Influence of Prosthetic Designs on Peri-Implant Bone in a Single Posterior Implant Supported Prosthesis: A 3 Dimensional Finite Element Analysis

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Abstract

Background: Relationship between occlusal load and dental implant prognosis in particular, the peri implant bone is still in ambiguity. Such opacities have been attributed to difficulties in computing the occlusal forces and lack of precise indices to correlate occlusal load and implant failure Prosthetic rehabilitation involving dental implants comprises of cement or screw retained prosthesis retained on the abutment, which essentially become the first components to bear the occlusal forces. The prosthetic designs used in the present study are cement retained (CR), screw retained (SR) and a combination screw cement retained prosthesis (SCR). We intend to evaluate the influence of prosthetic designs particularly in single posterior metal ceramic molar crowns with finite element analysis, a popular computational tool to simulate masticatory loads on the various prosthetic design options so to predict stress in the peri implant bone. Peri implant bone around edentulous mandibular first molar was three-dimensionally modelled using Mimics software. Neo Biotech dental implant, abutments with abutment screws and models of SR,CR and SCR metal ceramic prosthesis were modelled three dimensionally using Solid Edge (2004) software. Numerical models of tetrahedral elements were generated with Hyper mesh Software. Static vertical load of 100N were applied on the central groove of the occlusal surface of the mandibular first molar crowns in all the three prosthetic designs. **Results:** Increased stress seem to be occurring at the implant neck and maximum effective stress on the peri implant bone in the SR, CR and SCR prosthetic designs remain almost comparable, **Conclusions:** Finite element analysis on prosthetic designs such as cement retained, screw retained and a combination screw cement retained prosthesis in a single posterior implant crowns demonstrate more stress at the implant neck presenting with no significant influence on peri implant bone.

Keywords: *Dental Implant, Finite Element Analysis, Cement Retained Implant Prosthesis, Screw Retained Implant Prosthesis*

1. INTRODUCTION

While associations between implant failures and oral microflora have been clearly established, relationship between occlusal load and dental implant prognosis in particular, the effect of load on the peri-implant bone is still in ambiguity[1,2]. Certain clinical investigations of occlusal loading on peri-implant tissues have reported loss of osseointegration with an initial crevicular bone loss, while a few others have demonstrated no effect of occlusal forces on bone loss[3–10]. Such opacities have been attributed to difficulties in computing the occlusal forces and lack of precise indices to correlate occlusal load and implant failure[1]. It is important to note that interfacial load transfer has been one of the influencing factors on the dynamics of dental implant and the surrounding bone[11]. Efforts to understand the influence of implant abutment connections on the peri-implant bone have been attempted through investigations using finite element, strain gauge analysis and in vitro loadings[12–15].

Prosthetic rehabilitation involving dental implants generally comprises of cement or screw retained prosthesis retained over the implant-abutment for replacing a single mandibular molar. The prosthesis essentially becomes the first components to bear the occlusal forces in the oral cavity, before the abutment and the implant. The prosthetic designs used in the present study are cement retained (CR), screw retained (SR) and a combination screw cement retained prosthesis (SCR) over the implant. It is known that cement retained prosthesis (CR) presents with a good occlusal design, superior esthetics, axial loading, passive fit with problems of retrievability, residual cement in the peri implant sulcus.

A screw retained prosthesis (SR) on the other hand, presents with retrievability and ease of hygiene, with problems of screw loosening and fracture[16]. However, a novel combination of a screw cement retained prosthesis (SCR) has the advantage of passive fit with the cement connecting the abutment and crown, ease of retrievability through the screw and repair without replacing the abutment, when compared to cement and screw retained. This combination provides the clinician, the ease of removing the excess cement around the abutment extra orally [17,18].

Therefore, we intend to evaluate the influence of prosthetic designs particularly in single posterior metal ceramic molar crowns with finite element analysis to simulate masticatory loads on the various prosthetic design options so to predict stress in the peri-implant bone. Finite element analysis is a computational tool that provides analytical solutions for mechanical problems involving complex geometries.

Given the complex geometry of the dental prosthesis-implant-bone system, finite element method has been explored for analysing bio-mechanical problems involving such complex structures. Although effects of implant macro-geometry on peri-implant bone and benefits and drawbacks of cement and screw retained prosthesis have been vastly explained in the literature, the effect of the above mentioned prosthetic designs on peri-implant bone particularly in a single posterior implant supported molar crown has not been investigated[19,20].

2. MATERIALS AND METHODS:

2.1 Modelling of Bone and Dental Implant

Peri-implant bone around edentulous mandibular first molar was three-dimensionally (3D) modelled as a cylindrical segment from cone beam computed tomographic images using Mimics software. CAD models of three Neo Biotech dental implants (4.0×13mm), three straight abutments of internal hex with abutment screws and the three models of screw retained(SR), cement retained (CR) and screw cement retained (SCR) metal ceramic prosthesis were modelled three dimensionally using Solid Edge (2004) software. Numerical models of tetrahedral elements were generated with ANSYS Software. The number of elements and nodes of the models of bone and the dental implants with each prosthetic designs of SR, CR and SCR are mentioned in Table 1. Metal ceramic restoration was chosen as it is the most commonly used prosthesis for partially edentulous patients. The design of SR, CR and SCR consists of cobalt chromium metal framework of thickness 0.5 mm and ceramic veneer of 2 mm thickness. An access hole of 0.5mm thickness was provided on the occlusal surface of SR and SCR. Clinically, the design of cement retained prosthesis is similar to the conventional fixed dental prosthesis with a cement interface between the crown and the abutment, with no access hole. However, in a screw retained prosthesis (SR), the crown and the abutment (UCLA) are casted as a monolith which is finally torqued to the implant. On the other hand, in a screw cement retained prosthesis, the crown is cemented to the abutment in the laboratory, outside the patient mouth, with excess cement removed and is torqued to the implant. Access holes are provided in SR and SCR for future retrieval.

Table 1. Number of elements and nodes in the prosthetic designs assemblies

Prosthesis	NUMBER OF ELEMENTS	NUMBER OF NODES
SR	85148	16907
CR	84698	17215
SCR	85801	17343

2.2 Material Properties

The corresponding material properties of bone, dental implant, abutments and prosthesis are shown in Table 2. The finite element study was designed based on the following assumptions that all materials used in the models were isotropic, homogeneous and linearly elastic. Numerical model of tetrahedral elements and number of elements and nodes may influence the accuracy of results. Assembled finite element models were imported into ANSYS 12.1 software for analysis.

Table 2. Mechanical properties of the materials involved in FEA analysis

Material	Young Modulus (GPa)	Poisons Ratio
Titanium (Ti-6Al-4V)	110×10^3	0.35
Titanium Abutment and Screw	110×10^3	0.28
Cortical bone	1.37×10^4	0.30
Cobalt-Chromium alloy	218×10^3	0.33
Feldspathic Porcelain	8.28×10^3	0.35
Resin	2.7×10^2	0.35

2.3 Boundary Conditions

With respect to the boundary conditions, constraints were applied to the inferior border of the bone segment and were assumed to be fixed.

2.4 Bone Implant and Abutment Interface

Most FEA models assume an optimum osseointegration, therefore, the implant-bone interfaces were assumed to be rigidly bonded. Abutment screw-implant interfaces were also assumed to be rigidly bonded.

2.5 Loading Conditions

Load distribution at the bone implant interface depends many factors such as the type of loading, material properties of the implant and prosthesis, implant geometry, nature of the bone–implant interface; and quality and quantity of the surrounding bone. With all the other factors being the same, except loading conditions, static vertical load of 100N was applied on the central groove of the occlusal surface of the mandibular first molar crowns in the three prosthetic designs. The reason for choosing 100N was an approximate value of masticatory load at the posterior molar crown[22–24.]

3. RESULTS

Von Mises stress values are defined as the beginning of plastic deformation when the stress exceeds the material's yield strength. In other words, failure of a design of a material occurs when Von Mises stress values exceed the yield strength of a material. The Von Mises values for each model was recorded. The magnitude of stress is represented in a color spectra ranging from highest stress, color coded in red to the least stress presented as blue[25]. Stress distribution on the assembled prosthesis of SR, CR and SCR under vertical loading of 100N are shown in Figure.1, Figure. 2 and Figure. 3. Maximum effective stress (MPa) on the peri implant bone and on the respective assembled prosthesis has been presented in Figure 4.

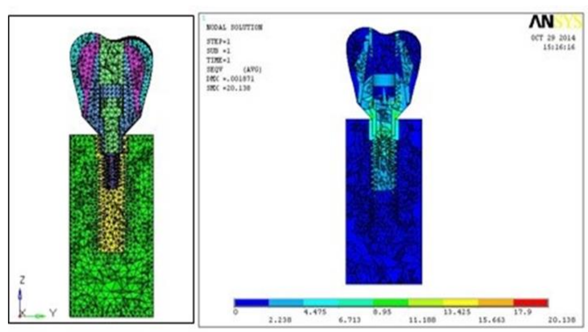

Fig. 1 Mesh model and stress distribution on assembled prosthesis of screw retained (SR) prosthesis on vertical loading of 100 N

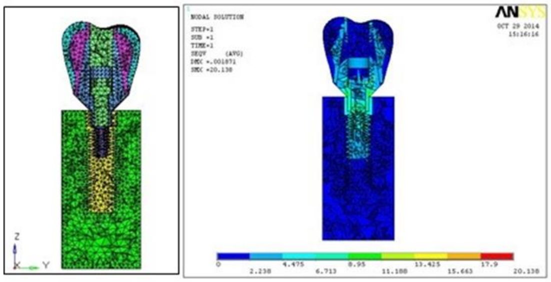

Fig. 2 Mesh model and Stress distribution on cement retained (CR) mandibular prosthesis on vertical loading of 100 N

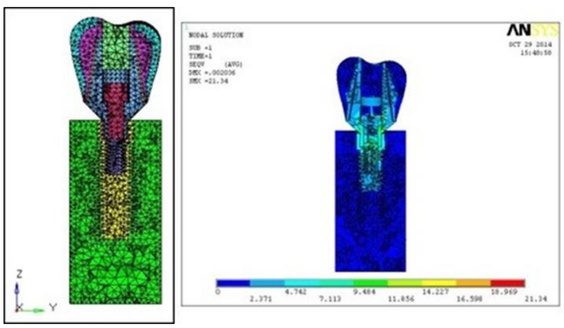

Fig. 3 Mesh model and Stress distribution on screw cement retained (SCR) mandibular first molar implant prosthesis on vertical loading of 100 N

4. DISCUSSION

Clinical choice of screw and cement retained prosthesis for single tooth replacement depends on factors such as retention, retrievability,

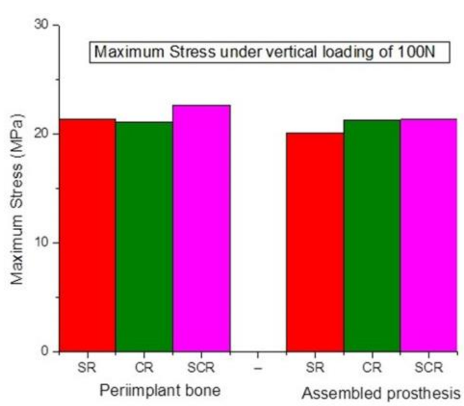

Fig. 4 Comparison of maximum stress in the peri implant bone and assembled prosthetic designs of SR, CR and SCR on vertical loading

Passivity, occlusal loading, esthetics, hygiene, ease and cost involved in the fabrication of the prosthesis[16]. A cement retained prosthesis (CR) is contently similar to a conventional crown and bridge procedure with effecting factors such as abutment height, taper, width and choice of a soft cement. A screw retained prosthesis (SR), on the other hand, depends on preload, torque, material yield strength and passivity. A screw cement retained prosthesis (SCR) is an innovative technique proposed by Rajan for single tooth replacement which combines both passive fit and retrievability in a prosthesis[26]. With this background, our objective was to compare the effect of the above mentioned prosthetic designs on the peri-implant bone.

The pattern of stress distribution in all the prosthetic designs observed at the implant neck are shown in Fig.1, Fig.2 and Fig.3. The incidence of stress at the implant neck region in the present study could be reasoned to the vertical load applied on the prosthesis. One of the desirable requirements of load distribution in dental implants is axial loading. On vertical loading of 100N, the stresses were distributed on the implant, abutment and abutment screw in all the models with stress transfer through the components to the bone. While axial loading is possible with a cement retained prosthesis, loading is offset in a screw retained prosthesis where the occlusal surface is accommodated with an obturating material at the screw access hole[16]. However, in the present study, irrespective of the prosthetic designs, increased stress seem to be occurring at the implant neck. This could also be attributed to the weakest link, the abutment implant interface that bears the stress. It is important to understand the load transfer mechanism particularly at the abutment screw-abutment interface of prosthesis where in a sufficient amount of preload is applied to the abutment screw with tensile force. Factors such as cyclic loading, micro movements between the screw and the threads and wear of the surfaces influence prosthetic complications[21]. The mechanism of load transfer under vertical loading in CR, SR and SCR prosthesis is an interesting area to be investigated further. Increased stress at the head of the two-piece straight abutment screw has been demonstrated through a finite element study in an external hex system[14].

It can be seen from Fig.4, that the maximum effective stress on the peri-implant bone in the SR, CR and SCR prosthetic designs remain almost comparable, suggesting that there may not be any effect of prosthetic restorative designs on the peri-implant bone. The results differ with other finite element studies on bone loss initiating around the implant crest[6,27,28]. The aetiology related to early crestal bone loss has been attributed to surgical trauma, occlusal overload, peri-implantitis, micro gap and implant crest module design[29]. It is to be noted the mechanical factors for loading and stress distribution at the implant bone interface area are determined by the type of loading, prosthetic material properties, type of implant macro geometry such as diameter, length and bone density[21]. With vertical loading, bone density and implant geometry being same in all the above mentioned design situations, the prosthetic design does not seem to have any effect on stress distribution in peri-implant bone. From a biomechanical point of view, prosthetic designs do not seem to influence the load transfer mechanism under static axial loading in an implant supported single tooth prosthesis. However, application of dynamic and oblique loading to implant prosthesis is recommended to be explored in future. A systematic review of randomised controlled trials found greater 5 year survival rates in a cemented than a screw retained implant single crowns. The clinical findings also collate with increased occurrence of technical complications such as screw loosening in screw retained prosthesis. However, biologic complications such as bone loss seem to occur more in cement retained than screw retained prosthesis[30].

To simplify modelling and solving in the methodology, a few assumptions are made in the FEA studies. The limitations of the present study are assumptions of isotropic bone, a fixed bone implant interface and use of static loads. We recommend use of advanced digital imaging techniques for modelling of bone, determination of friction coefficient between bone implant interfaces, refined meshing of nodes in the finite element models and validation with clinical results. Further validation of the results of finite element must be investigated with long term clinical studies on the survival rates of different prosthetic designs in a single implant for a mandibular molar. Role of cement between the abutment and the crown in CR prosthesis may be a limiting factor in stress distribution and must further be investigated.

5. CLINICAL SIGNIFICANCE

Though cement and screw retained prosthesis have been quite popular in mandibular single implant supported prosthesis, screw cement retained prosthesis offer better advantages of passive fit, ease of retrievability and repair. In an effort to understand the biomechanics in a mandibular single implant supported prosthesis, a finite element study on all prosthetic designs was attempted. Within the limitations of the study, the prosthetic designs of cement retained, screw retained and a combination screw cement retained prosthesis in a single posterior mandibular crown, seem to demonstrate no significant influence on peri implant bone, however, all prosthesis presenting a pattern of increased stress at the implant neck. Clinicians can choose the best possible prosthetic design while replacing a single mandibular molar with an implant prosthesis, as they seem to be of minimal influence.

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