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Evaluation of Stress Distribution in Overdenture-Retaining Bar with Different Levels of Vertical Misfit

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Abstract

Purpose: To evaluate the effects of different levels of vertical misfit between implant and bar framework on distribution of static stresses in an overdenture-retaining bar system using finite element analysis.
Material and Methods: A 3D finite element model (11,718 elements and 21,625 nodes) was created and included two titanium implants and a bar framework placed in the medial region of the anterior part of a severely reabsorbed-jaw. All materials were presumed to be linear elastic, homogenous, and isotropic. Mechanical simulation software (NEiNastran 9.0) was used, where displacements were applied on the end of the bar framework to simulate the closure of the vertical misfits (5, 25, 50, 100, 200, and 300 μm) after tightening of the screws. Data were qualitatively evaluated using Von Mises stress given by the software.
Results: The models showed stress concentration in cortical bone, corresponding to the cervical part of the implant, and in cancellous bone, corresponding to the apical part of the implant; however, in these regions few changes were observed in stress to the misfits studied. While in the bar framework, retaining-screw neck, and implant platform, a considerable stress increase proportional to the misfit amplification was observed.
Conclusions: The different levels of vertical misfit did not considerably influence the static stress levels in the peri-implant bone tissue; however, the mechanical components of the overdenture-retaining bar system are more sensitive to lack of passive fit.

Implant-retained overdentures can be attached in two ways—with resilient attachments on freestanding implant abutments, and with resilient attachments to attach the denture to a rigid bar assembly interconnecting the osseointegrated implants.[1] The literature suggests the requirement for a passive fit between the prosthesis framework and implant fixtures.[2-5] The resiliency of the periodontal membrane found in natural dentition is absent in the case of osseointegrated dental implants,[6,7] therefore being unable to adapt to the misfits.

When there is poor fit between structures, tensile, compressive, and bending forces may be introduced into an implant-retained restoration and may result in failure of the components.[5,8-10] Moreover, a poor-fitting framework may transfer unwelcome stress onto the bone/implant interface, possibly inducing loss of osseointegration.[4,11-13] Nevertheless, several studies have shown some biologic tolerance of osseointegrated dental implants to certain levels of misfit.[14-17] However, there is difficulty in determining these states due the limitations of these studies and also ethical principles involved in in vivo studies.

Some authors have attempted to define an acceptable level of implant denture fit.[18,19] In 1983, Branemark was the first to define passive fit, and he proposed that this should be at the level of 10 μm to enable bone maturation and remodeling in response to occlusal loads.[18] In 1991, Jemt defined passive fit as the level that did not cause any long-term clinical complications and suggested misfits smaller than 150 μm were acceptable.[19] Although the preceding values have been reported and used as reference, they are of empirical origin.

Potential distortion can be created at any step of the fabrication process. Errors are due to changes occurring during indirect procedures, including taking impressions, gypsum casts, waxing frameworks, investing wax patterns, and casting frameworks. If all the materials are carefully handled, then the compounded errors are still relatively small.[20-26] Several different post-casting techniques have been developed to correct

Table 1 Material properties

Material	Young's modulus (GPa)	Poisson's ratio(v)
Cortical bone[33]	**13.7**	**0.3**
Cancellous bone[33]	**1.37**	**0.3**
Titanium (implant)[34]	**110**	**0.33**
Titanium (screw)[35]	**110**	**0.28**
Type IV gold alloy (framework)[36]	**80**	**0.33**

inaccuracies of fit resulting from the fabrication process.[27-30] However, denture misfits are a clinical reality, as even these procedures are not able to completely eliminate misfits.

Numerical analysis can help overcome the limitations of traditional experimental methods by offering accurate and reliable information about the biomechanical efficiency of multiple-implant prostheses with regard to bar framework, implant, and bone response.[31] Some studies evaluated the influence of the misfit on stress distribution in implant-supported prostheses,[13,31] but information about the influence of misfit changes between framework and implants is limited. Therefore, the aim of this study was to evaluate the effects of different levels of vertical misfit (5, 25, 50, 100, 200, and 300 μm) between implant and bar framework on 3D distribution of the static stresses in an overdenture-retaining bar system using finite element analysis (FEA).

Materials and methods

The anterior part of a severely resorbed jaw and an overdenture-retaining bar system above two osseointegrated implants were modeled using a 3D parametric solid modeler (Rhinoceros 3.0 software; McNeel, Seattle, WA). The geometry of the jaw portion modeled was obtained starting from computed tomography data with type III bone condition.[32] Two external

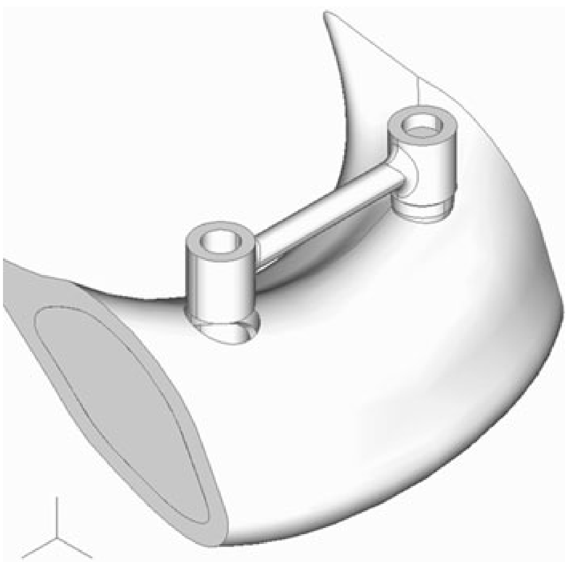

Figure 1 Design of the investigated model.

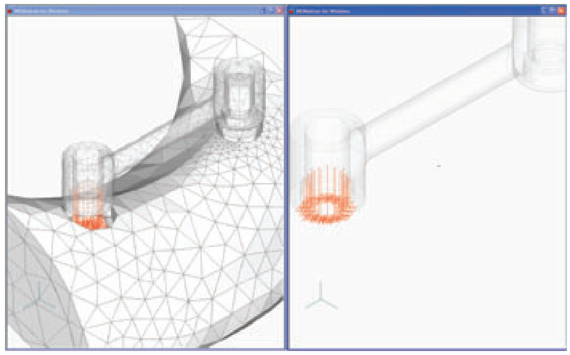

Figure 2 The orange lines indicate the displacements created to simulate the closure of the misfit.

hexagonal 3.75 × 10 mm titanium implants (Nobel Biocare, Yorba Linda, CA) were selected. A 2-mm diameter circular bar and two UCLAs of an overdenture-retaining bar system were also modeled, with a distance of 18.5 mm between the UCLA centers. A gold alloy was used as bar framework material. The FE model was obtained by importing the solid model into mechanical simulation software (NEiNastran 9.0; Noran Engineering Inc., Westminster, CA) using STEP (*.stp) format. The corresponding elastic properties, such as Young's modulus and Poisson ratio, were determined from values obtained from the literature[33-36] (Table 1).

All materials were presumed to be linear elastic, homogenous, and isotropic. Because of the lack of precise information regarding the material properties of bone, the cortical and cancellous bone were assumed to have these properties.[37] The implant thread and cancellous and cortical bone were removed, because after several convergence tests, they were found not to be relevant to the analysis and provided a relevant reduction in elements. Complete adhesion was assumed between bone and implant, and bar and implant, provided by osseointegration and screw torque, respectively. Screw and implant were considered a single structure, because they were not relevant to the purpose of the analysis. The model stability was carried out to obtain a reliable model, regarded as relevant to engineering and clinical aspects.

A 3D FE model was constructed using a tetrahedral element with ten nodes. The volumes were redefined in the new environment and meshed, finally resulting in a model with 11,718 elements and 21,625 nodes. The investigated model showed the configurations presented in Figure 1. All the nodes on the bone external surface were constrained in all directions to allow application of the displacement condition and stresses to be created in the models. Displacements limited by different levels of vertical misfit were applied on the end of the bar framework, simulating the tightening of the screws (Fig 2). Therefore, six models with different displacement values (5, 25, 50, 100, 200, and 300 μm) were created. Stability of the model was checked, and particular attention was paid to the refinement of the mesh at the bone/implant interface. The results for qualitative analysis were represented by figures and color gradients of stresses and presented in terms of Von Mises stress values, because a higher Von Mises stress is a strong indication of a greater possibility of failure.

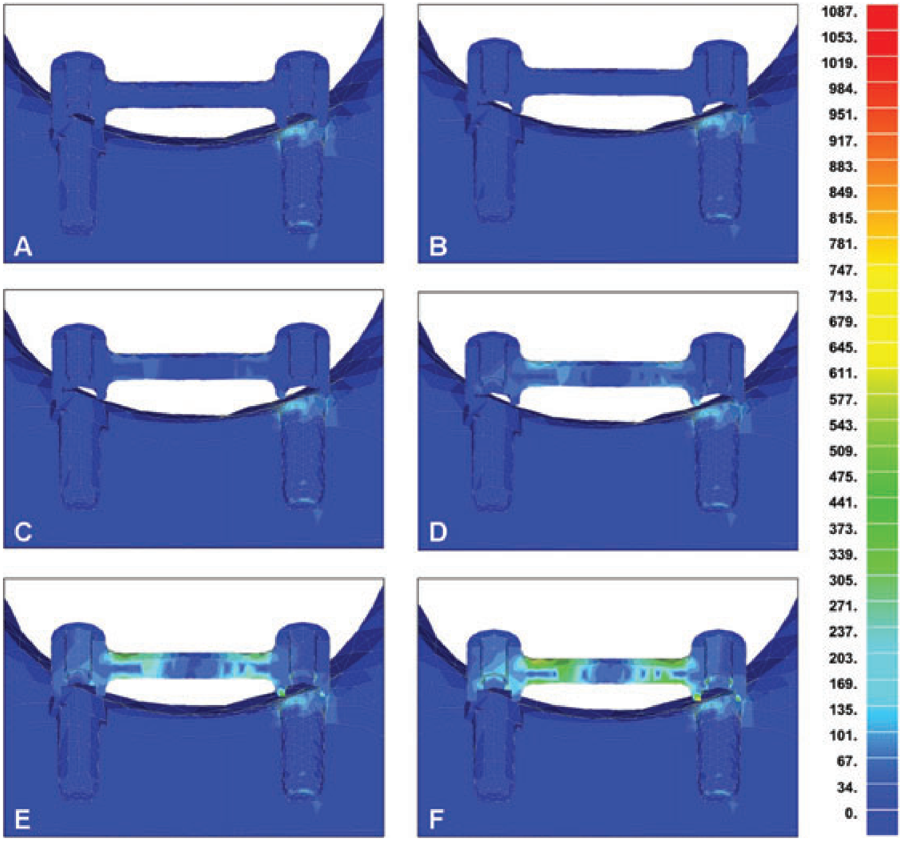

Figure 3 Von Mises stress (MPa) distribution in the bar framework and peri-implant bone tissue for the different levels of vertical misfit: (A) 5 μm; (B) 25 μm; (C) 50 μm; (D) 100 μm; (E) 200 μm; (F) 300 μm.

Results

Figure 3 shows Von Mises stress distribution in the bar framework and peri-implant bone tissue for different misfits. The models showed stress concentration in the cortical bone, corresponding to the cervical area of the implant, and in the cancellous bone, corresponding to the implant apical area; however, different misfits showed little influence on the stress levels in these areas, whereas in the bar framework there was considerable increase in stress due to misfit amplification.

Figure 4 shows Von Mises stress distribution in the retaining screw and implant for different misfits. The models showed concentration in the retaining-screw neck, and implant platform and neck. The different bar misfits showed little influence on the stress levels in the implant neck, corresponding to cortical bone; however, there was considerable increase in the stress levels to misfit amplification in the screw neck and implant platform.

Discussion

FEA is an established theoretical technique used in engineering. The role of bioengineering cannot be underestimated, and biomechanical principles have been analyzed in many studies. The basic purpose of these studies was to extrapolate the findings relevant to the risk factors instead of experiencing them empirically in clinical applications; however, the levels that actually cause biological response, such as resorption and remodeling of the bone, are not comprehensively known. Therefore, the stress data provided for FEA required substantiation by clinical research.[38]

The model used in the present study implied several assumptions regarding the simulated structures. The structures in the model were all assumed to be homogeneous and isotropic and to possess linear elasticity. The properties of the materials modeled in this study, particularly the living tissues, however, are different. For instance, the cortical bone of the mandible is transversely isotropic and inhomogeneous. In addition, a 100% implant/bone interface was established, which does not match clinical situations. The effect of bone/implant contact ratio at the bone/implant interface on the stress distribution in the peri-implant bone has been studied. A study presented a new FE model simulating the whole structure of the peri-implant cancellous bone showing a stress distribution more homogeneous compared with conventional bone used in other studies.[39] In contrast, the degree of osseointegration did not affect stress distributions by FEA. This controversy may be the result of bone model structures.[40] Thus, the inherent limitations of FEA of stress distribution should always be taken into consideration.

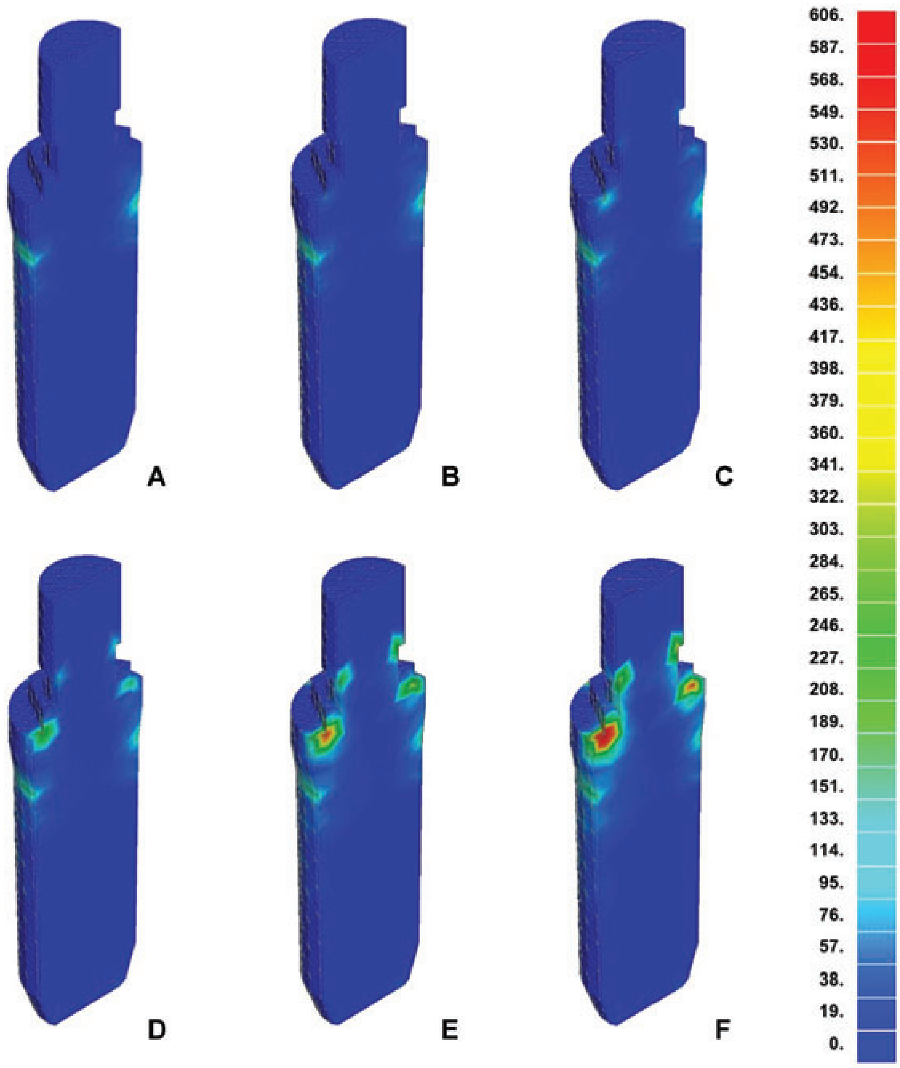

Figure 4 Von Mises stress (MPa) distribution in the retaining screw and implant for the different levels of vertical misfit: (A) 5 μm; (B) 25 μm; (C) 50 μm; (D) 100 μm; (E) 200 μm; (F) 300 μm.

The FEA showed considerable changes on the stresses induced in the bar framework, retaining-screw neck, and implant platform for the misfits investigated, whereas in the peri-implant bone tissue and implant neck, few changes in stress levels were observed. As related by Watanabe et al,[7] osseointegrated implants have limited movement, in the range of 10 μm, and small misfits could create a high degree of strain around the implant bodies. In the present study, this can be seen by high stress levels in peri-implant bone tissue starting with 5 μm of misfit; however, the misfit amplification, from 5 to 300 μm, did not considerably increase stress in peri-implant bone tissue. Several studies indicated a certain biological tolerance for prosthetic misfit in living bone.[14-17] A longitudinal study has verified marginal bone loss means of 0.5 and 0.2 mm to screw-retained prosthesis with misfit of 111 μm and 91 μm, respectively. The authors indicated no statistical correlation between marginal bone level changes and different prosthesis misfits. Moreover, the authors observed that the implants were stable and immovable after years in function, suggesting certain biological tolerance to prosthesis misfits.[15] Marginal bone loss is considered acceptable between 0.4 and 1.6 mm in the first year, and around 0.1 mm of subsequent loss per year after the first year.

The increase of the static stress levels concerning misfit amplification in the framework bar, retaining screw, and implant suggest that the mechanical components are in part more sensible to lack of passive fit. Some studies using photoelastic-coating technique are in agreement with these findings, showing increase of the static stresses in the prosthetic framework due the misfit amplification.[41,42] This stress concentration in the mechanical components may explain the failures found clinically, so as to loosen or fracture the prosthetic or abutment screw, and fracture the framework or veneers.[10,43]

These data may suggest a different level of tolerance between the biologic and mechanical complications of implant-supported prostheses concerning the lack of passive fit; however, affirmation that misfits are not prejudicial to bone/implant interface is not yet appropriate, as there is not enough basis in the literature to make this conclusion. In addition, to acknowledge and supplement studies using FEA to evaluate stress in bone tissue, it is essential more studies quantitatively show stress in positive remodeling to the osseointegration. Other factors already under investigation, such as loading geared by clip and material and configuration of the bar framework, may influence the stress distribution in the overdenture-retaining bar system.

Conclusions

Within the limitations of this FEA, the following conclusions can be drawn:

1. The vertical misfit showed great influence on the static stress levels in the bar framework, retaining screw, and implant, once considerable increase of the stresses was seen by misfit amplification.
2. The changes in vertical misfits had little influence on the static stress levels in the peri-implant bone tissue, suggesting that mechanical components are more susceptible to failure by misfit amplification.

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