Bone Remodeling Response During Mastication on Free-End Removable Prosthesis – a 3D Finite Element Analysis

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Abstract: An understanding of functional responses in oral bone is a crucial component of dental biomechanics. The purpose of this study was to investigate the use of an osseointegrated implant as support for a free-end removable partial denture (RPD) on the potential biological remodelling response during mastication. A three-dimensional (3D) finite element analysis (FEA) was performed to determine the biomechanical responses to masticatory loading in the posterior mandible. Stresses and strains were analysed at lingual/buccal and mesial/distal areas of the premolar to molar region to anticipate bone remodeling response. Mandibular bone incorporating an implant-supported RPD experienced substantially greater stress/ strain magnitudes than that prior to placement of implant, which is suggestive of engagements of bone remodelling. The results suggest similar outcomes to those reported clinically. Developing a simulation reflecting the outcomes of restorative treatment can provide meaningful insight into restorative treatment planning, clinical outcomes, and removable prosthodontics designs.

Keywords: Bone Biomechanics, Osseointegrated Implants, Removable Partial Denture.

1. Introduction

Although there is a tendency to offer fixed prostheses to our patients, this might change again with the demographic changes and with an ageing population, an increase in their reduced dentition and low socioeconomic wealth in large parts of the world (Mericske-Stern, 2009). Rehabilitation of partially edentulous mandibles with Kennedy class I removable partial dentures (RPDs) requires anatomic reconstruction of the lost alveolar bone, replacement of posterior teeth and stable occlusal contacts to allow for functional mastication.

Treatment planning for free-end RPDs became highly complex over time, and a set of reliable criteria is necessary for decision-making and problem managing. The functional needs of the distal part of mandible, combined with the physiologic differences among the support system of the prosthesis, continue to present major problems to dental surgeons. The physiological movement capacity of a tooth, due to it's periodontal ligament, is limited to 0,1mm, whereas the compressibility of the mucosa varies from 0,4mm to 4mm (Biagi & Elbrech, 1955).

Implant supported free-end RPDs are suggested as a solution for the biomechanical problems, providing long-term occlusal stability (Keltjens *et al.*, 1993; Cho *et al.*, 2002). However, the presence of a RPD, supported or not by an implant, changes the local biomechanical status, whereby bone may model and remodel to accommodate a new loading environment.

Resorption is an inevitable consequence of extraction of a natural tooth due to local bone disuse (Field *et al.*, 2008). Although the resorption may not be eliminated completely, its severity can be reduced by ensuring that the prosthesis transmits mechanical loads to the underlying bone structure properly (Sennerby et al, 1988).
Many authors have performed biomechanical studies of Kennedy class I RPDs. Most of these are based on clinical studies with conventional and implant supported removable partial dentures (Shahmiri & Atieh, 2010). Cho *et al.* (2002) photoelastically compared the load transfer characteristics of distal extension RPDs with and without implant assisted support in the posterior mandible. Their results showed that loads applied to the denture base supported by implants with healing abutments generated high stress concentrations around the apices of the ipsilateral implant and abutment tooth.
Finite element analysis is well suited to the analysis of stress in teeth and dental restorations because it can closely simulate the geometries, loads and material inhomogeneities in the system being studied (Selna *et al.*, 1975). The advantage of computer simulations is that they allow for parametric analysis, personalized virtual tests, and testing of different situations, impossible to simulate in real practice.
We performed a finite element analysis of two free-end RPDs, one conventional and one with implant assisted support. Our hypothesis was that the presence of the implant would transfer the load to the medular bone, acting as a mechanical stimulus to prevent bone resorption. The aim of this study was to compare the stress/strains on the residual ridge between conventional RPD and an RPD with implant assisted support.

2. Material and Methods

Abaqus/Standard 6.9-1 (Simulia, USA) was used for finite element analysis and Abaqus/CAE for selected geometry construction and mesh generation. The raw data from CT was rebuilt using RHINOCEROS® 3D for Windows 4.0 (Robert McNeel&Assoc., USA).

Three-dimensional computational models of a section of a partially edentated mandible were established in this study, representing the left lateral incisor, canine and first premolar rehabilitated with a fixed metal crown attached to a removable partial denture, supported or not by an osseointegrated implant (Figure 1). The geometry of the mandible was reconstructed from a computed tomography (CT) and computer aided design (CAD) methods were used to obtain the geometry of the prosthesis.

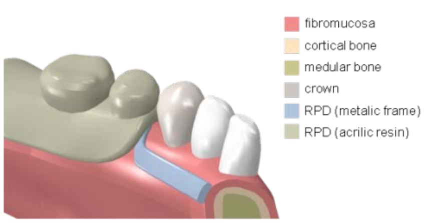

Figure 1. Model geometry.

Models A and B (Figure 2) were the basis for the comparative finite element analyses (FEA) that were conducted with Abaqus/Standard. Model A is an association between fixed prosthesis (crown) on the first premolar and RPD retained by a resilient attachment, and Model B is the same but the RPD is supported by an osseointegrated implant. The resilient attachment was represented with a connector element of type JOIN as for the range of expected movement rotations are not restricted.

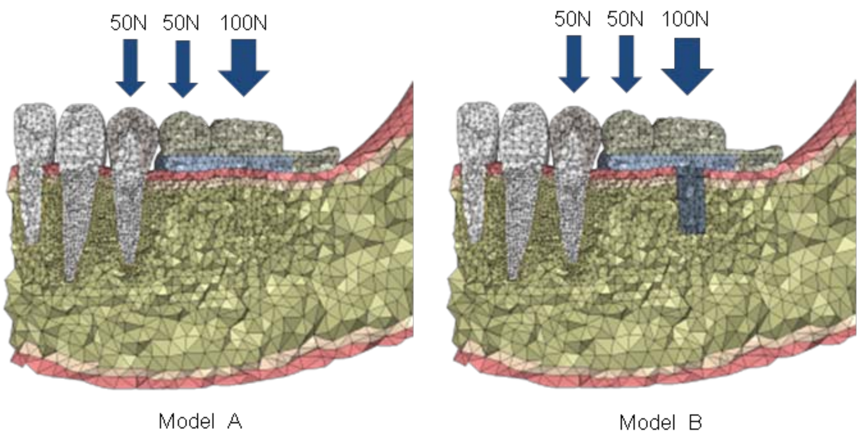

Figure 2. Geometry, mesh and load cases for models A and B.

To apply near-physiological loading conditions, the loads were chosen based on the physiologic forces described at the literature (Howell & Brudevold, 1950). Loads classified within an upper range of normal biting forces were applied: 50N to the first and second premolar, and 100N to the first molar.

Each model had a total of 135.662 elements and 174.100 nodes. The models consisted mostly of a 10-node tetrahedral solid mesh (C3D10M for fibromucosa, cortical bone, medular bone, periodontal ligament, teeth and implant); solid elements of type C3D20R and C3D4 were used for the RPD metal frame and prosthesis acrylic base respectively.

All the materials were presumed linear, elastic, homogeneous, and isotropic for the analyses as widely adopted in existing literature (Field et al., 2008), and the mechanical properties were taken from the literature as shown in Table 1.

Although PDL is viscoelastic in nature, the isotropic elastic properties were assigned as the load response lies within the linear elastic range (Pietrzak et al., 2002). Bone in this study is also modeled isotropically since it was already stated that isotropic models of the mandible were able to distinguish meaningful strain differences when replicating functional loading (Ichim et al., 2006), which have been widely accepted by clinicians when evaluating patients (Lekholm & Zarb, 1987).

Table 1. Material properties.

Material	Young's modulus (Mpa)	Poisson's ratio	Reference
Dentin	18.600	0,31	Farah *et al.* (1988)
PDL	68,9	0,45	Farah *et al.* (1988)
Cortical Bone	13.700	0,30	Farah *et al.* (1988)

Medular Bone	1.370	0,30	Farah *et al.* (1988)
Mucosa	680	0,45	Ko *et al.* (1992)
Crown (Pg/Pd)	90000	0,33	Nagata *et al.* (2009)
RPD (Co/Cr)	206.900	0,33	Craig & Farah (1978)
RPD (acrilic resin)	3000	0,35	Zyl (1995)
Implant (Ti)	103.400	0,35	Sertgoz & Guvener (1996)

3. Results

The FEA of Models A and B focused upon the stress and strains within the alveolar and cortical bony tissues. The biomechanical differences due to mastication in the presence and absence of the implant cases are evident within the contiguous bone. Comparisons between the models were made through the von Mises stresses and principal stresses/strains. Firstly, von Mises stresses were evaluated as an indicator to overall tissue deformation. Then, minimum principal stress and strain were characterised to highlight compression behaviors, since the nature of these stresses may affect bone remodeling (Field et al., 2008).

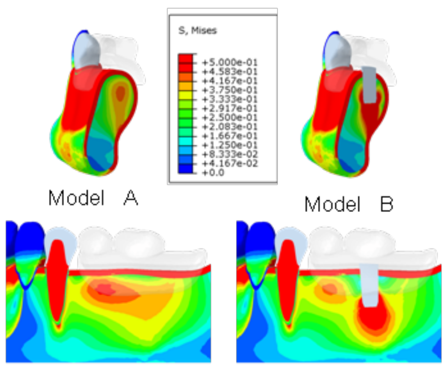

Figure 3. Von Mises Stresses on mandibular cortical and medular bone.

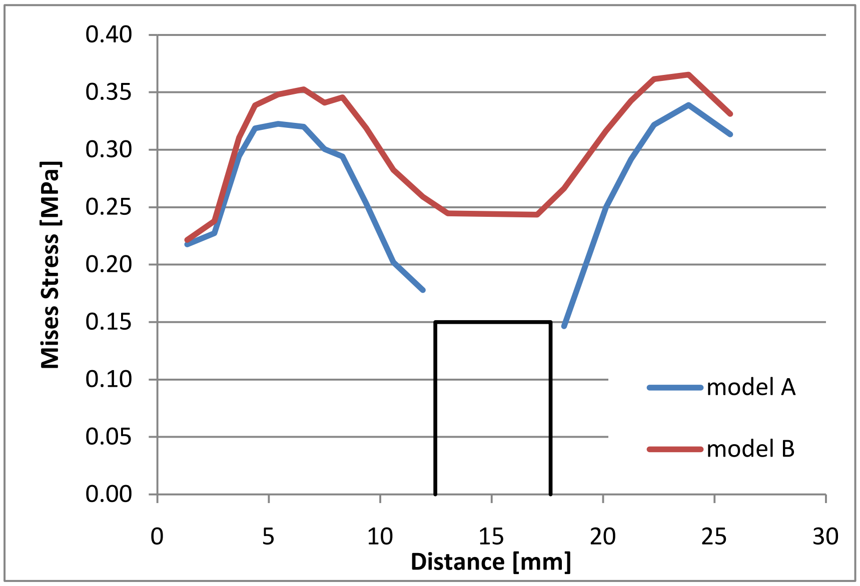

Figure 4. Von Mises stresses in cortical bone (path from distal premolar to end of prosthesis base).

As shown in **Figures 3** and **4**, the von Mises stresses on the cortical/medular bone interface were reduced along all the residual bridge. It's noted that the stresses in the cortical ridged regions of the cortical bone is of primary interest in determining initiation of bone remodelling .

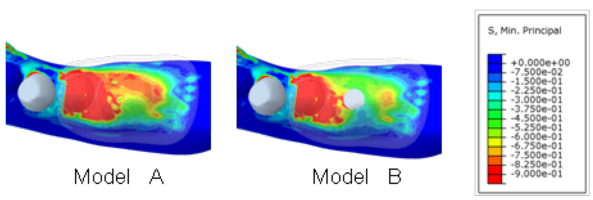

Figure 5. Minimum principal stresses on fibromucosa.

The minimum principal stresses on the fibromucosa showed the load distribution under the prosthesis base. There was a stress concentration on the principal support zone of the residual bridge and the stresses were reduced in about 30% with the presence of the implant.

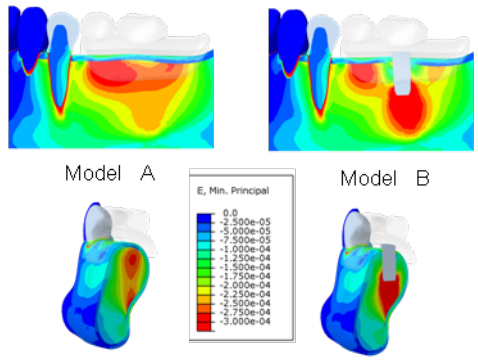

Figure 6. Minimum principal strains on mandibular cortical and medular bone.

The minimum principal strains show that the presence of the implant transfer the loads to the inner medular bone, simulating what is observed in the dentate areas.

4. Discussion

The vitality of bone about an RPD is of primary importance as the condition of bone can in turn affect the stability of the RPD considerably (Sennerby *et al.*, 1988). However, it has remained unclear how the alteration of local oral condition induced by extraction of natural tooth and prosthetic treatment could affect the alveolar bone.

According to Sennerby *et al.* (1988), certain levels of mechanical masticatory stimulation are vital in maintaining sufficient underlying bone health. It's suggested that compression behaviors in cortical bone can lead to resorption, and there's a range of strain necessary to enable the dynamics of bone turnover to reach equilibrium.

In this study, the results of the 3D FE analyses suggested similar outcomes of those reported in clinical and photoelastic studies (Keltjens *et al.*,1993; Cho *et al.*, 2002), confirming that osseointegrated implants can improve the biomechanics of RPDs. The implant supported RPD yielded a significant reduction of von Mises stress in the cortical bone. It was also seen that the presence of the implant reduces the minimum principal stress on the fibromucosa, suggesting that the vertical intrusion of the prosthesis base was prevented. Other than that, minimum principal strains were transferred by the implant from the cortical/ medular bone interface to the inner region of the medular bone. This is a realistic indication that an implant assisted supported RPD treatment could better maintain an appropriate bone remodeling equilibrium, thereby preserving a healthy status of bone.

5. Conclusion

The present study defines the initial biomechanical responses and possible adaptive changes within RPD surrounding bone with or without implant support. This method can supplement existing experience-based clinical predicative procedures. It is revealed that the insertion of a osseointegrated implant to support an RPD leads to a noticeable alteration in stress/strain patterns undergone within alveolar bone. This status of biomechanics can be associated with specific biological cellular reactions as a consequence of biomechanical stimuli. The results provide supportive evidence that an osseointegrated implant supporting a free-end RPD would help maintain a proper equilibrium of bone turnover.

6. References

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