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

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Abstract.
Aims: This study aims to evaluate the effect of prosthetic framework material on the stress distribution patterns of the all-on-six implant support system under vertical and oblique loading.

Materials and Methods: The cone beam computed tomography (CBCT) images of the maxilla were converted to a stereo lithography file. HyperMesh software system was accustomed to convert 3D pictures into numerical models. Geometric models of short implant and zirconia, cobalt chromium, and polyetheretherketone (PEEK) framework material were created using SOLID EDGE software and were then 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 the 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 150N with 30° inclination in the linguo-buccal direction and vertical loads parallel to the 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 the PEEK framework were least when compared to stresses in the zirconia and cobalt chromium framework on vertical loading and oblique loading.

Conclusions: PEEK as a framework material had the 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 [1]. 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 [2].

Recently, zirconia and PEEK frameworks were proposed as an esthetic alternative for the metallic implant framework [3]. It is because of their chemical durability, biocompatibility, and superior mechanical properties, thus solving the limitations of the metal alloys [4].

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 affecting the bone stress distribution around implants [5]. Generated stress varies with the stiffness of the framework materials [6]. 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 the atrophic maxilla.

MATERIALS AND 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 CBCT images of the maxilla were converted to a stereolithography file. Geometric models of short implant and zirconia, cobalt chromium, and polyetheretherketone (PEEK) framework material were created using SOLID EDGE version 19 software and were then inserted within the bone model (Figure 1a,b).

The properties of the implants and the zirconia, cobalt chromium, polyetheretherketone (PEEK) framework materials were obtained and incorporated from the standard textbook reference of implantology and dental material [7].

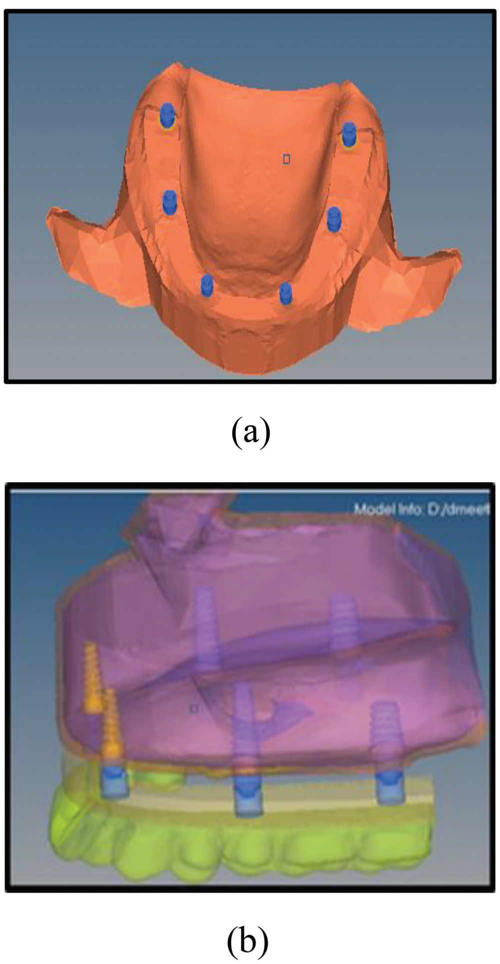


Figure 1. (a) Superimposition of implant, abutment, and bone models. (b) Transparent view of the assembly.

MODELS

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

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

The displacement of each of these nodes was calculated to determine maximum stress throughout the structure.

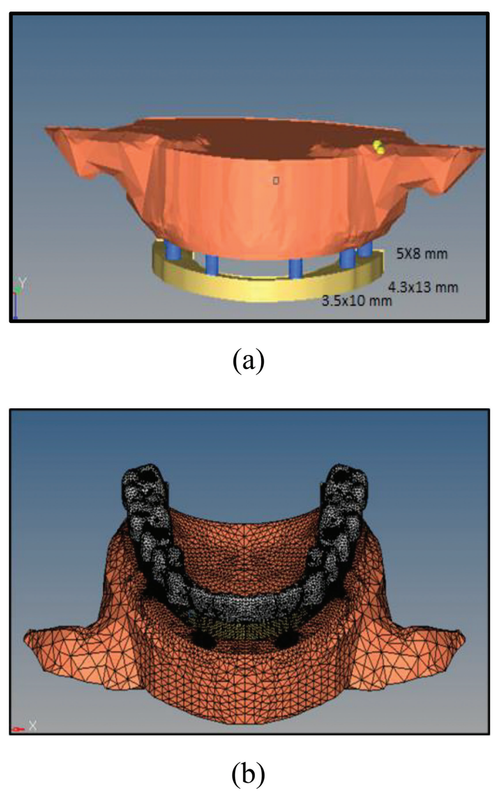
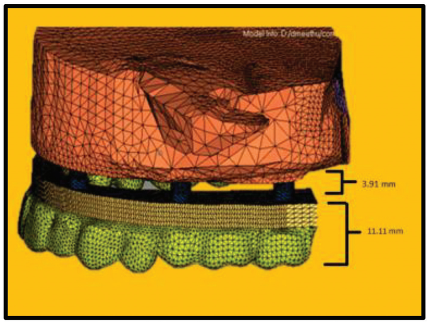


Figure 2. (a) Position and dimensional view of implants. (b) Framework model with 14 teeth.



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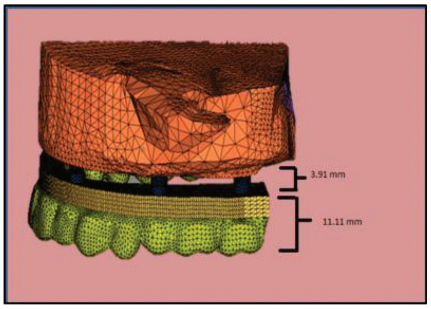

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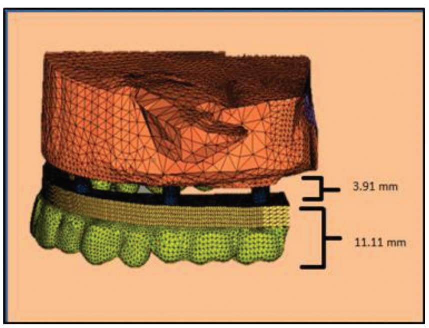

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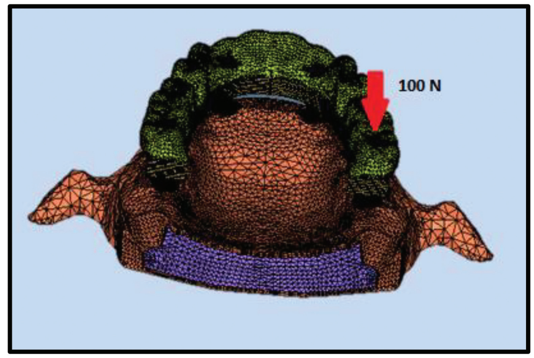
Figure 3. (a) Mesh model of the zirconia framework with 14 teeth. (b) Mesh model of the cobalt chromium framework with 14 teeth. (c) Mesh model of the PEEK framework with 14 teeth.



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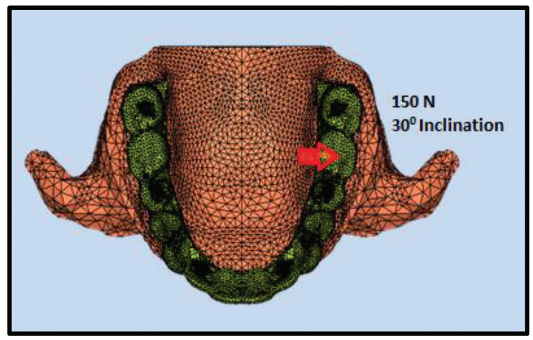


(b)

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

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 the direction of x, y, and z axes).

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

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

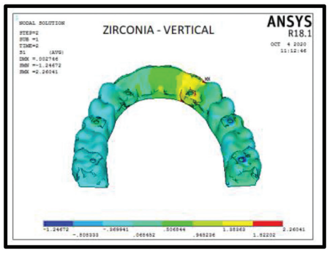
RESULTS

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

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

Maximum principal stress in the zirconia framework on vertical loading of 100N magnitude parallel to the long axis of the tooth is 1.41523 Mpa. **Minimum principal stress** in the zirconia framework on vertical loading of 100N magnitude parallel to the long axis of the tooth is −0.542988 Mpa.

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



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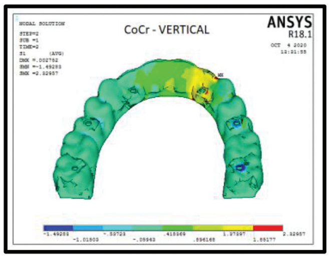

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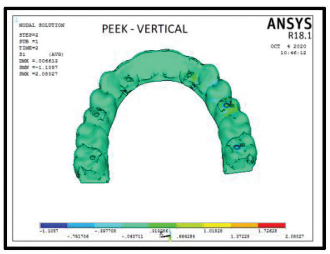

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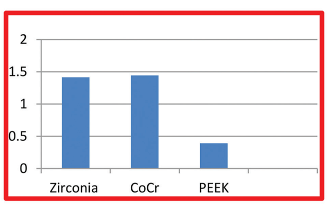
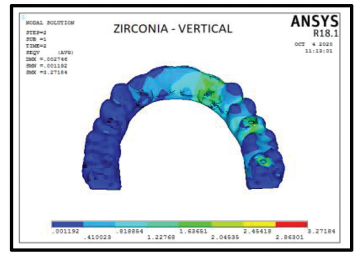


(d)

Figure 5. (a) Principal stress in the zirconia framework on vertical loading. (b) Principal stress in the CoCr framework on vertical loading. (c) Principal stress in the PEEK framework on vertical loading. (d) Principal stress in different framework materials on vertical loading of 100N.



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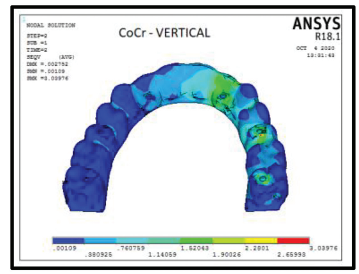

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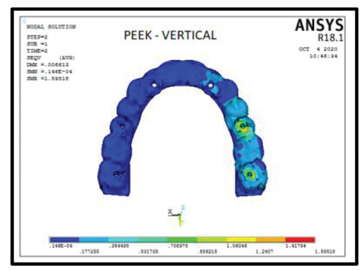

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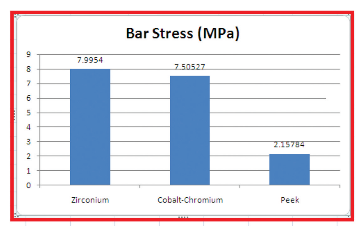

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Figure 6. (a) Von Mises stress in the zirconia framework on vertical loading. (b) Von Mises stress in the CoCr framework on vertical loading. (c) Von Mises stress in the PEEK framework on vertical loading. (d) Von Mises stress in different framework materials on vertical loading of 100N.

the CoCr framework on vertical loading of 100N magnitude parallel to the long axis of the tooth is −1.11443 Mpa.

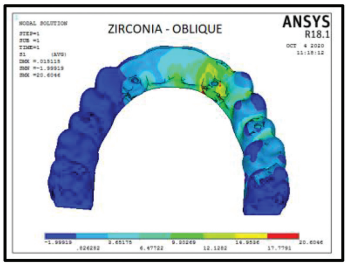
Maximum principal stress in the PEEK framework on vertical loading of 100N magnitude parallel to the long axis of the tooth is 0.391785 Mpa. **Minimum principal stress** in the PEEK framework on vertical loading of 100N magnitude parallel to the long axis of the tooth is −0.37863 Mpa (Figure 5d).

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

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

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

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



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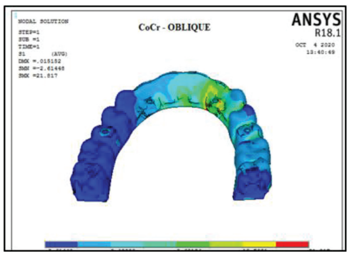

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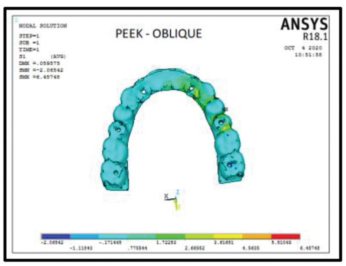

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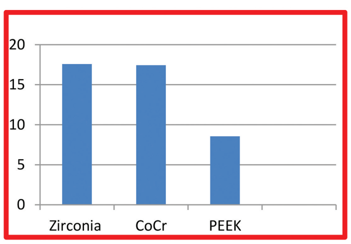

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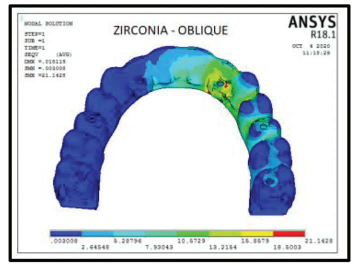
Figure 7. (a) Principal stress in the zirconia framework on oblique loading. (b) Principal stress in the CoCr framework on oblique loading. (c) Principal stress in the PEEK framework on oblique loading. (d) Principal stress in different framework materials on an oblique load of 150N with 30° inclination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



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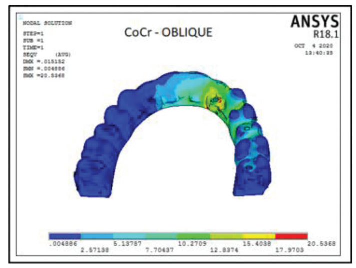

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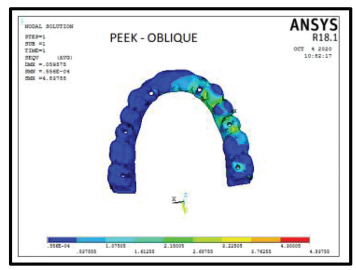

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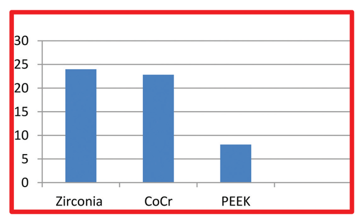

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Figure 8. (a) Von Mises stress in the zirconia framework on oblique loading. (b) Von Mises stress in CoCr framework on oblique loading. (c) Von Mises stress in the PEEK framework on oblique loading. (d) Von Mises stress in different framework materials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

in the zirconia framework on an oblique load of 150N with 30° inclination in the linguo-buccal direction is −1.80783 Mpa.

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

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

Von mises stress in different framework materials on oblique load of 150N with 30° inclination in the linguo-buccal direction ((Figure 8a,b,c).

Von Mises stress in the zirconia framework on an oblique load of 150N with 30° inclination in the linguo-buccal direction is 23.9843 Mpa. **Von Mises stress** in the CoCr framework on an oblique load of 150N with 30° inclination in the linguo-buccal direction is 22.8241 Mpa.

Von Mises stress in the PEEK framework on an oblique load of 150N with 30° inclination in the linguo-buccal direction is 8.06213 Mpa (Figure 8d).

DISCUSSION

Implant-supported fixed partial dentures are viable alternatives to traditional full-coverage FPDs [8]. 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 stress distribution and deformation profiles. The precise representation of the geometry of interest in the analyzed model gives the accuracy of results [9].

Knowledge on the amount of mechanical stress generated within the framework when the load is applied is essential for the planning, execution, and longevity of the treatment with implant-supported prostheses [10].

This study used a tomography of a patient to create the model of atrophic maxilla and implants to simulate three different framework materials for the 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 [11].

Bhering et al. in their study have shown that the all-on-six treatment concept had the most favorable biomechanical behavior and can be considered a viable alternative for moderate atrophic maxilla rehabilitation [2].

According to Möllers et al., the framework design and material properties of the superstructure play a significant role in stress distribution [12]. When loads are applied, stresses that are created within them are then transferred to the bone–implant interface, implant, and prosthetic components. This influences the survival of the restoration [13].

In this 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 [14].

Rababah et al. in their study suggested PEEK as a framework material because of its excellent properties, proved to be more cost-effective, and ensured better stability of the peri-implant tissue [4]. This study showed the stress distribution pattern, generated by applying static vertical and oblique loads of 100N and 150N 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 [15, 16].

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 the PEEK.
3. 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 favorable biomechanical behavior.

REFERENCES

[1] Bacchi A, Consani RL, Mesquita MF, dos Santos MB. Stress distribution in fixed-partial prosthesis and peri-implant bone tissue with different framework materials and vertical misfit levels: a three-dimensional finite element analysis. J Oral Sci 2013;55(3):239–44.

[2] Bhering CL, Mesquita MF, Kemmoku DT, Noritomi PY, Consani RL, Barão VA. Comparison between all-on-four and all-on-six treatment concepts and framework material on stress distribution in atrophic maxilla: A prototyping guided 3D-FEA study. Mater Sci Eng C Mater Biol Appl 2016;69(1):715–25.

[3] Calha N, Messias A, Guerra F, Martinho B, Neto MA, Nicolau P. Effect of geometry on deformation of anterior implant-supported zirconia frameworks: An in vitro study using digital image correlation. J Prosthodont Res 2017;61(2):139–148.

[4] Al-Rabab'ah M, Hamadneh W, Alsalem I, Khraisat A, Abu Karaky A. Use of High Performance Polymers as Dental Implant Abutments and Frameworks: A Case Series Report. J Prosthodont 2019;28(4):365–372.

[5] Meric G, Erkmen E, Kurt A, Tunc Y, Eser A. Influence of prosthesis type and material on the stress distribution in bone around implants: a 3-dimensional finite element analysis. J Dent Sci 2011;6:25–32.

[6] Arinc H. Effects of Prosthetic Material and Framework Design on Stress Distribution in Dental Implants and Peripheral Bone: A Three-Dimensional Finite Element Analysis. Med Sci Monit 2018;22(24):4279–4287.

[7] Anusavice, Phillip's Science of Dental Materials, 11th edition, Saunders publications; Page 768–780.

[8] De França DG, Morais MH, das Neves FD, Barbosa GA. Influence of CAD/CAM on the fit accuracy of implant-supported zirconia and cobalt-chromium fixed dental prostheses. J Prosthet Dent 2015;113(1):22–8.

[9] Ozan O, Kurtulmus-Yilmaz S. Biomechanical Comparison of Different Implant Inclinations and Cantilever Lengths in All-on-4 Treatment Concept by Three-Dimensional Finite Element Analysis. Int J Oral Maxillofac Implants 2018;33(1):64–71.

[10] Calha N, Messias A, Guerra F, Martinho B, Neto MA, Nicolau P. Effect of geometry on deformation of anterior implant-supported zirconia frameworks: An in vitro study using digital image correlation. J Prosthodont Res 2017;61(2):139–148.

[11] Durkan R, Oyar P, Deste G. Effects of Cantilever Length and Implant Inclination on the Stress Distribution of Mandibular Prosthetic Restorations Constructed from Monolithic Zirconia Ceramic. Int J Oral Maxillofac Implants 2020;35(1):121–129.

[12] Möllers K, Pätzold W, Parkot D, Kirsten A, Guth JF, Edelhoff D *et al.* Influence of connector design and material composition and veneering on the stress distribution of all-ceramic fixed dental prostheses: a finite element study. Dent Mater 2011;27(8):171–5.

[13] Meric G, Erkmen E, Kurt A, Tunc Y, Eser A. Influence of prosthesis type and material on the stress distribution in bone around implants: a 3-dimensional finite element analysis. J Dent Sci 2011;6: 25–32.

[14] Sertgöz A. Finite element analysis study of the effect of superstructure material on stress distribution in an implant-supported fixed prosthesis. Int J Prosthodont 1997;10(1):19–27.

[15] Zoidis P. The all-on-4 modified polyetheretherketone treatment approach: A clinical report. J Prosthet Dent 2018;119(4):516–521.

[16] Rayyan MM, Abdallah J, Segaan LG, Bonfante EA, Osman E. Static and Fatigue Loading of Veneered Implant-Supported Fixed Dental Prostheses. J Prosthodont 2020;29(8):679–685.