that low stress and strain magnitudes were encountered in the bone labial to the non-integrated implant. Analogous observation was accomplished by Cehreli *et al.* (2005) in a cadaver model. The authors argued that little load was transferred to the labial marginal bone due to the absence of direct contact with the implant, because of the site-specific three-dimensional shape of the bone defect. However, in the real clinical situation, once an implant is immediately placed, the coagulum and thereafter the initial connective tissue in the bone defect (Claes *et al.*, 1998; Berglundh *et al.*, 2003) can transfer functional load and stimulate bone that is not contacting the implant.

The bone strains' distribution and magnitude are of high importance in the clinical practice. Experimental studies have shown that strain concentrations may cause incapacity to repair bone breakdown (microfracture) and may lead to bone loss (Frost, 1994; Duyck *et al.*, 2001; Melsen & Lang, 2001).

In essence, one of the most critical element for the promotion of a safe biomechanical environment for an uneventful bone tissue formation around an immediately loaded implant is a stiff bone-implant interface, allowing low implant micromovement in bone (Pilliar *et al.*, 1986; Kenwright *et al.*, 1991; Szmukler-Moncler *et al.*, 1998, Akkocaoglu *et al.*, 2005). An additional difficulty, when considering immediate loading for immediately placed implants, is the inevitably initial bone defect at the marginal region (Nemcovsky *et al.*, 2002; Schropp *et al.*, 2003). This bone defect increases the crown/implant ratio and theoretically leads to higher bending moments acting upon the implant (Akkocaoglu *et al.*, 2005). Nevertheless, the simulation of non-integrated implant showed a low value of relative displacement between the implant and the bone. In a taper connection, the loading is resisted mainly by the taper interface, which prevents the abutment from tilting off (Merz *et al.*, 2000). There is no possibility of tilting about a single point or small area. In this case, the superior joint stability of morse-taper interface probable provides its reduced micromovement (Sutter *et al.*, 1993).

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