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EFFECT OF TWO DIFFERENT IMPLANT STRUCTURES ON STRESSES INDUCED WITHIN THE SURROUNDING BONE USING THREE DIMENSIONAL FINITE ELEMENT ANALYSIS

Fardos N Rizk*

ABSTRACT

Objective: The purpose of this study is to compare the stresses induced within the bone surrounding the Trabecular Metal Dental Implant (Zimmer Dental Inc., Carlsbad, CA, USA) in comparison to the stresses induced within the bone surrounding its predicate Tapered Screw Vent Implant (Zimmer Dental Inc., Carlsbad, CA, USA) using three dimensional finite element analysis.

Materials and Methds: The current finite element analysis simulated a clinical situation where an edentulous mandible was restored with an entirely implant supported cantilever bar overdenture retained by five implants placed parallel to each other in the interforaminal region opposed by a complete denture. Two models were constructed with difference only in the structures of the implants used. In model I Tapered Screw Vent Implants with MTX Surface were used. In model II Trabecular Metal Dental Implants the premium addition to Tapered Screw Vent Implants were used. 150 N vertical load was applied at the area of second premolar and first molar.

Results: Trabecular Metal Dental Implants induced less stresses within the surrounding bone than Tapered Screw Vent Implants.

Conclusion: Trabecular Metal Dental Implant introduces a new dimension to implant dentistry.

KEY WORDS: Implants, Trabecular Metal Material, Finite element analysis

INTRODUCTION

Continuing dental and orthopedic research has focused on various techniques for enhancing bone apposition to implanted titanium surfaces. Despite differences in anatomical locations and bone structures, a variety of surface modification techniques that were developed in orthopedics have been successfully adapted for dental implant use. Among these are hydroxylapatite (HA), titanium plasma spray (TPS), and porous surface coatings, such as porous bead surfaces and cancellous-structured titanium (CSTi) coating. Research in implant biomaterials and surface technologies has led to development of Trabecular Metal Material

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which is a three dimensional porous biomaterial not an implant surface coating. It is composed of a carbon substrate (2%) that has elemental tantalum (98%) deposited on the surface to create a metallic strut configuration similar in structure to cancellous bone.[1-7] It also has low modulus of elasticity similar to cancellous bone[8-10] and it is highly biocompatible and corrosion-resistant [11-16]. In compression testing, it exhibits high ductility without mechanical failure.[17] This material has been used extensively in orthopedic reconstructions for over a decade and recent advancements have led to the development of a new Trabecular Metal Dental Implant (Zimmer Dental Inc., Carlsbad, CA, USA) which introduces a new dimension to implant dentistry.

Trabecular Metal Technology significantly differs from sintered bead surfaces, titanium plasma-sprayed surfaces, titanium fiber mesh and titanium foam in the high degree of its interconnected porosity (up to 80%) and the regularity of its pore size and shape.[1,3,4, 6,7,18] In contrast to conventional bone-to-implant contact achieved by non-porous surfaces, Trabecular Metal Technology's geometrical network of interconnected pores provides a scaffold for bone in growth and interconnection, allowing for rapid and substantial mechanical attachment. Research on the Trabecular Metal Dental Implant showed that new bone formation inside Trabecular Metal Material pores was evident at two weeks and bone in growth across the full thickness of the porous surface was observed at four weeks after the surgery. This allows restoring Trabecular Metal Dental Implants much sooner than traditional dental implants thus reducing the amount of time without a tooth or teeth. In addition to bone in growth, Trabecular Metal Dental Implants also allow bone on growth on its surface which creates a new process in implant dentistry called osseoincorporation. Osseoincorporation refers to the healing potential of bone onto an implant surface and into an implant structure providing high potentials for immediate stabilization of the implants. [2-4,8-10,18 -22]

The purpose of this study is to compare the stresses induced within the bone surrounding the Trabecular Metal Dental Implant (Zimmer Dental Inc., Carlsbad, CA, USA) in comparison to the stresses induced within the bone surrounding its predicate Tapered Screw Vent Implant (Zimmer Dental Inc., Carlsbad, CA, USA) using three dimensional finite element analysis. Finite element analysis can simulate the inter-action phenomena between implants and the surrounding structures and this makes it a useful tool to investigate the various loading of implants and surrounding tissue variables. Two and three dimensional finite element stress analysis had been used extensively in dentistry but, three-dimensional stress analysis technique is preferred over a two-dimensional one due to its ability to analyzing complex dental structures. In addition, it gives a close simulation of the components of the dental structure under investigation, thus providing an actual presentation of the stress behavior in the object being examined. However, it is more time consuming than the two dimensional finite element analysis. [23,24]

MATERIALS AND METHODS

Materials

The current finite element analysis simulates a clinical situation where an edentulous mandible was restored with an entirely implant supported cantilever bar overdenture retained by five implants placed parallel to each other in the interforaminal region opposed by a complete denture. Two models were constructed according to the strategy suggested by Misch[25] with difference only in the structures of the implants used. In model I Tapered Screw Vent Implants with MTX Surface (Zimmer Dental Inc., Carlsbad, CA, USA) were used. In model II Trabecular Metal Dental Implants (Zimmer Dental Inc., Carlsbad, CA, USA) the premium addition to Tapered Screw Vent Implants were used.

The computer simulation of the suggested clinical situations utilized the following:

- A personal computer with a dual core processor (Intel) 3.4 GHz, 4.19 GB RAM, and 320 GB hard disk.

- Cosmos works 2010 software which is a finite element analysis program included in the Solid works 2010 premium package (Solid Works corporation).

Methods:

The following steps were carried out:

1. Three dimensional drawing of the model components.
2. Assembly of the components to construct the two models.
3. Assigning the proper material properties for each component.
4. Specifying loads and restraints for each model.

1- Three dimensional (3D) drawing of the model components:

A-The mandible

A 3D model of part of the mandible was designed to suit the dimensions and distribution of the implants used in this study with the following concerns:

1- The proposed places of the implants were shown as circles A, B, C, D, and F which should be within the outline of all the designed body (Fig.1).

2- Extruded cylinders associated with these circles corresponded to the bone cylinders representing the implant and 1 mm surrounding bone.

B-The Implants

Model I:

Tapered Screw Vent Implants with MTX Surface were used (Fig.2). The implant is a tapered micro threaded endosseous design made of titanium alloy (Ti-6Al-4V grade 5) with a microtextured surface (*MTX* Surface).

Implant dimensions: 13mm length and 4.1mm diameter tapering to 3.5mm at the apical end.

Threads: Starts 2.5mm apical to the top with a pitch distance 1mm.The threads extend the whole length of the implant with a vent 3mm in hieght and 1.8mm diameter at the apical end of the implant.

Model II:

Trabecular Metal Dental Implants, the premium addition to Tapered Screw Vent Implants were used (Fig.3). The implant is a tapered, multi-threaded, endosseous design similar to its predicate the *Tapered Screw-Vent* Implant, but modified with a Trabecular Metal Material midsection made of

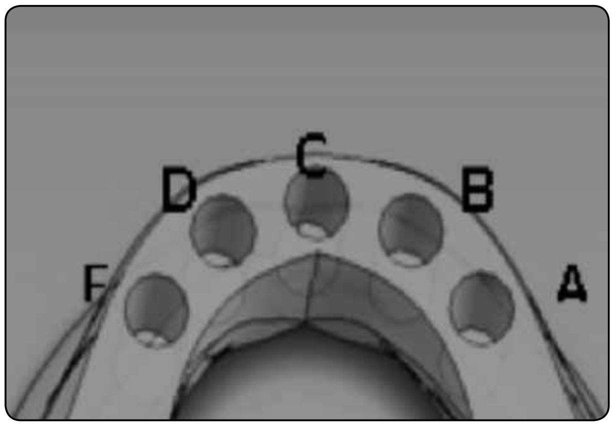

FIG. (1) Model of the mandible with the positions of the implants

FIG. (2) Tapered Screw Vent Implants with MTX Surface

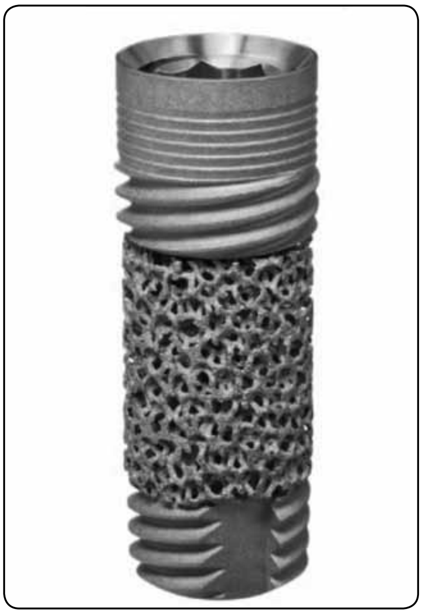

FIG (3) Trabecular Metal Dental Implants

tantalum (98%) deposited on a vitreous carbon substrate (2%). The coronal and apical implant structures are made of titanium alloy (Ti-6Al-4V grade 5) with a microtextured surface (*MTX* Surface).

Implant dimensions: 13mm length and 4.1mm diameter. The coronal section with height 4.5mm features cervical micro-grooves and self-tapping threads having a pitch distance 1mm. The midsection with height 6 mm features the interconnected porosity of the Trabecular Metal Material with regular size and shape. The apical section with height 2.5mm features self-tapping threads having a pitch distance 1mm. Due to the complexity of representing such irregular volume in strictly defined three dimensional drawing, the well known approach of incorporating the material properties of the different constituents of the body according to their cross-sectional proportions, was considered.

C-The Bone cylinders

These are cylinders having 6.1mm diameter and 15 mm height. Each cylinder is composed of 6 parts. A coronal slice of 2mm thickness which is divided into 4 equal quarters named mesial, distal, buccal, and lingual quarters. The fifth part is the middle part which is 10mm in height. The sixth part is the apical 3 mm of the cylinder.

- Model 1: The shape and dimensions of the implant were engraved inside the cylinder.
- Model 2: The shape and dimensions of the coronal and apical sections of the implant were engraved inside the cylinder. The midsection was matted coincidently.

D-The Abutments

The abutments used were 5mm in height, straight, screw retained abutments.

E-The cantilever bar

- One piece cemented bar was designed to suit the 2 models.
- The bar contains 5 holes that fit accurately on the abutments.
- The bar extends about 15 mm distal to the most distal abutment.

F-The Overdenture

- The denture was designed to suit the dimensions and curvatures of the mandible.
- The denture base was designed to contain the bar completely without any space in between (no clips or spacer were allowed).

2-Defining the Assembly of the Components

- The constructed components were assembled together to form the 2 models
- The technique of the model assembly depended on the mating function present in the assembly mode of the software.
- The mates used in the study were the coincident and parallel mates.

3- Assigning the proper material properties for each component

- All materials in the study were considered to be homogenous, isotropic and linearly elastic.

TABLE (1) The materials used for every component and its properties

Material	Component	Material properties	
		Modulus elasticity (Mpa)	**Poisson's ratio**
Compact bone	1. Mandible 2. Bone cylinder at positions B,C,D 3. Coronal 2 mm of the bone cylinder at position A and F	15000	0.3
Cancellous bone	Middle and apical part of the bone cylinder at positions A and F	1500	0.3
Titanium	Tapered Screw Vent Implant, coronal and apical portions of Trabecular Metal Dental Implant	110000	0.33
Base metal alloy (Co-Cr)	Cantilever Bar Abutments	218000	0.33
Acrylic	Overdenture	2700	0.35
Trabecular metal	Mid section of Trabecular Metal Dental Implant	3000	0.33
Composite material (20% metal & 80% bone)	The middle part of implant in model 2 • At positions B, C & D, composite of trabecular metal and compact bone. • At positions A and F, composite of trabecular metal and cancellous bone.	12600 1800	0.3 0.3

- The modulus of elasticity and Poisson's ratio of the different component materials used in the study[2,10,26] were listed in the table below:

4- Specifying Loads and Restraints for Each Model.

- 150N vertical load was distributed over the area of the second premolar and first molar.
- The inferior border of the mandible was assumed to be fixed with zero degrees of freedom.

RESULTS

In model I and II the stresses transmitted from the superstructure to the bone surrounding the implants were concentrated at the coronal portion and it decreased in the middle portion then it diminished apically in both working and non working sides. Also in both models the stresses at the working side were greater than the stresses at the non working side and the highest area of stress concentration was the distal quarter of the coronal part of the crestal bone at the working side. (Table II and III)

The stresses generated at the coronal portion of bone surrounding the implants of model I (Tapered Screw Vent Implants) were greater than the stresses generated at the coronal portion of bone surrounding the implants of model II (Trabecular Metal Dental Implants) in mesial, distal, buccal and lingual surfaces at both working and non working sides. At the working side, in the coronal mesial portion the stresses were greater by 22%, in the coronal distal portion the stresses were greater by 11%, in the coronal buccal portion the stresses were greater by 9% and in the coronal lingual portion the stresses were greater by 11%. At the non working side, in the coronal mesial portion the stresses were greater by 33%, in the coronal distal portion the stresses were greater by 17%, in the coronal buccal portion the stresses were greater by 20% and in the coronal lingual portion the stresses were greater by 11%. There was no difference between the two models in the stresses generated within the middle and the apical portion of bone. (Table II and III)

TABLE (II) The values of maximum stresses induced due to a 150 N vertical unilaterally distributed load in model I (Tapered Screw Vent Implants)

Model I	**Working side**	**Non working side**
Coronal mesial	54	3
Coronal distal	90	12
Coronal buccal	55	5
Coronal lingual	70	9
Cylindrical body (middle part)	10	2
Apical	1	0

Table (III) The values of maximum stresses induced due to a 150 N vertical unilaterally distributed load in model II (Trabecular Metal Dental Implants)

Model I	**Working side**	**Non working side**
Coronal mesial	42	2
Coronal distal	80	10
Coronal buccal	50	4
Coronal lingual	62	8
Cylindrical body (middle part)	10	2
Apical	0	0

DISCUSSION

In the two models the stresses transmitted from the superstructure to the bone surrounding the implants were greater in the working side than the non working side and were concentrated at the implant collar and diminished apically. This may be due to the fact that the magnitude of stresses increases as the distance from the point of application decreases and vice versa. This agrees with the results of several studies [27-30] who found that the stresses increased as the point of load application was reached.

In the two models the highest area of stress concentration was the distal quarter of the coronal part of the crestal bone at the working side. This agrees with the findings of White et al,[31] and is mechanically explained by Misch[25] to be the result of magnification of the applied force at the fulcrum point (distal bone in this situation) by force magnifiers which are the cantilever length, occlusal height and occlusal width. These magnifiers change the cantilever force into a moment load called "Torque".

In the present study the stresses generated in the coronal portion of bone surrounding the implants of model II (Trabecular Metal Dental Implants) were less than the stresses generated in the coronal portion of bone surrounding the implants of model I (Tapered Screw Vent Implants). This could be explained by the difference in structure and material of the implants used in both models. In model I the Trabecular Metal Material has an 80% porous structure which allows in growth of bone in it.[1-9,18-20] The stiffness of this composite material (20% Trabecular Metal Material and 80% bone) is less than the stiffness of Titanium which induces less stresses within the surrounding bone.[2,10] The difference in the generated stresses between the two models occurred in the coronal portion not the middle and apical portion due to the fact that the distribution pattern of stresses is concentrated coronally.

CONCLUSION

1-The stresses induced within the bone surrounding the Trabecular Metal Dental Implant are less than the stresses induced within the bone surrounding its predicate Tapered Screw Vent Implant.

2-Trabecular Metal Dental Implant introduces a new dimension to implant dentistry.

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