Analysis of Stress Distribution in Retention Screw of Different Crown Implant Ratio: A Three-Dimensional Finite Element Analysis

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Analysis of Stress Distribution in Retention Screw of Different Crown Implant Ratio: A Three-Dimensional Finite Element Analysis

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ABSTRACT

Aim: To evaluate the effect of stress distribution in retention screw of different crown- implant ratio.

Materials & Methods: - This study was intended to evaluate the effect of stress distribution in retention screw, in implant-supported dental prosthesis with different heights of crowns to internal hexagonal implants. Implant: Nobel Biocare, Implant dimension: length 11.5 mm and Diameter 4 mm. Model: Model of mandibular first molar region. Solid models of mandibular segment, a porcelain crown, abutment, retention screw, Bones and dental Implant Systems are developed by using Computer Aided Design and Drafting technique (CAD). Three screw retained single crowns were modelled with different heights of crown of 10 mm, 12.5 mm and 15 mm, following a study by Misch. Three different models were created in Solid Edge V19 software with design parameters given above. The geometries of This Models are then imported in ANSYS Workbench 18.1 analysis software to build FE Model.

Results: Higher stress was produced when an oblique load was applied, and the crown height corresponded with large size of the stress concentration area.

Conclusion: The increase in crown height increases the intensity of stress in the retention screw with under oblique loading.

Keywords: Internal hexagonal Implants, Retention screw, Crown- implant ratio, Finite Element Analysis.

INTRODUCTION

The goal of modern dentistry is to restore the patient to normal contour, function, comfort, esthetics, speech, and health[1].Over the years, traditional method of tooth replacement are slowly and steadily being replaced by newer modalities[2]. What makes implant dentistry unique is the ability to achieve this goal, regardless of the atrophy, disease, or injury of the stomatognathic system. The key factor for the success and failure of a dental implant is the manner in which stresses are transferred to the surrounding biologic tissue when subjected to occlusal loads[3,4]. Some biomechanical prosthetic factors often complicated in implant failure include the following: occlusal overload cantilevers, occlusal table width, off-axis loading and unfavorable crown implant ratio[5].Cantilever

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length, crown height and occlusal width can act as levers and force magnifiers.

The magnitude of the force may be decreased by reducing these significant magnifiers of force[1]. The greater the crown height, the greater the moment of force or lever arm with any lateral force. Forces may increases by 20% for every 1mm of increase in 2 crown height. Therefore, an increased crown-to-implant ratio (C/IR) will introduce significant moment arms on the implant and surrounding crestal bone when the implant is subjected to lateral forces[4,6].

The three dimensional (3D) finite element analyses is a method that originated in engineering. The degree of accuracy of the FEM is related to knowledge of the real load and supporting condition. Different studies agree that biomechanical behavior plays an important role in the survival of an implant, the crown to implant ratio is the key factor associated with stress distribution, and that the FEM can be reliable method for studying the biomechanical behavior of implants.

The aim of this 3-D dimensional finite element analysis was to analyze the effect of stress distribution in retention screw in implant-supported dental prosthesis with different heights of the crowns to internal hexagonal implants. The null hypothesis is that increasing the height of the crown is not detrimental to the stress distribution.

MATERIALS AND METHODS

This study was intended to evaluate the effect of stress distribution in retention screw, in implant-supported dental prosthesis with different heights of crowns to internal hexagonal implants

Design parameters:

Implant: Nobel Biocare

Implant dimension: Length 11.5 mm and Diameter 4 mm

Model: Model of mandibular first molar region.

Table 1: Properties of material

Material properties for analysis: Material.	Young's modulus	Poisson's ratio
-Titanium (implant system)	110.0 (GPa)	0.35
-Feldspathic porcelain	82.8 (GPa)	0.35
-NiCr alloy	206.0 (GPa)	0.33
-Cortical bone	13.7 (GPa)	0.30
-Trabecular bone	1.37 (GPa)	0.30

CAD Modelling:

Solid models of mandibular segment, a porcelain crown, abutment, retention screw, Bones and dental Implant Systems are developed by using Computer Aided Design and Drafting technique (CAD). Further, the CAD model was used to construct FE (Finite Element) Model in analysis software.

The posterior mandible (Distal to second premolar and mesial to second molar) was harvested from from a dry human skull and 26 frontal sections of computerized tomography (CT) images were obtained (1 mm interval between images). From each CT image material boundaries were delineated by an in house imaging program.

The co-ordinates of points forming the contour lines were then imported into the FE software ANSYS to generate a solid 3D model of mandible. The implant and its superstructure were simulated using finite element software (Hypermesh V11). ANSYS 18.1 software was used for stress analysis.

Bone implant interface:

The FEA model assumed a state of optimal osseointegration, which means that the cortical and cancellous bones are assumed to be perfectly bonded to the implant.

Geometry preparation:

For this study, a three-dimensional finite element model of mandibular section bone was constructed (fig. 1). D-2 type of bone (According to Lekholm and Zarb classification) which is more commonly found bone density in mandibular posterior region, thick layer of cortical bone surrounds a core of dense cancellous bone was modeled having 24 mm length and 16 mm width.

Three screw retained single crowns were modelled with different heights of crown of 10 mm, 12.5 mm and 15 mm following a study by Misch (2005). Feldspathic porcelain was used for the occlusal surface and the crown substructure framework was constructed of nickel-chromium alloy. Placement of abutment, implant and screw connection into the bone.

Three different models were created in Solid Edge V19 software with design parameters given above. The geometries of This Models are then imported in ANSYS Workbench 18.1 analysis software to build FE Model. Unite

Boolean operation was used to combine two or more parts so that it cannot affect the mesh quality. For example, Bones, implant and abutment are united through Boolean operation and made one body although, they have different material properties.

The three models are explained in the study.

Model A: 10 mm crown with abutment, screw, implant and bone (cortical and cancellous bone) assembly.

Model B: 12.5 mm crown with abutment, screw, implant and bone (cortical and cancellous bone) assembly.

Model C: 15 mm crown with abutment, screw, implant and bone (cortical and cancellous bone) assembly.

Methodology for Finite Element Analysis

FEA uses a complex system of points called nodes which make a grid called mesh. This mesh was programmed to contain the material and structural properties which define how the structure will react to certain loading conditions. Nodes are assigned a certain density throughout the material depending on the anticipated stress levels of particular area. Regions which will receive larger amount of stress usually have a higher density node than those which experience little or no stress. All the nodes are converted into a mathematical load and the stress evaluated.

The constraints on the bone segment and force application on top of the crown roughly approximate the complex balance between masticatory forces and their reactions. These simplifications result from limitations of the modeling procedure and thus give only a general insight into the tendencies of stress/ strain variations under average conditions.

Mesh Parameters:

Method: Tetrahedron

Element Sizing:

For Implants and Abutments 0.1 mm, for tooth 1 mm, For Bones 2 mm

Table 2: Element sizing

Quality Check	Acceptable Value	Achieved Value
Aspect Ratio	< 5	1.88
Jacobian Ratio	> 0.5	1.01
Skewness	< 0.70	0.23
Element Quality	> 0.1	0.83

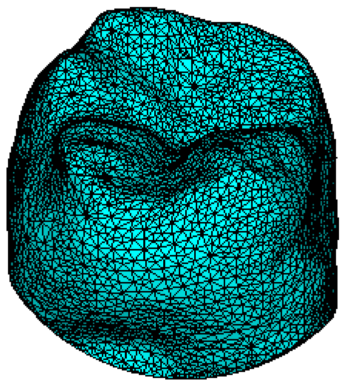

Fig 1: Crown mesh.

This was a sample mesh of crown as seen above fig. no1. For 10 mm crown the numbers of nodes were 487273 and elements were 325922, for 12.5 mm crown the number of nodes were 501282 and elements were 339281 and for 15 mm crown the nodes were 505278 and elements were 344293 as shown in table no.3.

Table 3: Elements and nodes in different crowns

Crown height	Number of elements	Number of nodes
10 mm Crown	325922	487273
12.5 mm Crown	339281	501282
15mm Crown	344293	505278

Mesh size varies for crown, implants, abutments, screw and bone. The fig. no. 2 shows mesh for complete 3D model with cross section

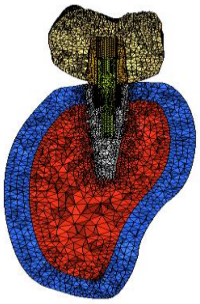

Fig 2: Sectional mesh with assembly

B. Finite Element Analysis

The output from the Finite Element Analysis is primarily in numerical form. It usually consists of nodal values of the field variables and its derivate. For example, in solid mechanical problems, the output is nodal displacement and element stresses. In heat transfer problems; the output is nodal temperature and element heat fluxes. Graphical outputs and displays are more informative. The curves and contours of the field variable can be plotted and displayed. Also deformed shapes can be displayed and superimposed on under formed shapes. The output is primarily in the form of colour-coded maps. The qualitative analysis is determined by interpreting these maps.The result involves the calculation of stress by Von-Mises criteria for each node. This is helpful for interpreting Finite Element Analysis or FEA result. It determines total state of stress at a predetermined location. The magnitude of equivalent stress indicates that local sensitivity of the model to the load in question.

Load Case:

A load of 200 N was applied towards axial direction in the long axis of the crown and a load of 100 N was applied towards oblique direction (45 degrees) guided to the lingual cusps from buccolingual direction on mandibular first molar simulating eccentric contacts.

RESULTS

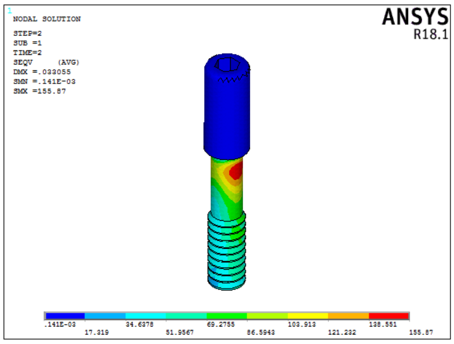

Fig 3: vonMises Stress in the retention screw in Model C (Maximum stress: 155.87 MPa)

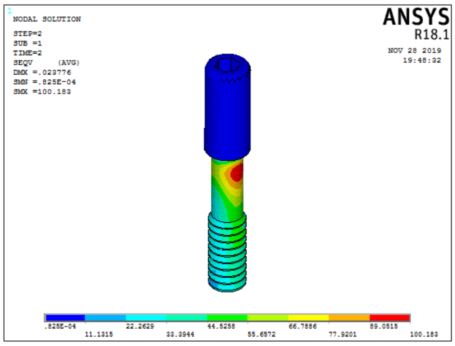

Fig 4: vonMises Stress in the retention screw in Model A (Maximum stress: 100.182 MPa)

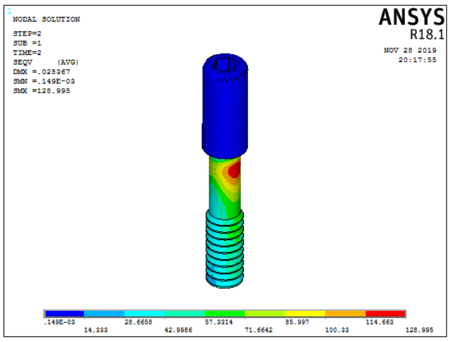

Fig 5: vonMises Stress in the retention screw in Model B (Maximum stress: 128.995MPa)

The maximum stress distribution was found in Model C (155.87 MPa) and minimum in Model A (100.182MPa)

Retention screw

Comparing the axial and oblique loads, the highest stress was concentrated in the inner surface of neck of the screw in all the models. The pattern of stress distribution was not similar for both types of loading. Higher stress was produced when an oblique load was applied, and the crown height corresponded with large size of the stress concentration area.

DISCUSSION

In the present study three different models of right mandibular first molar region was made as lower molars are the most mechanically loaded teeth in the natural dentition[7].For crown, porcelain of (1.5 mm) was used for the occlusal surface. Ni- Cr alloy was used as a crown sub-structure framework (0.5mm) which was in accordance with Duyck et.al.[8] who demonstrated in his study a better distribution of bending moments.

Model A with 10 mm crown height, Model B with 12.5 mm crown height and Model C with 15 mm crown height respectively and stress distribution was evaluated in each of the model in the retention screw. These results are also consistent with Misch (2005), Blanes et al. (2007), and Urdaneta et al. (2010) who all described the potential of increasing the crown in the transmission of occlusal forces[9,10].

In implant-supported prosthesis biomechanics, the prosthetic screw was considered the most fragile structure even when compared to external hexagon implants and various studies have examined the prosthetic screw[11].Some studies focusing on internal hexagon implants reported some advantages of these implants because there is a decrease of 4.5% in the screw-loosening index of implant-supported prostheses[12].

The null hypothesis was therefore rejected. Increasing crown/implant ratio increases the stress distribution in the retaining-screw and surrounding bone. Therefore, under oblique loading high C/I ratio should be considered a risk of biomechanical complications in dental implants.

Therefore, careful planning is needed when conducting rehabilitation with patients using implants and higher C/I ratios.

CONCLUSION

Based on the methodology used, the following conclusions can be drawn about C/I ration in internal hexagonal implants:

The increase in crown height increases the intensity of stress in the screw under oblique loading.

CONFLICTS OF INTEREST

The authors declare they have no potential conflict of interests regarding this article.

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