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ASSESSMENT OF STRESS DISTRIBUTION AROUND IMPLANT WITH DIFFERENT INCLINATION IN IMPLANT RETAINED MANDIBULAR OVER DENTURE USING TWO DIFFERENT STUDS ATTACHMENT DESIGN (EQUATOR AND LOCATOR): 3D FINITE ELEMENT ANALYSIS

Mohamed Mostafa Gabr *, Hamdi Abo Alfotouh Hamed**
and Nora Mohamed Cheta ***

ABSTRACT

Overdenture supported by two intraforaminal implants become the most applicable treatment for completely edentulous mandible to overcome the problems of complete denture as lack of stability, retention and insufficient chewing ability.

Aim: This study aims to compare the stress distribution pattern between Equators and Locator attachment systems of implant retained overdenture around implant with different inclination in the mandible by computing the distribution of stresses in bone/implant interface in different zone and different direction of force applied using finite element analysis software.

Methods: A three-dimensional finite element analysis model (3D FEA) of an edentulous mandible restored with 2 implant supported overdenture was designed. The attachment systems used was planned to be locator and equator attachments with different angulations between the two implants (0°, 10°, 20°, 30°). Therefore, 8 models were designed; 4 models for equator and 4 models for locator attachment. Each model was duplicated so that one model is subjected to vertical load (200 N) and its duplicate was subjected to oblique load with angle 45° (200 N) in molar/premolar area.

Results: Equator attachment recorded lesser stresses on the peri-implant bone than locator attachment and, increasing the angle between the two implants in both attachment lead to more stresses in peri-implant bone especially under oblique load

Conclusion: The cervical part of peri-implant bone is the most affected part whatever the type of the attachment used and whatever the angulation between the two intraforaminal implants supported mandibular overdenture under vertical or oblique loads. Increasing the angle between the two implant from 0° to 10°, 20 ° or 30° lead to increase the stresses received by the per-implant bone especially in the cervical part.

KEYWORD: Force, bone, cervicalthird

* MSc, Department of oral Implantology, Faculty of Dentistry, Cairo university
** Professor of Prosthodontics, Faculty of Dentistry, Cairo University
*** Prosthodontics Department, Faculty of Dentistry, Cairo University, Egypt

INTRODUCTION

Two intraforaminal implants supported overdenture become the most applicable treatment for completely edentulous mandible to overcome the problems of complete denture as lack of stability, retention and insufficient chewing ability. [1] Selection of the proper attachment system depend on a variety of factors that must be determined early in the treatment sequence. [2]

The newly developed locator and equator attachment systems has become widely applied. Though, there is no enough in-vivo or in-vitro studies concerning the evaluation of these systems and according to Kleis et al (3)., until 2010 there is no in-vivo study of this attachment system available

The locator attachment becomes one of the most common overdenture attachments used, the self-correcting adjustment of the locators reduces tear and wear on the attachment components. Locator attachments are found in variable vertical heights. They are retentive, durable and resilient and have some built-in different angulation designs. In addition, replacement and repair are quick and easy. [4]

OT Equator profile has the least overall displacement of any attachment system in the market giving the dentist and the technician superior case design options for esthetics and function, which is ease in the use, and can be successfully used in the treatment of low vertical dimension and increased retention force. [5]

Three-dimensional (3D) finite element analysis (FEA) has been commonly used for the proper evaluation of the stresses on the implant and its surrounding alveolar bone. [6]

The design and attachment type affect the stress distribution in the implant supported overdenture and also increasing the implant angulation lead to increase the stresses on the peri-implant bone. There are vertical and oblique loads occurred in the oral cavity with different direction. Are there is a differences of stress distribution around the implant with different inclination and different direction of load in implant retained mandibular overdenture when using two different studs attachment design EQUATOR and LOCATOR?

MATERIALS AND METHODS

A three-dimensional finite element analysis model (3D FEA) of an edentulous mandible restored with 2 intraforaminal implant supported overdenture was to be designed. The attachment systems used was planned to be locator and equator attachments with different angulations between the two implants (0˚,10˚, 20˚, 30˚). Therefore, 8 models were designed; 4 models for equator and 4 models for locator attachment. Each model was duplicated so that one model is subjected to vertical load and its duplicate was subjected to oblique load.

The computer simulation of the suggested clinical situations was done using a personal computer and two softwares which are: "SOLIDWORKS 2016 x64 Edition premium package" and "ANSYS Mechanical workbench 18.0".

The computer simulation was done through two main stages:

I) Designing the model (using Solidworks)

1. Three-dimensional drawing of the model components.
2. Assembling of the components.

II) Analysis of the model (using ANSYS)

1. Defining the material properties for each component.
2. Defining contacts and gaps between components.
3. Meshing of the models.
4. Defining loads and restraints for each model.
5. Running of the analysis.
6. Collecting the results.

III) Designing the model

A) Three-dimensional drawing of the model components.

1) The mandible:

- The mandible was drawn in two parts; cortical bone and cancellous bone. Both was drawn using the same technique in which a 2D sketch was used to draw sagittal sections of the mandible based on CBCT of a real mandible.
- However, for the cancellous bone, the planes and sketches of compact bone were used as reference to draw the sketches of cancellous bone on a smaller dimension.
- The sketches were connected using the "loft tool" to create 3D model of half the mandible.
- The other half was created by mirroring the existing part.

2) Mucosa

- To simulate the overlaying mucosa, sketches of the compact bone are used as reference to draw sketches of the mucosa. Sketches of mucosa were drawn to be 2 mm above the highest point of the compact bone sketches and this 2 mm represent the thickness of ridge mucosa. All mucosa sketches are drawn using "spline curve" tool and the sketches were connected using the loft tool to form the 3D model and the other half was created using the mirror tool.

3) Denture Bas

- The same steps were followed; sketches of the mucosa were used as reference to draw sketches of the denture base.
- The sketches of denture base were drawn to be 2 mm above the highest point of mucosa sketches which represent the thickness of the acrylic denture base. Finally, the sketches were connected using "loft" tool and mirrored to form 3D model.

4) Teeth

- Each tooth was drawn separately using five 2D sketches representing the cross sections of the teeth. The sketches were connected by loft tool to form 3D object.

5) Bone cylinder:

- A sketch was opened in the top plane and a circle of 5.5 mm in diameter was drawn then using the command "***Boss extrude",*** the circle was extruded to 12 mm length so that a cylinder of 5.5 mm diameter and 12 mm length was obtained.
- A new plane was created parallel to the top plane and 2 mm away from the main sketch in the top part of the cylinder and a split was made in the cervical part of the cylinder along the new plane by using the command ***"Split".***

5) Implant:

The implant size was fixed in all models which was 4 X 10 mm, the implant dimensions was drawn along the following steps:

- A 2D sketch of circle with 4 mm diameter was drawn in the top plane
- Then, the circle was extruded using boss extrude tool to form a cylinder of 10 mm length and with draft angle of 2 degrees.
- To create implant threads, a helix was done over the whole length of the cylinder and using pitch distance of 0.7 mm and with taper angle 2 degrees. That was done using the "Helix/spline" tool of the software.
- Then, the cross section of the threads was drawn and finally, the threads were cut using the "Sweep cut" tool, to cut the threads along the helix.
- The final model of the implant was created as in the figure 7D.

6) Equator:

A) Head

- A 2D sketch of the outline of the equator head was drawn in the front plane with the dimensions shown in
- After that, the "revolve tool" was used to create the final model of equator. (Fig:2)

In order to make different angulations for the head

- The model was duplicated into 3 additional models. Then, a triangle was drawn in a 2D sketch for each model but with different angles. (Fig:3 A)
- The angles used were 5, 10, 15 degrees. Then this triangle was removed using "cut extrude" tool to provide an angle for the head of each model. (Fig:3 B)

B) Threaded part of the attachment

- A sketch that represents half the equator screw was drawn in the front plane.
- The dimensions used for drawing the sketch are demonstrated in (Fig: 4 A)
- Then using the command "***Revolve Boss/Base***", the sketch was converted to 3D model. (Fig: 4 B , 4 C)
- Threads were made in the same way as the implants. (Fig: 11 C)
- Equator attachments with different angulation (0, 5, 10 and 15°) (Fig:5)

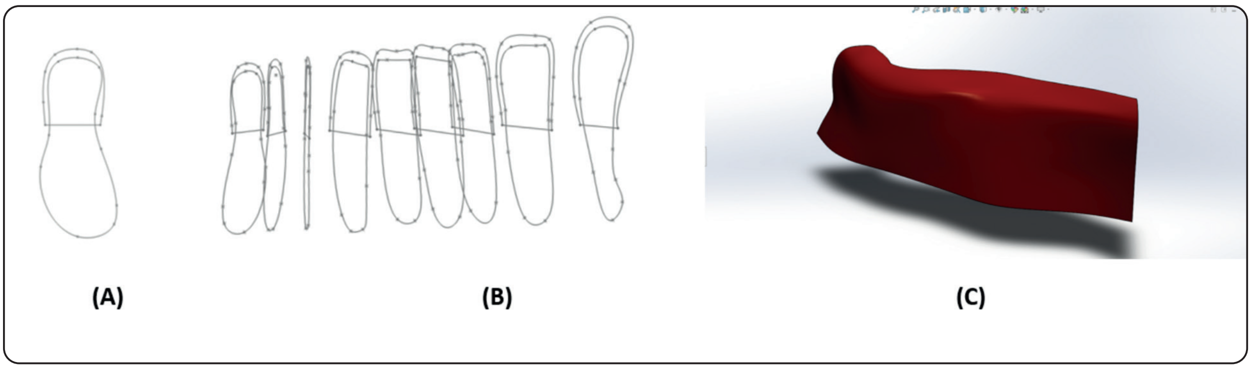

Fig. (1) (A) sagittal section of the mucosa over the cortical bone in the molar region, (B) sections of the mucosa (C) final 3d model of mucosa

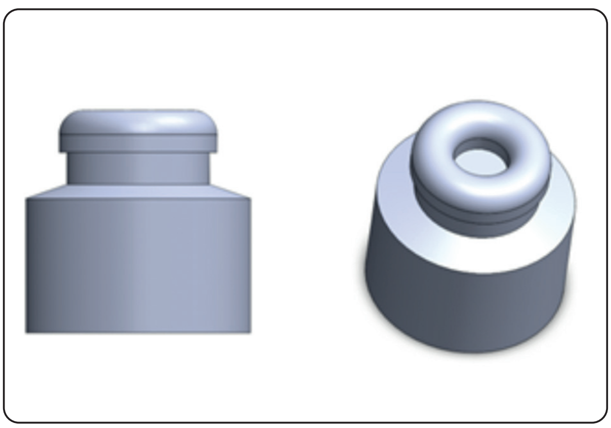

Fig. (2) Final model of equator head

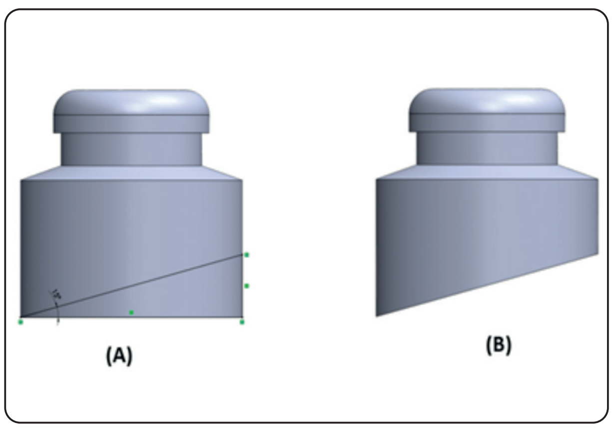

Fig. (3) (A) sketch a triangle with 15° angle, (B) 15° angled equator head

C) Nylon cap

- A sketch that represents half the nylon cap was drawn in the front plane.
- The dimensions used for drawing the sketch are demonstrated in (Fig:6 A)
- Then using the command "***Revolve Boss/Base***", the sketch was converted to 3D model. (Fig:6 B)

D) Metal housing

- A sketch that represents half the metal housing was drawn in the front plane.
- The dimensions used for drawing the sketch are demonstrated in (Fig: 7 A)

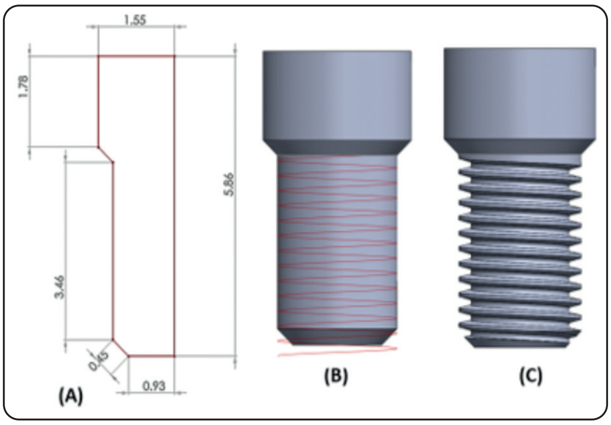

Fig. (4) (A) sketch for half the screw with dimensions, (B) helix of the screw, (C) screw threads

- Then using the command "***Revolve Boss/Base***", the sketch was converted to 3D model. (Fig:7 B)

7) Locator

A) Head

- A 2D sketch of the outline of the locator head was drawn in the front plane with the dimensions shown in (Fig: 8)
- After that, the "revolve tool" was used to create the final model of locator. (Fig:8)

In order to make different angulations for the head

- The model was duplicated into 3 additional models. Then, a triangle was drawn in a 2D sketch for each model but with different angles. (Fig:9 A)
- The angles used were 5, 10, 15 degrees. Then this triangle was removed using "cut extrude" tool to provide an angle for the head of each model. (Fig:9 B)

B) Threaded part of the attachment

- A sketch that represents half the locator screw was drawn in the front plane.
- The dimensions used for drawing the sketch are demonstrated in (Fig: 10 A)
- Then using the command "Revolve Boss/Base", the sketch was converted to 3D model. (Fig: 10 B)

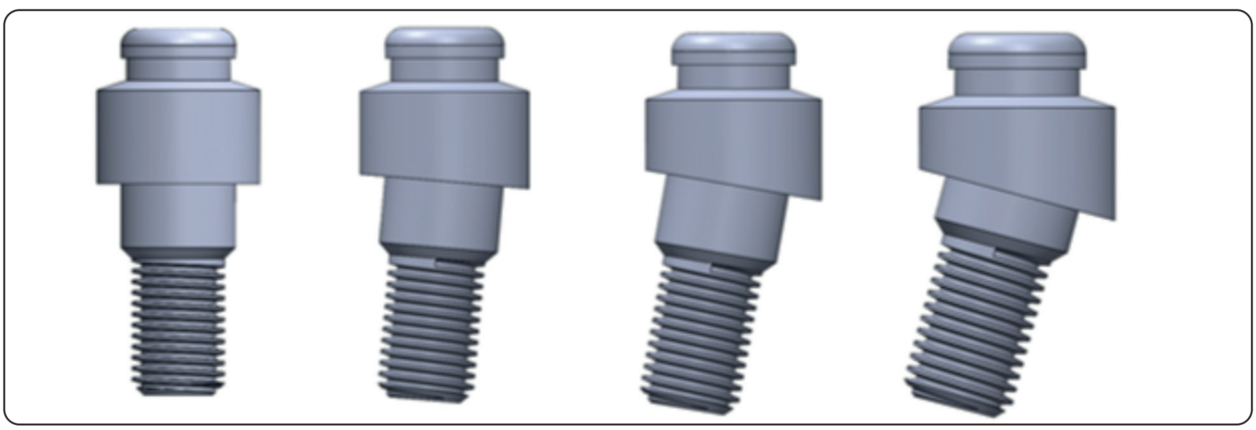

Fig. (5) Equator attachments with different angulations (0 – 5 -10- 15 °) respectively

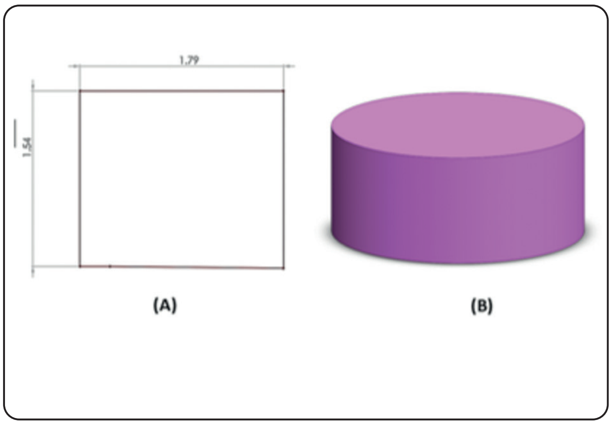

Fig. (6) (A) Sketch for half the nylon cap with the dimensions, (B) final model of the nylon cap

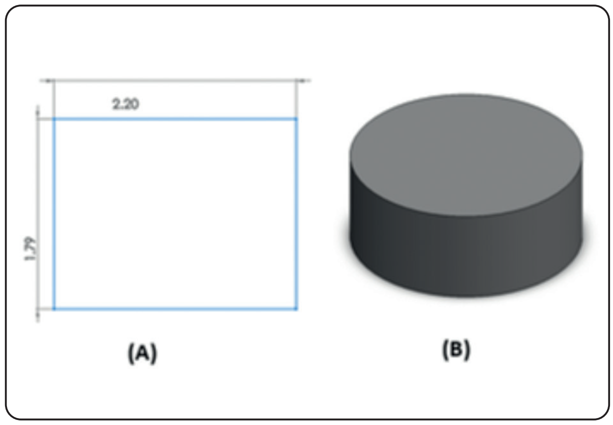

Fig. (7) (A) Sketch for half the metal housing with dimensions, (B) final model of the metal housing

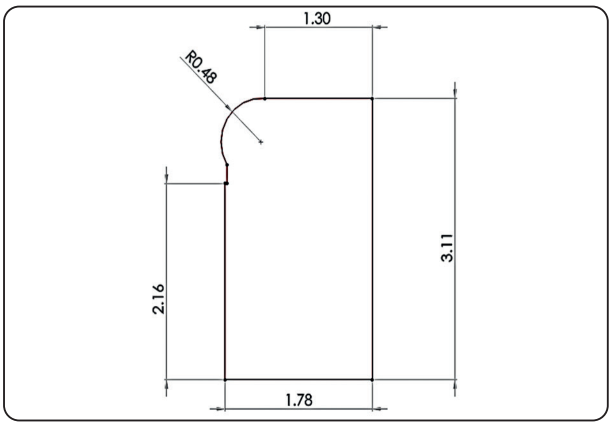

Fig. (15) Sketch of the outline of the Locator head

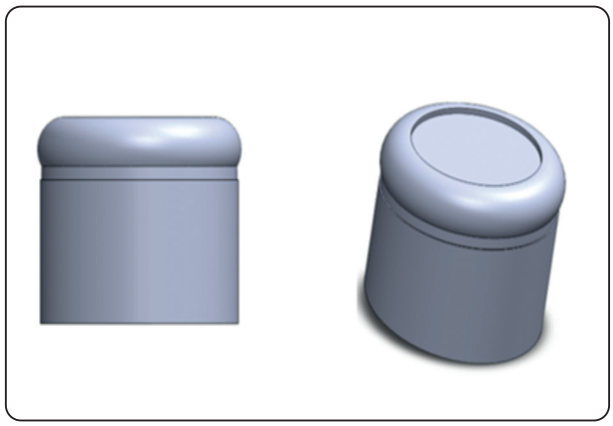

Fig. (16) Final model of locator head

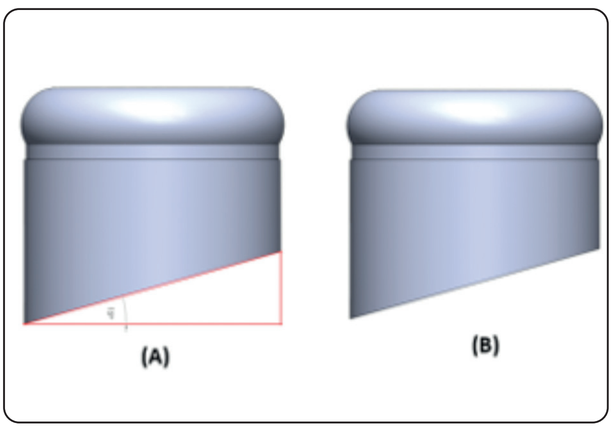

Fig. (9) (A) Sketch a triangle with 15° angle, (B) 15° angled locator head

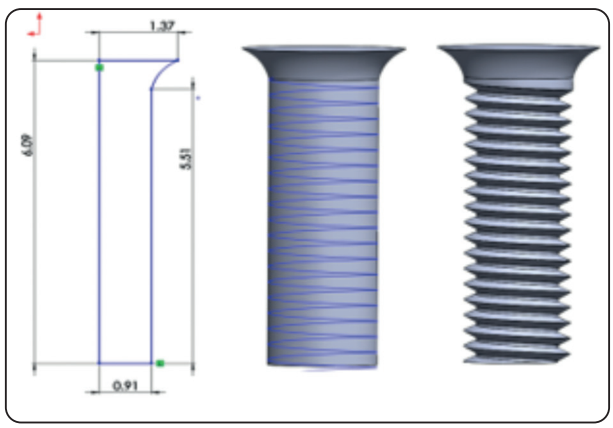

Fig. (10)(A) Sketch for half the screw with dimensions, (B) helix of the screw, (C) screw threads

- Threads were made in the same way as the implants. (Fig: 10 C)
- Locator attachments with different angulation (0, 5, 10 and 15°) (Fig:11)

C) Nylon cap

- A sketch that represents half the nylon cap was drawn in the front plane.
- The dimensions used for drawing the sketch are demonstrated in (Fig:12 A)
- Then using the command “Revolve Boss/Base”, the sketch was converted to 3D model. (Fig:12 B)

D) Metal housing

- A sketch that represents half the metal housing was drawn in the front plane.
- The dimensions used for drawing the sketch are demonstrated in (Fig: 13 A)
- Then using the command “***Revolve Boss/Base***”, the sketch was converted to 3D model. (Fig:13 B)
- The internal view of the nylon cap of equator demonstrated in (Fig: 14A)
- The internal view of the nylon cap of locator demonstrated in (Fig: 14B)The internal view of the Metal housing of both attachments demonstrated in (Fig: 14C)

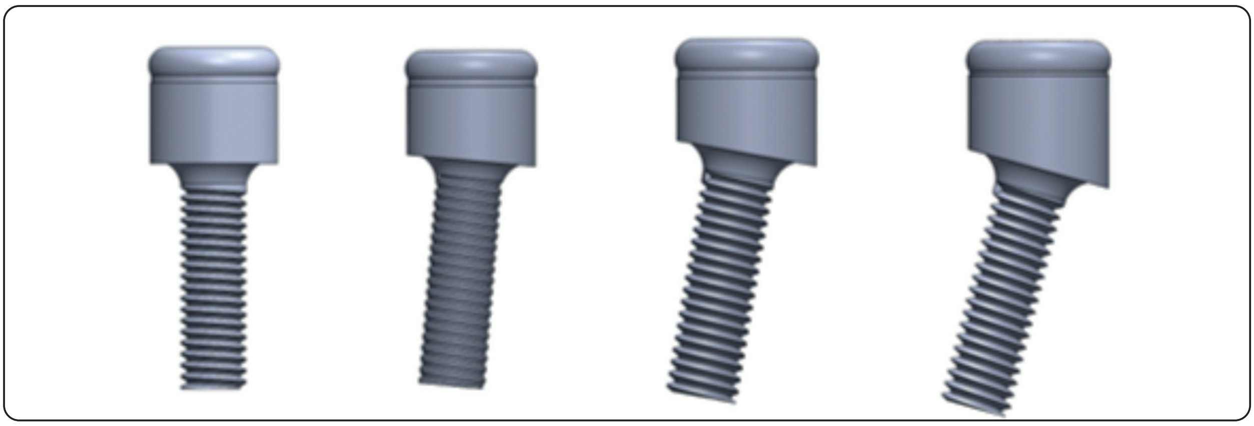

Fig. (11) Locator attachments with different angulations (0 – 5 -10- 15°) respectively.

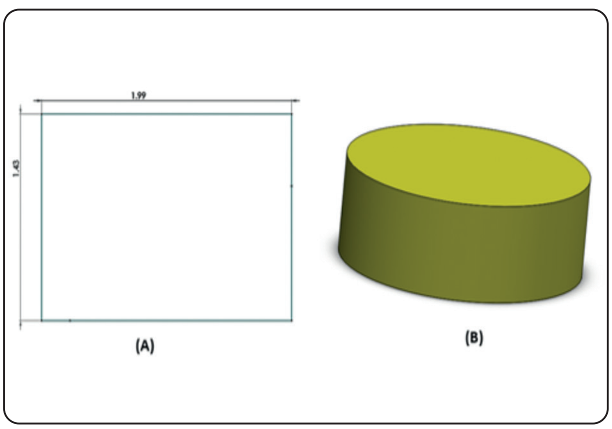

Fig. (15) Sketch of the outline of the Locator head

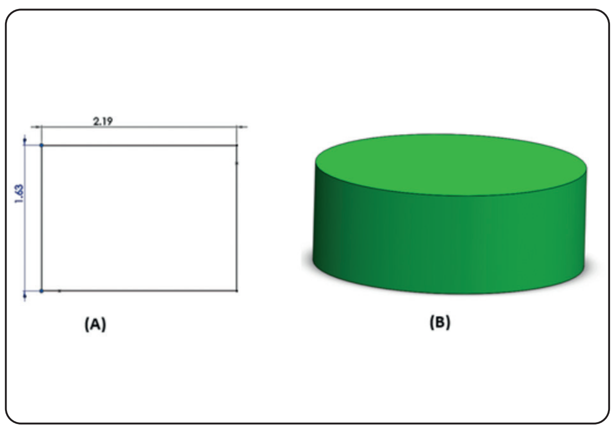

Fig. (16) Final model of locator head

B) Assembling the Components:

Assembling the components on each other on the right position was done by "Mating" according to the point of origin between compact bone, cancellous bone, mucosa and the overdenture

The parts are assembled together without interference by making a cavity in each part with the overlying component as follows: (Fig: 15)

1. For the compact bone component as an example, the component is selected.
2. Then, the component is edited by inserting feature called "cavity" to create a cavity inside which the cancellous bone component would fit in.
3. Finally, the component that would fit in the cavity was selected.
4. The same was done for all other components.

The final model was created, the locators and equators heads are placed in the bone and in the overdenture and duplicating the model eight times so that the angle between each two implants were 0, 10, 20, 30°. Therefore, we have 4 models for equators and 4 models for locators. The models were then ready for analysis.

The implant body is edited by inserting feature called "cavity" to create a cavity inside which the indentations of screw thread are presented. (Fig 16A). The Bony cylinder is edited by inserting feature called "cavity" to create a cavity inside which the indentations of implant threads are presented. (Fig 16B)

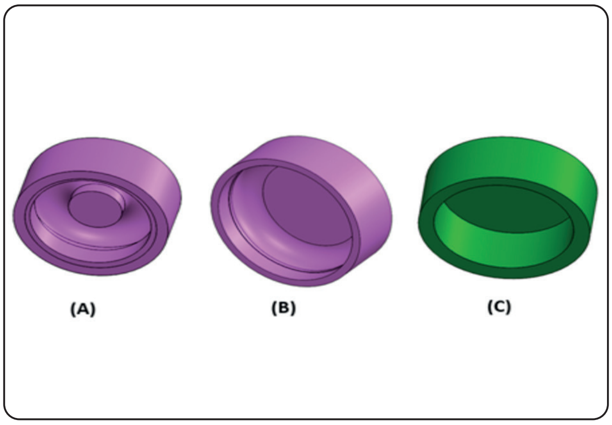

Fig. (15) Sketch of the outline of the Locator head

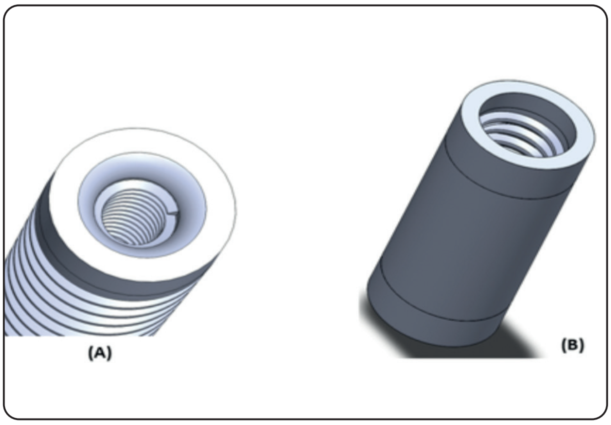

Fig. (16) (A) Indentations of screw thread in the implant, (B) indentations of implant threads in bone cylinder

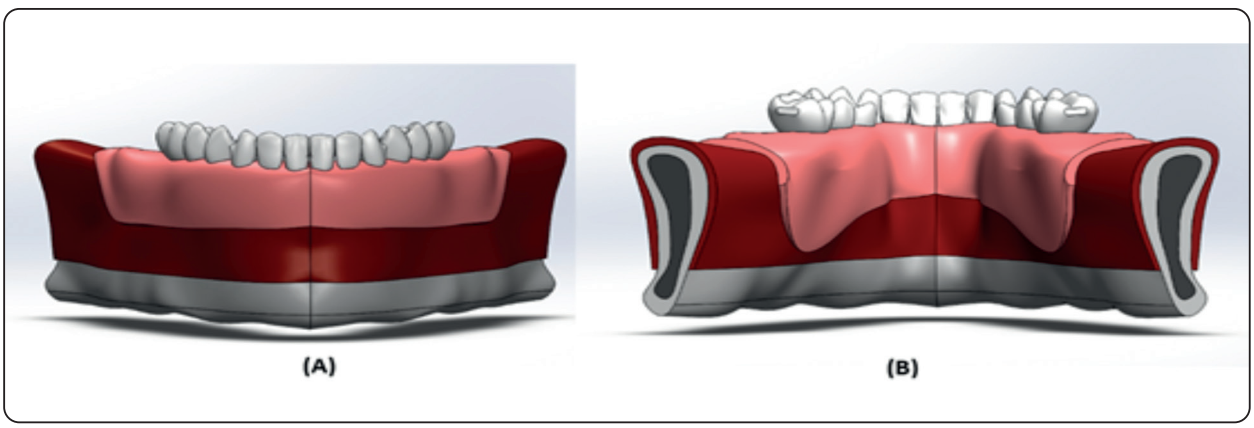

Fig. (15) The whole assembly (A) Anterior view, (B) Posterior view

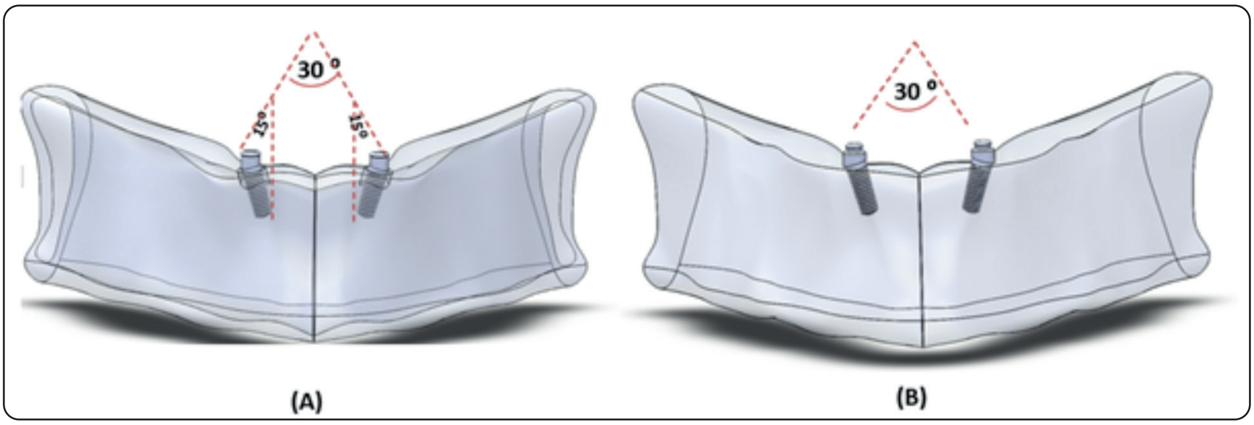

Fig. (17) 30˚ angulation between implants in (A) locator, (B) Equator

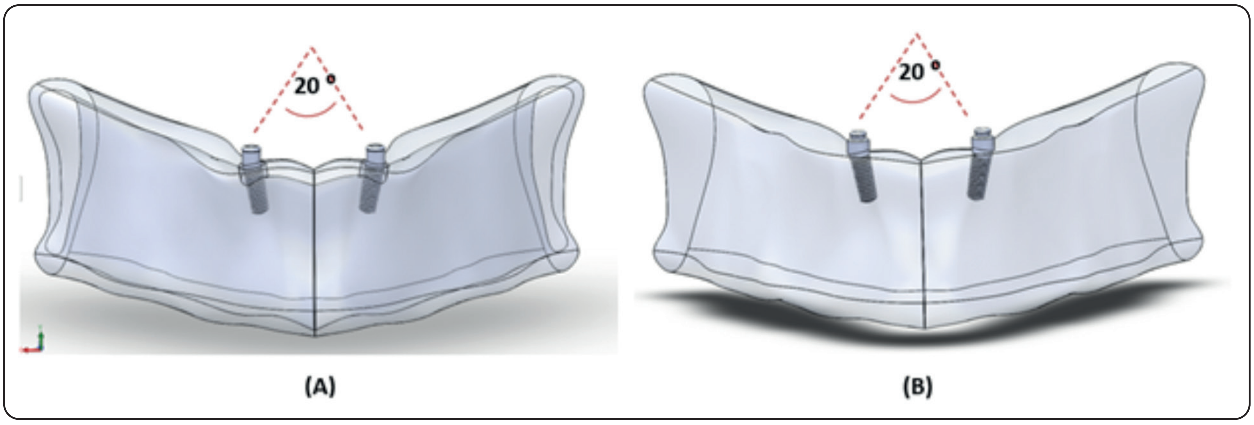

Fig. (18) 20˚ angulation between implants in (A) locator, (B) Equator

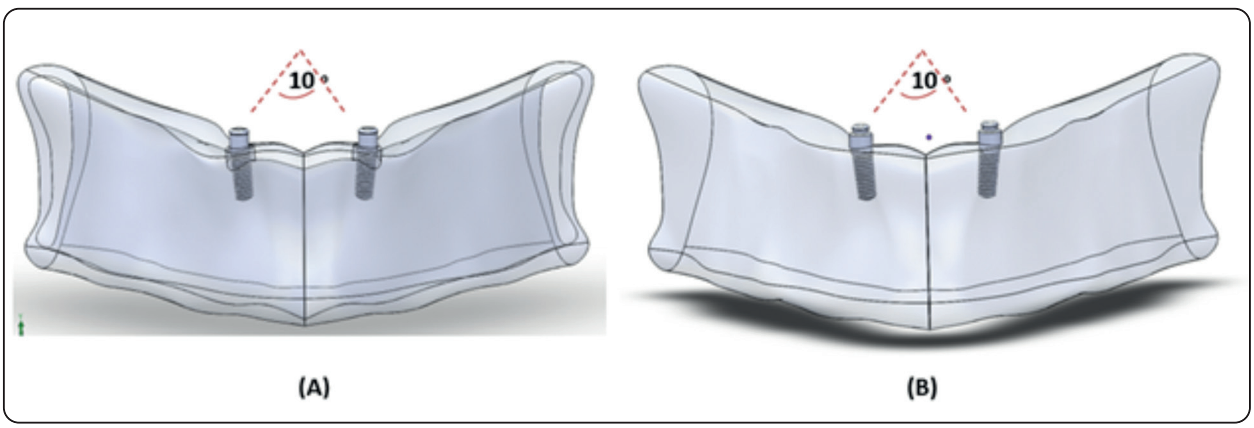

Fig. (19) 10˚ angulation between implants in (A) locator, (B) Equator

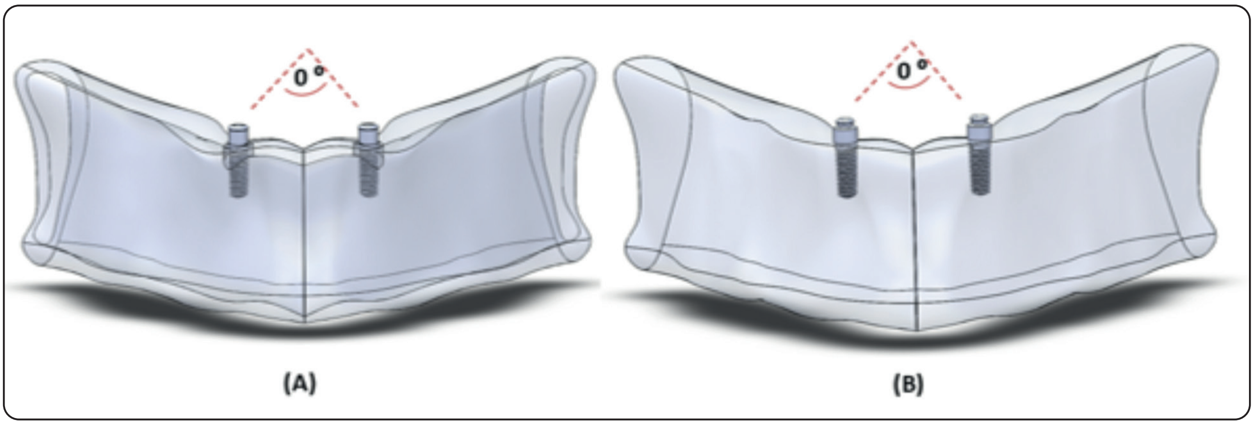

Fig. (20) No angulation between implants in (A) locator, (B) Equator

II) Analysis of the model:

The assembly was imported and opened in ANSYS software and the following steps were followed respectively:

1. Defining the material properties for each component:

- All materials in the study were considered homogenous, isotropic and linearly elastic.
- The modulus of elasticity and Poisson's ratio for the different component materials used in the study are listed in the (table 1)

TABLE (1) The modulus of elasticity and Poisson's ratio for the different component materials

Element	Poisson's ratio	Modulus of elasticity (MPa)
Compact bone	0.3	15,000
Cancellous bone	0.3	1,500
Mucosa	0.45	10
Titanium	0.3	110,000
Nylon	0.4	70
Acrylic resin	0.35	2,770
Stainless steel	0.28	200,000

Defining contacts and gaps between components:

- All components were constructed in a way that assures 100% contact along the interfaces with no gaps or interferences.
- A "bonded contact" was defined for every two contacting surfaces along the interface which means that these objects would be displaced as one unit upon load application and that the two contacting bodies cannot be separated nor penetrated.
- "No separation contact" was assumed between the following components:
  i. The Abutment head and the nylon cap
  ii. The overdenture and mucosa
- No separation contact means that once the part moves, the contacting surfaces can slide over each other without penetrating each other.
- The implants are assumed to be completely osseointegrated, with 100% bone-implant contact.

Meshing the models

- Meshing is the process of subdividing the geometric model into small pieces called elements connected at common points called nodes.
- A high-quality solid mesh was used in this study to create 3D parabolic tetrahedral solid elements.

Mesh Parameters:

- The mesh is adjusted to be "Adaptive medium mesh" in all models. (Fig:21)
- All the models have the same size of elements and nodes.

Applying restraints and defining loads

I) Restraints:

Only one restraint is used which is a fixed restraint is applied to the inferior aspect of the mandible to avoid any bodily displacement during loading, i.e., no translation is allowed for this surface in all directions. (Fig:22)

II) Defining Loads:

Each model was duplicated so that the original model was subjected to vertical load and the duplicated was subjected to oblique load. The total applied load was 200 N applied unilaterally; 100 N for the first molar and 50 N for each premolar.

For the vertical load, it was applied as followed:

- 0 N was applied to the central fossae of the first molar unilaterally.
- 0 N was applied to the central fossae of the first and second premolars. (Fig:23A)

For the lateral load, it was applied as followed:

- 100 N was applied to the lingual inclines of the buccal cusps of the first molar unilaterally with an angle of about 45 degrees to the vertical axis.50 N was applied to the lingual inclines of the buccal cusps of the first and second premolars unilaterally. (Fig:23B)

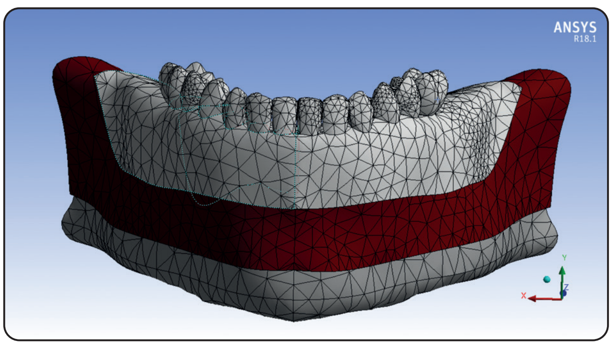

Fig. (21) Mesh of the model

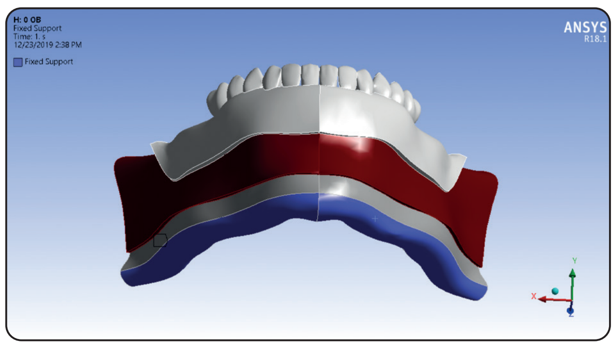

Fig. (22) Restraining the model at the inferior border

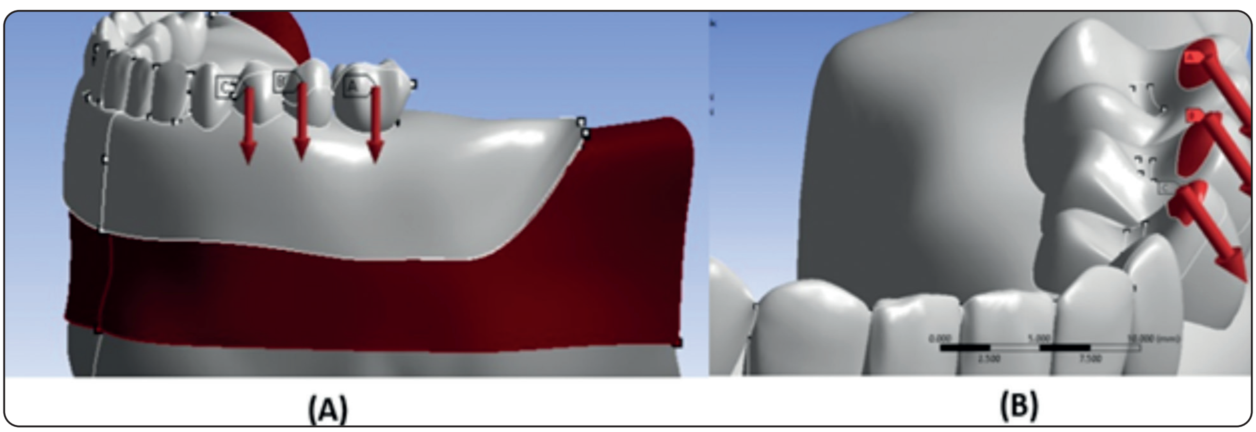

Fig. (23) (A) Vertical load on the fossae, (B) lateral load on the lingual inclines of the buccal cusps"

Determining the wanted values:

- *Von Misses stress* was determined for the following the cervical, middle and apical part of the peri-implant bone cylinder.
- The *von Mises stress* was calculated at the elements in MPa (Mega pascal) as unaveraged values.

1. Running the analysis

- The analysis was run using iterative solver.
- Iterative methods solve the equations using approximate techniques. In each iteration, a solution was assumed, and the associated errors were evaluated. The iterations continue until the errors reach an acceptable level.

2. Collection of the results

Maximum stress was collected from all models and the results were tabulated.

RESULTS

These results of stress distribution on the peri-implant bone of 8 models; 4 models for equator and 4 models for locator attachment with different angulations between the two implants (0˚, 10˚, 20˚, 30˚). Each model was duplicated so that one model is subjected to vertical load (200 N) and its duplicate was subjected to oblique load (200N) with direction 45°.

TABLE (2) Difference of stress distribution with MPa (Mega Pascal) between locator and equator attachments under vertical load in cervical part at with different implant inclination (0°, 10°, 20°and 30°)

Stress in cervical part (MPa)	Locator	Equator
0°	5.755	0.847
10°	8.035	3.103
20°	9.504	3.678
30°	10.093	3.975

Difference of stress distribution between both groups under vertical load

1. Difference of stress distribution of the peri-implant bone under vertical load (200 N) between two attachments in the cervical part when the angle between two implants is (0º, 10, 20º and 30º) as showing in table (6)

As showing in the table (2), the stress distribution under vertical load on the both attachments increase with increasing the angle between two implants from 0° to 30° in cervical part. The equator attachment show less stresses than locator attachment in cervical part of peri-implant bone at all different angles between the two implants.

Difference of stress distribution of the peri-implant bone under vertical load (200 N) between two attachments in the middle part when the angle between two implants is (0º, 10, 20º and 30º) as showing in (Fig: 24)

As showing in the Fig (24) the stress distribution under vertical load on the both attachments have negligible changes in middle part with different angles between two implants from 0° to 30°. The equator attachment shows less stresses than locator attachment in middle part of peri-implant bone at all different angles especially at 0°.

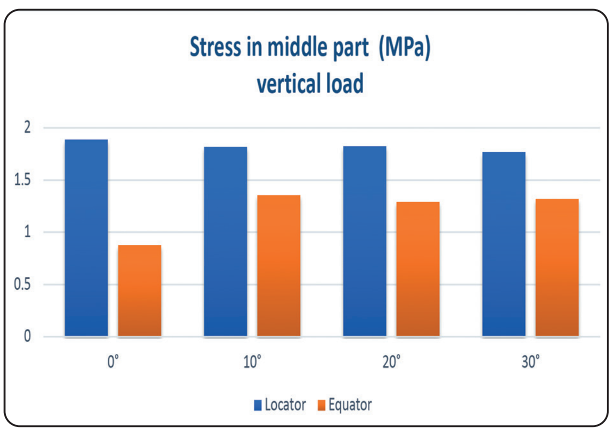

Fig. (24) Difference of stress distribution with MPa (Mega Pascal) between locator and equator attachments under vertical load in cervical part at with different implant inclination (0°, 10°, 20°and 30°)

Difference of stress distribution of the peri-implant bone under vertical load (200 N) between two attachments in the apical part when the angle between two implants is (0 º, 10, 20º and 30º) as showing in table (3)

As showing in the table (3) the stress distribution under vertical load on the both attachments have negligible changes in apical part with different angles between two implants from 0° to 30°. The equator attachment shows less stresses than locator attachment in apical part of peri-implant bone at all different angles especially at 0°.

TABLE (3) Difference of stress distribution with MPa (Mega Pascal) between locator and equator attachments under vertical load in apical part at with different implant inclination (0°, 10°, 20°and 30°)

Stress in apical part (MPa)	Locator	Equator
0°	0.793	0.294
10°	0.731	0.409
20°	0.758	0.407
30°	0.723	0.389

Difference of stress distribution between both groups under oblique load

2. Difference of stress distribution of the peri-implant bone under oblique load (200 N) between two attachments in the cervical part when the angle between two implants is (0 º, 10, 20º and 30º) as showing in (Fig: 25)

As showing in the figure (25), the stress distribution under oblique load on the both attachments increase with increasing the angle between two implants from 0° to 30° in cervical part. The equator attachment show less stresses than locator attachment in cervical part of peri-implant bone at all different angles between the two implants.

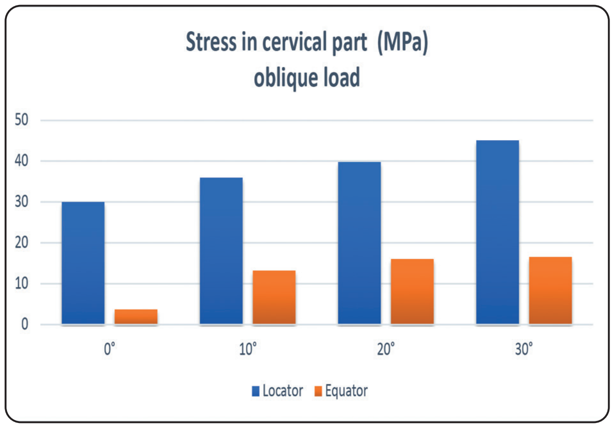

Fig. (25) Difference of stress distribution with MPa (Mega Pascal) between locator and equator attachments under oblique load in cervical part at with different implant inclination (0°, 10°, 20°and 30°)

3. Difference of stress distribution of the peri-implant bone under oblique load (200 N) between two attachments in the middle part when the angle between two implants is (0 º, 10, 20º and 30º) as showing in table (4)

TABLE (4) Difference of stress distribution with MPa (Mega Pascal) between locator and equator attachments under oblique load in middle part at with different implant inclination (0°, 10°, 20°and 30°)

Stress in middle part (MPa)	**Locator**	**Equator**
0°	**4.276**	**2.034**
10°	**3.891**	**2.654**
20°	**4.080**	**2.662**
30°	**3.864**	**2.616**

As showing in the table (4), the stress distribution under oblique load on the both attachments have negligible changes in middle part with different angles between two implants from 0° to 30°. The equator attachment show less stresses than locator attachment in middle part of peri-implant bone at all different angles especially at 0°.

4. Difference of stress distribution of the peri-implant bone under oblique load (200 N) between two attachments in the apical part when the angle between two implants is (0 º, 10, 20º and 30º) as showing in (Fig: 26)

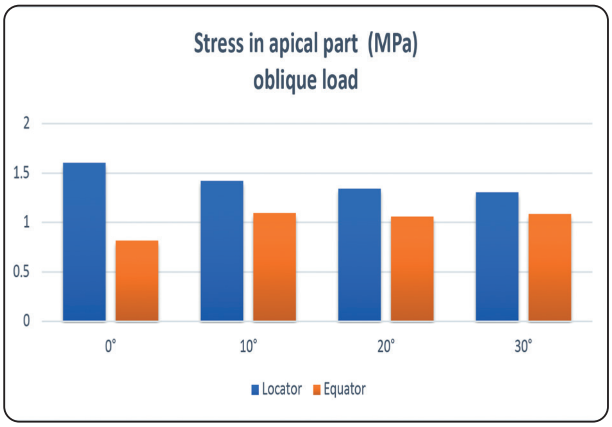

Fig. (26) Difference of stress distribution with MPa (Mega Pascal) between locator and equator attachments under oblique load in cervical part at with different implant inclination (0°, 10°, 20°and 30°)

As showing in figure (26), the stress distribution under oblique load on the both attachments have negligible changes in apical part with different angles between two implants from 0° to 30°. The equator attachment show less stresses than locator attachment in apical part of peri-implant bone at all different angles especially at 0°.

DISCUSSION

OT-Equator and Locator attachments are used in this study is due to it characterized by low-profile direct implant overdenture attachment has a minimum overall vertical height and diameter. Several advantages of these attachments make them a superior choice when compared to available other attachment systems. [7]

The stress distribution on peri-implant bone in implant supported overdenture affected by the design and the height of the attachment.[8] The present work can be summarized as follows:

During using the locator attachment, changing the angle between two implants affect the stress distribution of the peri-implant bone especially in cervical part. The least stress appear when the angle between two implants is 0º and the cervical part of the bone around implants is more affected than middle and apical thirds. This is due to high stress concentrations in the area of crestal bone around the polished neck of dental implants. [9]

Increasing the angle between the two implant from 0º to 10º, 20º or 30º lead to increase the stresses received by the per-implant bone in cervical, middle and apical parts, so the placement of the two implants should be parallel to each other as much as possible because the stresses directed through the long axis of the implants and this minimize the stresses transmitted to the peri-implant bone. [10] [11]

The stresses affect the bone around the implants during the oblique loads about 4 times more than the vertical load in cervical and middle third and about 2 times in apical third, So the oblique loading angle is the most unfavorable for stress distribution in bone and implant. [12]

During using the equator attachment, the least stress appear when the angle between two implants is 0º and the middle part of the bone around implants have more stresses than the cervical and apical thirds. In contrast when the angle between two implants is 10º, 20º or 30º, the most affected part is the cervical one. This may be due to the design of the equator and prospective clinical studies are required to verify the results. [12]

Changing the angle between the 2 implants from 10º to 20º or 30º show negligible change in the stresses received by the per-implant bone in cervical, middle and apical parts. It may be due to the favorable design of the equator attachment [12]

The stresses affect the bone around the implants during the oblique loads about 4 times more than the vertical load in cervical third and about 2 times in middle and apical thirds because oblique loads generate bending moment at the implant fixture.

This bending moment generates larger stress values at the implant-bone interface which usually exceeds the bearing capacity of the peri-implant support bone. This ultimately initiates bone loss at the implant-bone interface. Continuation of applying this off-axis loads may induce further bone loss and likely will lead to implant failure. [11]

The stresses located in the bone around the implants when the angle between 2 implant is 0º, the locator show more stresses than the equator especially in the cervical third about 5 times when subjected to the vertical load and about 10 times when subjected to oblique load so using the equator instead of the locator preserve the cervical part of peri-implant bone for longer time. This may be due to equator attachment has the minimum diameter and vertical height than locator attachment for the overdenture abutments. [13]

The stress increase rate in the cervical part of the peri-implant bone during using the locator attachments have more value than the equator attachments when the angle between two implants change to 10º, 20º or 30º during vertical and oblique load. But in the middle and the apical thirds there are negligible changes in the stress increase rate of both the locators and the equators when the angle is changed

So using the equator attachment is preferred than the locator attachment because it is recorded lesser stresses on the peri-implant bone whatever the angle between the two implants [14]

CONCLUSION

- The cervical part of peri-implant bone is the most affected part whatever the type of the attachment used and whatever the angulation between the two intraforaminal implants supported mandibular overdenture under vertical or oblique loads.
- Increasing the angle between the two implant from 0º to 10º, 20º or 30º lead to increase the stresses received by the per-implant bone especially in the cervical part

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