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3D Finite Element Study on Incomplete Osseointegration: Locator Attachment versus Ball Attachment

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Abstract

BACKGROUND: Incomplete implant osseointegration may affect the choice of the type of attachment to ensure less amount of bone resorption, periods of maintenance, and longer implant/attachment life-time.

AIM: The aim of this study was to evaluate, using 3D FE analysis (FEA), the influence of two different types of attachments on the rate of bone resorption, need for maintenance and implant/attachment life time in cases of unpredictable osseointegration in various bone types and using different implant angulations.

METHODS: Six finite element models were prepared; three for the locator attachment while the other three for the ball attachment. Each of the three models simulates vertical implant and inclined implants by 10° and 20° degrees. Frictional contact between implant and cortical bone simulated the incomplete osseointegration scenario.

RESULTS: Non-linear static analysis results showed that locator attachment and its cap may have longer time life in comparison with the ball attachment and its cap.

CONCLUSIONS: Both attachments were safe for cortical and spongy bone, while the cortical bone receives less Von Mises stress by up to 33% with the increased implant angulation.

Introduction

As life spans lengthen, teeth lose becomes significant for a wide patients' population. Older patient's treatment, especially those with disabilities, becomes a challenge. The primary goal for such patients' treatment is to restore their condition to an acceptable level of satisfactory esthetics and function. The main reason that mandibular dentures show functional problems is because of compromised denture foundation area and thus the poor retention. And since complete dentures support and retention depend mainly on the residual alveolar ridge, it is the mandibular dentures that suffer the most.

Nevertheless, mandibular overdentures can be used as the unique treatment of choice for compromised completely edentulous patients; where overdenture retention is gained by the implant supporting retentive attachments. Furthermore, the use of a fewer implants' number that provides good support and retention is also more favorable for such patients [1].

Huang *et al*. (2008) studied the effects of implant surface roughness and stiffness of grafted bone on an immediately loaded implant using finite element (FE) models and three conditions of implant-bone interfaces. It was concluded that bone stresses increased by 57%, with 0.3 frictional coefficient with the implant, in comparison to complete osseointegration. It was concluded that bone stresses increased by 57%, with 0.3 frictional coefficient with the implant, in comparison to complete osseointegration and that raising the grafted bone stiffness, diminished the bone stress by about 10% in both the immediately loaded implants and the osseointegrated ones. It was also noted that increasing graft stiffness and implant surface roughness reduced the sliding at the implant-bone interface which may improve the implant long-term stability and survival rate [2].

Furthermore, adequate available horizontal and vertical bone dimensions are considered as an essential prerequisite for successful and predictable implant osseointegration. However, bone resorption usually continuous following teeth extraction. Thus, implant placement might result in crestal bone dehiscence with exposed implants threads. Consequently, an esthetic problem is to be expected, especially in the anterior region which may be further complicated with peri-implantitis or peri-implant mucositis [3].

The purpose of this study was to evaluate, using 3D FE analysis (FEA), the influence of two different types of attachments on the rate of bone resorption, need for maintenance and implant/attachment life time in cases of unpredictable osseointegration in various bone types and using different implant angulations.

Materials and Methods

Design of experiment

This comparative study was performed for comparing between locator and ball attachments joined to a vertical and inclined implant in two angulations; 10° and 20°, subjected to vertical load of 100 N placed on the cap center point of its top surface.

Geometry and modeling

The geometrical models were created manually using commercial 3-D modeling package, Inventor version 8 (Autodesk Inc., San Rafael, CA, USA). The system analyzed in this investigation consisted of the commonly available root form threaded titanium dental implant (Zimmer Dental Inc., USA) with ball attachment of 6.0 mm height or locator attachment 6.5 mm height (Zest Anchors, Escondido, CA). The root form dental implant had a nominal diameter of 3.7 mm, a length of 13 mm. and the shape of internal hex with a hex width 3.5 mm (Figure 1a and b).

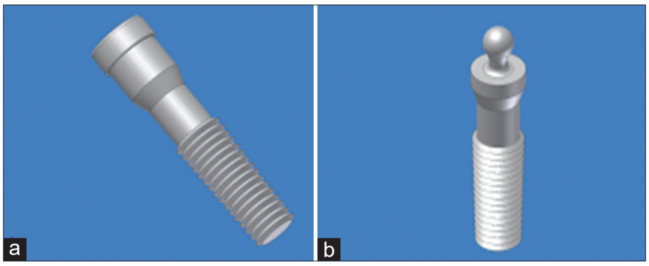


Figure 1: Geometrical model of the implant with (a) locator abutment and (b) ball abutment

The model was designed that the implant was placed in two coaxial cylinders; the outer layer represented cortical bone of 1 mm thickness, 16 mm diameter, and 24 mm height. The inner cylinder represented the cancellous bone of 14 mm diameter and 22 mm height. It was assumed that incomplete osseointegration was present between implants and bone. Thus, it was expected to have relative motion (sliding) between the implant neck and cortical bone [4], [5], [6], [7].

Material properties

Values of material properties were based on previously published data and listed in Table 1. All materials were assumed to be isotropic, homogenous, and linearly elastic [8], [9].

Table 1: Material properties of assembly components

Material	Young's modulus [MPa]	Poisson's
Cortical	13,700	0.30
Cancellous	1370	0.30
Implant/abutment (Titanium)	110,000	0.35
Nylon ring	350	0.40

Meshing

After construction of all of the components of the model, they were exported to the ANSYS APDL version 12 ® (ANSYS Inc., Canonsburg, PA, USA) as IGES files and were assembled together to obtain a FE model after set of Boolean operations between the imported components. The meshing element was 8-nodes Brick element (SOLID 185), which has three degrees of freedom (translations in the global directions). Frictional contact was defined by the elements CONTACT 174 and TARGET 170 as surface to surface contact with friction coefficient of 0.4 between cortical bone and implant neck (Figure 2).

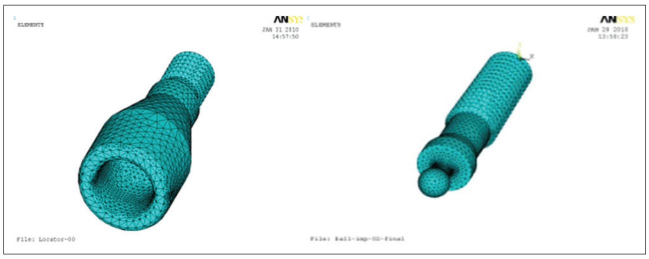


Figure 2: Meshed models' components

Table 2 lists number of nodes and elements of the models of the meshed models [10].

Table 2: Models meshing details of ball and locator abutments

Item	Locator attachment		Ball attachment	
	Nodes	Elements	Nodes	Elements
Cortical bone	1375	4233	1790	28,346
Cancellous bone	6280	28,737	68,571	95,829
Implant abutment	11,998	57,829	36,071	4180
Resilient cap	1865	8842	2242	63,303
Total	18,511	99,641	49,597	63,303

Application of load and boundary conditions

A vertical load of 100 N was applied at the central node of the top surface of either attachment's cap. The lowest area of cortical bone (outer cylinder base) was considered as a fixed in all directions as a boundary condition.

FE calculations

Non-linear static analysis of the models was performed on a personal computer (Intel Core™ 2 Duo, processor 2.8 GHz, 3.0 GB RAM) that each run takes about 6.5 h.

Results

Demonstration of cap results to indicate cap life time = longer maintenance periods.

As presented in Table 3, ball attachment nylon cap is suffering with inclined implant. Its Von Mises stress is close to its yield point in case of implant angulation of 10 and exceed the yield stress with implant angulation of 20. Locator attachment nylon cap is safe and can survive with increasing implant angulation up to 20°.

Demonstration of implant results to indicate implant life time

As presented in Table 4, ball attachment is generally safe that its angulation of 20° showed maximum Von Mises stress of order 146 MPa, which is far from its material yield stress and below its endurance limit. Locator attachment is extremely safe, and its Von Mises stresses with different implant angulations were less than ball attachment.

As presented in Table 5, cancellous bone is insensitive to changing the implant attachment (ball or locator). Its' stresses and deformation values are indicating negligible differences and far below critical points.

As presented in Table 6, both attachments are showing acceptable effect on cortical bone (did

Table 3: Von Mises stress on nylon caps

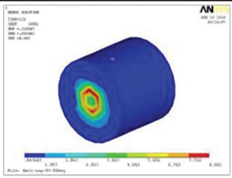
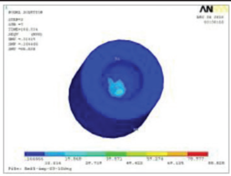
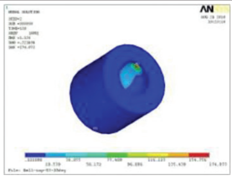
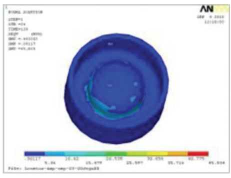
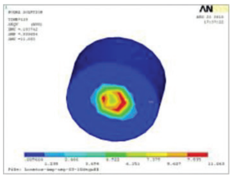
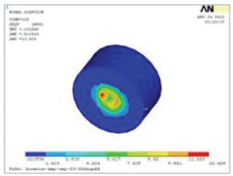
Attachment	Vertical implant	Angulated 10°	Angulated 20°
Ball attachment	 8.681	 88.828	 174.073
Locator attachment	 45.034	 11.063	 12.624

Table 4: Von Mises stress on implant/abutment

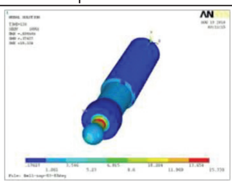
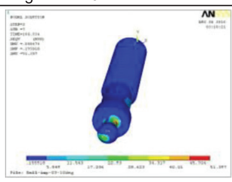
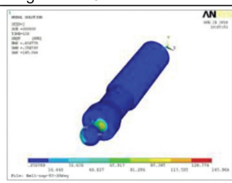
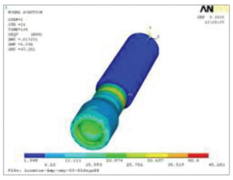
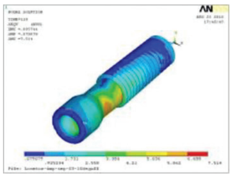
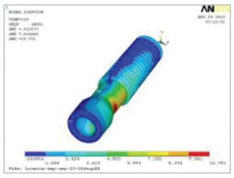
Attachment	Vertical implant	Angulated 10°	Angulated 20°
Ball attachment	 15.338	 51.397	 145.964
Locator attachment	 45.281	 7.514	 10.751

Table 5: Von Mises stress on cancellous bone

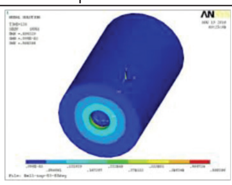
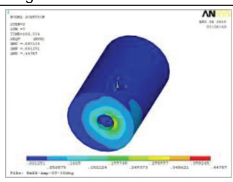
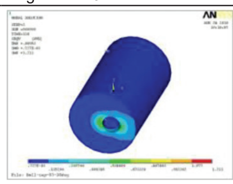
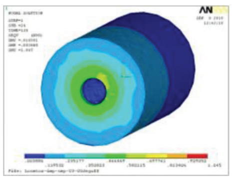
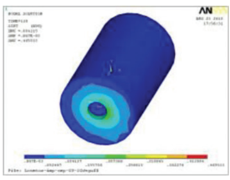
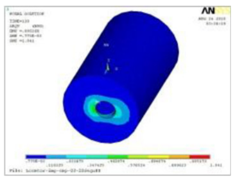
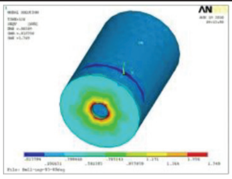
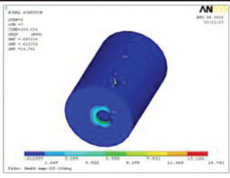
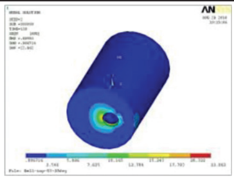
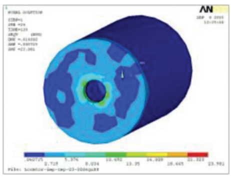
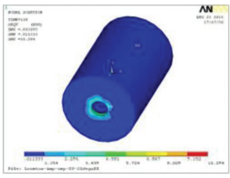
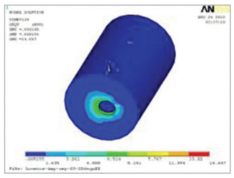
Attachment	Vertical implant	Angulated 10°	Angulated 20°
Ball attachment	 0.5002	 0.44787	 1.211
Locator attachment	 1.045	 0.423072	 1.041

Table 6: Von Mises stress on cortical bone

Attachment	Vertical implant	Angulated 10°	Angulated 20°
Ball attachment	 1.749	 14.741	 22.862
Locator attachment	 23.981	 10.294	 14.647

not exceed 25 MPa). Ball attachment showed superior behavior with vertical implants. On the other hand, inclined implants are recommended to be used with locator attachments that stresses generated on cortical bone are of order 33% less with using locator attachment.

Discussion

Design and analysis of threaded dental implants are a very interesting research topic. Thread-related parameters are of great importance due to their effects on stress and strain distribution [11].

It has been well recognized for decades that neither implant nor bone should be stressed beyond a limited range for physiologic homeostasis as overloading usually results in excessive bone resorption or even implant's fracture. On the other hand, no load over the bone can induce atrophy or subsequent bone loss [12].

According to literature, two implant-supported mandibular overdentures were considered to be the gold standard for edentulous patients. Studies have shown that differences do exist and are evident in the way stresses are being transferred to the surrounding bone not only in tooth-supported overdentures but also in the implant-supported overdentures. The load at the bone-implant interface depends mainly on implant geometry, loading type, material properties of both implant and prosthesis, bone nature at implant interface, and bone quality/quantity [1], [13], [14].

Meanwhile, various types of attachments have been used with implant-supported overdentures, the most commonly used are the ball attachment, bar attachment, and the magnet attachment. *In vitro* and *in vivo* studies show that the ball and O-ring attachment transferred the least stresses to the implants when compared to the bar clip attachment.

It has been reported that the retentive properties of magnet attachment in addition to its low retentive energy could assist in abutments preservation. On the other hand, ball attachments are considered the simplest type of attachment of all times for various clinical overdenture situations; being untimely resilient, whereas the special ball attachment design sometimes influences the amount of its free movement thus, limiting its resiliency. As for the magnetic attachment, alloy corrosion and wear are to be considered regarding its retentive capability. Furthermore, comparative studies on the retentive force of ball and magnetic attachment reported that the magnetic attachment offers the weakest retentive attachment system [15], [16].

It is to be mentioned that the most important aspect supposed to affect implant success or failure is the manner in which stresses are transferred from the implant to the bone. Thus, it is of utmost importance that neither the implant nor the bone to be stressed beyond their fatigue capacity after loading. Any type of micromotion that can produce either bone lose or implant failure should be avoided as much as possible. Proper implant-bone contact means that under any type of loading, it moves as single unit without bone lose or the implant loosening and with the possibility of transferring stress to all parts of the implant-bone interface [17], [12].

Implants' surrounding stresses are of great importance that several methods have been reported to minimize these stresses. Accordingly, the present study results offer good suggestions for placing different types of dental implant attachments where stresses over prosthodontic components and bone could be better tolerated and distributed [12].

Furthermore, dental implant systems biomechanical performance, the way of load distribution, and the different stresses located at the bone-implant interface have been extensively studied using FEA. It has be reported frequently that the variables that affect greatly the load transfer at the bone-implant interface in addition to the loading type are, the properties of the prosthesis material, implant length and diameter, implant surface, nature of the bone-implant interface, and the quantity and quality of surrounding bone [12], [18].

The data reported from the present study underline which type of dental implant attachment supporting overdenture prosthesis is better to be used in cases of unpredictable osseointegration in different bone types and various implant angulations.

Conclusions

Within the limitations of this study, the following conclusions were drawn:

1. Both attachment types showed acceptable effect on cortical bone. Ball attachment showed superior behavior with vertical implants
2. Ball attachment is generally preferred in case of vertical implant fixation. On the other hand, locator attachment is much better in case of angulated implant fixation
3. The greatest stress concentrations were noted at the cortical bone crest in all the models irrespective of the loading conditions. This conclusion was made based on sensitivity analysis in FEA.

Ethical Approval

This research does not require ethical approval and followed the Helsinki Declaration.

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