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A THREE-DIMENSIONAL FINITE ELEMENT ANALYSIS OF MANDIBULAR OVERDENTURE SUPPORTED BY CYLINDRICAL AND CONICAL IMPLANTS

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Abstract. *This 3D finite element study assessed the stress distribution in mandibular overdenture supported by the 3i Locator system attached to two cylindrical or conical implants placed at the canine region. A 100 N vertical load was applied over the right first molar of the two overdenture models. The von Mises stresses were concentrated at the cervical and middle implant thirds. Cylindrical implants showed larger crestal bone area of high stresses in comparison to the conical implants. The results suggest that conical implants reduce the stresses in peri-implant crestal bone at both loading and non-loading sides.*

Keywords: Dental implants; implant-supported overdenture; biomechanics; finite element analysis.

1. INTRODUCTION

Conical implants have been introduced to mimic the convergence of natural dental roots. Previous studies reported that conical implants present good clinical predictability in mandibular fixed prosthesis with early loading (Kronström *et al.*, 2003) and provide easier surgical insertion and greater primary stability than cylindrical implants (Sakoh *et al.*, 2006).

An optimal implant geometry should prevent concentration of high stresses at the bone crest to minimize marginal bone resorption, although the clinical cut-off limit is unknown. Cylindrical or conical implant shapes may modify the stress distribution at bone, implant, and prosthetic component interfaces. Most biomechanical studies on this topic have focused implant-supported fixed prostheses and single implants (Sakoh *et al.* 2006, Huang *et al.* 2007, Petrie *et al.* 2005), and data on overdentures supported by conical implants are scarce. Therefore, this study aims to compare the von Mises stresses generated by the application of a static vertical load in a mandibular overdenture supported by two cylindrical and conical implants.

2. MATERIALS AND METHODS

Two three-dimensional solid models were built with the individual models containing cylindrical and conical (5 degrees of apical convergence) 4.1 x 11.5 implants (3i Implant Innovations, Palm Beach, Florida, USA), locator 4 mm attachment components (3i, Implant Innovations, Palm Beach, Florida, USA), edentulous mandible, complete denture, and a simulated 3mm-thick mucosa. The individual images of implants, abutments, mucosa, complete denture, and bone were obtained by laser scanning, computed tomography of the mandible (seventy 1mm-thick slices), and computer-aided design using the softwares Matlab® (The MathWorks, Natick, Massachusetts, USA), Geomagic® 7.0 (Raindrop, Research Triangle Park, USA), Rhynoceros 3D® 3.0 (McNeel & Associates, Seattle, USA), and SolidWorks® 2006 (SolidWorks Corporation, Concord, Massachusetts , USA).

The geometric models of implants and abutments were mounted at the canine region (teeth 43 and 33) to build two models: model 1 – overdenture supported by two cylindrical implants, and model 2 – overdenture supported by two conical implants. The finite element models were generated and analyzed in the software Ansys (Ansys Inc., Houston, USA) using three types of structural solid p-elements (10-Node Quadratic Tetrahedron, Quadratic Triangular Contact, and Quadratic Triangular Target). The grid refinement until the estimator is smaller than a prescribed bound. The mechanical elastic properties of bone, implants, attachment components, simulated mucosa, and denture are displayed in Table 1. The materials were considered homogeneous, isotropic, and linearly elastic. A perfect contact between bone and implants (100% osseointegration) was assumed. (Huang *et al.* 2007, Petrie *et al.*, 2005). Boundary conditions were applied by constraining three degrees of freedom at each of the nodes located at the mandibular condyles.

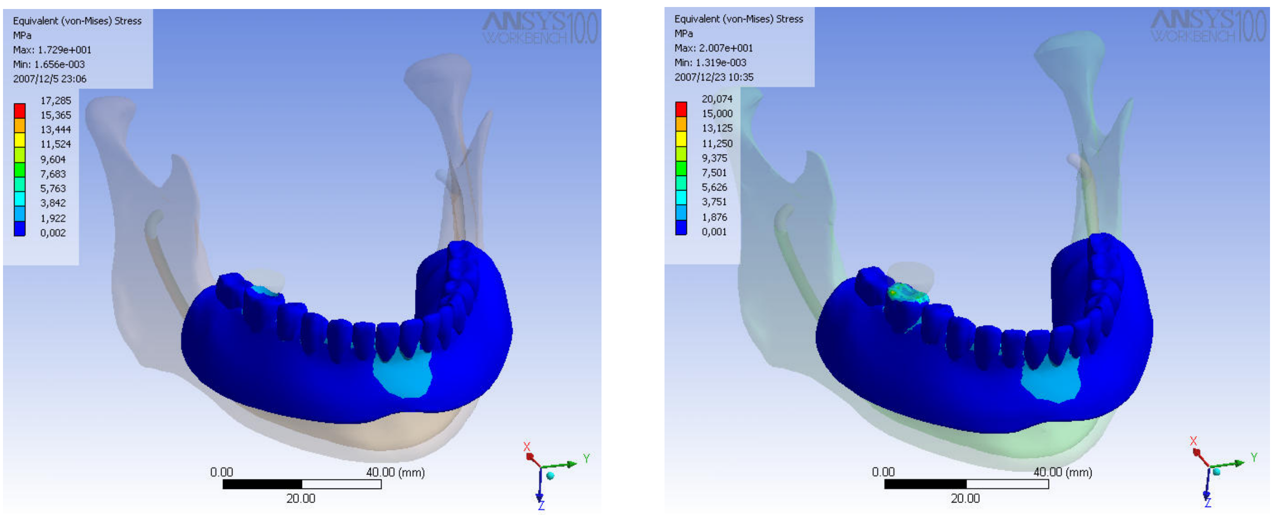
Table 1. Mechanical elastic properties of bone and materials used in the anisotropic models.

	Young's modulus (MPa)	Poisson's ratio
Cortical bone	13,700	0.3
Cancellous bone	1,370	0.3
Mucosa	1	0.37
Mandibular nerve	0.1	0.3
Overdenture (acrylic resin)	4,500	0.35
Implant (titanium)	135,000	0.3
Screw (titanium)	114,000	0.3
Attachment (titanium)	114,000	0.3
PTPE attachment component	19,000	0.3

The models were loaded by an axial vertical load of 100 N applied on the right first molar, using a masticatory bolus simulation modeled as a rigid semi-sphere placed over the denture tooth (Daas et. al, 2008). The von Mises stresses were qualitatively analyzed in selected areas.

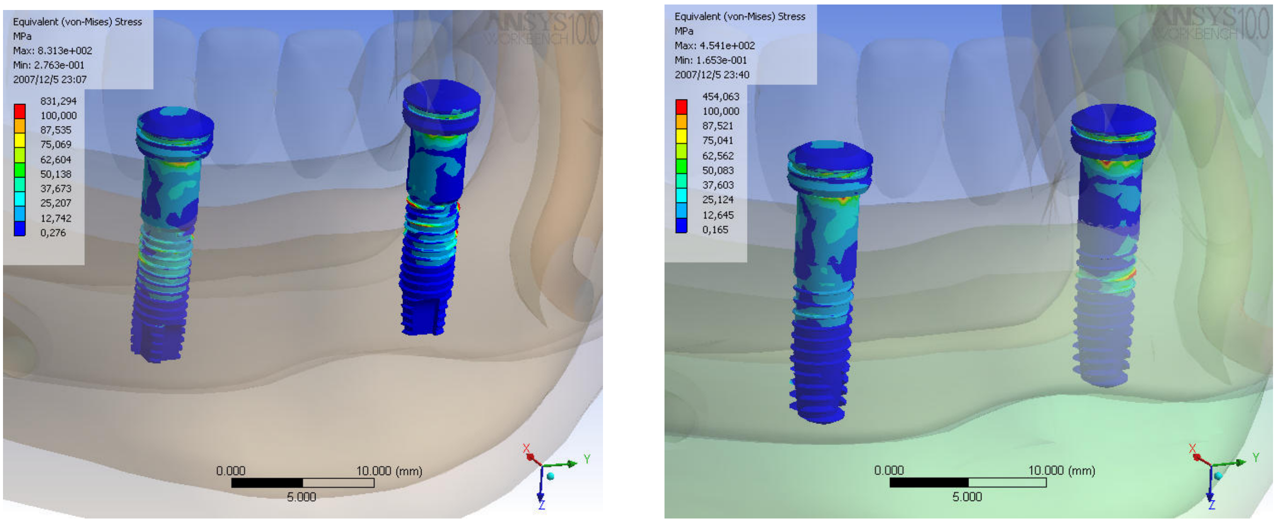
3. RESULTS

Lower magnitude von Mises stress areas were concentrated on the buccal anterior region of the overdentures supported by either cylindrical or conical implants (Fig.1). The stress levels on both implants resulted similar and concentrated in the cervical and middle thirds (Fig.2).



(a) (b)

Figure 1. Von Mises stress levels in overdentures supported by (a) cylindrical and conical (b) implants.



(a) (b)

Figure 2. Von Mises stress levels in the (a) cylindrical and the (b) conical implants placed at the teeth 43 and 33 sites (loading and non-loading sides, respectively).

Figure 2 shows that high stress levels on the implants occur on localized areas, due to stress concentration or contact. Since the stress analysis of the implants is not the objective of the present work, no effort was made to study in better detail these areas.

On the other hand, Fig. 3 shows the stress distribution in peri-implant crestal bone at the loading side (tooth 43 site). The stress magnitude was similar for both types of implant but the area subjected to higher stress was larger for the cylindrical implant. At the non-loading side, the cylindrical implant also generated a larger area of high stress in comparison to the conical implant (Fig.4).

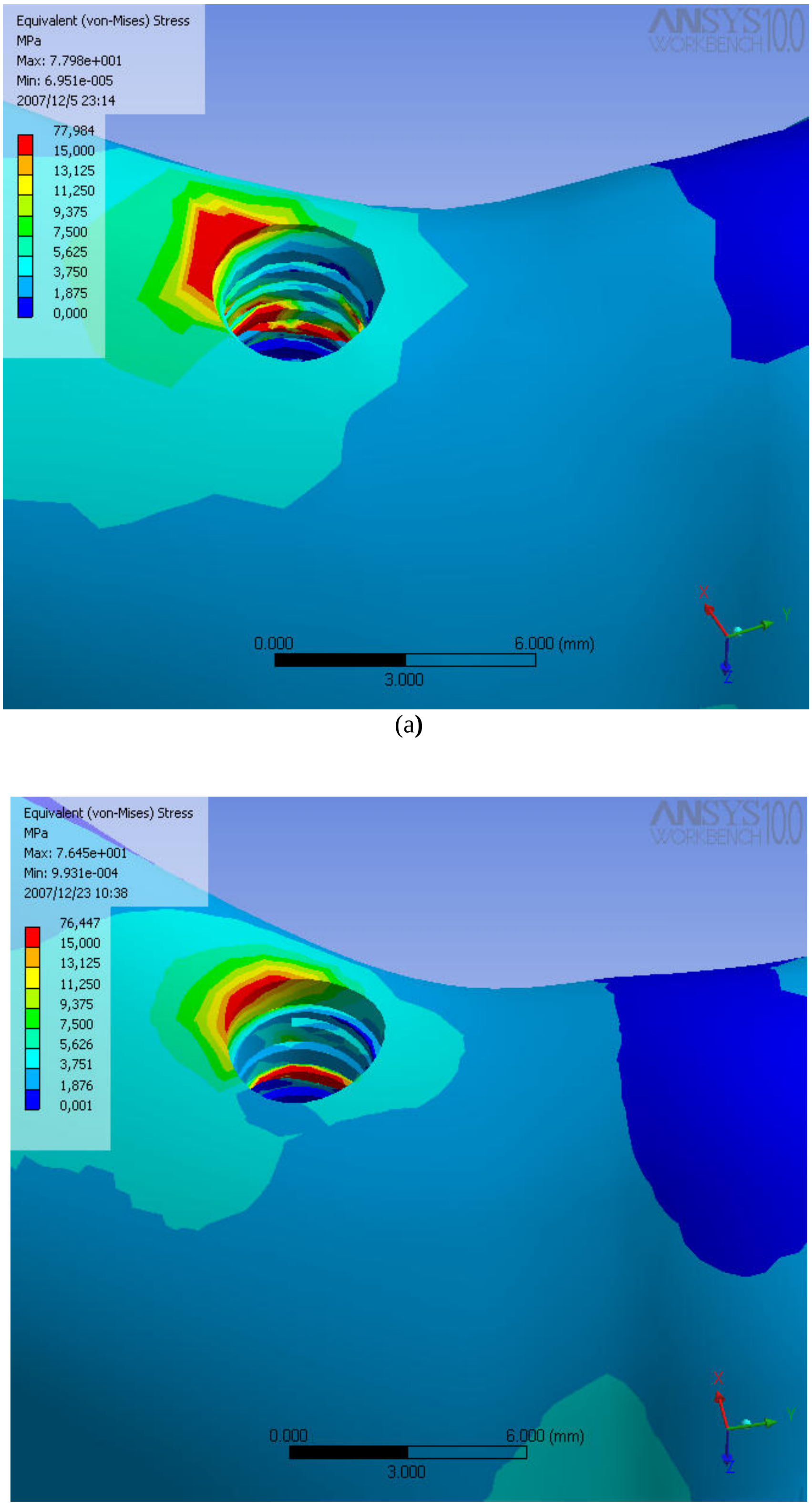
4. DISCUSSION

This finite element analysis work presented the stress distribution in a mandibular overdenture supported by the 3i Locator system attached to two types of implants placed at the canine region. It is worth to note that over-simplifications traditionally used in these models were avoided here, so that the numerical models included a detailed representation of the implants' threads. The stresses in both cylindrical and conical implants were concentrated at the cervical and middle thirds. The implants placed at the loading side showed larger area of stress than the contralateral implants, but the stress magnitude was similar. In relation to the mandibular bone, the anterior surface had larger stress concentration at the distal area of both types of implants on the loading side than that of the contralateral side. The stress magnitude on the bone surface was similar but the area of higher stress distribution was larger for the cylindrical implant at the loading side. In a longitudinal section of the bone at the tooth 43 site, the higher stresses were concentrated at the cervical region of both implant shapes corresponding to the cortical bone. In relation to the bone at the tooth 33 region, the stresses were higher at the mesial side of the cylindrical implant compared to the conical implant.

The numerical results for stress showed that the use of two conical implants reduced the area of higher von Mises stresses in the peri-implant crestal bone at the loading and non-loading sides of the implant-supported overdenture. Nevertheless, implants and denture did not show relevant variations of stress magnitude and distribution, indicating that the small geometric differences in the shape of the implants do not affect significantly the nominal stress levels. This occurred because the conical implant used has a slight apical convergence. Certainly, it is expected that conical implants with greater apical convergence show higher crestal strain in single implants (Petrie *et al.*, 2005).

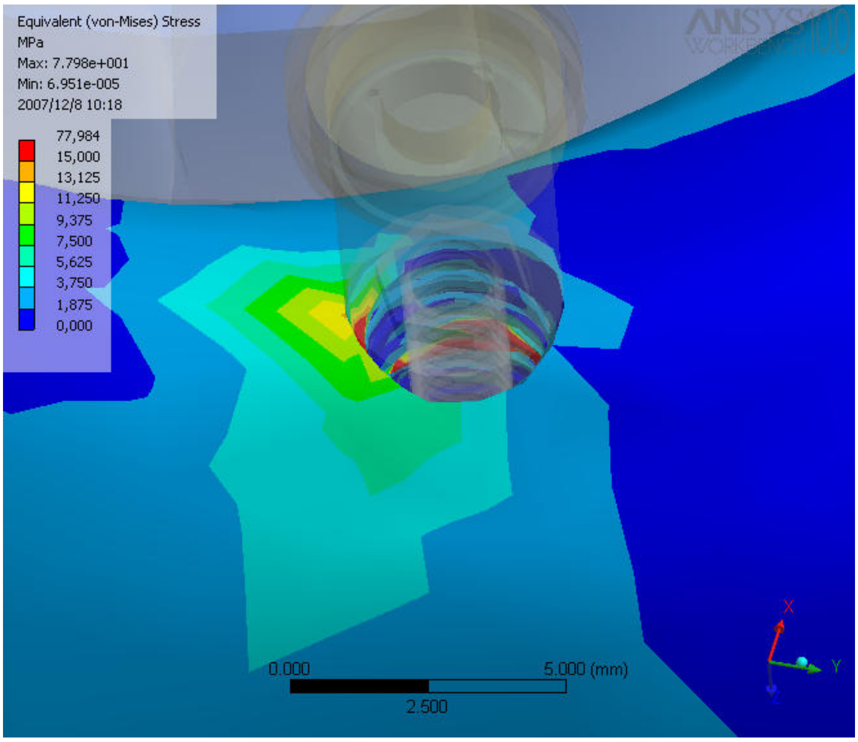
The present study assumed various simplifications to simplify the numerical model and reduce the computational cost of the analysis, and therefore one cannot extrapolate the main conclusions drew from the stress analysis to other situations. Further studies can incorporate better definition of the contact areas (osseointegration), analyze the stress generated by different load incidences, dynamic loadings, functionally graded properties, and non-linear material behavior. Nonetheless, even within these limitations, the results obtained in the present work suggest that conical implants may offer biomechanical advantages with no detectable risk to support mandibular overdentures in comparison with the standard, more widely used cylindrical implants.

The methodology used is, however, very simple and can be used by implant manufacturers to design/analyze other conical implants and attachment systems with little effort.

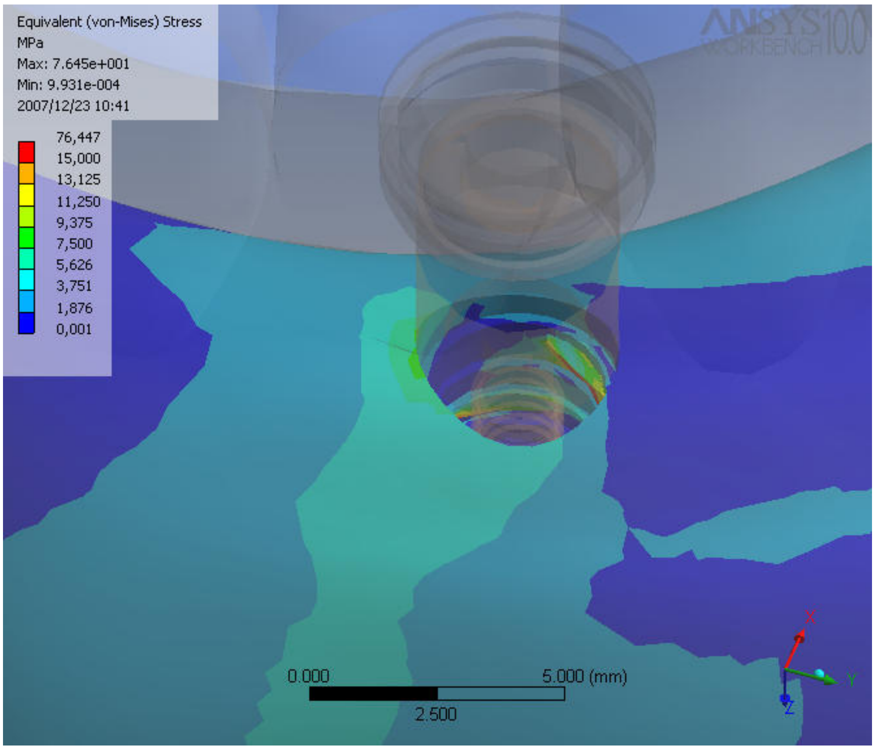


(b)

Figure 3. Von Mises stress levels in the crestal bone surrounding the (a) cylindrical and the (b) conical implants at the loading side.



(a)



(b)

Figure 3. Von Mises stress levels in the crestal bone surrounding the (a) cylindrical and the (b) conical implants at the loading side.

5. CONCLUSIONS

Within the limitations of this study, the results suggest that conical implants may provide reduction of the area of stress in the mandibular bone at the loading side of the overdenture. At the contralateral side the stress was similar for both implants.

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7. RESPONSIBILITY NOTICE

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