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EVALUATION OF STRESS IN AN IMPLANT RETAINED OVERDENTURE USING DIFFERENT ATTACHMENT SYSTEMS.

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ABSTRACT Today implant dentistry offers good options for edentulous patients. Popularity of a two-implant retained overdenture has created a necessity to examine the various attachment systems being used and the stresses that are transmitted to the alveolar bone. The aim of this study was to evaluate the stresses induced on the supporting mucosa and bone in a maxillary implant retained overdenture with (i) ball attachment and (ii) bar and clip attachment using three dimensional (3D) finite element analysis. 3D models were designed using CATIA program (Version 5).Each model consisted of maxillary arch with mucosa, cortical and cancellous bone with implants and overdenture retained by ball or bar and clip attachment. The models were constrained at the base of cancellous bone and then subjected to a load of 100N applied near the left first molar tooth position. Load was applied in buccolingual and anteroposterior directions. Analysis was carried out using Ansys software (Version 9) to evaluate the resultant Von- Mises stress induced on the supporting mucosa, cortical bone and cancellous bone. Conclusion: The ball attachment favors more equitable load distribution to the under lying mucosa and peri-implant bone when compared to bar and clip attachment .

KEYWORDS : Maxillary implant supported overdenture, Ball attachment, Bar and clip attachment,

Introduction

Complete edentulism is a debilitating condition as it deprives the nutritional, psychological and esthetic status of an individual. Prosthetic restoration with conventional complete dentures was considered as the only treatment of choice previously. These dentures in due course of time lose retention due to degenerative/resorptive changes of the supporting tissues with advancing age. The introduction of the concept of Osseointegration by Per-Ingvar Branemark has revolutionized the treatment modalities of complete and partial edentulous individuals. Implants improve the retention of the prosthesis and promote proprioception and bone preservation. The maximum bite force of subjects with implant supported dentures is reported to be 60–200% higher than that of subjects with a conventional denture.[1,2]

Although a minimum amount of stress is necessary for bone remodeling, very high amounts of stress could lead to micro damage and induce resorptive modeling and ultimately loss of implant.[3,4] To avoid such consequences, it is advisable to use resilient attachments around implants. [5]

Attachment fixation for overdentures originated in Switzerland around 1898 and was popularized by Gilmore[6]. These include ball attachment, locator attachment, magnetic attachment, rigid and non-rigid telescopic copings when the implants are left unsplinted or a bar and clip attachment when the implants are splinted.

Experimental observations found a direct correlation between highly stressed regions and bone resorption[7]. Failure to detect the peri-implant stress using different commercially available stress breaking attachments would be a trial and error method. It is therefore necessary to evaluate the difference in stress caused by different attachments.

Recent introduction of finite element analysis has bridged this gap. Finite element analysis can simulate stress dynamics using a computer-created 3D models to calculate stress, strain, and displacement. Such analysis has the advantage of allowing several conditions to be evaluated qualitatively and quantitatively [8] that are difficult to examine clinically. The aim of this study was to evaluate the stresses induced on the supporting mucosa and surrounding bone in a maxillary implant retained overdenture with (i) ball attachment and (ii) bar and clip attachment, under buccolingual and anteroposterior loading using three dimensional (3D) finite element analysis.

Materials and methods

In the present study, two 3D geometric models were created using 3D CATIA program (Version 5) and then converted into 3D finite element models by using Hypermesh software, to represent an edentulous human maxilla with overdentures retained by two different anchorage systems. The model included mucosa, cortical bone, cancellous bone with 4 implants (Maestro, Biohorizon, USA 4 mm in diameter and 12 mm in length) distributed over the canine and second premolar region and an overdenture retained by ball attachment or a Hader bar and clip attachment (Fig 2) .Each component was designed separately and then assembled.

The models were constrained at the base of cancellous bone and then subjected to a load of 100N applied near the left first molar tooth position. Load was applied in buccolingual and anteroposterior directions. Accordingly four models were designed i.e Ball attachment under bucco lingual and antero posterior loading and Bar and clip attachment under bucco lingual and antero posterior loading (Fig 1).Analysis was carried out using Ansys software (Version 9) to evaluate the resultant Von- Mises stress induced on the supporting mucosa, cortical bone and cancellous bone .

Model Settings

Eight noded solid brick elements were used for the models. The number of elements and nodes were 12,966 and17,249 in model with Ball attachment and 30,016and 18,176 in model with Bar and clip attachment respectively. Element type was Solid 45, contact 174, Target 170. Constrain was applied on all directions at the base of the cancellous bone. All materials were assumed to be homogenous, linearly elastic and isotropic. The material properties (Table I) of the dentures, mucosa, cortical bone, cancellous bone, implants and attachments were then incorporated. All conditions were set and analysis was carried out by using Ansys software Version 9.

Results

Following loading, stresses were induced in each of the supporting layer. The stress color plots obtained were studied and the maximum von Mises stress induced in each supporting layer was compared and tabulated. Table 2 and Table 3 show the cumulative stresses induced in each layer in bucco lingual and antero posterior loading respectively comparing ball and bar attachment systems.

Stresses induced on the mucosa:
In case of ball attachment the stresses induced on the mucosa were 0.05 MPa(Model I)and 0.03 MPa (Model II) under bucco lingual and anteroposterior loading respectively.The stresses were concentrated along the entire mucosa on the working (Loading side) irrespective of loading condition and the stresses were predominant on the buccal aspect.Additionally anteroposterior loading induces stresses which cross the midline which is not seen in case of bucco lingual loading.

In case of bar and clip attachment the stresses induced on the mucosa were 0.04 (model III) and 0.03 (model IV) Mpa under bucco lingual and anteroposterior loading respectively. The stresses were concentrated along the distal end of the mucosal model on the Working (Loading side) and did not involve the implant interface under both bucco lingual and anteroposterior loading.

It is observed that there is no significant difference in the magnitude of stresses induced on the mucosa in case of ball and bar and clip attachment under different loading conditions. However significant difference exists with regards to the distribution of stresses. In case of ball attachment the stresses were found to be distributed over a wider area of mucosa, whereas with bar and clip attachment the stresses remain concentrated along the distal most aspect of mucosal model on loading side.

Stresses induced on the cortical bone:
In case of ball attachment the stresses induced on the cortical bone were 1.0 MPa (Model I) and 0.2 MPa (Model II) under bucco lingual and anteroposterior loading respectively. In case of bar and clip attachment the stresses induced on the cortical bone were 1.9 MPa(model III) and 1.4 MPa (model IV) under bucco lingual and anteroposterior loading respectively(Fig3) .With both the attachments the stresses were concentrated along the implant interface of first, second and third implants($I_{1,} I_{2,} I_3$) in case of bucco lingual loading and along the implant interface of first, second ($I_{1,} I_2$) and buccal aspect of only second imlant I_2 in case of anteroposterior loading. However significant difference in the magnitude of stress was observed in both loading and attachment conditions.

It is observed that in case of stresses induced on the cortical bone between ball attachment and bar and clip attachment, greater stress with respect to magnitude is induced with bar attachment when compared to ball attachment. Whereas the area of distribution of stress is similar with both attachments irrespective of loading conditions. Comparatively greater stress was induced under bucco lingual loading than anteroposterior loading with both attachment systems.

Stresses induced on the cancellous bone:
In case of cancellous bone the stresses induced with both the attachments were 0.2 Mpa and 0.5 MPa in case of bucco lingual and antero posterior loading respectively.The stresses were concentrated along the implant interface of first and second imlant ($I_{1,} I_2$) and predominantly on buccal aspect of working side extending throughout the length in case of bucco lingual loading. Additionally stress was also observed along the midline between the anterior implants in case of bucco lingual loading. In case of antero posterior loading , stresses were concentrated along the implant interface ($I_{1,} I_2$) and on the buccal aspect of working side extending throughout the length.

It is observed that in case of stresses induced on the cancellous bone between ball attachment and bar and clip attachment, nearly equal magnitude of stress was induced around the implant interface irrespective of loading in both attachment types. Greater stress concentration was observed along the buccal aspect of working side in case of bucco lingual loading than anteroposterior loading with both attachment types. Comparatively greater magnitude of stress (maximum stress) was induced in cancellous bone with bar and clip attachment than with ball attachment. No stress was observed along the midline in case of bar attachment, as seen in ball attachment.

Discussion

Overdentures supported by a few implants appear to be highly successful in the edentulous mandible. In contrast, treatment outcomes with maxillary overdentures seem to be less predictable. Goodacre et al[9] reported that the highest failure rate (21.3%) for any type of prosthesis occurred with maxillary overdentures. The lower success rates have been attributed primarily to the quality of bone in edentulous maxilla, since a looser arrangement of trabecular bone with a thin, or even absent, cortical plate is generally considered to be less capable of stabilizing and supporting implants.[10,11]These failures can be avoided by increasing the number and length; or the diameter of implant, but the limiting features of maxilla like the presence of nasal fossa, maxillary sinusitis pneumatisation with age along with resorption of alveolar ridge delineate this treatment option. [12] Stress breaking attachments provide an alternative treatment modality as they improve the retention and stability of the prosthesis and at the same time promote equitable load distribution with minimum number of implants. [13,14] However, the nature of force transmission by these different commercially available attachments is not well documented.

A consistent observation from the results was that in case of mucosa, difference with regards to the distribution of stress was noticed. Relatively distribution of stresses to wider area of mucosa was observed under both loading conditions with ball attachment. Whereas, with bar and clip attachment the stress was concentrated along the distal most aspect on the loading side under both loading conditions which can be attributed to the difference in the resiliency of the rubber housings and the clips used over the ball and bar respectively (MOE of rubber housing = 5, MOE of clip =3000). This increased resiliency in case of ball attachment provides rotational freedom and promotes distribution of stresses over a wider area of mucosa. With respect to magnitude, both the attachment systems induce nearly similar stress on the mucosa.

In case of cortical bone comparatively increased stress with respect to magnitude was induced at the implant interface with bar and clip attachment (1.9 MPa) than ball attachment (1.0MPa). This can be attributed to the increased modulus of elasticity of cortical bone which makes it stiffer and resistant to forces. The increased magnitude of stress with respect to bar and clip attachment is due to the absence of resilient counter parts immediately on the implants.With respect to area of stress distribution, the stress remained concentrated along the interface of first,second and third implants under bucco lingual loading for both the attachments. Where as in case of antero posterior loading the stress was seen only near the interface of second implant with both the attachments.

In case of cancellous bone also greater stresses were induced with respect to magnitude in bar and clip attachment than with ball attachment. This is probably due to the deformation of bone during chewing [15.] Deformation of the bone is greater on the working side than that on the non-working side, this creates torsion in the central part of the bone. With ball anchored over denture the implants are independent and can thus follow the distortion of the bone without affecting it, however with bar and clip anchored overdenture the rigid bar connecting the implants tends to counter act this movement leading to increased stresses in the surrounding bone. Additionally stress was concentrated along the midline between the anterior implants with ball attachment which was not seen in case of bar and clip attachment this is because incase of bar and clip attachment the stresess rather than remaining concentrated between the implants along the midline , was discharged by the bar in the cortical bone beyond the distal implant. Considering the above stress patterns, the following conclusions are drawn:

i. Greater magnitude of stress was induced with bar and clip attachment when compared to ball attachment.
ii. Ball attachment promotes distribution of stress to a wider area when compared to bar and clip attachment.
iii. With both the attachments greater stress was observed with bucco lingual loading i.e. laterotrusive movement when compared to antero posterior loading i.e protrusive movement.

These results are in agreement with an in vivo study conducted by Cavallaro and Tarnow[16]. The authors concluded that unsplinting the implants in maxillary overdentures using ball attachment would provide advantages like enhanced esthetics, phonetics, decreased cost, ease of placement, simplification of hygienic procedures. Another in vivo study conducted by Olivier [17]confirms the results of the present study which supports the impression that the FEM model used behaved well.

In a photo elastic study conducted by Fedrick and Caputo[18] it was concluded that ERA attachments alone tend to provide more equitable load transfer to the bone surrounding the implants when compared to bar and clip and combination of bar and clip with ERA.

The results of the present study are also in agreement with various other studies[19,23,24] which support that ball attachments promote equitable load distribution when compared to bar and clip attachment.

However, the results are in contradiction to the findings of a 2D FEA study conducted by W.G. Assuncao et al [14]which compares the stress distribution between complete denture and implant retained overdenture using ball and bar and clip attachment. A possible explanation for this apparent contradiction is that the authors used a simpler 2D model and calculated the stresses with axial loading alone, whereas in real clinical situation there exists more of non-axial load components that are detrimental to the preservation of crestal bone under function. Studies comparing 2D and 3D FEA conducted by Ismail et al[20] and Meijer et al[21] claim that 2D model did not adequately represent the clinical situation and suggested that it not be used to analyze the stress distribution around dental implants for parameter studies.

In the present study, several assumptions and simplifications were made regarding the model generation and material properties. In FEA models bone is frequently modeled as isotropic, when in fact it is anisotropic. The properties of the materials modeled in the study, particularly the living tissues, however are different. It is a well-known fact that the actual cortical bone is transversely isotropic and inhomogenous[22]. The structures in the model were all assumed to be homogenous, isotropic and linearly elastic. The implants were assumed to be 100% osseointegrated, whereas some histomorpho metric and FEM studies indicated that there is never a 100% osseointegrated bone implant interface. Therefore, the inherent limitations of FEA must be acknowledged.

Conclusion

Hence within the limitations of this study it can be concluded that ball attachment favors more equitable load distribution to the under lying mucosa and surrounding bone when compared to bar and clip attachment when used for implant supported overdentures in the maxilla.

Table No 1: Young's modulus and Poison's ratio of materials used in the study

Material	Young's modulus (MPa)	Poison's ratio (v)	Reference
Cancellous bone	1370	0.30	23
Cortical bone	13700	0.30	23
Mucosa	1	0.37	24
Titanium alloy	103400	0.35	23
Ni-Cr alloy	24900	0.32	23
Rubber cap	5	0.45	23
Stainless steel	19000	0.31	23
Acrylic resin	3000	0.35	24
Clip	3000	0.28	23

Table No 2: Stress induced in MPa in bucco lingual loading

	Ball Attachment	Bar and clip Attachment
Mucosa	0.05	0.04
Cortical Bone	1.0	1.9
Cancellous Bone	0.25	0.5

Table No 3: Stress induced in MPa in anterior- posterior loading

	Ball Attachment	Bar and clip Attachment
Mucosa	0.03	0.03
Cortical Bone	0.2	1.4
Cancellous Bone	0.2	0.5

Figure.1 FLOW CHART SHOWING THE CLASSIFICATION OF MODELS IN THE STUDY

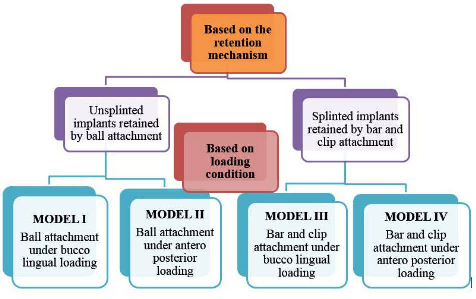
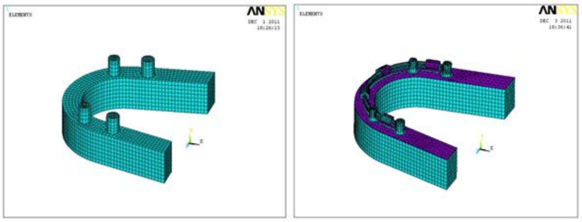
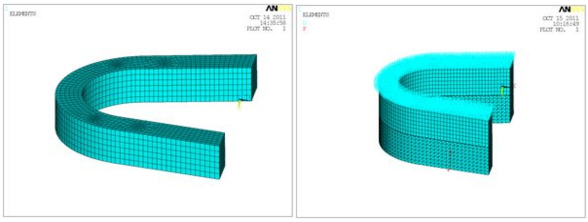


Figure.2 EVOLUTION OF FINITE ELEMENT MODELS OF INDIVIDUAL COMPONENTS

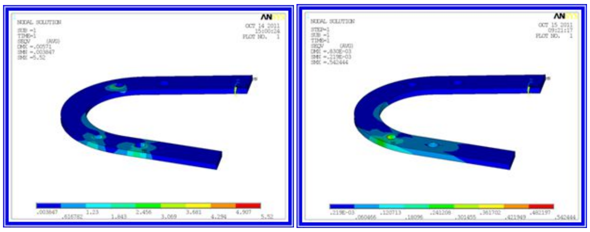

MODEL WITH BALL ATTACHMENT

MODEL WITH BAR AND CLIP ATTACHMENT

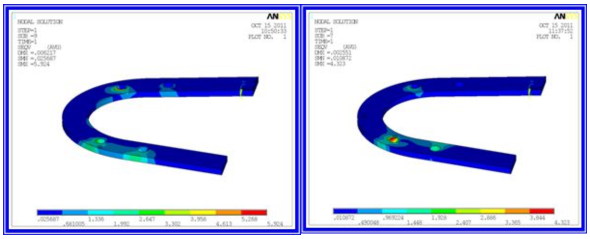

OVER DENTURE PROSTHESIS

ALL COMPONANTS ASSEMBLED

Figure.3 COMPARISON OF VON MISES STRESSES INDUCED ON THE CORTICAL BONE IN FOUR MODELS


MODEL—I

MODEL—II


MODEL—III

MODEL—IV

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