http://dx.doi.org/10.1590/1677-3225v14n4a13

Original Article

**Braz J Oral Sci.**
October | December 2015 - Volume 14, Number 4

# Influence of implant-abutment angulations and crown material on stress distribution on central incisor: a 3D FEA

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## Abstract

**Aim:** To investigate the effect of implant-abutment angulation and crown material on stress distribution of central incisors. Finite element method was used to simulate the clinical situation of a maxillary right central incisor restored by two different implant-abutment angulations, 15° and 25°, using two different crown materials (IPS E-Max CAD and zirconia). **Methods:** Two 3D finite element models were specially prepared for this research simulating the abutment angulations. Commercial engineering CAD/CAM package was used to model crown, implant abutment complex and bone (cortical and spongy) in 3D. Linear static analysis was performed by applying a 178 N oblique load. The obtained results were compared with former experimental results. **Results:** Implant Von Mises stress level was negligibly changed with increasing abutment angulation. The abutment with higher angulation is mechanically weaker and expected to fail at lower loading in comparison with the steeper one. Similarly, screw used with abutment angulation of 25° will fail at lower (about one-third) load value the failure load of similar screw used with abutment angulated by 15°. **Conclusions:** Bone (cortical and spongy) is insensitive to crown material. Increasing abutment angulation from 15° to 25°, increases stress on cortical bone by about 20% and reduces it by about 12% on spongy bone. Crown fracture resistance is dramatically reduced by increasing abutment angulation. Zirconia crown showed better performance than E-Max one.

**Keywords:** finite element analysis; dental implant-abutment design; incisor; materials.

## Introduction

Dental implant restoration has been widely accepted as one of the treatment modalities to replace missing teeth and restore human masticatory function. The biomechanical properties of the bone–implant interface determine the implant stability. The bone–implant interface properties depend on amount of implant surface in contact with mineralized bone tissue and bone tissue quality around the interface[1]. The interface has a complex biomechanical nature due to (i) its roughness, (ii) the fact that bone is in partial contact with the implant, (iii) adhesion phenomena between bone and the implant and (iv) the time-evolving nature of the interface properties. Therefore, remodeling phenomena of bone tissue around the interface are difficult and highly complicated.

A single tooth implant with crown has greater survival rate than a fixed partial denture (FPD)[2]. The abutment angulation is a mechanical variable in implantology[3]

**Received for publication:** November 15, 2015
**Accepted:** December 13, 2015

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that may influence the internal and external structure of bone tissue[3]. Thus, the bone behavior is related to the stress and deformation induced on it. The influence of angled abutments on stress is a matter of debate[4]. It has been widely accepted that increased stress on implants and bone has been associated with the use of angled abutments[5].

The dental implants design is driven by an imitator marketing approach rather than by scientific advances[1]. Clinicians used implants in new applications before research was carried out based on their basic science. Empirical approaches may have some advantages but remain limited when it comes to understand the interaction of the various mechanisms, playing a role in bone healing around an implant[1].

IPS E-max lithium disilicate glass ceramic, a material that provides optimum esthetics, yet has the strength to enable conventional or adhesive cementation. It has a needle-like crystal structure that offers excellent high flexural strength, roughly 360 to 400 MPa and durability, as well as outstanding optical properties. It can be traditionally pressed or contemporarily processed via CAD/CAM technology. Due to its strength and versatility, the material can be utilized for anterior/posterior crowns, inlays/onlays, veneers, thin veneers, telescopic crowns, implant restorations and anterior three units bridgework up to the second premolar (press only)[6].

Yttrium-stabilized tetragonal zirconia (Y-TZP) is having increased use in dentistry due to its good mechanical properties. It is currently used as a core material in all-ceramic dental restorations and implant superstructures[7]. Compared to other dental ceramics, its superior mechanical properties, such as higher strength and fracture toughness, are due to the transformation toughening mechanism, similar to that observed in quenched steel[8].

Finite element analysis (FEA) is an accepted and accurate numerical technique used for solving complicated stress analysis problems. It has proven to be a reliable method in dentistry as it provides reliable evaluation of stresses in complex geometries[9].

In this study, the influence of implant-abutment angulation (15° and 25°) supporting different central incisor crown material on stress distribution was estimated.

## Material and methods

Implant fixture (Hexacone HC2 3.7 13 mm) and two abutments (TLA15 HC1, and TLA25 HC1; Dr. Ihde Dental GmbH, Eching, Germany), were modeled using commercial CAD/CAM "AutoDesk Inventor" software version 8.0 (Autodesk Inc., San Rafael, CA, USA). Bone geometry was simplified and simulated as two co-axial cylinders. The inner one represents the spongy bone (14 mm diameter x 22 mm high) filling the internal space of the outer cylinder (1 mm thick shell) that represents cortical bone (16 mm diameter x 24 mm high)[10-11]. The crown dimensions were obtained from the anatomical data[12] of the maxillary right central incisor. The cement layer was designed with a 50 µm thickness.

The geometric models were exported from the CAD/CAM software as several components (SAT and IGES files) to be assembled together in ANSYS version 14.5 environment (ANSYS Inc., Canonsburg, PA, USA). A set of Boolean operations was performed to obtain two FE models, for 15° and 25° abutment angulations.

Element type "Solid 186" (higher order 20 node) was utilized for meshing the model's components, as it has three degrees of freedom (translations in the global directions X, Y and Z).

Complete osseointegration was assumed. In addition isotropic, homogenous, and linearly elastic materials' properties were fed into the finite element (FE) software based on previous studies[9-11,13] and manufacturer's information (Table 1).

**Table 1:** Material's properties used in the FE models[13].

| Material | Modulus of elasticity [MPa] | Poisson's ratio |
|---|---|---|
| **Cortical bone** | 13600 | 0.26 |
| **Cancellous bone** | 1360 | 0.31 |
| **Titanium** | 110000 | 0.25 |
| **IPS E-Max CAD** | 96000 | 0.23 |
| **Zirconia** | 205000 | 0.22 |
| **Rely X unicem aplicap cement** | 4900 | 0.30 |
| **Gutta-percha** | 0.00069 | 0.45 |

Meshing density was then evaluated and adequate mesh of the models' components was used in the analysis. The number of nodes and elements in each component are in Table 2. Figures 1 and 2a illustrate models' components on ANSYS screen.

Load of 178 N[14] was applied on each model on the palatal surface of the maxillary right central incisor at oblique directions 45° to the long axis of the implant fixture (Figure 2b)[15]. The boundary conditions were defined by fixing the lower surface of the cylinder representing cortical bone. Additionally, the implant fixture, abutment, screw, cement-layer, gutta-percha, crown, cortical and spongy bone were assumed to be perfectly bonded together[16].

The finite element models were verified against previous experimental studies[13,15], where two groups each of 14 implant-abutment complexes (angled 15° and 25°) were gradually loaded up to failure in a universal testing machine. The FEA results showed very good agreement with experiments' results.

**Table 2:** Number of nodes and elements after meshing models' components.

| | Model 1 | | Model 2 | |
|---|---|---|---|---|
| | Implant abutment 15˚ | | Implant abutment 25˚ | |
| | Nodes | Elements | Nodes | Elements |
| **Implant** | 28463 | 25131 | 28017 | 24918 |
| **Abutment** | 86354 | 78355 | 7819 | 7624 |
| **Screw** | 10605 | 9227 | 9881 | 8597 |
| **Crown** | 84959 | 73388 | 23643 | 20816 |
| **Cortical bone** | 2708 | 3676 | 2966 | 3940 |
| **Spongy bone** | 44070 | 36174 | 43492 | 35801 |
| **Gutta-percha** | 18948 | 15835 | 1598 | 1658 |
| **Cement layer** | 23036 | 35108 | 1858 | 2825 |

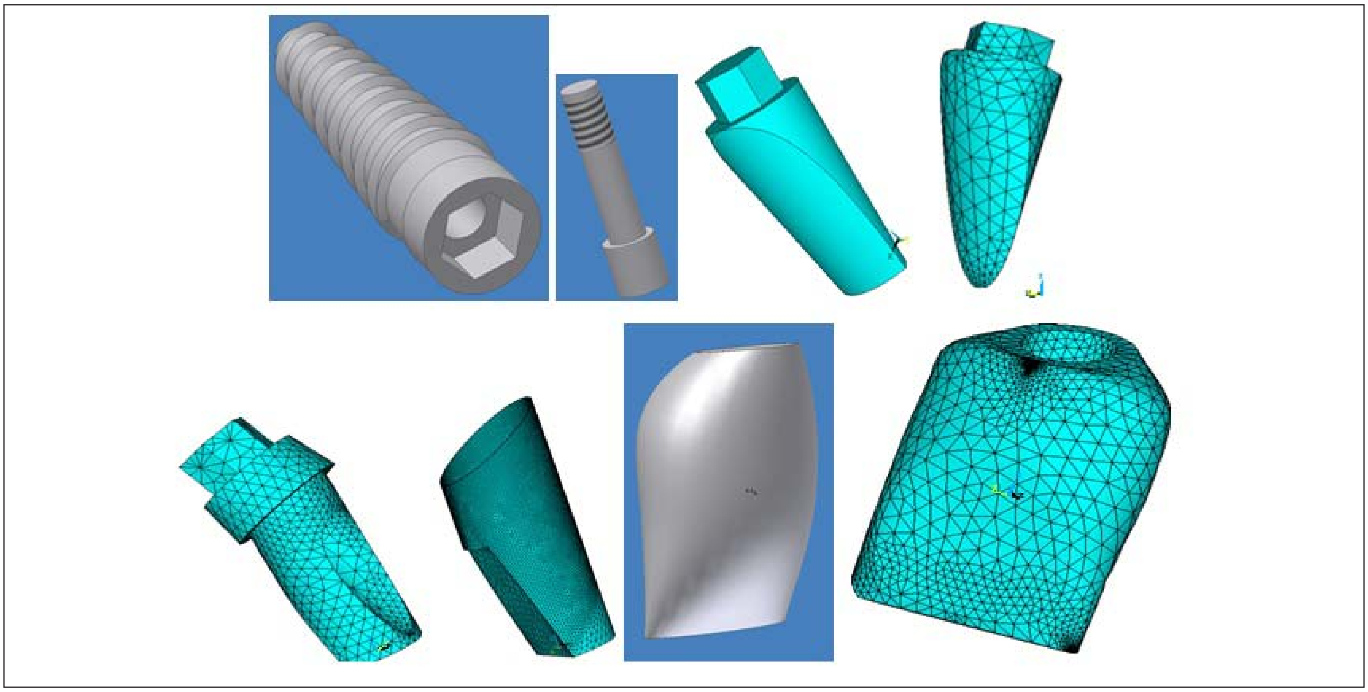

**Fig. 1:** Modeled and meshed components (implant, screw, GP, abutment, cement layer, crown) screen shots from Inventor / ANSYS screens

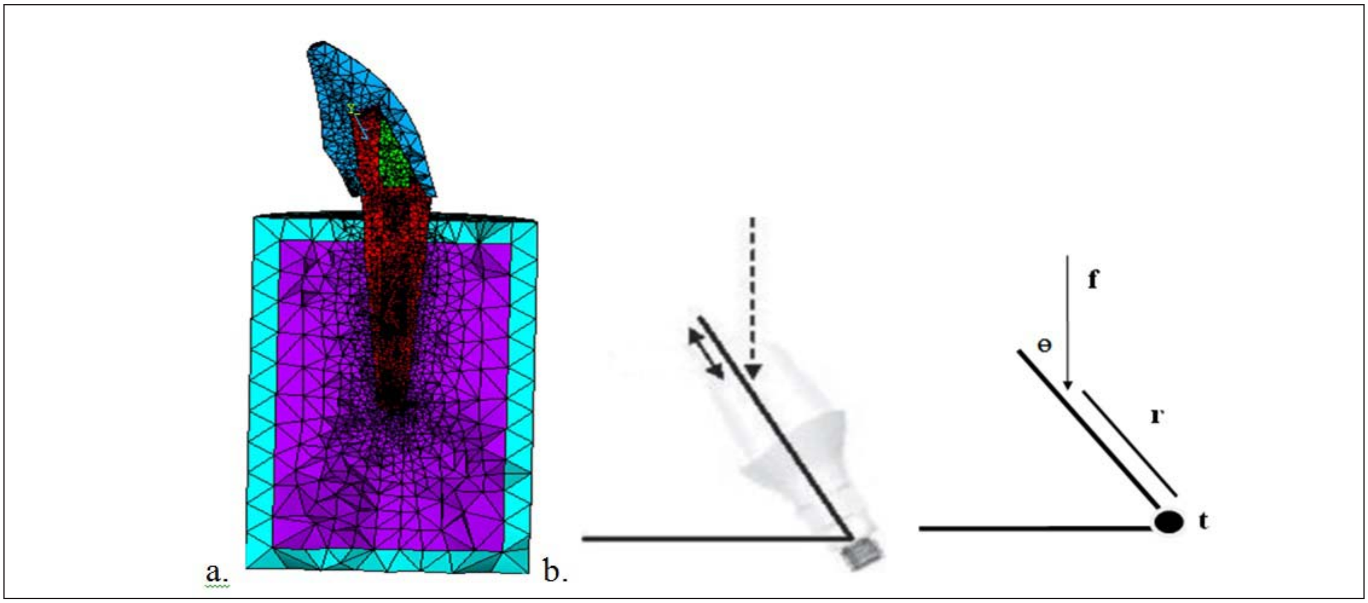

**Fig. 2:** (a) complete meshed model (b) schematic for load direction

## Results

The Von Mises stress distributions and their maximum values were discussed in details. Figure 3 illustrates the increase of maximum value of Von Mises stress with increasing abutment angulation from 15° to 25° on cortical bone, and the stress distribution did not change. On the other hand, spongy bone Von Mises stress distribution with different abutment angulation is in Figure 4, where the spongy bone showed lower values with increasing abutment angulation. Contrarily, crown material change did not affect bone stress.

From mechanical point of view, the lower-angulated abutment was expected to survive against more loading than the higher-angulated ones. Increasing abutment angulation increases the abutment Von Mises stress and may change its distribution. As indicated in Figure 5, the 15° angulated abutment stress level is about 25% less than the one of the 25 angulated one. Similarly, screw behavior with different abutment angulations indicated higher stress values under the screw head for 25° angulated abutment (Figure 6), which may fail by its head removal, and/or screw bent with load (in the same direction).

Figure 7, illustrates that the cement layer will suffer

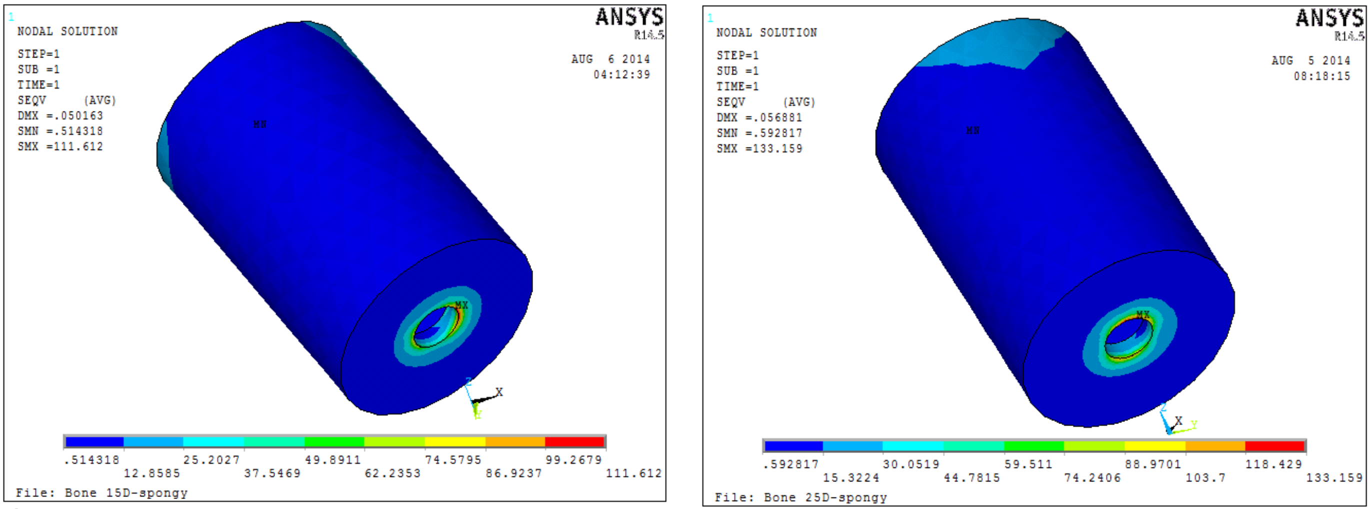

**Fig. 3:** Cortical bone Von Mises stress distribution comparison between (a) 15°, (b) 25° angulated abutment under Zirconia crown

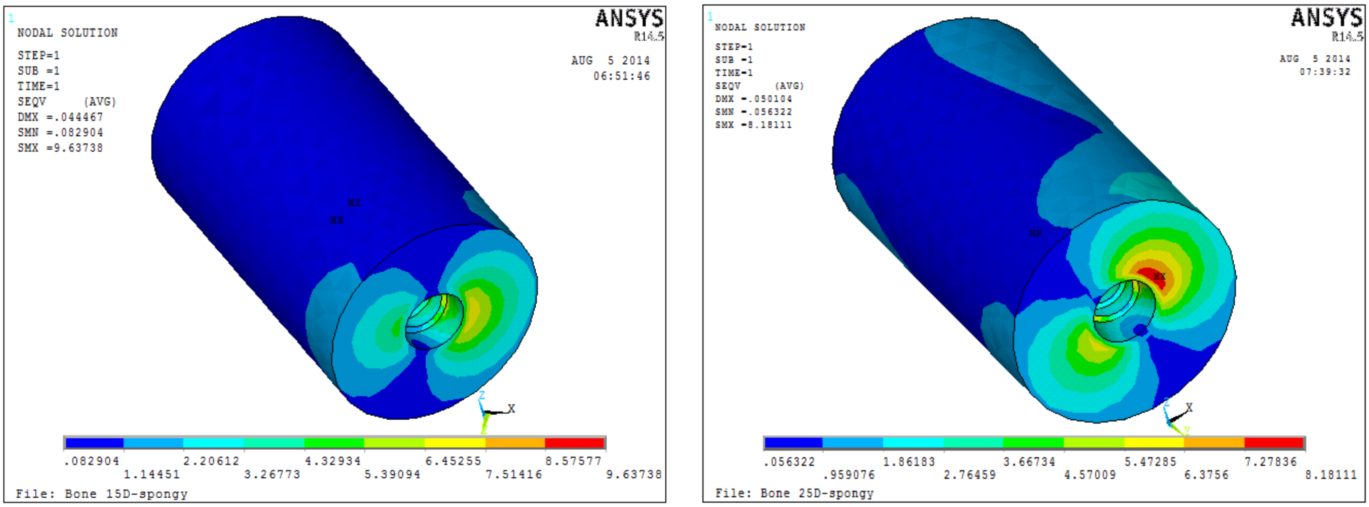

Fig. 4: Spongy bone Von Mises stress distribution comparison between (a) 15°, (b) 25° angulated abutment under IPS E-Max CAD crown.

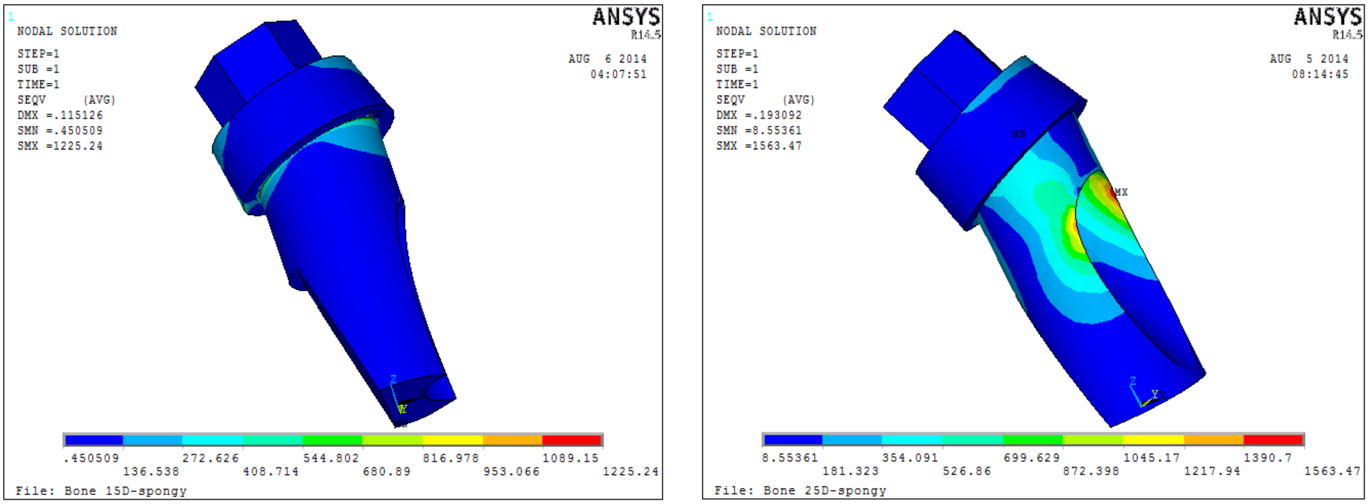

**Fig. 5:** Abutment Von Mises stress distribution comparison between (a) 15°, (b) 25° angulated abutment under Zirconia crown.

more with 15° abutment angulation, about double the Von Mises stress, in comparison with 25° abutment angulation. The location of maximum Von Mises stress was expected to be at the finish line with 15° abutment angulation, and at abutment step with 25° abutment angulation (as crown will tend to slide inward from its original position).

Comparing the different crown materials investigated in this study, as shown in Figure 8, the place of maximum

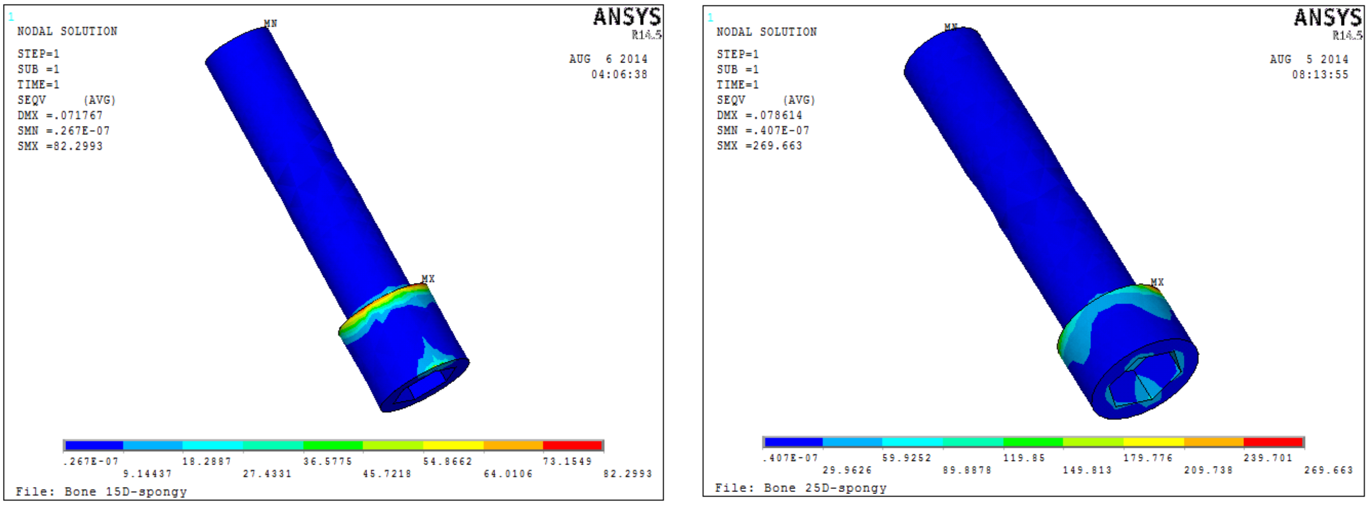

**Fig. 6:** Screw Von Mises stress distribution comparison between (a) 15°, (b) 25° angulated abutment under Zirconia crown.

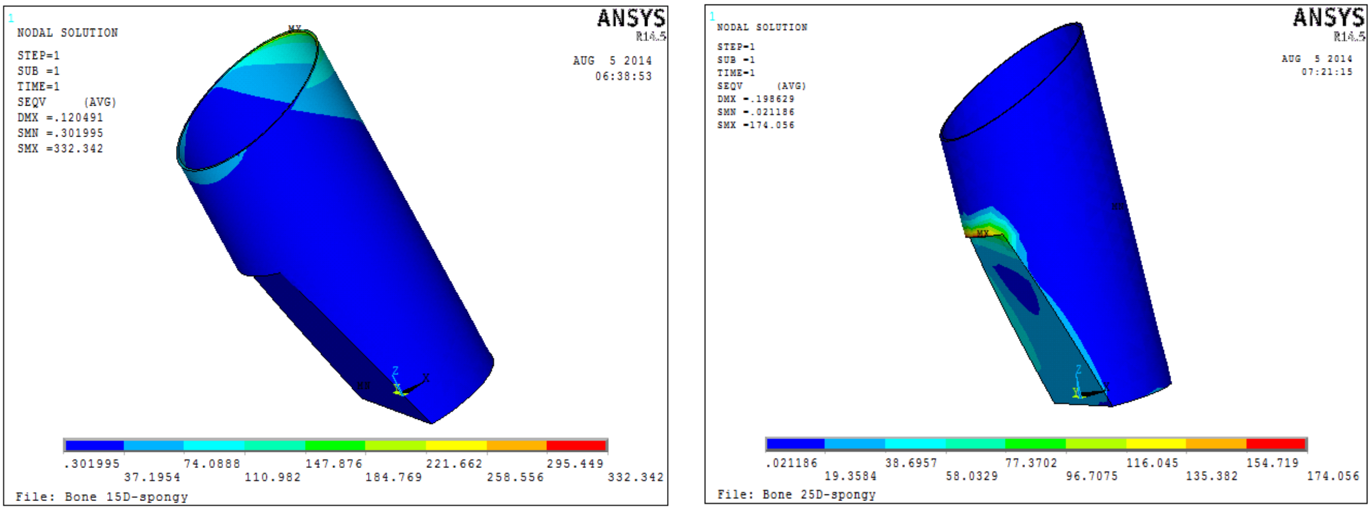

**Fig. 7:** Cement layer Von Mises stress distribution comparison between (a) 15°, (b) 25° angulated abutment under IPS E-Max CAD crown.

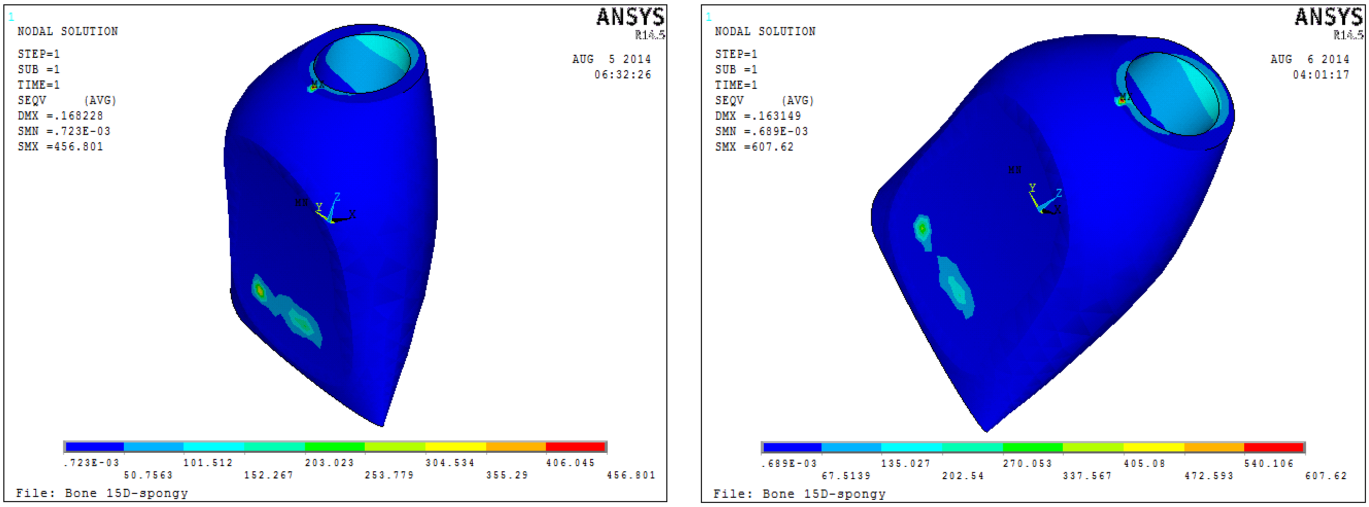

**Fig.8:** Von Mises stress distribution on different crown materials (a) IPS emax CAD, (b) Zirconia supported by 15° abutment.

Von Mises stress of indicated expected crown failure as two similar parts with using vertical cutting plane. Finally, Table 3 compares maximum values of Von Mises stress exerted on all components on the studied models.

## Discussion

Nowadays the advantages of monolithic zirconia restorations with an increased mechanical stability made them

**Table 3:** Values of maximum Von Mises stresses [in MPa] induced in the side of load application under oblique loading condition in all models.

| | Model 1: E-Max | Model 1: Zirconia | Model 2: E-Max | Model 2: Zirconia |
|---|---|---|---|---|
| **Cortical bone** | 111.67 | 111.61 | 133.14 | 133.15 |
| **Spongy bone** | 9.637 | 9.636 | 8.181 | 8.181 |
| **Implant** | 218.30 | 218.22 | 224.50 | 244.51 |
| **Abutment** | 1193.52 | 1225.24 | 1566.55 | 1563.47 |
| **Screw** | 82.29 | 89.19 | 269.66 | 269.36 |
| **Gutta-percha** | 53.09 | 49.29 | 30.79 | 30.02 |
| **Cement layer** | 332.34 | 342.11 | 174.05 | 175.74 |
| **Crown** | 456.80 | 607.62 | 822.91 | 824.76 |

possible to expand their clinical indications[17]. Many dentists and patients choose zirconia for its advantages, like high strength similar to metals, high biocompatibility, similar color and translucency to natural teeth and low risk of inflammation due to an unlikely dental plaque in accumulation. In a recent clinical report[18], elimination of veneered porcelain on posterior zirconia crowns and fixed dental prostheses was performed for a clinical trial and presented an acceptable esthetic result.

In this study, zirconia crowns showed better performance than the E-Max due to their high rigidity. Thus, better load transfer pattern was expected on the following parts, in comparison with less rigid material (IPS E-Max CAD).

The obtained results in this research matched previous studies' findings, that using low rigidity crown material reduces the stresses generated on the jaw bone (cortical and spongy), that it absorbs more energy from the applied load and transfers less energy to implant-abutment complex and bone[10]. In addition, this finding was proven experimentally[13], that all zirconia crowns did not fail under 178 N oblique load. Failure occurred in screws supporting angulated abutments whatever the abutment angulation (15° or 25°). About 50% of E-Max crowns failed under load and the other failures occurred in screw.

In other words, regardless the crown material, the increased abutment angulation resulted in increasing the lateral stresses exerted on the whole assembly rather than the apical stresses. Lateral stress increases may affect the screw of the abutment, as it represents the weakest component of the whole assembly. These results were in full agreement with those found by Ellakwa et al.[19] as their results assessed the effect of three implant abutment angulations and three core thicknesses on the fracture resistance of overlaying CAM milled zirconia, and found that the 30° implant abutment angulation significantly reduced the fracture resistance of the overlaying CAM milled zirconia single crowns.

In addition, the cervical areas are the most critical on the abutments due to the force concentration that may be a reason for failures, i.e. increasing the abutment angulation had a negative influence on the fracture load.

Former experimental studies[13,15] showed different modes of failure for the 15° and 25° implant abutment angulations with IPS E-max CAD crowns. About half the specimens had screw fracture and the other half had crown fracture. This was assigned to the fact that the flexural strength of IPS E-Max CAD crown (460 MPa) is near to that of titanium screw (500 MPa). On the other hand, zirconia crowns have flexural strength of 900-1400 MPa, which is superior to the titanium screw.

The fractures in the ceramic crowns typically occurred at the cervical portion of the abutment and at the screw. According to previous studies[20-22], these abutment areas have the highest stress concentrations due to levering effects.

Using angulated abutments with different types of restorative materials to construct the overlaying crowns are significant factors in determining the amount and distribution of stresses loaded onto the superstructure and implant under functional forces[23].

Most FE models in dental researches[9-10,24] assumed perfect bond between assembled model components to simulate natural condition, in addition to assuming linear, static and isotropic material properties.

The film thickness of the resin cement might significantly affect the short- and long-term bond strengths. It was reported that greater resin cement film thickness (100 ìm vs. 50 ìm) resulted in lower bond strength of resin materials to lithium disilicate ceramics[13]. Another study[25] showed that the zirconia bond strengths were significantly reduced with thicker (100 ìm) resin cement layer. Thus, in this study the film thickness was considered to be 50 µm.

Finally, the results of this study were in agreement with literature[3] when abutments with 0, 15°, and 25° angulations were evaluated in the maxilla by 3D FEM. That concluded to the superiority of abutments with less-angulation than 25°, which increased stresses on the peri-implant region and demonstrated higher stress concentration on the opposite side of loading with angulated abutments.

Within the limitations of this study, the following conclusions can be drawn:

1- Implant Von Mises stress level was negligibly changed with increased abutment angulation, which indicated good implant-abutment complex design.

2- Abutment with higher angulation is mechanically weaker and is expected to fail at lower load level in comparison with steeper one.

3- Screw used with abutment angulation of 25° will fail at lower (about one-third) of the failure load of similar screw used with abutment angulated by 15°.

4- Cement layer placed above the 15° angulated-abutment will fail at lower load than that one placed on the

25° angulated-abutment, as it rests on smaller area of abutment lowest surface.

5- Bone (cortical and spongy) is insensitive to crown material. Increasing abutment angulation from 15° to 25°, increased stress on cortical bone by about 20%, and reduced it by about 12% on spongy bone.

6- More rigid crown material (zirconia), showed better distribution of load on the following parts, in comparison with less rigid material (IPS E-Max CAD).

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