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Original Research Article

Effect of different angulation of forces on mini implant and abutment at various levels

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ABSTRACT

Objective: The objective of the study was to evaluate the effect of varying loads of forces at different angulation at various levels of orthodontic mini implant system by using finite element analysis.
Materials and Methods: A 3-dimensional model of the mini implant was constructed to simulate force magnitudes and directions, screw diameters and lengths, and implanted depths of mini implants. Finite element study was conducted with horizontal forces of 100, 150, and 200 g were applied to the mini implant and abutment at angulations 90° and 120. Von Mises stress, strain and displacement values were then evaluated using the ANSYS software.
Results: Both stress and displacement increased with increasing the amount of loading force. These 2 indexes were linearly proportional to the force magnitude and produced the highest values when the force was 200 g applied at 120° to the long axis of the miniimplant. The peak deformation and von Mises stress was concentrated on the miniscrew at the cervical level under 200 g at 120°. A wider screw diameter provided superior mechanical advantages. No remarkable differences in the strain distribution were observed at both angulations. However, the stress distribution of the abutment models showed a remarkable difference as compared with the models of mini implant. The high-level area (shown in orange) was localized to the head of the implant and the abutment (cervical part). Compared with 90° group, the orange coloured area was easily observed more in the cervical part of abutment.
Conclusion: The von Mises stress values in the MI, were found to be lowest under 100 g force at 90°. Higher initial loading on the mini implant should be avoided and horizontal force on the cervical level of MI should be prevented or minimized for better stability. The abutment has maximum stress concentration which is significantly useful in decreasing the stress concentration on the bone, and has a buffering action on MI. Force range used is within clinically recommended levels; however, the increase in load causes a proportional increase in the stress values.

1. Introduction

The emergence of skeletal anchorage in orthodontics is slowly replacing the traditional methods of orthodontic anchorage.[1] Mini-implants have proven to be an essential tool in orthodontic treatment. Mini implants are placed in the jaw bone between the roots of teeth to serve as anchorage for the forces being applied.[2] Compared with conventional dental implants, the orthodontic miniscrew, as a temporary mini-implant, offers many advantages, such as minimal discomfort, miniature size which allows for an increase in potential intraoral placement sites, even interdentally between the roots, low cost, and ability to withstand immediate or early loading is appreciated by

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many clinicians. MI placement and removal is simple due to their small dimensions, and minimal surgical trauma.[3]

Stress generated on bone around the mini implants influence their success rate. Factors such as the length and diameter of an implant and its direction of insertion in bone can affect the stress generated on the bone surrounding the implant.[4] The geometry of mini-implant is one of the most critical mechanical factors.

The geometry related parameters which influences the initial stability of the mini implants are the length, diameter of the screw (Holmgren et al. 1998), shape (conical /cylindrical), pitch, thread shape and abutment. The stability assessment is performed usually by applying forces and measuring lateral displacement. The lower the displacement on force application, the higher is the implant stability.[2] Finite element analysis (FEA) is commonly used in the research field in dentistry to investigate the influence of various implant design factors such as diameter and length of mini-screws, thread shape, thread size, degree of taper, pull out strength, stiffness on the stress distribution within the bone supporting the implants.[4] Finite element analysis (FEA) or finite element model (FEM) is a computer-based numerical simulation method that has extensive application in mathematical physics and has been widely used in estimating the mechanical behaviour of engineering structures.[1]

The purpose of this finite element study was to estimate the effect of varying loads of forces at various angulations on conventional mini implants and abutment, at various levels in an attempt to design a mini-implant that endures more orthodontic force during treatment. This will help to determine an optimal orthodontic force that can be loaded safely on MI to achieve adequate primary stability, and thus reduce the failure of MI in orthodontics.

2. Materials and Methods

A FEM was created using a software (ANSYS 13 version 14.5 Creo 3.0). The FEM was composed of these elements: 1- MI model (diameter, length, and screw); 2- modeling of cortical and cancellous bones; 3- FEM of MI when placed into bone at 90° angulation; and 4- Young's modulus and Poisson's ratio for all constituent structures under experiment.

To verify influences of the varying loads of forces at various angulations on mini implants and abutment, 12 three-dimensional FEMs were conducted. Orthodontic MI made of pure titanium (diameter, 2.6 mm; length, 10 mm; thread ridge height 0.33 mm; thread pitch 0.8 mm) was modeled. For the ease of modelling and based on the classical theory of elasticity, it was assumed that the constituent material was isotropic and homogeneous. The behaviour of the constituent material of FEM was quantified by Poisson's ratio and Young's modulus. The material properties for MI and bone are given in Table 1.

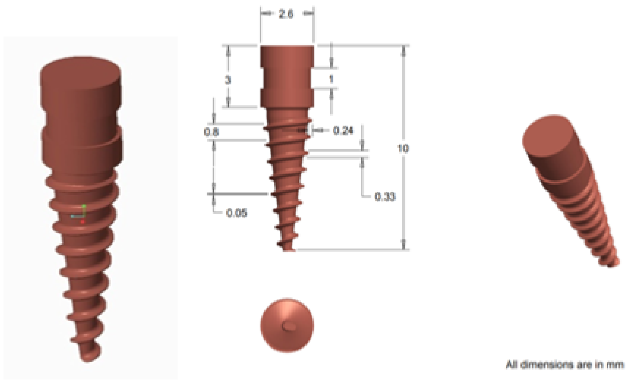

Fig. 1: Schematic representation of implant design used in this finite element study

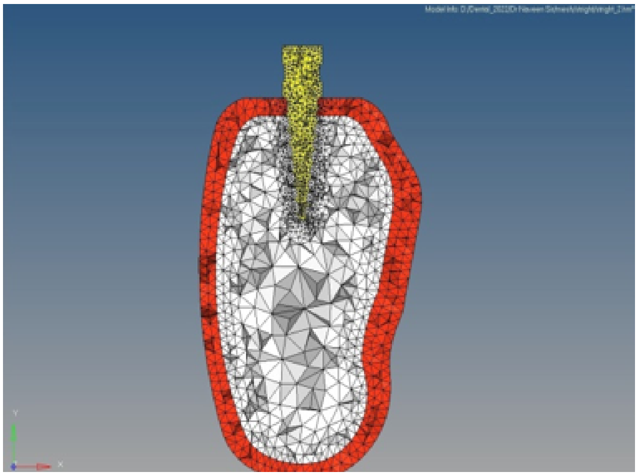

Fig. 2: Final model with colour coding

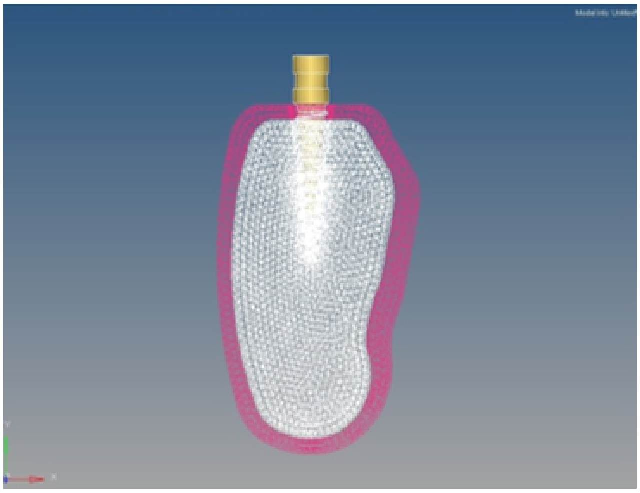

Fig. 3: Model after meshing process

Table 1: Material properties of constituent materials

Materials	Young's modulus (MPa)	Poisson's ratio
Titanium	110,000	0.35
Cortical bone	14,000	0.30
Cancellous bone	1,370	0.30

This model is then transferred to the software "HYPERMESH13 version 11.0" for the process of meshing. (Figure 3) Meshing divides the entire model into smaller nodes and elements which make a grid called as "mesh". The mesh acts like a spider web, from each node there extends a mesh element to each of the adjacent nodes. The basic idea is to make calculations at only limited (finite) number of points and then interpolate the results for the entire domain.

Any continuous object has infinite degree of freedom (dofs) and practically it is impossible to solve the problem in this format. FEM reduces the dofs from infinite to finite with the help of meshing (nodes and elements) and all the calculations are made at finite number of nodes. This mesh is programmed to contain the material properties (elastic modulus, Poisson's ratio), which define how the structure will react to certain loading conditions i.e., with the incorporation of material properties the structure simulates the normal model.

3. Load Application

Variable forces occur on the mini-screw and abutment during orthodontic treatment. When various orthodontic traction force is applied from the key-ridge to the canine, tractional direction slants to the major axis of the mini-implant with abutment. FEM was created with MI insertion at 90° and to determine the loading effect, 3 force magnitudes (100 g, 150 g, and 200 g) and force directions (90° and 120°) to mimic various clinical conditions were investigated. Force direction was defined as the angle between the loading direction and the long axis of the miniscrew, and a force direction of 90° was the force perpendicular to the long axis of the miniscrew.[5] Similarly, 3 forces (100 g, 150 g, and 200 g) were applied to the head of the mini-implant or abutment at an angle of 90° and 120° to the bone surface. (11) On the application of different loads at 90° and 120° angulation, stress values were calculated in all component structures of the MI.

The analysis is done using the software "ANSYS 13 version 14.5 Creo 3.0". The maximum equivalent Von Mises stresses were analyzed in all the models at the entire given load at 90° and 120° angle. The stresses were visualized in colour coding ranging from dark blue (minimum stress) to red (maximum stress) in the models. All the stress values attained were represented in Megapascals (MPa). The collected data had been entered in MS Excel followed by the analysis using SPSS Trial version.

4. Results

In the present study the model was subjected to different forces at 90° and 120° angulation and thus the generated stress values and patterns on the implant at different levels were observed. The stresses were represented in colour coding ranging from dark blue (minimum stress) to red (maximum stress) in the models. All the stress values attained were presented in Megapascals (MPa).

4.1. Effect of force on the mini implant at 90° angulation

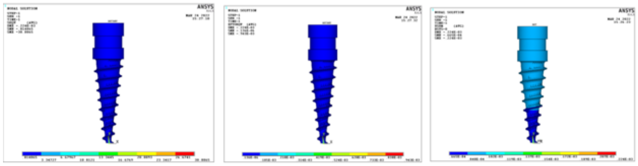

Fig. 4: 100 grams (a) Stress (b) Strain (c) Displacement

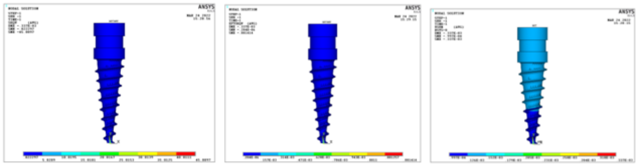

Fig. 5: 150 grams (a) Stress (b) Strain (c) Displacement

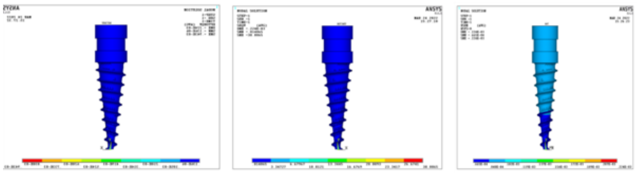

Fig. 6: 200 grams (a) Stress (b) Strain (C) Displacement

In table 2, at 100 Grams of force, the stress and strain observed in cervical third, middle third and apical third is same with 3.347 Mpa and 0.136e-6 independently. The amount of deformation observed in apical third is 0.840e-4 mm, maximum when compared to cervical and middle third with 0.102e-3 mm. (Figure 4)

At 150 Grams of force, the amount of stress and strain observed in cervical third, middle third and apical third is same with 5.020 Mpa and 0.157e-3 respectively. The amount deformation observed in apical third is minimum with 0.126e-3 mm when compared to cervical and middle third with 0.152e-3 mm. (Figure 5)

At 200 Grams of force, the amount of stress and strain observed in cervical third, middle third and apical third is same with 6.694 Mpa and 0.210e-3 respectively. The amount deformation observed in apical third is minimum with 0.168e-3 mm when compared to cervical and middle third with 0.203e-3 mm. (Figure 6)

Table 2: Maximum stress, strain and deformation seen on miniimplant due to the effect of different forces (100 grams, 150 grams and 200 grams) at 90° angulation at different levels.

Straight		Stress(Mpa)	Strain	Deformation-(mm)
		Implant	Implant	Implant
100 Grams	Cervical	3.347	0.136e-6	0.102e-3
	Middle	3.347	0.136e-6	0.102e-3
	Apical	3.347	0.136e-6	0.840e-4
150 Grams	Cervical	5.020	0.157e-3	0.152e-3
	Middle	5.020	0.157e-3	0.152e-3
	Apical	5.020	0.157e-3	0.126e-3
200 Grams	Cervical	6.694	0.210e-3	0.203e-3
	Middle	6.694	0.210e-3	0.203e-3
	Apical	6.694	0.210e-3	0.168e-3

4.2. *Effect of force on the mini implant at 120° angulation*

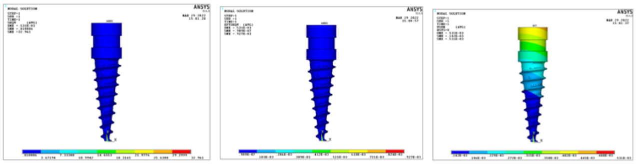

Fig. 7: 100 grams (a) Stress (b) Strain (c) Displacement

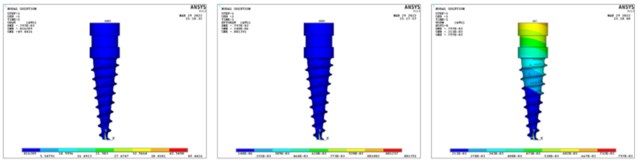

Fig. 8: 150 grams (a) Stress (b) Strain (c) Displacement

In Table 3, at 100 g of force, the stress and strain observed in cervical third, middle third and apical third is same with 3.671 Mpa and 0.103e-3 respectively.

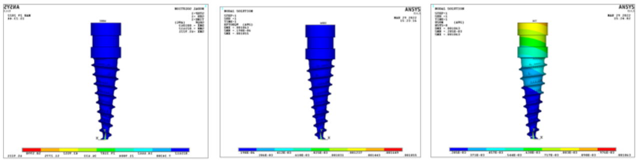

Fig. 9: 200 grams (a) Stress (b) Strain (c) Displacement

The amount deformation observed in cervical third is maximum with 0.272e-3 mm when compared to middle and apical third with 0.229e-3 mm and 0.186e-3 mm respectively.(Figure 7)

At 150 g of force, the amount of stress and strain observed in cervical third, middle third and apical third is same with 5.507 Mpa and 0.155e-3 respectively. The amount deformation observed in cervical third is maximum with 0.408e-3 when compared to middle and apical third with 0.343e-3 mm and 0.278e-3 mm respectively.(Figure 8)

At 200 g of force, the amount of stress and strain observed in cervical third, middle third and apical third is same with 7.343 Mpa and 0.206e-3 respectively. The amount of deformation observed in cervical third is maximum with 0.544e-3 mm when compared to middle and apical third with 0.457e-3 mm and 0.371e-3 mm respectively.(Figure 9)

Table 3: Maximum stress, strain and deformation seen on mini implant due to the effect of different forces (100 grams, 150 grams and 200 grams) at 120° angulation at different levels.

Straight 120 Degree		Stress (Mpa)	Strain	Deformation-(mm)
		Implant	Implant	Implant
100 Grams	Cervical	3.671	0.103e-3	0.272e-3
	Middle	3.671	0.103e-3	0.229e-3
	Apical	3.671	0.103e-3	0.186e-3
150 Grams	Cervical	5.507	0.155e-3	0.408e-3
	Middle	5.507	0.155e-3	0.343e-3
	Apical	5.507	0.155e-3	0.278e-3
200 Grams	Cervical	7.343	0.206e-3	0.544e-3
	Middle	7.343	0.206e-3	0.457e-3
	Apical	7.343	0.206e-3	0.371e-3

Table 4: Maximum stress, strain and deformation seen onabutment due to the effect of different forces (100 grams, 150 grams and 200grams) at 90° angulation

Straight _90deg	Stress (Mpa)	Strain	Deformation (mm)
	Abutment	Abutment	Abutment
100 Grams	30.006	0.943e-3	0.224e-3
150 Grams	45.009	0.00141	0.337e-3
200 Grams	60.0129	0.00188	0.449e-3

4.3. Effect of force on the abutment at 90° angulation

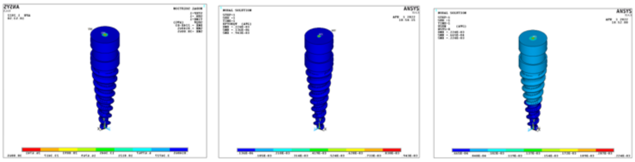

Fig. 10: 100 grams (a) Stress (b) Strain (c) Displacement

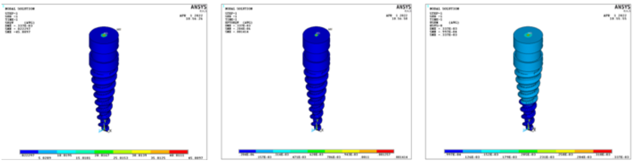

Fig. 11: 150 grams (a) Stress (b) Strain (c) Displacement

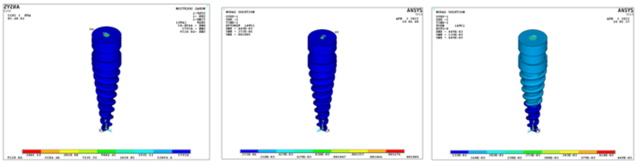

Fig. 12: 200 grams (a) Stress (b) Strain (c) Displacement

The stress and strain distribution with deformation on the abutment at 90° angulation is shown in Table 4. At 100 g of force, the amount of stress, strain and deformation observed is 30.006 MPa, 0.943e-3 and 0.224e-3 mm respectively.(Figure 10) At 150 g of force, the amount of stress, strain and deformation observed is 45.009 MPa, 0.00141 and 0.337e-3 mm respectively.(Figure 11) At 200 g of force, the amount of stress, strain and deformation observed is 60.0129 MPa, 0.00188 and 0.449e-3 mm respectively.(Figure 12) The amount of stress and deformation seen in the abutment is maximum with 200 grams force at 90° angulation.

4.4. Effect of force on the abutment at 120° angulation

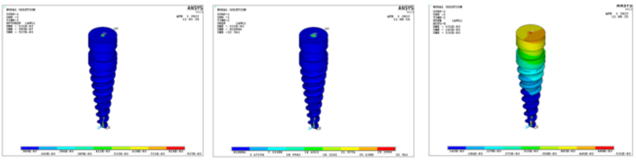

Fig. 13: 100 grams (a) Stress (b) Strain (c) Displacement

The stress and strain distribution with deformation on the abutment at 120° angulation is shown in Table 5. At 100 g of force, the amount of stress, strain and deformation observed is 32.961 MPa, 0.927e-3 and 0.513e-3 mm respectively. (Figure 13) At 150 g of force, the amount of stress, strain and deformation observed is 49.441 MPa, 0.0013 and 0.797e-3 mm respectively. (Figure 14) At 200 g of force, the amount of stress, strain and deformation observed is 65.922 MPa, 0.00185 and 0.00106 respectively. (Figure 15)

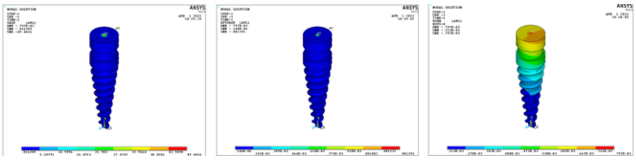

Fig. 14: 150 grams (a) Stress (b) Strain (c) Displacement

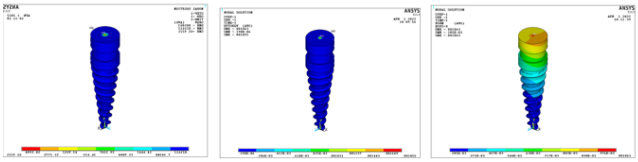

Fig. 15: 200 grams (a) Stress (b) Strain (c) Displacement

Table 5: Maximum stress, strain anddeformation seen on abutment due to the effect of different forces (100 grams, 150 grams and 200 grams) at 120° angulation

Straight _120deg	**Stress (Mpa)**	**Strain**	**Deformation (mm)**
	Abutment	Abutment	Abutment
100 Grams	32.961	0.927e-3	0.513e-3
150 Grams	49.441	0.0013	0.797e-3
200 Grams	65.922	0.00185	0.00106

5. Discussion

The FEM simulated the biomechanical force system that is applied clinically and the response of dentoalveolar system was evaluated. When the mini implant diameter exceeds 1.5 mm, the mini-implant achieves the best stability and the lowest level of stress and displacement.[6] Morris et al. (2001) assessed short-term (18 months) clinical performance of the newly designed implants and concluded that wide-diameter implants and longer implants exhibited higher survival rates. Screw diameter of 2.6 mm was chosen as it would provide sufficient mechanical properties without requiring a wide insertion space.

The loading forces considered in this study were within the optimum ranges for clinical conditions. Buchter L et al. reported in their study that the immediate loading of mini-implants can be performed without any loss of stability. When the load related biomechanics do not exceed an upper loading level it may even enhance the osseo-integration process.[7] In previous studies it has been reported that the majority of the MIs have the ability to stand early or immediate horizontal load of 100-200 g with ease and this level of force magnitude is sufficient for various tooth movements.[7,8] In this study, the orthodontic force levels selected were 150, 200, and 250 g, to simulate clinically viable conditions such as individual canine retraction using force of 150 g or en masse retraction using horizontal component of force in the range of 200-250 g.

The simulated outcomes, stress, strain and displacement, were almost linearly proportional to the force magnitude in this study. These results were reasonable and predictable, because the material properties in all components were assumed to be isotropic and homogeneous. Nevertheless, the 150 g model had 1.5 times the stress on mini implant compared with the 100 g model at both 90° and 120°. The 200 g model had 2 times the stress on implant compared with the 100 g model at both 90° and 120°, so a higher initial load should be avoided. This possibly agrees with other studies that found no detectable mobility or loosening of miniscrews when applying a light to moderate initial force.[9]

In this study, the peak von Mises stress on the mini implant were significantly similar with a force direction of 90° and 120°. The force direction of 90° is a pure bending load, whereas the force directions of 120°, is bending plus axial loading. Axial load induced higher stress than bending load. Barbier et al. in their finite element analysis emphasized the importance of preventing or minimizing horizontal force on the implants.[10] Another finite element analysis study also reported that, with a load tilted in a buccal direction of 45° to a mini screw, the stresses were reduced by 35%.[5] Considering that mini implants are made of pure titanium possessing superior properties, the stress values at both angulations were low enough to presume that there may not be implant breakage up to 250 g of horizontal force.[1]

In the present study the strain values in the mini implant also increased with the increase in horizontal loading forces. The strain values were highest for 200 g at 90° angulation of force on mini implant. The least amount of strain was recorded for 100g of orthodontic force at 120°. Thus, it indicates that stress / strain values positively increases with the increase in loading orthodontic force levels.

The maximum level of deformation of 0.544e-3 mm was recorded under 200 grams at cervical level of mini implant at 120° angulation. The results of the present study is in accordance with the study by Liu TC et al. where the peak von Mises stress was concentrated on the miniscrew near the entrance point to the cortical bone, which shows a pivot point of the bending and the maximum displacement was always present at the top of the miniscrew head in all the models.[5] Similar findings have been presented by Barbier et al.[10], Sidhu M[1], Meijer et al.[11] and Clelland et al.[12] Sidhu M et al. observed that the von Mises stress in the mini implant was present mostly at the neck of the implant close to bone-implant interface and the maximum stress concentrations were detected in the MI at the cervical margin.[1]

The maximum stress was observed on the abutment at 200g load. The stress concentration on abutment is nearly 10 times the stress values recorded on mini implant. The existence of the abutment is obviously useful to decrease the stress concentration on the bone as stated by Motoyoshi M et al.[13] The reason for this abutment effect can be explained by the mechanical principles of equivalent force–moment system. Initial stability is one of the important factors for success of mini implant.

Deformation calculated in this study can be regarded as an indicator of the initial stability. The proportionate increase in the stress value was observed at both 90° and 120° angulation. The amount of stress and deformation seen in the abutment is maximum with 200 grams force at 120° angulation. No remarkable differences in the strain distribution were observed at both angulations. However, the stress distribution of the abutment models showed a remarkable difference as compared with the models of mini implant. The high-level area (shown in orange) was localized to the head of the implant and the abutment (cervical part). Compared with 90° group, the orange colored area was easily observed more in the cervical part of abutment.

6. Conclusion

The present study have attempted with FEM to accurately evaluate the amount of stress, strain and deformation generated in the mini-implant; however, there is wide variation in the clinical response and this will be dependent on many factors, including the host response, mini-screw dimensions, insertion technique, sterilization protocol and type of loading, amongst others. Higher initial loading on the mini implant should be avoided and it is recommended to prevent or minimize the horizontal forces on the cervical level of MI for better stability. The abutment of the mini-implant plays a role of a hook, which hangs ligature wires, spring closed coils, and helps in primary stability of MI. The abutment has maximum stress concentration which has buffering action on MI. Hence, further studies with similar criterias are required to substantiate the present results.

Within the limitations of the present study it can be concluded that, the magnitude of orthodontic forces as well as the angulation of force influences the stress, strain and deformation values within the mini-implant however, whether it is statistically significant or not has to be further evaluated. With the current knowledge, it is difficult to exactly predict the changes that might occur with the passage of time with the same loading conditions. This study is a predictive analysis and must be used as a reference to aid clinical judgment.

7. Source of Funding

None.

8. Conflict of Interest

None.

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