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# A Pilot Study to Evaluate the Influence of Implant Supported Prosthesis Framework Material on the Stress Distribution in Peri-Implant Bone in Anterior Mandible: A Three-Dimensional Finite Element Analysis

**Nikita Jaiswal*, Anjana Raut and P. C. Mishra**

Department of Prosthodontics and Crown and Bridge, Kalinga Institute of Dental Sciences, Kalinga Institute of Industrial Technology University, Bhubaneswar, Odisha, India; dr.nikitajaiswal04@gmail.com

## Abstract

**Context:** Original research. **Aims:** The aim of the present study to evaluate the effects of prosthetic material on the stress distribution of implant-supported prosthesis in the bone around implants using finite element analysis and to draw a comparison so as to which material causes the least amount of stress on the bone. **Settings and Design:** In vitro finite element analysis - Comparative study. **Methods and Materials:** Models of the implants and the mandible were constructed using SOLID WORKS software and then they were transferred to another software ANSYS Work bench for FEA. A four-unit prosthesis was designed in the region of anterior mandible with implants being placed in 32 and 42 regions. The prosthesis was made of different materials in different models, M1 was of made of cobalt chromium framework, M2 was made of Titanium framework, M3 was made of zirconia framework each with layered ceramic. M4 was a monolithic zirconia prosthesis. The values of the Von Mises stresses generated in the implant, superstructure and alveolar bone around were calculated. The total deformation and stress generated in different models were calculated and compared. Statistical analysis used: Von mises Stress Analysis, Unpaired t test. **Results:** Zirconia and Monolithic zirconia showed comparatively less total deformation and stress levels in peri-implant bone. Titanium prosthesis caused less total deformation and stress distribution as compared to cobalt chromium. **Conclusions:** The distribution of stress in peri implant bone is evidently dependent on the prosthesis material and different materials cause different amount of deformations as they differ in their clinical properties.

**Keywords:** Cobalt Chromium Framework Material, Implant Prosthesis Framework Material, Monolithic Zirconia Implant Prosthesis, Stress, Titanium Framework Material

**Key Messages:** Zirconia and Full contoured monolithic zirconia can be used as excellent implant framework materials as cause they cause least amount of stress in peri-implant bone and consequently, the crestal bone resorption is evidently reduced, increasing the longevity of the treatment.

## 1. Introduction

Implant supported prosthesis are one of the common clinical approaches to treat edentulous cases because of their high success rates and their biological and biomechanical advantages such as preservation of adjacent and opposite teeth, simulation of supporting bone and production of higher mastication force as compared to other removable prostheses[1].

The different materials that a prosthesis is made up of affect the loading of implants and eventually causes bone deformation. The clinical success rate of osseo-integrated

*Author for correspondence

dental implants is majorly influenced by the fashion in which generated mechanical stresses are transferred from the implant to the alveolar bone in mandible and maxilla. The prostheses designs and materials selection is essential for the survival, stability and longevity of dental implant treatments[2].

A three-dimensional finite element analysis has already been extremely helpful and has an extensive use in dental bio-mechanical studies. Dental implants can sometimes fail because of biological and biomechanical factors[3-5]. To maintain high success rates after loading, biomechanical factors like the design and material of the prosthesis/superstructure[5,7], occlusal forces, occlusion, type of abutment connection, number of dental implant supports, and density of the supporting bone should be considered[8,9]. Good planning and application of a prosthesis is essential as well as immensely crucial to prevent bone and dental implants from excessive and detrimental forces[9]. Because of the high success rates of all-ceramic crowns[10], all-ceramic systems for three-unit Fixed Dental Prostheses (FDPs) has become a feasible treatment alternative[11]. These systems must achieve the bio-mechanical requirements of restorations, provide a longer survival similar to metal ceramic restorations, and feature better aesthetics[12,13]. Lately, zirconia-supported ceramic restorations were proposed as an substitute to metal-ceramic in FPD especially in posterior region[13]. Unfortunately, because of its high-elasticity modulus, cracks may occur under high mastication force. Chipping of the ceramic veneer is the most common type of failure in these restorations[14]. Despite the increase in the use of all-ceramic restorative systems, metal-ceramic systems continue to be used because of their clinical longevity, lower cost and enhanced biocompatibility. Metal-ceramic FDPs are advantageous because of their predictable structural performance, versatility, and low cost. Recently, resin-based materials have been increasingly used in dental practices because of their desirable properties, such as their aesthetic appearance, ease of repair, affordability and low-elastic modulus (similar to that of dentin). However, not only the composition of the materials used, but also the design of the prostheses, the bone quality and various other factors can affect the success of the restoration in terms of stress distribution and magnitude[14].

According to Möllers et al. the framework design and material properties of the superstructure in a prosthesis play a significant role in stress distribution[14]. Another study[15] also concluded that stress distribution was affected by the type of ceramic used for the infrastructure.

Aim of this study is to evaluate the effects of prosthetic material on the stress distribution of implant-supported prosthesis in the peripheral bone using Finite Element Analysis (FEA) and to draw a comparison so as to which material causes the least amount of stress on the bone.

Finite Element Analysis is an easy, effective and inexpensive way to evaluate the mechanical behavior of complex structures. Therefore, it is suitable for this study and carry out analysis with promising and reliable results.

## 2. Subjects and Methods

### 2.1 The Main Concept

A finite element model is constructed by dividing solid structures into numerous micro elements which are linked to a common nodal point. The primary step is to first divide the complex solid object geometry into a favourable set of 'smaller' elements of 'finite' dimensions. The collection of nodes and elements form the finite element mesh. After mesh generation is completed, the properties of the material in question are assigned to the elements and nodes.

By applying the basic principles of mechanics, the relationship between the forces and the displacement at each node of the element is analysed. Hence for each element, its mathematical behaviour is taken as the function of the displacement of nodes. The behaviour of the structure is obtained by considering the collective behaviour of discrete elements.

Four 3D Finite Element Analysis models were created of mandibular implant-supported fixed dental prosthesis with different prosthetic materials. The model was created digitally using SolidWorks software and then meshed. Analysis is carried out in another software. The Sample Size consists of 4 models:

M1 Cobalt-chromium framework with layered ceramic.
M2 Titanium framework with layered ceramic.
M3 Zirconia framework with layered ceramic.
M4 Full contour monolithic zirconia prosthesis.

Finite element models created featured the ssimilar physical/mechanical properties of actual structures and objects as intimately as possible.

## 2.2 Construction of FEA Models

In this study, solid models of the implants, prostheses and the mandible were constructed using SOLIDWORKS software and then transferred to another software named ANSYS Workbench for FEA.

FEA models are three dimensional tetrahedral structural solid finite elements.

Mandibular segments with implant embedded in the lateral incisors sites 32 and 42 were modeled. A 40 mm x 30 mm x 20 mm bone was modeled as a cortical block. This approximated the bone qualityy of D1 type of bone which is the most commonly observed bone density type in anterior mandible of partially edentulous individuals.

## 2.3 Implant Size and Prosthesis Model

Solid tapered screw type implants were used of dimensions 3.5x11 mm in each of the model.

All the implants were threaded with internal hex connection.

A four-unit prosthesis was designed in the region of anterior mandible with implants being placed in 32 and 42 regions. The prosthesis was made of different materials in different models, M1 was of made of cobalt chromium framework, M2 was made of Titanium framework, M3 was made of zirconia framework each with layered ceramic. M4 was a monolithic zirconia prosthesis. These four models were given a standardized connector width of 2mm. The height and width of the implants remained the same in all four models (Figure 1).

## 2.4 Mesh Creation

Models were subjected to **ANSYS Workbench** (analysis system software), a software that is used to carry out FEA and process results. The fully constructed models were meshed by parabolic tetrahedral elements. Every node at the base of 3D solid models was restrained to determine the boundary conditions. The implants, abutments, abutment screws, crowns, and cortical bones were considered to be homogeneous, isotropic and linearly elastic (Figure 2).

Different Mechanical Properties assigned to the FEA models to carry out the analysis (Table 1).

## 2.5 Forces Applied and Von Mises Stress

**Statistical Analysis** comprised of Von Mises Stress Analysis. The numerical values of the Von Mises stresses generated through colour coding in the prosthesis, abutment, implant, and supporting alveolar bone in the mandibular block were calculated. In the prostheses, the maximum Von Mises stresses were concentrated at the points of application of load and stress generation in the models.

For evaluation of stress and deformation, vertical, horizontal and oblique forces were subjected on the models. Models were constrained in all the directions in three dimensions at the nodes at the incisal edges and outer surfaces.

A total vertical load of 160 N was distributed over the entire incisal surface of super structure.

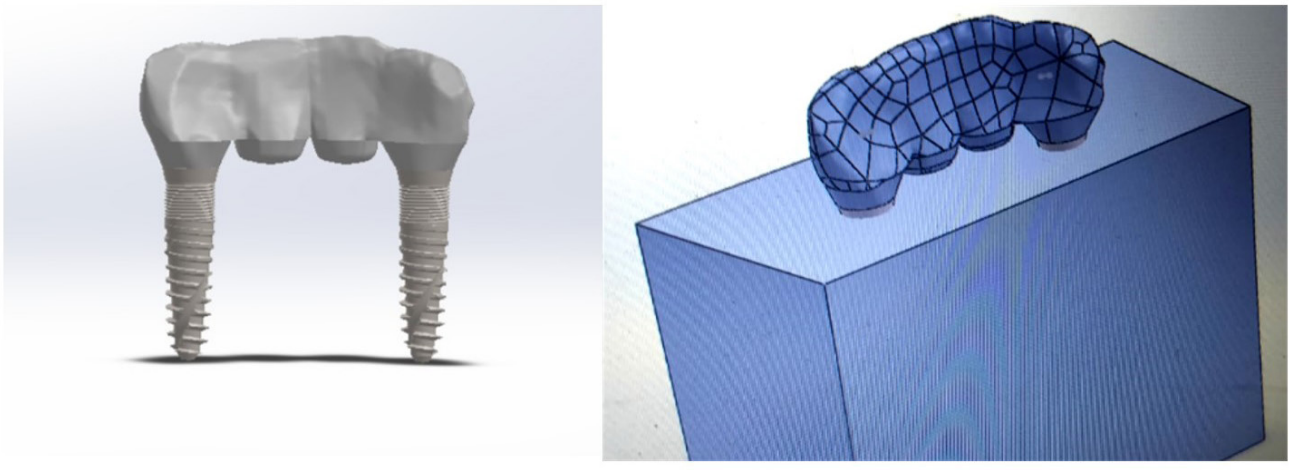


**Figure 1.** Three dimensional solid Implant supported prosthesis model and surrounding bone generated using SolidWorks Software.

**Table 1.** Mechanical properties important to carry out the analysis assigned to the FEA models.

| Materials | Density (g/cm³) | Modulous of Elasticity (GPa) | Poisson's rate |
|---|---|---|---|
| Cortical Bone | 3.88 | 13.7 | 0.3 |
| Titanium | 4.51 | 110 | 0.35 |
| Cobalt Chromium | 8.42 | 218 | 0.33 |
| Zirconia | 5.86 | 269 | 0.25 |
| Ceramic | 2.45 | 61.2 | 0.19 |
| Monolithic Zirconia | 5.86 | 269 | 0.25 |

**Table 2.** Comparison of total deformation and stress caused by different prosthesis framework material as compared to cobalt Chromium framework material.

| Prosthesis Materials | Total Deformation (as compared to Cobalt Chromium) | Stress Distribution (as compared to Cobalt Chromium) |
|---|---|---|
| **On application of Vertical Forces** | | |
| Titanium | 10.11% more | 29.54% less |
| Zirconia and Monolithic Zirconia | 2.33% less | 0.43% less |
| **On application of Horizontal Forces** | | |
| Titanium | 5.18% more | 23.23% less |
| Zirconia and Monolithic Zirconia | 1.19% less | 1.42% less |
| **On Application of Oblique Forces** | | |
| Titanium | 4.13% more | 21.55% less |
| Zirconia and Monolithic Zirconia | 0.94% less | 1.67% less |

To stimulate an oblique loading condition, an oblique force of 170 N was applied to 60 degree from the vertical.

Static loads of 60N were horizontally applied to mimic the para-functional moment of the jaw. (Figure 3).

The Von Mises stresses are used as prime indicators to evaluate concentration of stress and evaluate stress distributions and total deformation at implant bone interface. Stress distributions in the bone correlated

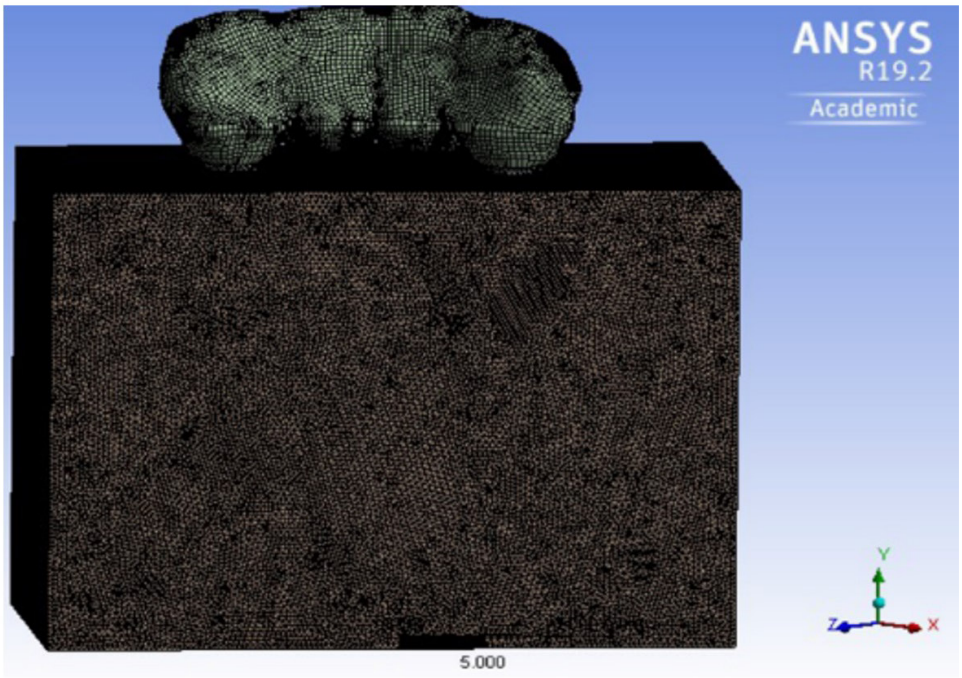



**Figure 2.** Meshed model with the help of Ansys Workbench software.

with implant-supported prosthesis was calculated and compared.

Softwares used: 3D modelling software Solid Works and stress analysis software (ANSYS).

## 3. Results

On Application of vertical forces, it was found that in all the four prostheses a different amount of total deformation and stress was caused as depicted in Figure 4, Figure 7, Figure 10(a).

Horizontal Forces when applied on all the four prostheses resulted in total deformation and stress as depicted in Figure 5, Figure 8, Figure 11.

Lastly when these prostheses were subjected to oblique forces, It was found that total deformation and stress was caused as depicted in Figure 6, Figure 9 and Figure 10(b).

However, in all the cases similar results were obtained in the prostheses which had zirconia framework material and full countered monolithic zirconia as zirconia was the same core material used in both the models.

### 3.1 Comparison Drawn Between the Values Obtained and Inference (Table 2)

Zirconia and Monolithic zirconia showed comparatively less total deformation and stress levels in peri implant bone. Titanium prosthesis caused less total deformation and stress distribution as compared to cobalt chromium.

One Way ANOVA unpaired t test was conducted and P value obtained on comparing the 3 groups with Cobalt Chromium Group was found to be less than 0.00001 which shows the results to be statistically significant.

## 4. Discussion

Metal alloys are the most commonly used materials for making framework in implant-supported prosthesis. Nickel Chromium and the other base-metal alloys have extensively been used in dental prosthesis framework in USA. However, In Europe, base-metal alloys in fixed prosthodontics are not encouraged because of the well documented risks such as hypersensitivity and reported nickel allergies. Hence, Titanium was the key focus. Lately, Cobalt-chromium alloys have come forward, majorly because of their most favorable and excellent mechanical properties and enhanced aesthetic results when these frameworks are super structured with ceramic. Likewise, in tooth-supported prosthodontics, All-ceramic restorations have proved to be very promising in implant prosthodontics. Particularly, Oxidized ceramics like zirconia and alumina are mainly focused on because of their increased aesthetic properties and high mechanical strength.

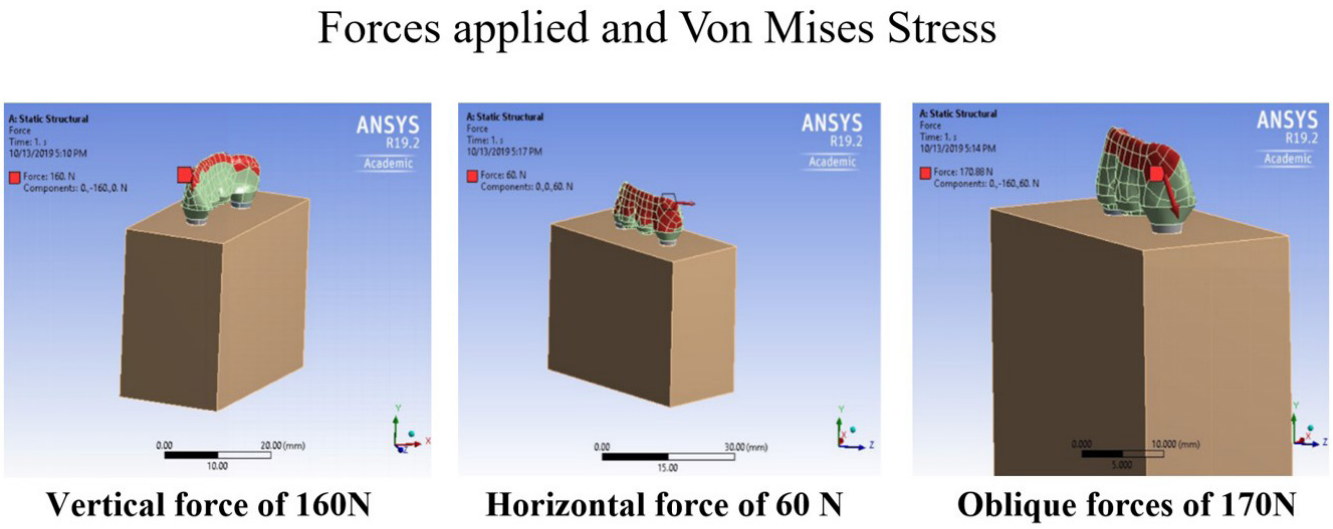



**Figure 3.** Vertical Horizontal and Oblique Forces Applied to the FEA Models.

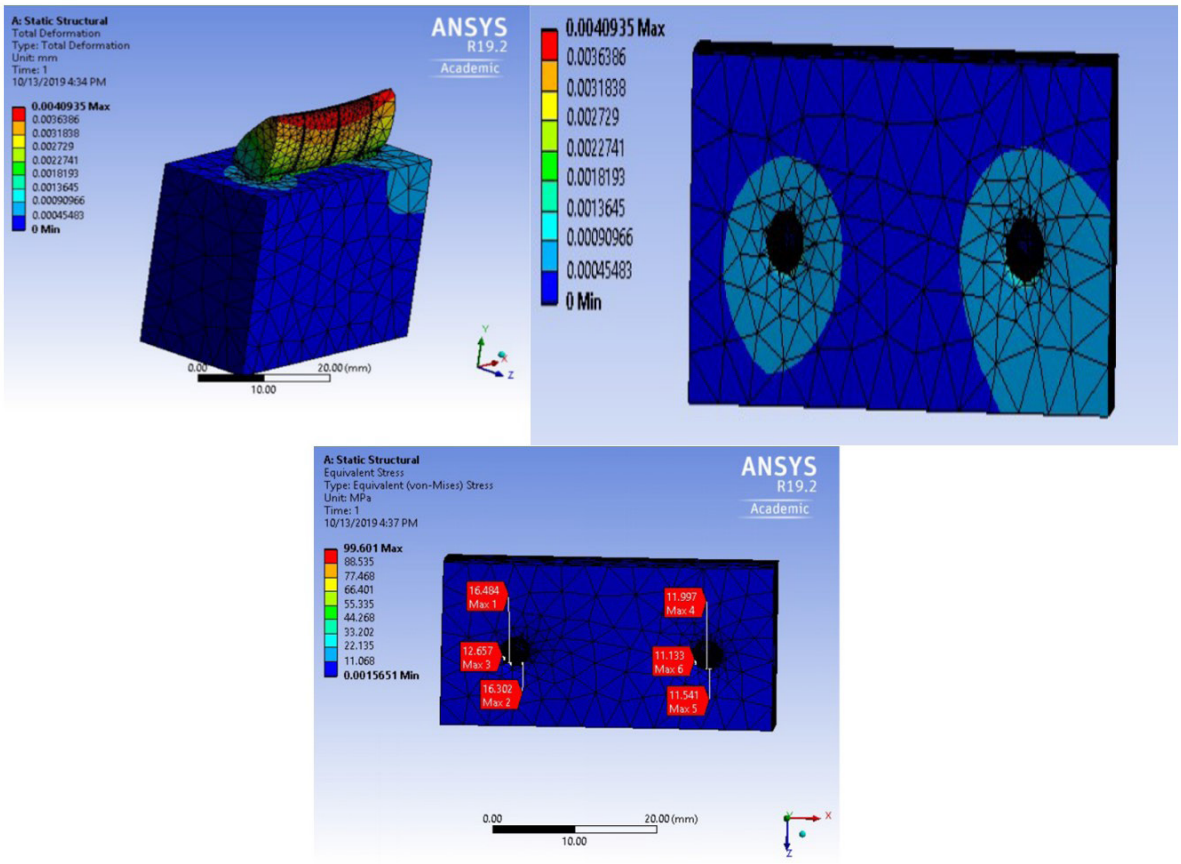



**Figure 4.** Total Deformation and Stress patterns depicted in M1 model (cobalt chromium framework) under the influence of vertical forces.

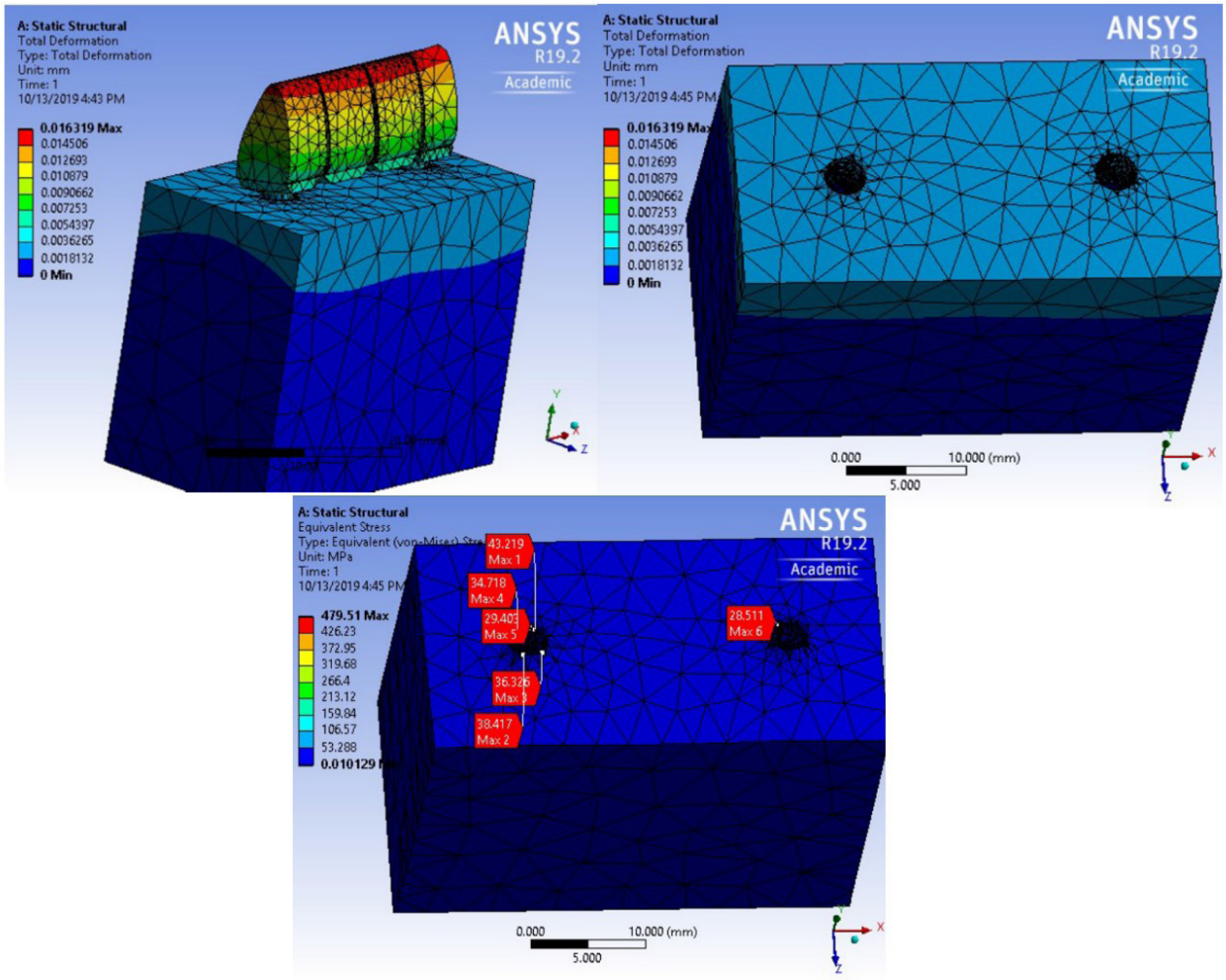



**Figure 5.** Total Deformation and Stress patterns depicted in M1 model (cobalt chromium framework) under the influence of horizontal forces.

A five-year survival of implant-supported single-crowns was reviewed and it was found by Jung et al. that survival rate for implant-supported metal-ceramic crowns was 95.4% and it was significantly better than all-ceramic crowns survival rate which was 91.2%. Also, a five-year survival review recommended that implant abutments performed comparatively, be it of metal or ceramic.

The main aim was to compare and evaluate the distribution of stress in caused by different prosthesis framework materials and by conducting the finite element analysis, it was found out that different implant supported prostheses framework materials cause different stress patterns in the alveolar bone surrounding implants, as the materials Cobalt Chromium, Titanium and zirconia differ in their physical and mechanical properties. According to some studies[15] the stiffer a material, the more load it will attract. Similarly, in the present study, the stiffest prosthetic material (Cobalt Chromium) attracted more stress, and the most elastic prosthetic material (Zirconia) attracted the least stress; however, they transferred the loads independently of the stiffness.

Zirconia and Monolithic Zirconia are mathematically proven to cause least amount of bone deformation and stress in the peri-implant bone, hence proven to be the best framework materials. Titanium prosthesis material causes less amount of stress patterns as compared to Cobalt chromium.

Porcelain Layering does not cause much difference in stress patterns. However, studies conducted in past, have shown if different veneering material used, there will be difference in stress patterns around bones. According to a study[19], the ceramic veneer materials that have similar elastic modulus values to enamel supported the enamel better than resin composites. Recently, resin-based

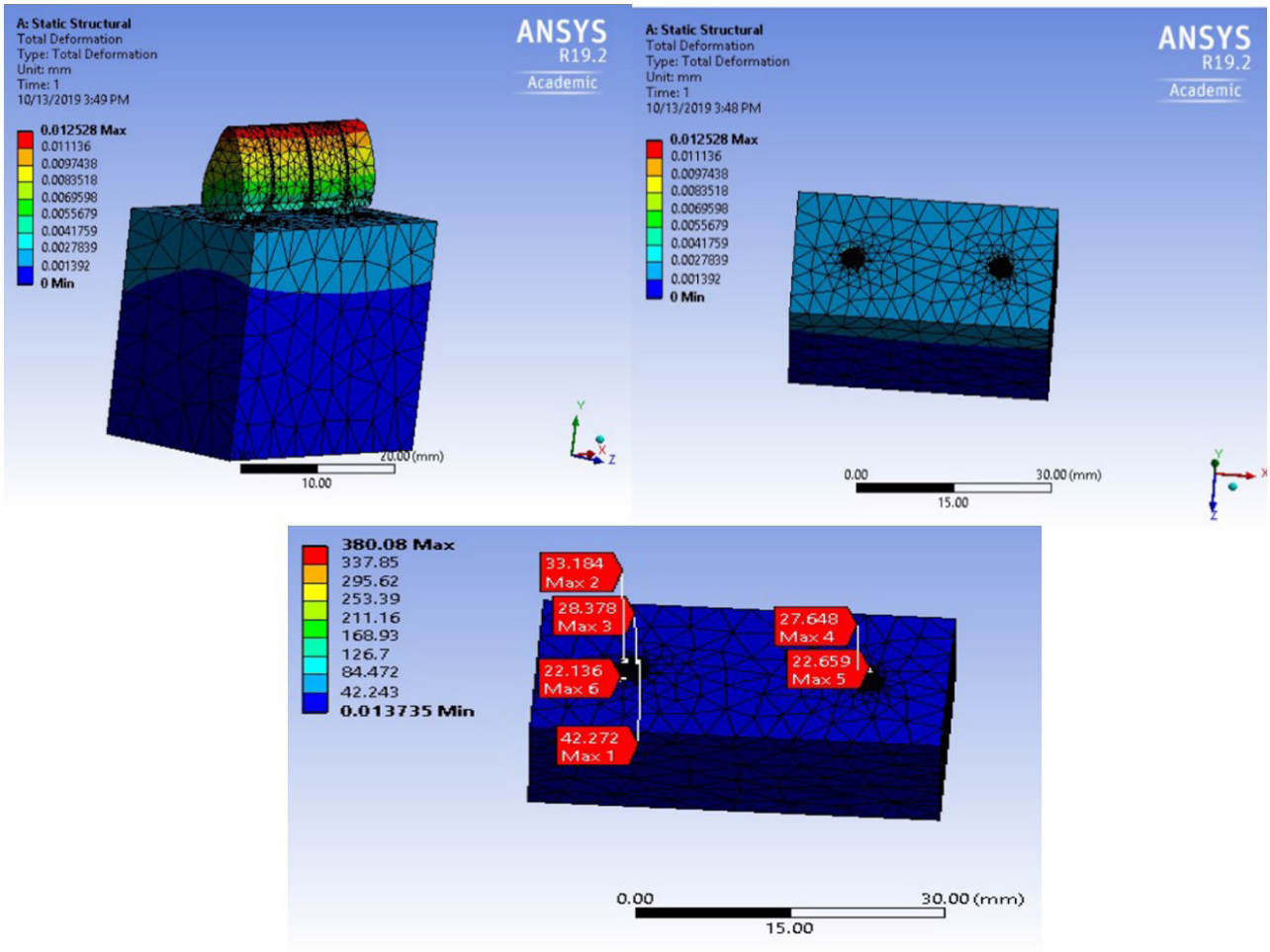



**Figure 6.** Total Deformation and Stress patterns depicted in M1 model (cobalt chromium framework) under the influence of oblique forces.

materials have been increasingly used in dental practices because of their desirable properties, such as their aesthetic appearance, ease of repair, affordability, and low-elastic modulus (similar to that of dentin). However, not only the composition of the materials used, but also the design, can affect the success of the restoration in terms of magnitude and distribution of stress [16, 21].

Similar to another research[18, 22], we determined that stress was mainly concentrated around the neck of dental implants in cortical bone. The probable reason for this is that the difference in the elasticity modulus of the cortical and cancellous bone, and the rotational center in implants is at the cortical bone level[19, 24]. Since this study was conducted in anterior mandible region, the bone was of D1 type with only cortical density. Hence, the stress concentration was at crestal bone around the neck of dental implants.

Zarb and Schmitt considered the structure of the bone to be the most essential element in selecting the most appropriate treatment option in implantology. Sevimay et al., conducted a finite element analysis and evaluated the bone quality effects on the stress distribution in implants and implant-supported crown. Comparatively, lower stresses were recorded in D1 and D2 bone types while higher stresses were recorded in D3 and D4 bone types since trabecular bone was not so strong enough and was more prone to deformation. Thicker cortical bone (D2) lowers concentration of stress and minimise deformation in alveolar bone around dental implants[17, 23].

Maximum stress patterns were obtained around the neck of implants which go on tampering as the force gets dampened at each thread along the length of implant.

The crestal bone resorption around the implant neck is more as compared to the apical and middle portion of

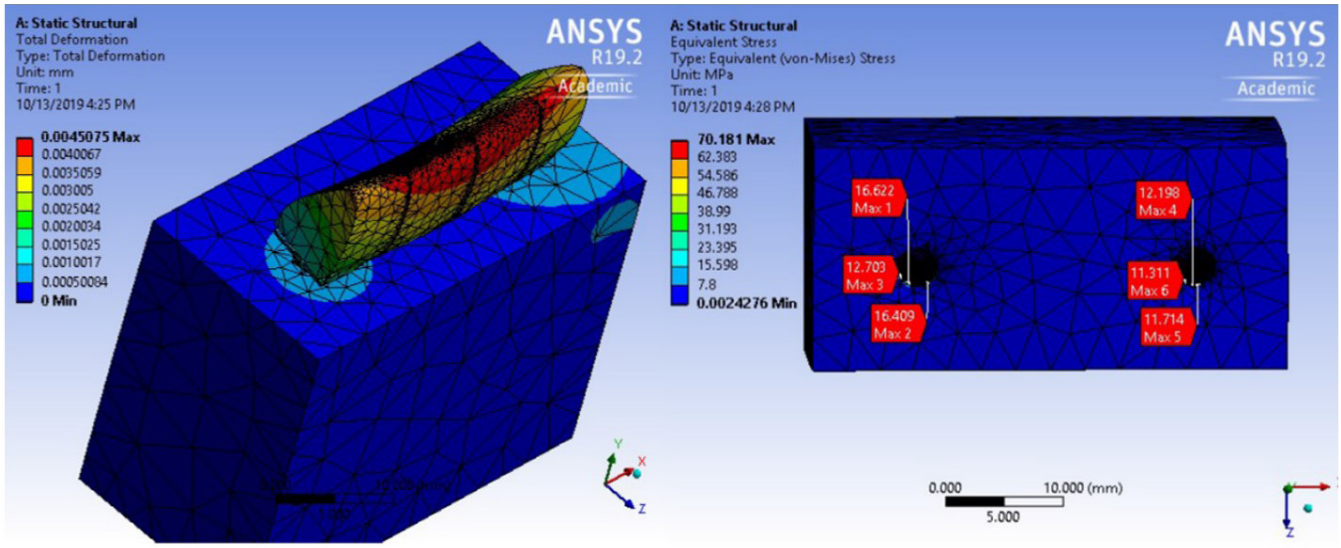



**Figure 7.** Total Deformation and Stress patterns depicted in M2 model (Titanium framework) under the influence of vertical forces.

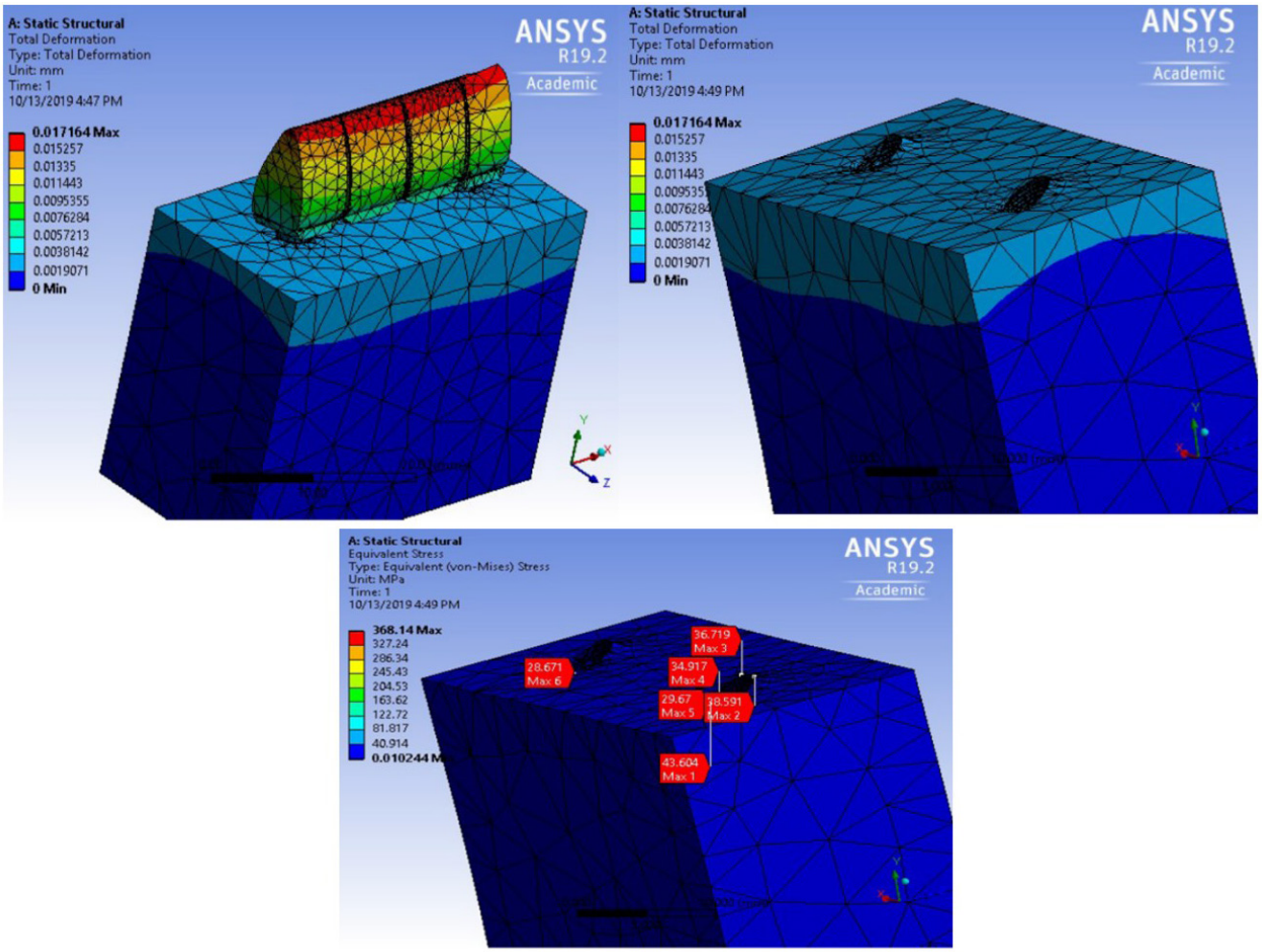



**Figure 8.** Total Deformation and Stress patterns depicted in M2 model (Titanium framework) under the influence of horizontal forces.

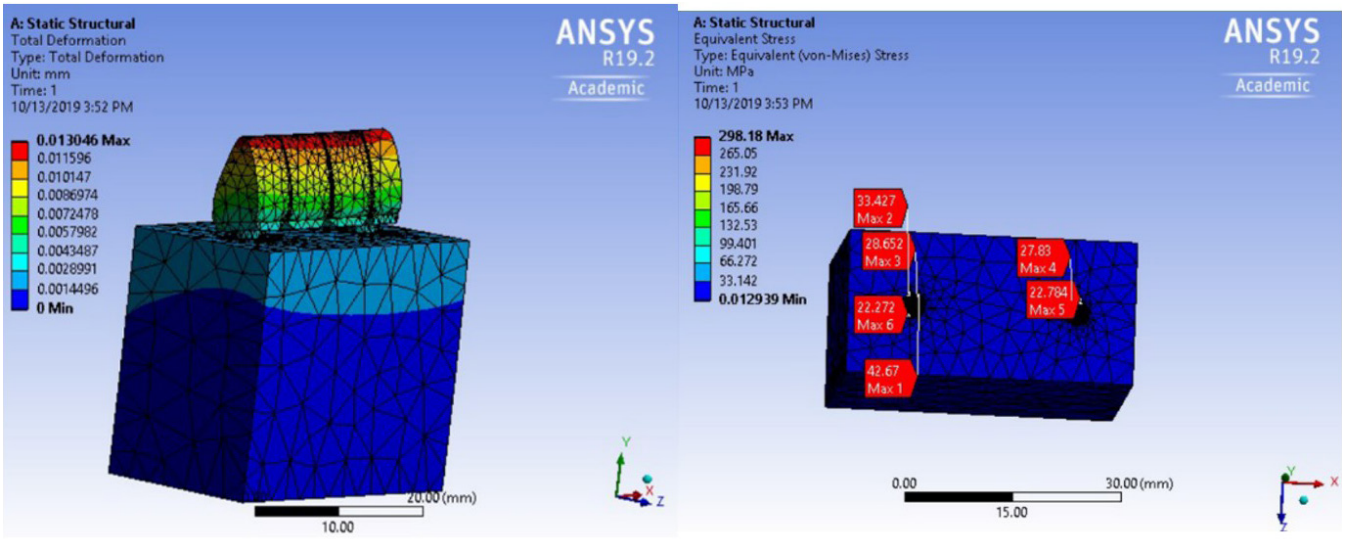



**Figure 9.** Total Deformation and Stress patterns depicted in M2 model (Titanium framework) under the influence of oblique forces.

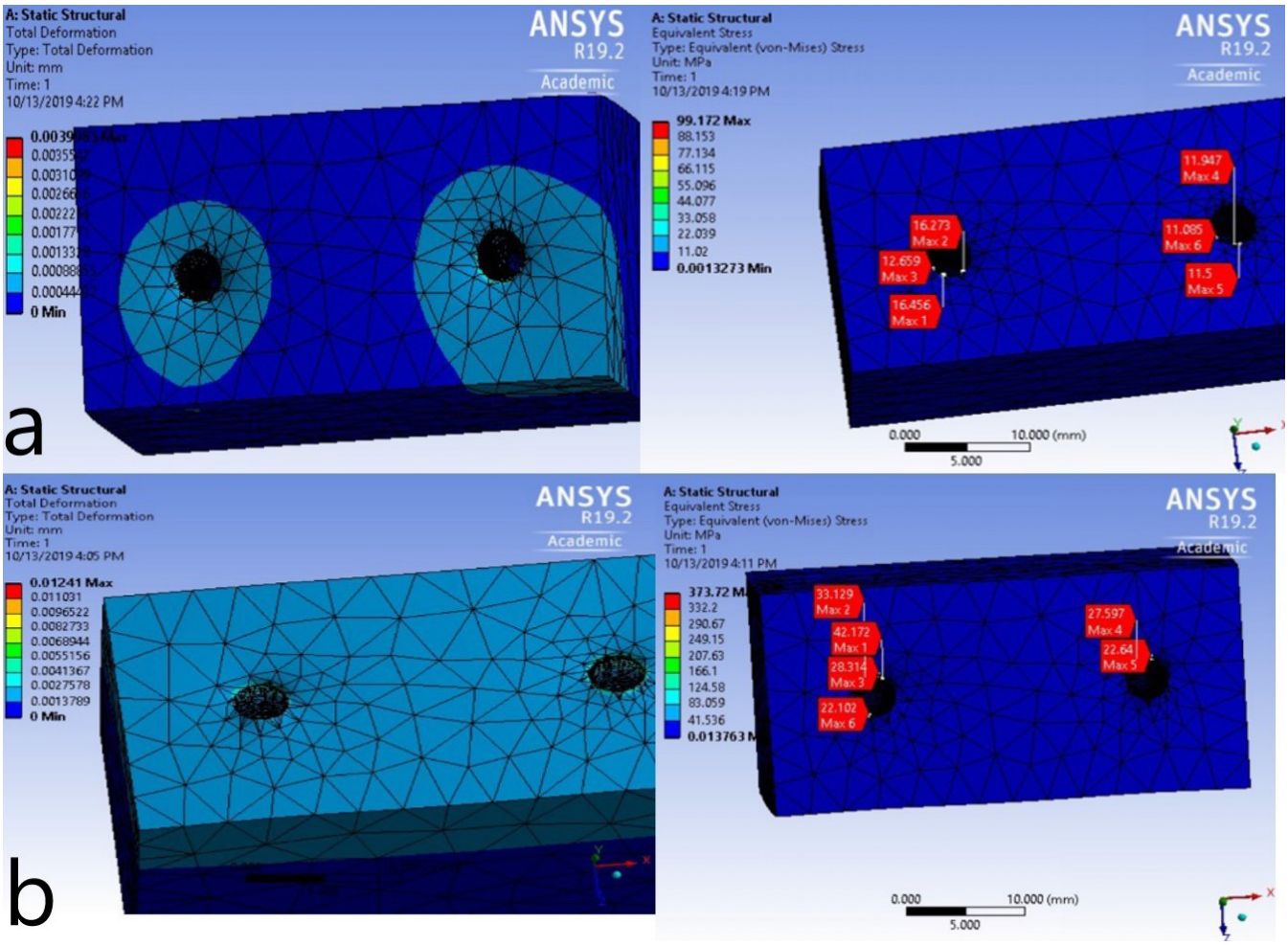



**Figure 10.** Total Deformation and Stress patterns depicted in M3 and M4 models (Zirconia framework) under the influence of a) Vertical forces b) Oblique forces.

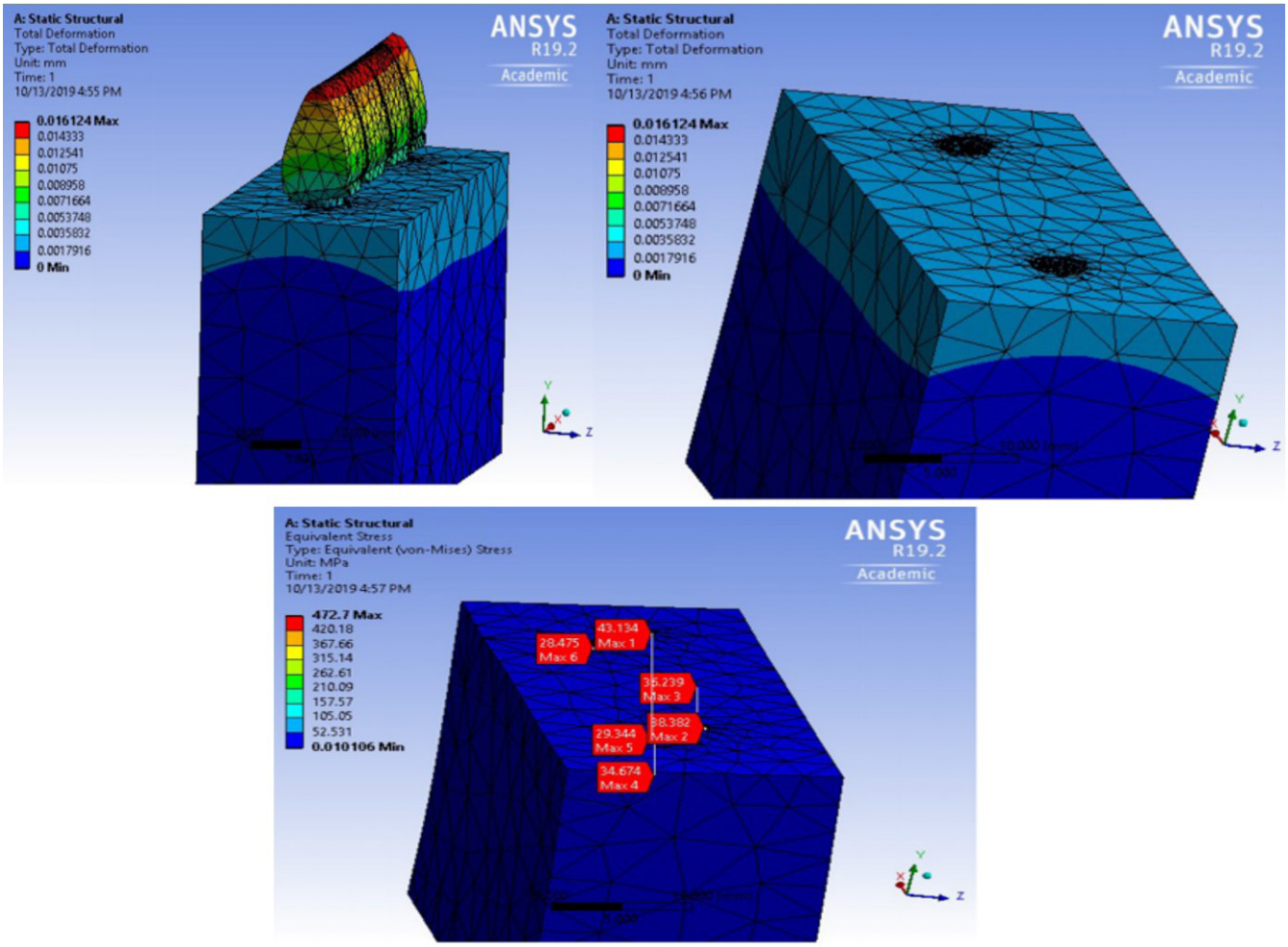



**Figure 11.** Total Deformation and Stress patterns depicted in M3 and M4 models (Zirconia framework and monolithic zirconia) under the influence of horizontal forces.

peri-implant bone. Hence, hard and soft tissue care should be taken with utmost importance while performing implant surgeries.

Therefore, it is mechanically proven that there lies a huge difference in force transmission in dental implants in comparison to natural tooth. In natural tooth, because of surrounding periodontal ligament, the stress 'distribution' occurs whereas, in the case of dental implants, which is an osseointegrated structure, stress 'concentration' occurs. In natural tooth the force transmitted causes stress in the apical portion of the root, which is the common site for resorption, while in dental implants, crestal bone resorption occurs which is majorly responsible for dental implant failures.

## 5. Drawbacks of the Study

This study was performed under ideal conditions when implants with uniform sizes were loaded in mandibular lateral incisor region, in D1 healthy bone.
However, the stress distribution patterns may vary in various clinical scenarios,

- If there is any underlying pathology of bone, physiological or pathological resorption of bone.
- If Implants are placed in teeth other than mandibular lateral incisors.
- Different implant sizes or types if used.
- If different prostheses materials used in different sites.

This study does not take 'time factor' into account. The deformation that takes place is time dependant and takes place over years when the forces are applied. Since the study has been performed in in vitro conditions, the deformation occurs rapidly which not take places in clinical scenario

## 6. Conclusion

The stress distribution and deformation in peri implant bone is dependent on the prosthesis material and different materials cause different amount of deformations as they differ in their clinical properties.

The clinical longevity of the treatment provided and success of osseo-integrated dental implants is mainly influenced by the manner in which mechanical stresses are distributed to the surrounding alveolar bone from the dental implant.

Zirconia prosthesis material has been mathematically proven to cause least amount of stress and total deformation under ideal conditions.

Further studies should be conducted to load implants under different clinical situations to obtain a more precise treatment planning and increase the longevity of the prosthodontic treatment.

## 7. Acknowlegement

We would like to convey our sincere thanks to Dr. PC Mishra, Dean of Research, School of Mechanical Engineering, KIIT Deemed to be University and his PhD student Mr. Shubham Shah for giving us an opportunity to carry out this research in their department of Mechanical Engineering under their constant guidance and assistance.

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