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Research Article

# Efficacy of Different Implant Abutment Materials on Stress Distribution. (3D Finite Element Study)

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## Abstract

**Aim:** Abutment materials effect on stress distribution of underneath structures and bone was investigated within this study.

**Materials:** One model was built under Ansys workbench version 16 environment. Scanning premolar with contact probe scanner generated the crown geometry. On the other hand, all the other components utilized in this study were modeled in 3D by engineering CAD software. Distributed load of 450N was applied on the model to evaluate the effect of wide range of abutment materials as; PEEK, Titanium (Ti), Zirconia (Zr), and Alumina.

**Results:** PEEK abutment results was extremely high in comparison to other tested materials, so PEEK is not recommended for this function. Deformation and stresses patterns did not change for the other three materials, where the values were slightly different.

**Conclusion:** Crown deformation highly affected by abutment material rigidity. Similarly, implant and screw receive better-distributed load by the more rigid abutment. While, bone is insensitive to abutment material.

***Keywords:*** *PEEK; Titanium (Ti); Zirconia (Zr); Alumina; Premolar; Finite Element Analysis*

## Introduction

Abutment design and material may play a crucial role in load transfer to underneath structures and bone. Polyetheretherketone (PEEK) is a synthetic polymer that showed good mechanical properties [1-3] and has been used since 1980s as a material in medical applications [4]. Nowadays, PEEK can be used as implant material [1,5-8] and abutment material [1,2]. The modulus of elasticity of PEEK may have good effect regarding the stresses on the supporting bone [1]. Schwitalla., *et al.* stated opposite results [7].

Finite element analysis studies are used to analyze stresses at structures as implant bone interface [9]. It has been used to evaluate the effect of masticatory forces on peri implant bone [10].

Some finite element analysis studies have evaluated different restorative and prosthetic materials, also abutment materials [11] were evaluated and effect on implants and surrounding bone. However, PEEK abutments still need more evaluation.

## Purpose of the Study

The purpose of this study is to evaluate the PEEK abutments and compare it with the zirconia, titanium and alumina abutments. The hypothesis is that the more rigid abutments are more preferred, so PEEK is not a favorable abutment material.

## Materials and Methods

Premolar complicated geometry lead to using a 3D contact probe scanner to acquire its surface geometry, Roland MDX-15 (Roland DG Corporation of Hamamatsu, Japan). The scanner produced cloud of points or triangulations [12] that was trimmed as presented in figure 1.

| Material | Young's modulus [MPa] | Poisson's ratio |
|---|---|---|
| **Bone** | | |
| Cortical | 13,700 | 0.30 |
| Spongy | 1,370 | 0.30 |
| **Implant Complex** | | |
| Implant Titanium (Ti) | 110,000 | 0.33 |
| Screw Titanium (Ti) | 110,000 | 0.33 |
| **Abutment** | | |
| PEEK | 18,000 | 0.39 |
| Titanium (Ti) | 110,000 | 0.33 |
| Zirconia (Zr) | 210,000 | 0.34 |
| Alumina | 350,000 | 0.22 |
| Cement: Glass Ionomer (40 µm layer thickness) | 12,000 | 0.25 |
| Crown: Porcelain Fused to Metal (PFM) | 149,450 | 0.34 |

***Table 1:*** *Material properties imported to the Finite Element program.*

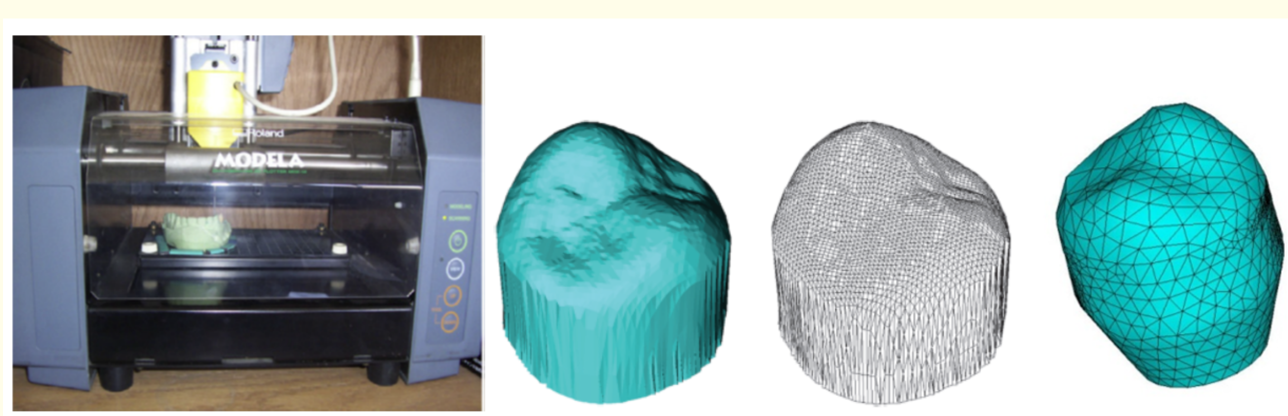


***Figure 1:*** *3D scanner and resultant surface after trimming and volume meshing.*

The implant-abutment complex was modeled in 3D using the commercial general-purpose CAD/CAM software 'Auto-Desk Inventor' version 8.0 (Autodesk Inc., San Rafael, California). Root form Titanium implant fixture (sky implant system by bredent, Chesterfield, UK) of 12 mm length, and 4 mm diameter [13] was used as supporting structure. These parts are regular and symmetric, and their dimensions can be simply measured with their full details (Figure 2). On the other hand, bone geometry was simplified and simulated as cylinders that consist of two coaxial cylinders. The inner one represents the spongy bone (diameter 14 mm and height 22 mm) that fills the internal space of the other cylinder (shell of 1 mm thickness), which represents cortical bone (diameter 16 mm and height 24 mm).

| | Volumes | Nodes | Elements |
|---|---|---|---|
| 1 | Abutment | 2,102 | 25,540 |
| 2 | Screw | 2,407 | 20,022 |
| 3 | Implant | 24,669 | 174,210 |
| 4 | Cortical | 1,150 | 51,341 |
| 5 | Spongy | 6,166 | 50,289 |
| 6 | Crown | 2,232 | 16,807 |
| 7 | Cement | 1,000 | 22,872 |

***Table 2:*** *Components mesh density.*

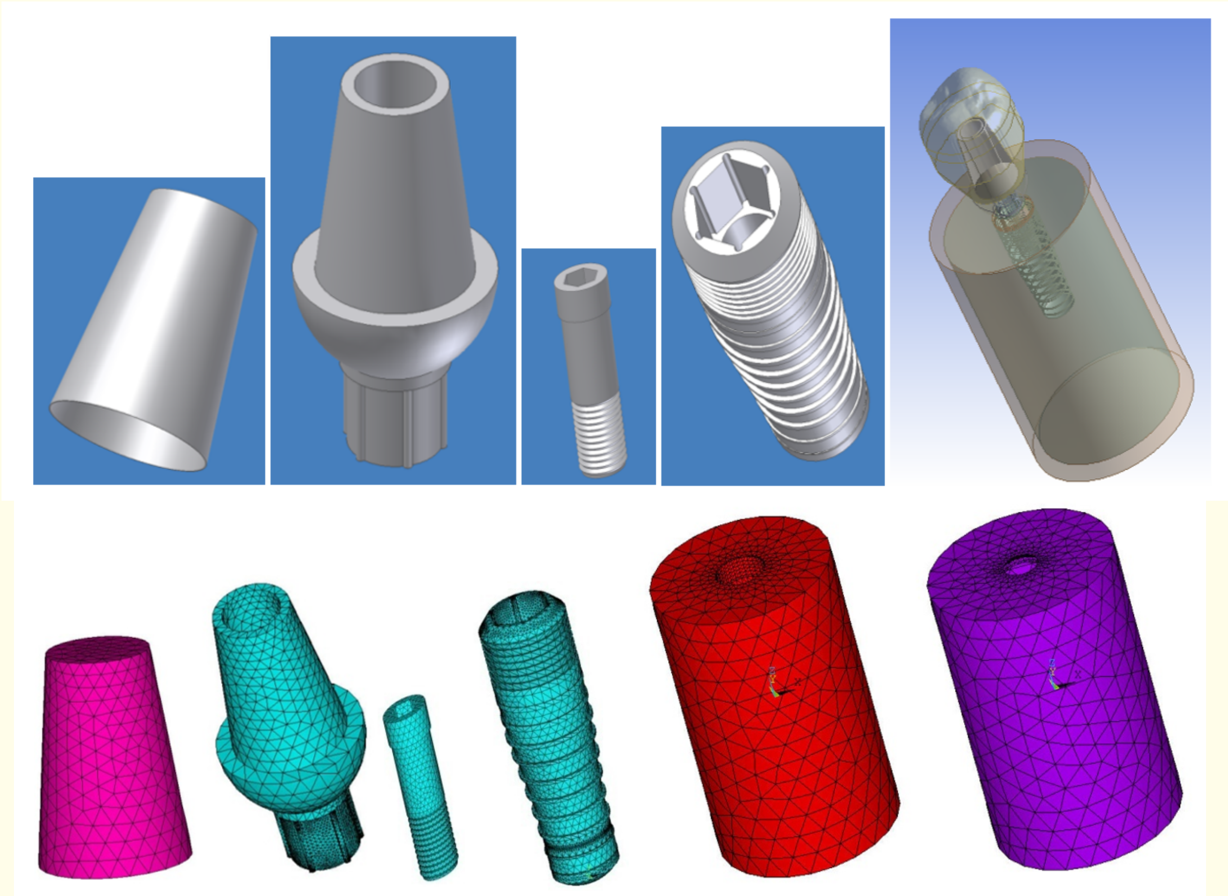

***Figure 2:*** *Modeled and meshed model components.*

Loading was applied vertically (z-axis) as a compressing load on five selected nodes on top of the coating as follows:

(1) 135 N, at the distolingual marginal ridge.

(2) 110 N, at the central fossa.

(3) 90 N, at the lingual cusp height.

(4) 70 N, at the distolingual slope.

(5) 45 N, at the mesiolingual marginal ridge.

The used finite element package was ANSYS Workbench version 16 (ANSYS Inc., Canonsburg, PA, USA) to be assembled and analyzed. While, the solid modeling and finite element analysis (linear static analysis) were performed on Workstation HP Z820, with Dual Intel Xeon E5-2660, 2.2 GHz processors, 64GB RAM.

## Results

PEEK abutment results (stresses and deformations) were relatively high in comparison to the other abutment materials. On the other hand, stresses distribution pattern did not change with all other cases, while values were slightly changed. Locations of extreme Von Mises stress values remain under point loads, abutment/implant interface, and cortical bone connecting zone with implant (See figure 3).

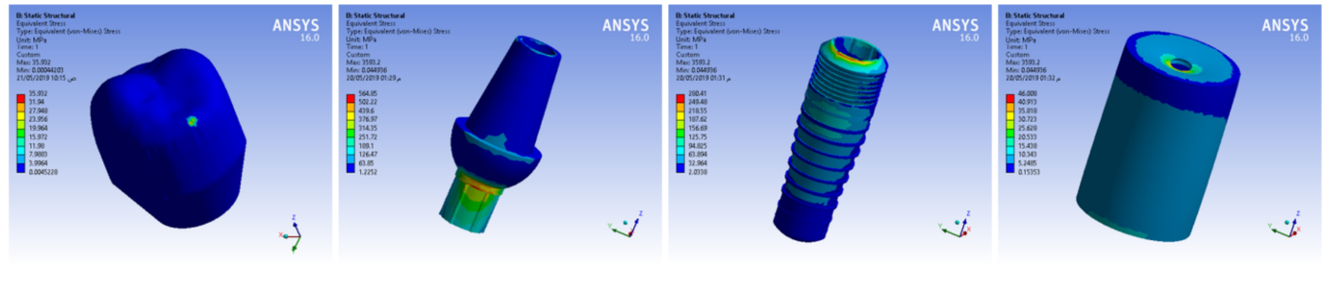


***Figure 3:*** *Sample of Von Mises stress distribution on model components (Al abutment).*

Maximum total deformation appeared in red color in figure 4, that the crown under the specified loading condition tend to tilt that all other underneath structures react accordingly.

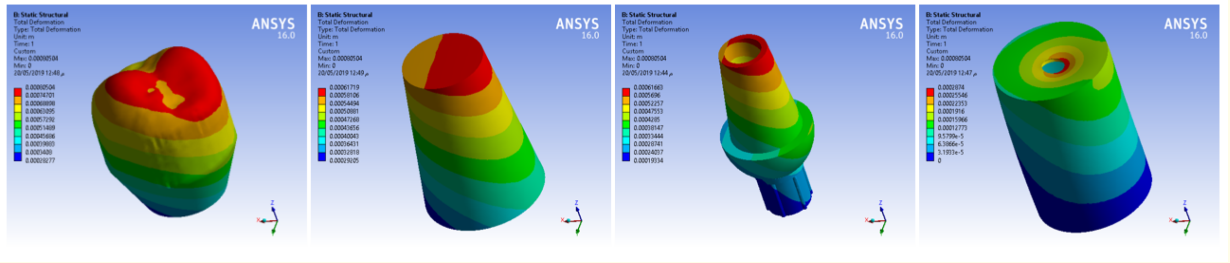


***Figure 4:*** *Sample of total deformation distribution on model components (Zr Abutment).*

Figure 5 summarized the study results by comparing them in order to extract conclusions. Like, bone (cortical and spongy) is not sensitive to the abutment material. On the other hand, cement layer, screw, and implant showed lower values of stresses and deformation as the abutment material changed to more rigid one.

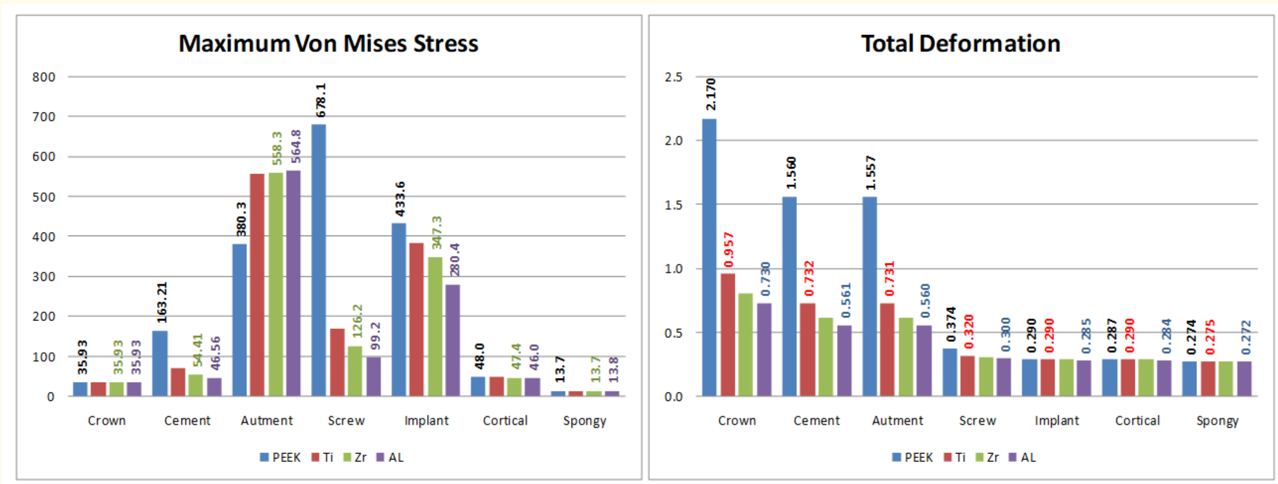


***Figure 5:*** *Results comparison.*

Whatever the abutment material, the crown received the same stresses, while abutment material rigidity (increase) affect (reduces) the crown deformations. Noting that, all deformations and stresses were within physiological (accepted) limits except the PEEK abutment case.

## Discussion

Implants and natural teeth have different response to masticatory stresses and this is because of the periodontal ligaments that acts as elastic buffer. Analyzing and studying biomechanical responses of these materials are complicated because they are complex structures [14]. The 3D finite element models produce more accurate and realistic results.

Different abutment materials are evaluated in this study. PEEK abutments, which have modulus of elasticity about 60 times less than zirconia showed low stress values but high stresses in the crown as stated by Kaleli., *et al.* in 2017. They found that although the abutment is supporting the crown, the crown is insensitive to abutment material change from stress point of view. While high deformation was recorded with less rigid abutment material due to abutment deformation [15].

Results of different studies evaluating zirconia and titanium abutments are contradicting [11,17,18].

Cement is relaxed (showed less stresses) above the more rigid abutment, that, the applied load was well distributed by crown to keep the cement layer deformation as value in between the crown (the same in all cases) and abutment.

Adhesive cementation with resin cement is recommended to increase the fracture resistance of the ceramic crown.

PEEK is not a suitable material for abutments [12]. As it is claimed that the low modulus of elasticity decrease the support for the surrounding structures [15]. And more stresses on bone [16].

Abutment body stresses and deformations distributions were negligibly changed, while the values of stresses increased with reducing abutment material rigidity. On the other hand, the abutment deformations increased by using less rigidity abutment materials. This was in contradiction with the study that showed that zirconia abutments have limitations due to its mechanical friability and low resistance to traction stresses [20]. When the material is subjected to load more than its plastic limit it will fracture. This is overcomed by high strength recent yttrium partially stabilized zirconia. Titanium bends more than zirconia due to its lower modulus of elasticity [21].

Implant and screw were slightly affected by changing abutment material. Their stresses and deformation were slightly reduced with changing abutment material to more rigid one(s).

Abutment design and geometry has great effect on the screw stresses. Peixoto., *et al.* in 2016 found that abutment geometry and material had a positive effect on the stresses on the abutment screw [11].

Bone (cortical and spongy) was not sensitive to abutment material. This was augmented by the results found by Kaleli., *et al.* in 2017 who found that the abutment material had no effect on stress distribution of implant and bone structures [15,19]. Linkevicius and Vaitelis have also reported lack of significant difference of different abutment materials on marginal bone level in a systematic review in 2015 [22], also in experimental in vivo studies by Blanco., *et al.* [23] in 2016 and Mehl., *et al.* in 2016 [24], different abutment materials have shown the same histological outcome in histomorphometric analysis of peri-implant hard tissues.

More clinical studies are to recommended to support the results of this study.

## Conclusion

Bone is insensitive to abutment material. PEEK as pure material is not suitable for manufacturing abutments. The more rigidity of the abutment material, the less stresses on implant and screw. i.e. Rigid or stiffer abutment can transfer the applied load better to underneath structures.

## Ethical Approval

This research does not require ethical approval and followed the Helsinki declaration.

## Conflict of Interest

The authors declare that they have no conflict of interest.

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