Effect of Two Different All-on-Four concept Framework Materials on Stress-Induced in the Supporting Structures of Implants: An in-Vitro Comparative Study

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Abstract

Background: Clinical success of dental implant depends on the biomechanics and proper distribution of the occlusal load, many material combinations including metal/acrylic, metal/ceramic, BioHPP (high performance polymer) and zircon/ceramic can be used for all on four implant frameworks. **Aim:** The aim of this in-vitro study is to compare the effect of two different all-on-four framework materials on stresses induced in the supporting structures of implants. **Methodology:** In-vitro study using strain gauge technology on 3D epoxy printed resin models are conducted to strain gauge measuring micro strain induced by different fixed detachable dental prosthesis materials (all zirconia fixed detachable prosthesis and BioHPP fixed detachable prosthesis) supported by implant using all-on-four treating concept, each prosthesis will contain 12 teeth with the distal cantilever. For each model, the load was applied five times vertically and obliquely to ensure the reproducibility of the results, **Results**: Statistical analysis showed a significant difference between Bio HP and zirconia for the microstrains around the implants (p=0.008), the zirconia group recorded high values (60.00±5.30) than Bio HP (18.75±2.15), **conclusion**: BioHPP framework has shown to be less traumatic to all on four implants especially in unilateral loading. So, it was recommended to be used as frameworks material for fixed detachable prosthesis.

Keywords: All-on-Four concept Framework, Stress-Induced, Implants, in-Vitro Study.

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Introduction

The "all-on-four" treatment concept was developed to treat Edentulous patients, allow immediate loading function, avoid bone augmentation and decrease the costs and complications after surgery, this concept is a good alternative to ridge augmentation and surgery especially in the severely resorbed mandible and maxilla **(1)**.

The clinical success of dental implants depends mainly on the biomechanical consideration and proper distribution of occlusal force. Proper diagnosis and treatment planning are the secrets of a successful dental implant. One of the ways to reduce the strain to crystal bone is by increasing the anteroposterior spread of dental implant, placement of the longer and wider implant, increasing the number of implants, and use stress breaking or stress releasing materials like (BioHPP).

Strain gauges have been used to study stress induced in the dental structure. This allowed in vivo and in vitro measurement of force on oral implant and supporting structures.

All previous studies had discussed the BioHPP coping veneered by CAD-CAM composite, Visio-align composite, or high impact PMMA composite which have many drawbacks like vertical marginal gap, discoloration (loss of esthetics), and finally debonding of the veneers. So, in this study, the comparison was between all zirconia (framework and crown) and BioHPP with zirconia crown in stress-induced around the supporting structures of implants **(2)**.

Materials and Methods

This stress analysis study was conducted in-vitro using a 3D printed model simulating a completely edentulous lower arch with four implants were positioned according to All-on-four concept as the following two in the canine region and two in the premolar region to support complete mandibular fixed detachable prosthesis.

In this study the sample were divided into two groups according to frameworks and veneering materials:

Group 1: five Complete-arch implant-supported monolithic all Zirconia frameworks fixed detachable dental prostheses.

Group 2: five Complete-arch implant-supported BioHPP frameworks with zirconia crowns fixed detachable dental prosthesis.

Construction of the 3D model cast:

Extraoral desktop scan of completely edentulous model of the lower mandibular arch was used for educational purposes was done using extra oral scanner (In EOS*). then the scanned file was converted to an STL (Standard Tesselation Language) formation. The STL format was uploaded to Exocad designing software.

In this STL file four virtual implants beds were designed representing the sites planned for the four implants with dimensions equal 3.5x11.5 mm.

Rectangular four holes (mesial, distal, buccal and lingual) were designed at each implant site for the attachment of the rectangular strain gauge rosettes with an estimated depth to allow just 2 mm thickness of epoxy resin between the strain gauge rosettes and the implant.

Implants (Neobiotech) were placed at their beds in the model by threading using implant driver, (Figure 1) then mucosa simulation is done via rubber base material mulisil-mask soft is an addition-linking silicone which was injected from the auto-mix cartridge directly into the mucosa key index.(**Figure**) This way reproduction of the mucosa on the working model was achieved. Thickness of the simulated mucosa was approximately two mm.

Figure 1: Cast after implant placement.

Figure 2: Cast after soft tissue simulating material

Neobiotech implant - korea

Multi-unit abutments were installed at the printed model after the implants were placed. Two straight multiunit abutment were installed at the anterior implants and two 30° angled abutments at the posterior implants. Four titanium sleeves were placed over the multi-unit abutments then an intra oral scanner using medit i500 was used. The file was exported as an STL format then transferred to the exocad designing software.

Two designs were made and named for two groups:

Construction of complete implant supported monolithic zirconia fixed detachable prosthesis: The titanium sleeves were screwed into place on the multiunit abutments then reduction of titanium sleeves height was done using a marker to mark proper height of the sleeves to the level of occlusal plane according to the anatomical and mechanical consideration before scanning the cast. The sleeves were unscrewed from the multiunit abutments and trimming of excess height was done by using metallic disc till the previously determined mark. Scanning of titanium sleaves with intra oral scanner using medit i500 was done. Job definition on Exocad 2016 (open system) was performed (Exocad, GmbH, Germany). Scanning gingiva separately to be easy manipulated during designing for accurate adaptation of the final restoration on the gingiva to prevent making pressure on it. Scanning was done first on the soft tissue alone then with the scan bodies. Full arch zirconium anatomic bridge with distal molar cantilever was made and merged as an STL format. The produced STL was milled using (Cercon HT) block. with inlab milling machine (MCX5)

After the milling procedure the bridge was finished and sintered for 8 Hours. Zirconia Bridge was produced, sandblasting for surface of metal abutments for good bonding to zirconia prosthesis which was properly fitted and seated on the cast. Seating and glazing was done for the bridge. For soft tissue part was characterized using pink porcelain from vita (Gingiva Vita Vm.9).

Construction of complete implant supported BioHPP frameworks with zirconia crowns fixed detachable prosthesis: The titanium sleeves were screwed into place on the multiunit abutments then reduction of titanium sleeves height was done using a marker to mark proper height of the sleeves to the level of occlusal plane according to the anatomical and mechanical consideration before scanning the cast. The sleeves were unscrewed from the multiunit abutments and trimming of excess height wasdone by using metallic disc till the previously determined mark.

Sleeves were screwed to the multiunit abutments and blocking out the undercut by soft wax the spraying the cast and the titanium sleeves via the scan spray for scanning the lower cast.

Scanning with intra oral scanner using medit 500 was done. Job definition on Exocad 2016 (open system) was performed (Exocad, GmbH, Germany).

Framework was designed at the previous scan then the designed framework was converted to an STL format the by using BioHPP (Bredent disk) the milling of the framework was done then finished and seated. (**Figure** , **Figure**).

Figure 3: bioHPP framework

Figure 4: bioHPP framework.

After seating the framework a new scan using the intraoral scanner (medit I 500) was done and the scanned STL file was sent again to the design software full arch crowns was designed by super imposition of the previous designed file of group A and merged for final milling. 12 crowns were milled using (cercon XTdisk).(**Figure** , **Figure**).

Figure 5: bioHPP framework with zircon crowns (Toronto bridge design).

Figure 6: bioHPP framework with zircon crowns

The zirconia crowns were sintered at 8 hours sintering program then finished and glazed.

Figure 7: zircon crowns after glazing.

Figure 8: bioHPP framework after soft tissue material and zirconia crown bonding.

Figure 9: bioHPP framework after soft tissue material.

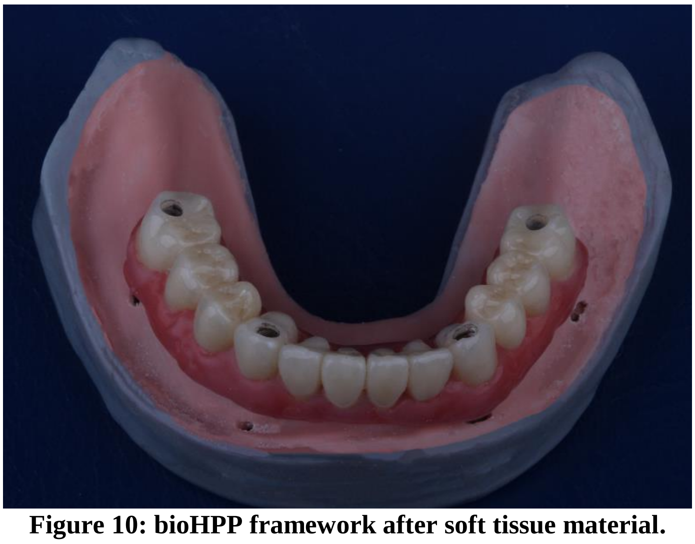

Figure 10: bioHPP framework after soft tissue material.

Polymerization was achieved via two stages, intermediate and final. Intermediat polymerization was done by hand lamp for fixation of the layers and final polymerization was done in a special UV curing unit (Photocure ANYCUBIC wash and cure machine 2.0_ China) for 360 sec.in case of crea. lign material.

Strain gauge sensors installation: The strain gauges (kyowa strain gauges, Japan) used in this study. The strain gauge used in this study was supplied with fully encapsulated grid and attached wires. The wire used for strain gauge was insulated by a packing material. The strain gauges were installed in their holes on the mesial, distal labial, lingual aspects of the four implants. The four strain gauges were positioned parallel to the long axes of the implants. Strain gauges were connected to lead wires 100 cm in length. All strain gauges were bonded in position on the model with delicate layer of Cyano -Acrylate base adhesive cement.

The loading device: Universal testing machine was used for applying vertical static loads of 100 Newton on the loading points for vertical loads and 65 Newton for oblique loads. The fixed detachable prosthesis to be tested were tightened into place following the manufacturer's recommendations.

Load application: Horizontal plate load applicator was fitted on the teeth bilaterally between the lower second premolars and lower first molars. The micro strain of each strain gauge was recorded by measure the strain developed at the mesial, distal, buccal and lingual aspect of the implants fixtures for each load application. For each model, the load was applied 5 times vertically bilateral, unilateral and obliquely to ensure the reproducibility of the results for each group. At least 5 minutes interval was calculated between each reading to allow relief of formed strains before making the next reading. Once the load was completely applied, the microstrain reading was transferred to microstrains units. Data were collected using the software (kyowa PCD-300A).

Statistical analysis: All data were collected and tabulated, one-way ANOVA analysis at a significant level P 0.05 was performed by statistical package for social science (SPSS) version 22.

Results

After loads application and data collected and statically analyzed using statistical pachage for social science (SPSS) version 22

The different mean and standard deviation between Bio HP and Zirconia for the microstrains around the implants under bilateral horizontal loading over all sides. Statistical analysis showed a significant difference between Bio HP and zirconia for the microstrains around the implants (p=0.011), the zirconia group recorded high values of mean (302.50±16.987) than Bio HP mean (255.63±19.162) using independent T-test at P value <0.05. (
Figure).

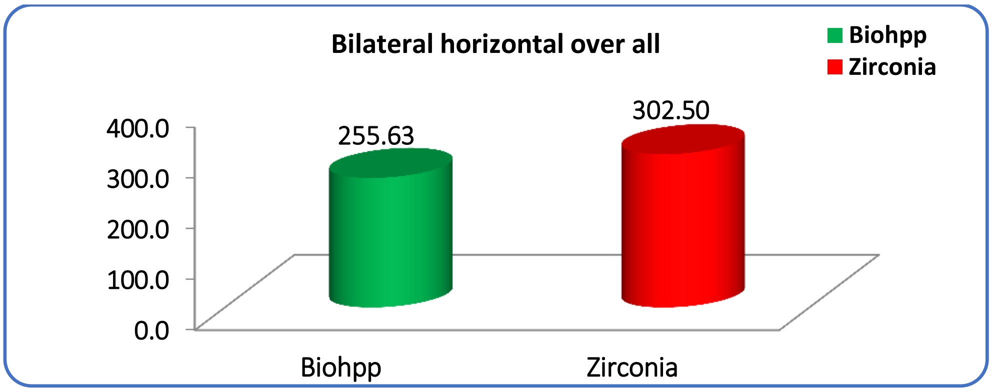

Figure 11: Bilateral horizontal overall.

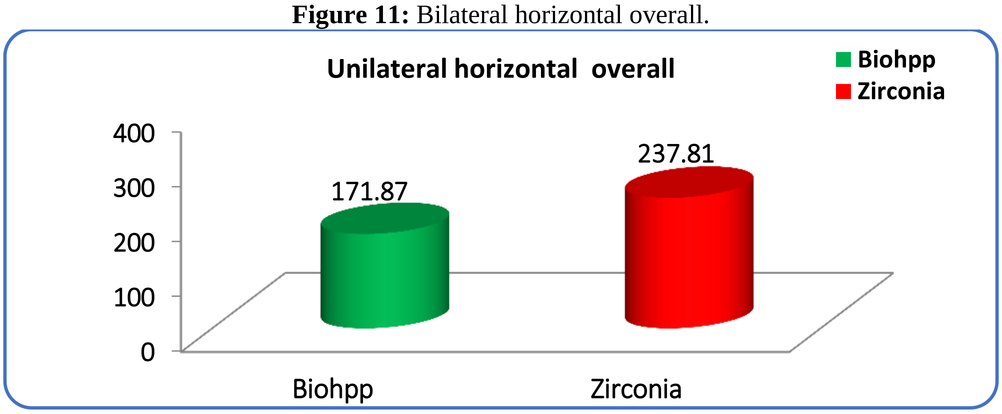

Figure 12: Unilateral horizonal overall.

Unloaded side

Table (1) showed the different mean and standard deviation between Bio HP and Zirconia for the microstrains around the implants under unilateral horizontal loading implants area 33-36. Statistical analysis showed a significant difference between Bio HP and zirconia for the microstrains around the implants (p=0.008), the zirconia group recorded high values (60.00±5.30) than Bio HP (18.75±2.15) using independent T-test at P value <0.05. (Figure).

Table 1: unloaded Unilateral horizonal implant area 33-36.

	Mean	Std. Deviation	95% Confidence Interval of the Difference		Indep. T-test	P-value <0.05
			Lower	Upper		
Biohpp	18.75	2.15	-57.38	25.11	**11.00**	**0.008****
Zirconia	60.00	5.30	-88.89	6.39		
****, means significant difference at P<0.05**						

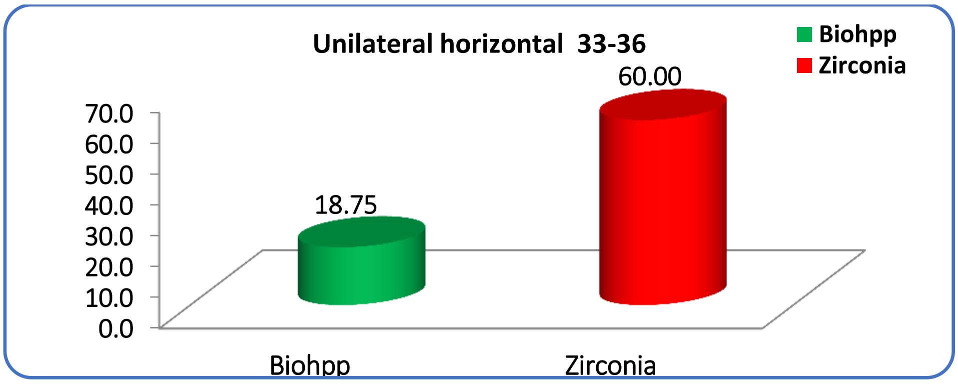

Figure 13: Unilateral horizontal 33-36.

Table (2) showed the comparison between Bio HP and Zirconia for the micro strains around the implants under unilateral horizontal loading 43-46. Statistical analysis showed a significant difference between Bio HP and zirconia for the micro strains around the implants (p=0.004), the zirconia group recorded high value (415.63±11.95) than Bio HP (325.00±13.76) using independent T-test at P value <0.05. (Figure).

Table 2: Unilateral horizontal 43-46 implants areas

	Mean	Std. Deviation	95% Confidence Interval of the Difference		Indep. T-test	P-value <0.05
			Lower	Upper		
Biohpp	325.00	13.76	-115.42	-65.83	**15.72**	**0.004****
Zirconia	415.63	11.95	-150.00	-31.24		
****, means significant difference at P<0.05**						

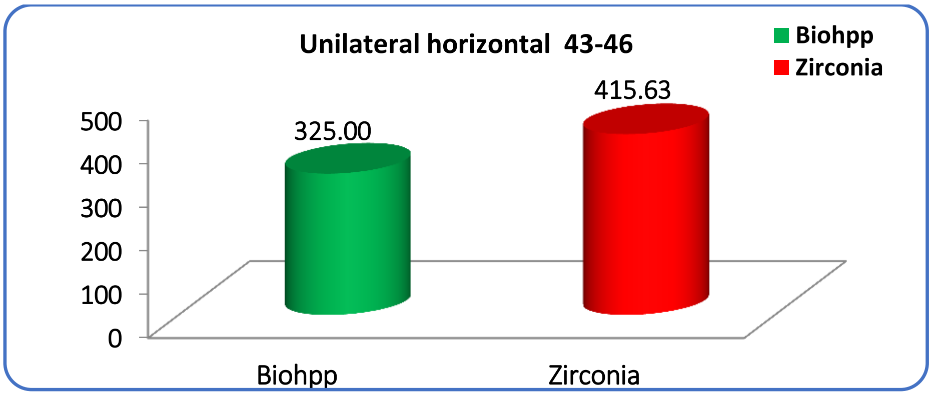

Figure 14: Unilateral horizontal 43-46.

Table (3) showed the comparison between Bio HP and Zirconia for the micro strains around the implants under unilateral oblique loading over all sides. Statistical analysis showed a significant difference between Bio HP and zirconia for the micro strains around the implants (p=0.016), the zirconia group recorded high value (191.87±17.22) than Bio HP (153.12±15.63) using independent T-test at P value <0.05. (Figure).

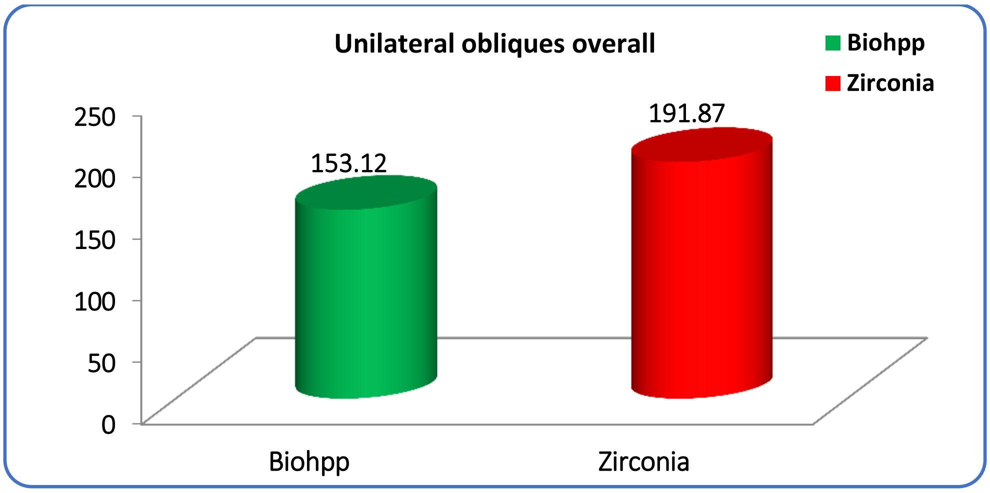

Figure 15: Unilateral oblique overall.

Table (4) showed the comparison between Bio HP and Zirconia for the micro strains around the implants under unilateral oblique loading 33-36. Statistical analysis showed a significant difference between Bio HP and zirconia for the microstrains around the implants (p=0.023), the zirconia group recorded high values (96.87±7.16) than Bio HP (68.75±5.37) using independent T-test at P value <0.05.

Table 4: Unilateral oblique 33,36 implants areas

	Mean	Std. Deviation	95% Confidence Interval of the Difference		Indep. T-test	P-value <0.05
			Lower	Upper		
Biohpp	68.75	5.37	-88.49	17.75	**6.462**	**0.023****
Zirconia	96.87	7.16	-147.06	40.81		
****, means significant difference at P<0.05**						

Table (5) showed the comparison between Bio HP and Zirconia for the microstrains around the implants under unilateral oblique loading 43-46. Statistical analysis showed a significant difference between Bio HP and zirconia for the microstrains around the implants (p=0.04), the zirconia group recorded high value (286.88±9.63) than Bio HP (237.50±8.44) using independent T-test at P value <0.05.

Table 5: Unilateral oblique 43,46 implants areas

	Mean	Std. Deviation	95% Confidence Interval of the Difference		Indep. T-test	P-value <0.05
			Lower	Upper		
Biohpp	237.50	8.44	-122.26	73.51	**3.07**	**0.04****
Zirconia	286.88	9.63	-129.39	80.64		
****, means significant difference at P<0.05**						

Discussion

This study was conducted to evaluate stresses induced around four implants positioned according to all-on-four concept of BioHPP framework (high performance polymer) and all zirconia framework materials in fixed detachable prosthesis.

Biomechanical studies have showed that the implants overloading is the main factor responsible for bone resorption, as functional loads are distributed directly to the bone. The excess of functional loads generated stresses were are dissipated from the retention system to implants and supporting tissue **(3)**.

The use of printing 3D technology with its software gives the operator authority to determine every wanted detail like dimension and orientation of implant beds and the distances between the strain gauge grooves and the implant which should be even and smooth which will minimize the possibility of obtaining incremental apparent strains that would result from curved surfaces **(3)**.

Four implants were planned to be positioned in the model according to the strategy suggested by Paulo Malo. This obtained an experimental cast representing the edentulous mandible with the four implants two vertically in the anterior region and two angled implants by 30" in the posterior region. The concept of ALL on four prosthesis give the advantage of avoiding bone grafting and ridge splitting and reduces posterior cantilever and so giving high success rate and good biomechanics, easier to clean, immediate function and aesthetic final restoration **(4)**.

The use of implants installed in the posterior part of the mandible and their effect on the stress distribution. denture mechanics and tissue response was investigated and the results showed that widely distributed implants causes proper distribution of masticatory force, improves patient's chewing efficiency and decreases the chance of components fracture and overloading of the surrounding bone **(5)**.

The marginal opening in screw retained restorations is less than cement retained prosthesis if glass ionomer cement was used and the marginal opening is associated with colonization of microflora within this space produced inflammation, In case of cement retained restorations; also there was a concern for cement dissolution **(6)**.

The all acrylic fixed detachable prosthesis had great number of advantages including reducing the impact force of dynamic occlusal load, being less expensive to fabricate and high esthetic restorations **(6)**.

Monolithic zirconia prostheses may provide improved wear, high esthetic quality, and improved biofilm accumulation **(7)**.

In particular, zirconia has been widely used as a first option in frameworks of Fixed Detachable Prosthesis due to its unique aesthetic potential and described mechanical properties **(8)**.

BioHPP is a new promising material which was a modification of the medically known material called PEEK; it was modified by addition of 20% ceramic fillers which eventually resulted in the strengthening of the mechanical properties of this material and making it a suitable alternative of the famous acrylic resin and stiff zirconia which usually used. Also, the elasticity of BioHPP resembles strongly the elasticity of human bone. This property makes it a very interesting material for the restoration of dental implants and their frameworks **(9)**.

Separate zirconia crowns coping were used to avoid the drawback of visiolign & composite veneering materials such as: water sorption, wear, discoloration and low fracture resistance **(2)**.

Strain gauge technology was reported as a sensitive accurate and reproducible method of in vitro stress analysis, hence, it was used in this study to assess the stresses transmitted to supporting structures when the use of two conventional implants are designed to support telescopic overdenture **(10)**.

The strain gauge assesses strains induced into a loaded structure by converting the change in resistance of an electric wire into strain measurement **(3)**.

The strain gauge were also properly located, cemented in position and connected in an attempt to eliminate incorrect recording resulting due to high sensitivity of strain gauge to any variation occurring during load application **(10)**.

The results obtained from this study showed that when the two models subjected to bilateral loading, stresses delivered to the supporting implants under the fixed detachable prosthesis were reduced and the load was distributed on the alveolar residual ridge and the implants in comparative to unilateral loadings, while unilateral loadings the stresses were concentrated at the loaded implant and ridge.

It was stated that the overdenture will tend to rotate anteriorly around fulcrum line when posterior loads are applied. As a result of this rotation, the denture disengaged from the unloaded side thus reduction in the micro-strain transmitted to the unloaded side **(5)**.

Stress analysis revealed that the average load falling on implants in the loaded side was higher in Zirconia subjected to oblique forces which may be attributed to that, oblique loads have been reported to increase stress values in peripheral bone and prosthetic components, and also generating great stress in the crown, implant, abutments, and cortical bone during mastication. Therefore, occlusal interferences must be eliminated, and an optimum occlusal relation should be established for long- term survival **(6)**.

Also, this study was shown that when a vertical &oblique load was applied, it was found that less stresses falling on the implants retaining BioHPP fixed detachable prosthesis. This may be attributed to that called off-peak property of the BioHPP as it presents an elastic behavior comparable with bone and reduces stresses on implants. BioHPP used as a framework material have a lot of advantages like: elasticity similar to that of bone and shock-absorbing effect. Also, the polymeric biomaterial PEEK may be a useful material for interbody fusion cages due to the polymer's increased radiolucency and decreased stiffness **(6)**.

Conclusion

BioHPP framework has shown to be less traumatic to all on four implants especially in unilateral loading. So, it was recommended to be used as frameworks material for fixed detachable prosthesis

Zirconia supra- structures yielded higher levels of stress on the supporting structures which could result in accelerated bone loss around implants.

Recommendation

Within the limitations of this study, I recommend to use the high performance polymer (BioHPP) with zirconia crown as a framework material for construction of the fixed detachable overdenture.

References

1. Maló, P., de Araújo Nobre, M., Lopes, A., Ferro, A., Nunes, M. (2019), “The All‐ on‐ 4 concept for full‐ arch rehabilitation of the edentulous maxillae: A longitudinal study with 5‐ 13 years of follow‐ up”, *Clinical Implant Dentistry and Related Research*, 21 (4): 538–549.
2. Meshreky, M., Halim, C., Katamish, H. (2020), “Vertical Marginal Gap Distance of CAD/CAM Milled BioHPP PEEK Coping Veneered by HIPC Compared to Zirconia Coping Veneered by CAD-On lithium disilicate ‘In-Vitro Study’”, *Advanced Dental Journal*, 2 (2): 43–50.
3. Mendes Tribst, J.P., de Oliveira Dal Piva, A.M., Borges, A.L.S., Nishioka, R.S., Bottino, M.A., Anéas Rodrigues, V. (2020), “Effect of Framework Type on the Biomechanical Behavior of Provisional Crowns: Strain Gauge and Finite Element Analyses.”, *International Journal of Periodontics & Restorative Dentistry*, 40 (1): 138–144.
4. Durkan, R., Oyar, P., Deste, G. (2019), “Maxillary and mandibular all-on-four implant designs: A review”, *Nigerian Journal of Clinical Practice*, 22 (8): 1033–1040.
5. Lo Giudice, R., Sindoni, A., Tribst, J.P.M., Dal Piva, A.M. de O., Lo Giudice, G., *et al.* (2022), “Evaluation of Zirconia and High Performance Polymer Abutment Surface Roughness and Stress Concentration for Implant-Supported Fixed Dental Prostheses”, 12 (2): 238–245.
6. Delucchi, F., De Giovanni, E., Pesce, P., Bagnasco, F., Pera, F., Baldi, D. et al. (2021), “Framework materials for full-arch implant-supported rehabilitations: A systematic review of clinical studies”, *Materials*, 14 (12): 1–18.
7. Tirone, F., Salzano, S., Rolando, E., Pozzatti, L., Rodi, D. (2022), “Framework Fracture of Zirconia Supported Full Arch Implant Rehabilitation: A Retrospective Evaluation of Cantilever Length and Distal Cross‐ Sectional Connection Area in 140 Patients Over an Up‐To‐ 7 Year Follow‐ Up Period”, *Journal of Prosthodontics*, 31 (2): 121–129.
8. AL‐ Rabab’ah, M.A., AlTarawneh, S., Jarad, F.D., Devlin, H. (2021), “Methodological Quality of Systematic Reviews Relating to Performance of All‐ Ceramic Implant Abutments, Frameworks, and Restorations”, *Journal of Prosthodontics*, 30(1): 36–46.
9. Iyer S, R., S.R, S., Hegde, D., A Coutinho, C. and Priya, A. (2020), “Biohpp: Properties and Applications in Prosthodontics a Review”, *Journal of Research in Dentistry*, 7(4): 72–80.
10. Rout, A.K., Sahoo, N, Kulkarni, V. (2020), “An Overview of Stress and Strain Measurement Techniques”, *Applications and Techniques for Experimental Stress Analysis*, 30: 39–56.