Comparative Evaluation of Stress Distribution of Zirconia, Cobalt Chromium and Polyetheretherketone (PEEK) Framework Material on an Atrophic Maxilla in All-on-6 Implant Treatment Concepts – A 3 Dimensional Finite Element Analysis

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Abstract.
Aims: To evaluate the effect of prosthetic framework material on the stress distribution patterns of All-on-Six implant support system under vertical and oblique loading.

Methods and Material: The CBCT images of the maxilla were converted to stereo lithography file. HYPERMESH software system was accustomed to convert 3D pictures into numerical models. Geometric model of short implant and zirconia, cobalt chromium and polyetheretherketone (PEEK) framework material were created using SOLID EDGE software and were then be inserted in the bone model. A total of six models were constructed with three different types of framework materials with four implants in the anterior maxilla region and two distal short implants and mini-abutments. The prosthetic frameworks were made with 14 teeth (central incisors to second molar bilaterally). The models were transferred through the solid works simulation program for finite element analysis and stress distribution investigation. An oblique load of 150 N with 30° inclination in the linguo-buccal direction and vertical loads parallel to long axis of the tooth with 100 N magnitude were applied unilaterally on the posterior teeth of each framework.

Results: Principal and Von misses stress in PEEK framework were least when compared to stresses in zirconia and cobalt chromium framework on vertical loading and oblique loading.

Conclusions: PEEK as a framework material had least stress for the All on Six implant treatment concepts on vertical and oblique forces than zirconia and cobalt chromium framework.

Keywords: All-on-Six implant, Finite Element Analysis, Zirconia, cobalt chromium and PEEK framework.

Introduction

Rehabilitation of atrophic maxilla with dental implant is challenging due to its anatomic characteristics. Procedures like bone augmentation are often required in edentulous patients which causes higher costs, increased risk of morbidity and longer treatment time. The All-on-Six implant treatment concept enables the rehabilitation of a fully edentulous jaw with a better quality of life.

Recently, zirconia and PEEK frameworks were proposed as an aesthetic alternative for the metallic implant framework. It is because of their chemical durability, bio-compatibility and superior mechanical properties thus solving the limitations of the metal alloys.

An implant-supported prosthetic framework should have a stress-free, simultaneous, circumferential contact at the implant-prosthesis interface before functional loading. On the application of loads to the superstructure, stresses are created within them and transferred to the bone-implant interface, implant and prosthetic components. Thus influencing the survival of the restoration and affect the bone stress distribution around implants. Generated stress varies with the stiffness of the framework materials. Hence the aim of the study is to compare zirconia, cobalt chromium and PEEK framework material on...
stress distribution in All-on-Six implant treatment concept in atrophic maxilla.

**Materials & Methods**

An edentulous atrophic maxilla specimen was taken from the Department Of Anatomy, The Oxford Dental College, Bangalore. A Cone Beam Computed Tomography (CBCT) of the atrophic maxilla was taken at Magnus diagnostics, Bangalore.

The Cone Beam Computerized Tomography (CBCT) images of the maxilla were converted to stereolithography file. Geometric model of short implant and zirconia, cobalt chromium and polyetheretherketone (PEEK) framework material were created by using SOLID EDGE version 19 software and was then inserted within the bone model (Fig. 1a,b).

The properties of the implants and therefore the zirconia, cobalt chromium, polyetheretherketone (PEEK) framework materials were obtained and incorporated from standard textbook reference of implantology and dental material.

**Figure 1.** (a) Superimposition of implant, abutment and bone models. (b) Transparent view of the assembly.

**Models**

Models include six implants (2 on lateral incisors, 2 on second premolar, 2 on second molar regions) were manually drawn from precise geometric measurements acquired from Noble Biocare implants. The dimension of vertically positioned implant features $3.5 \times 10, 4.3 \times 13, 5 \times 8$ mm respectively and mini-abutments features straight profile $4.0 \times 4.0$ mm (Fig. 2a).

The prosthetic framework was manufactured with 14 teeth (central incisors to second molar bilaterally). The distance between the prosthetic framework and the maxilla is $3.91$ mm and prosthetic frameworks are $11.11$ mm height and are constant for all models (Fig. 2b).

**Meshing**

The 3D models were exported to the HyperMesh version 11 software for mesh generation, leading to a virtual geometrical mesh arranged in a 3D manner (Fig. 3a,b,c). The tetrahedral elements were adjusted for all structures with minimum and maximum sizes (0.15 to 0.7 mm). Each element was interconnected at a number of discrete points called nodes.
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The displacement of each of these nodes was calculated to determine maximum stress throughout the structure.

Figure 3. (a) Mesh Model of the zirconia framework with 14 teeth. (b) Mesh Model of the cobalt chromium framework with 14 teeth. (c) Mesh Model of the PEEK framework with 14 teeth.

Loading

After the final models were obtained, ANSYS version 18.1 software was used for simulating and solving the loading condition and post processing analysis of the models. The models were transferred through the solid works simulation program for finite element analysis and stress distribution investigation. The models were subjected to a rigid fixation restriction within the upper maxilla to prevent displacement in the x, y and z axes (i.e. movement of nodes in direction of x, y and z axes).

An oblique load of 150 N with 30° inclination in the linguo-buccal direction and vertical loads parallel to the long axis of the tooth with 100 N magnitude was applied unilaterally on the posterior teeth of each framework (Fig. 4a,b).

The load applied was divided equally on the posterior teeth among the first premolar, second premolar, first molar and second molar.

Figure 4. (a) Vertical loads parallel to the long axis of the tooth of 100 N. (b) Oblique load of 150 N with 30° inclination.

Results

The results of the mathematical solutions were converted into visual results and expressed in colour gradients starting from red to blue with red representing the maximum stress values.

Principal stress in different framework material on vertical loading with 100 N magnitude parallel to long axis of the tooth (Fig. 5a,b,c).

Maximum Principal stress in zirconia framework on vertical loading of 100 N magnitude parallel to long axis of the tooth is 1.41523 Mpa. Minimum Principal stress in...
zirconia framework on vertical loading of 100 N magnitude parallel to long axis of the tooth is $-0.542988$ MPa.

**Maximum Principal stress** in CoCr framework on vertical loading of 100 N magnitude parallel to long axis of the tooth is $1.44413$ Mpa. **Minimum Principal stress** in CoCr framework on vertical loading of 100 N magnitude parallel to long axis of the tooth is $-1.11443$ Mpa.

**Maximum Principal stress** in PEEK framework on vertical loading of 100 N magnitude parallel to long axis of the tooth is $0.391785$ Mpa. **Minimum Principal stress** in PEEK framework on vertical loading of 100 N magnitude parallel to long axis of the tooth is $-0.37863$ Mpa (Fig. 5d).

Von mises stress in different framework material on vertical loading of 100 N magnitude parallel to long axis of the tooth (Fig. 6a,b,c).

**Von mises stress** on zirconia framework on vertical loading of 100 N magnitude parallel to long axis of the tooth is $7.9954$ MPa. **Von mises stress** on CoCr framework on vertical loading of 100 N magnitude parallel to long axis of the tooth is $7.50527$ MPa. **Von mises stress** on PEEK framework on vertical loading of 100 N magnitude parallel to long axis of the tooth is $2.15784$ MPa (Fig. 6d).

Principal stress in different framework material on oblique load of 150 N with 30° inclination in the linguo-buccal direction (Fig. 7a,b,c).
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Figure 7. (a) Principal stress in zirconia framework on oblique loading. (b) Principal stress in CoCr framework on oblique loading. (c) Principal stress in PEEK framework on oblique loading. (d) Principal stress in different framework material on oblique load of 150 N with 30° inclination in the linguo-buccal direction.

**Maximum Principal stress** in zirconia framework on oblique load of 150 N with 30° inclination in the linguo-buccal direction is 17.5811 Mpa. **Minimum Principal stress** in zirconia framework on oblique load of 150 N with 30° inclination in the linguo-buccal direction is −1.80783 Mpa.

**Maximum Principal stress** in CoCr framework on oblique load of 150 N with 30° inclination in the linguo-buccal direction is 17.4334 Mpa. **Minimum Principal stress** in CoCr framework on oblique load of 150 N with 30° inclination in the linguo-buccal direction is −3.94064 Mpa.

Figure 8. (a) Von mises stress in zirconia framework on oblique loading. (b) Von mises stress in CoCr framework on oblique loading. (c) Von mises stress in PEEK framework on oblique loading. (d) Von Mises stress in different framework material on oblique load of 150 N with 30° inclination in the linguo-buccal direction.

**Maximum Principal stress** in PEEK framework on oblique load of 150 N with 30° inclination in the linguo-buccal direction is 8.55008 Mpa. **Minimum Principal stress** in PEEK framework on oblique load of 150 N with 30° inclination in the linguo-buccal direction is −1.7654 Mpa (Fig. 7d).

Von mises stress in different framework material on oblique load of 150 N with 30° inclination in the linguo-buccal direction (Fig. 8a,b,c).
Von mises stress in zirconia framework on oblique load of 150 N with 30° inclination in the linguo-buccal direction is 22.8241 Mpa. Von mises stress in CoCr framework on oblique load of 150 N with 30° inclination in the linguo-buccal direction is 8.06213 Mpa. Von mises stress in PEEK framework on oblique load of 150 N with 30° inclination in the linguo-buccal direction is 8.06213 Mpa (Fig. 8d).

Discussion

Implant-supported fixed partial dentures are viable alternatives to traditional full coverage FPDs. Finite element analysis (FEA) is a tool of functional assessment used extensively in implant research. In engineering and biomedical fields, numerical simulations are widely used to understand the stress distribution and deformation profiles. The precise representation of the geometry of interest in the analysed model gives the accuracy of results.

Knowledge on the amount of mechanical stress generated within the framework when load is applied is essential for the planning, execution and longevity of the treatment with implant-supported prostheses.

The present study used a tomography of a patient to create the model of atrophic maxilla and implants to simulate three different framework materials for fixed restoration of a complete edentulous maxilla. Even though the use of fewer implants to support the prosthesis reduces the overall treatment cost, the reduced quantity of bone results in challenging scenarios for implant placement.

Bhering et al., in their study, have shown that the All-On-Six treatment concept had the most favourable biomechanical behaviour and can be considered a viable alternative for moderate atrophic maxilla rehabilitation.

According to Möllers et al., the framework design and material properties of the superstructure play a significant role in stress distribution. When loads are applied, stresses that are created within them is then transferred to the bone-implant interface, implant and prosthetic components. This influences the survival of the restoration.

In the present study, the prosthetic framework material was influential on the stress and displacement of the implant-support system. In general, the stiffer materials (i.e., Zr and CoCr) showed higher stress values (σmax and σVM) within the prosthetic framework than did soft materials.

Rababah et al.; in their study, suggested PEEK as a framework material because of its excellent properties and proved to be more cost effective and ensured better stability of the peri-implant tissue. The present study showed the stress distribution pattern, generated by applying static vertical and oblique load of 100 and 150 N on zirconia, cobalt chromium and PEEK framework.

The stress was least within the PEEK framework when compared to zirconia and cobalt-chromium framework, because of the lower elastic modulus of the PEEK. The stress was found to be greater in all the frameworks under oblique loading than in vertical loading.

A framework with a lower modulus of elasticity than that of metal or zirconia will further reduce the occlusal forces and can have a beneficial effect especially when used for implant restorations, where proprioception is reduced by the absence of periodontal ligaments.

Although all the structures were assumed to be isotropic, homogeneous and linearly elastic, it is known that these conditions don’t occur in live tissues like the cortical bone, which is transversely anisotropic and inhomogeneous.

Conclusion

Within the limitations of the study, the following conclusions were drawn:

1. PEEK as a framework material had the least stress for the All on Six implant treatment concepts on vertical and oblique forces.
2. Zirconia and cobalt chromium framework material showed similar stress distribution but was higher than PEEK.
3. Thus, the elastic modulus of the material has an influence on the stress distribution.

Generally, least stress and least deformation are desirable for the safety of the implant supported prosthesis. So, by observing the stress and deformation patterns in the frameworks, PEEK showed the most favourable biomechanical behaviour.

References