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ZIRCONIA VERSUS BIOHPP FRAMEWORKS ON STRESSES INDUCED IN IMPLANTS SUPPORTING STRUCTURES USING ALL-ON-4® PROTOCOL (STRAIN GAUGE ANALYSIS)

Ahmed Osama Shawky * *and* Shaimaa Lotfy **

ABSTRACT

Objectives: This study was carried out to compare Zirconia & BioHPP frameworks regarding stresses induced on implants supporting structures with ALL-ON-4®protocol using strain gauge analysis.

Materials and Methods: Completely edentulous maxillary cast was prototyped using 3D printing technology. This was done via scanning an educational model and designing a STL file including all the details required; implants beds, mucosal space for mucosa simulation and vertical slots for strain gauges which were 1mm distal and labial to each implant. Printing was ordered and mucosa simulation was done. Four dummy implants were placed in their beds. Multiunit abutments were secured to the implants, then fixed detachable prostheses were fabricated. In this study two models were conducted: Model (1): Complete implant supported Zirconia fixed detachable prosthesis. Model (2): Complete implant supported BioHPP (Bio-High Performance Polyether) fixed detachable prosthesis. Strain gauges were supplied with fully encapsulated grids and attached wires. The wire used for strain gauges were insulated by a packing material. Micro strains were recorded at each site of the strain gauges with enough time elapsed between each testing. The applied load started from zero up to 100N.

Results: The results obtained from this study revealed significant difference ($P \leq 0.05$) between the Zirconia and BioHPP fixed detachable prosthesis on the average stresses falling on the implants when vertical bilateral load was applied. It also revealed that there was a statistically significant difference between the two-fixed detachable prosthesis when unilateral (vertical& oblique) load was applied as it was found that the BioHPP transmitted less stresses than Zirconia.

Conclusion: Within the limitations of this study, it could be concluded that, Unilateral loading was more traumatic to the implants compared to bilateral loading regarding the fixed detachable prosthetic materials as bilateral loading provides wide distribution of stresses. Also, unilateral loading was more traumatic to the implants in the Zirconia than BioHPP fixed detachable prosthesis. Finally, Zirconia can be considered the last choice dental materials especially those used in implant over structure owing to high stresses it transmits to the implants and supporting structures although of its superior esthetics and durability.

KEY WORDS: Dental implant, ALL-ON-4, fixed detachable prosthesis, Zirconia, BioHPP and strain gauges analysis.

* Associate Professor of Removable Prosthodontics, Faculty of Dentistry Ain Shams University.
** Lecturer of Removable Prosthodontics, Faculty of Dentistry Ain Shams University.

INTRODUCTION

Prosthetic rehabilitation of completely edentulous patients with implants is a well-established and reliable mode of treatment. Availability of good quality and quantity of bone for implant placement is very important aspect. Patients with severe resorption of alveolar bone require surgical intervention prior to implant placement in the form of bone augmentation and sinus lift procedures for its successful outcome. [1,2]

Traditionally, it is well established that the masticatory forces must be directed along the long axis of the tooth or implant to increases the longevity and reduces the amount of bone resorption. Due to lesser amount of bone available in severely resorbed alveolar ridges, researchers have been trying to find a suitable alternative to bone augmentation and sinus lift procedures to avoid additional surgical procedures. [3]

Dr. Paulo Malo in 1993 used angulated placement of implants in such cases and named this concept as “All on four” in which two vertical implants are placed in anterior region and two angled implants are placed with angulation of 35-40 degrees in posterior region. [4,5] Clinical studies have shown that the all-on-four approach is promising and has an implant cumulative survival rate up to 99%. However, prosthetic survival is slightly smaller (up to 95% after 10 years). [6-9]

The prosthetic framework material plays an important role in stress transmission to the implant-support system and the peri-implant bone site. So, material selection is an important factor in management of the edentulous arch using endosseous implants. Titanium and a cobalt chromium alloy are widely used as prosthetic framework materials due to their biocompatibility, low density and favorable mechanical properties. [10]

In the recent years, zirconia technology had a significant impact on dentistry because of its biocompatibility, esthetics and material strength. [11–14] In vitro studies of zirconium dioxide specimens show a flexural strength of 900 to 1200 MPa and a fracture toughness of 9 to10 MPa.m½. Additionally, the white color of zirconia makes it beneficial in esthetic areas of the oral cavity, and its ability to transmit light makes it a suitable material for anterior restorations. [15]

Polyetheretherketone (PEEK) based materials have been used in orthopedics and medicine in the last decade. A modified PEEK-based polymer with 20%ceramic fillers (BioHPP; Bredent GmbH) has been recently introduced in dentistry. BioHPP provides excellent biocompatibility, good mechanical behavior, high temperature resistance, and chemical stability. [16,17]

CAD/CAM systems have enabled the fabrication of frameworks from solid blocks. It represents a modern method for designing, developing, and producing a dental restoration/prosthesis, partially or completely. Several reports have described the use of CAD/CAM technology to fabricate inlays, onlays, crowns, fixed and removable partial dental prostheses, implant abutments, maxillofacial prostheses, and substructures for removable and fixed implant-supported prostheses. [18,19]

It can either involve additive manufacturing (such as rapid prototyping) or subtractive manufacturing (such as computerized numerical control [CNC] machining). Additive manufacturing, or 3-dimensional (3D) printing, uses images from a digital file to create an object by laying down successive layers of a chosen material. Subtractive manufacturing uses images from a digital file to create an object by machining (cutting/milling) to physically remove material and achieve the desired geometry. [19]

Strain gauges have been used in different assemblies in an attempt to study stresses induced in dental structures. They allow in vivo and in vitro quantification and qualification of the forces on oral implants. They were also used to study the effect of occlusal scheme on the pressure distribution of complete denture supporting tissues. [20–22] Strain gauges can be used to explain the biomechanical behavior of implant-supported prosthesis simulating the variation of number or inclination of implants thus it can be used to assess the effect of the number of abutments and inclination of distal implants on the axial forces and bending moments in implant-supported prosthesis. [23]

A question now arises which material will transfer less stresses to implant supporting structure whether Zirconia or BioHPP ?

MATERIALS AND METHODS

This stress analysis study was conducted in-vitro using a 3D model simulating a completely edentulous upper arch with four implants positioned as follow : two in the anterior region and two in the posterior region to support complete maxillary fixed detachable prosthesis.

In this study two models were conducted

Model 1: Complete implant-supported Zirconia fixed detachable dental prostheses.

Model 2: Complete implant-supported BioHPP fixed detachable dental prostheses.

Construction of the 3D model cast:

A scan of educational completely edentulous maxillary model was done via desktop scanner (3Shape desktop scanner, Denmark), then an STL file was generated. In this STL file four implants beds were designed representing the sites planned for the four implants with dimensions equal 3.7x11.5 mm. They were planned to be at equal distance from the midline, two implants placed vertically in the anterior region and two distally angulated implants placed posteriorly at 30 degrees. Also, two grooves were designed distally to the posterior implants sites for the attachment of the strain gauge. These grooves were prepared 1 mm away from the implants. A 2-mm layer thickness was removed from the scanned model crest, which represented the future mucosa. The STL file was ready to be directly sent to the additive 3D printer device (ULTRA 3SP, the Envision TEC (Ferndale, MI) per factory®) which uses ground-breaking 3 SP (scan, spin & selectively photocure) technology to quickly 3 D print highly accurate parts from STL file which chip to print the cast layer by layer utilizing the projection of an UV light to polymerize the layers until the whole cast is printed starting with the base. The raw material used in production of the printed item was a photopolymer which in fact is a mixture of acrylic acid esters and photo initiator that was developed for dental model manufacturing.

A mucosa key index design was made over the scanned model (in2guide cybermed, seoul, korea), by (Envisiontec DDDP, Gmbh, Germany). Its design is similar to a special tray which would closely fit over the model to allow the mimic of the viscoelasticic behaviour of the fibrous mucoperiosteum covering the residual ridges. Then key index was fabricated on the 3D printed cast. Implants (implant direct) were placed at their places in the model by press fitting (Fig. 1), then mucosa simulation was done via rubber base material (Multisil-Mask soft, Bredent, senden, Germany). Multisil-Mask soft is

Fig. (1) Printed cast and implants were inserted in their site (4 interactive implants direct) an addition-linking silicone which was injected from the double-mix cartridge directly into the mucosa key index. This way reproduction of the mucosa on the working model was achieved. Thickness of the simulated mucosa was approximately 2 mm.

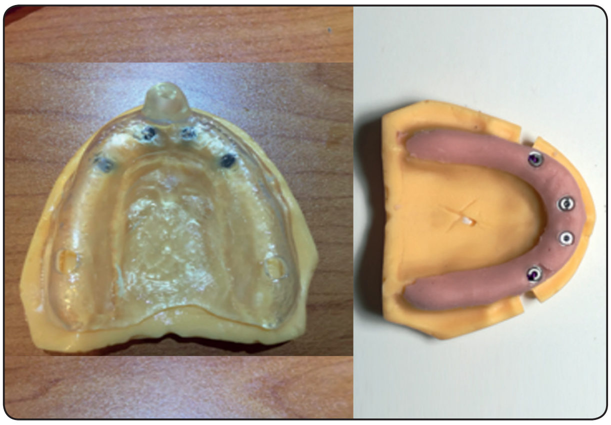

Fig. (2) Mucosa Key Index was fabricated & mucosa stimulator was made of Multisil Mask

II. Construction of complete implant supported zirconia fixed detachable prosthesis

Metal abutments placed on implants were sprayed with special spray (Shera scan) for obtaining a scannable abutments. Scanning with desk top scanner was done. Job definition on Exocad 2016 (open system) was performed (Exocad, GmbH, Germany). Anatomic wax-up was made virtually and produced as one unit. Scanning gingiva separately to be easily manipulated during designing for accurate adaptation of the final restoration on the gingiva to prevent making pressure on it. Scanning was done first to base then abutments and finally zirconia denture (on this system it's read as wax up) to be adapted on gingiva.

The final designed restoration was properly adapted on wax up, allowing free forming. Cut back was made on the surface of zirconia denture to provide a uniform thickness of veneering porcelain to imitate natural colour of the gingiva. Merging and saving restoration was done then STL file was produced, from which milling of restoration was performed. Finally, zirconia denture was produced, sandblasting for surfaces of metal abutments for good bonding to zirconia prosthesis which was properly fitted and seated on the cast. (Fig.3)

III. Construction of complete implant supported BioHPP fixed detachable prosthesis

The same steps were done for constructions of BioHPP fixed detachable prosthesis & the same STL file was used, from which milling of restoration was performed. During milling we used block of BioHPP material. BioHPP framework was returned to the cast and denture veneers* (novo-lign A44 for anterior teeth and novo-lign G3P for posterior teeth teeth) which are made from high-impact PMMA composite (PMMA = polymethyl methacrylate), were set and adhered to the framework by wax**, which is a dentine-coloured wax that has been developed for fixing novo-lign veneers during setting up and aesthetic try-in. Then a new silicon key was done, which is transparent and made labially to allow light curing using visio.sil ILT*** that had been specially developed for the inverse layering technique which made to preserve set teeth positions. The veneers were removed afterwards and cleaned thoroughly to remove any wax tracers and then returned to their positions in the silicon index. A special adhesive visio.link**** was applied on the BioHPP framework and the inner side of the veneers then light curing.

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* Novo-lign (Bredent, senden, Germany)
** Beauty et up was (Bredent, senden, Germany)
*** Visio.il ILT (Bredent, senden, Germany)
**** visio.link (Bredent, senden, Germany)

Polymerization was achieved via 2 stages, intermediate and final. Intermediate polymerization was done by a hand lamp for fixation of the layers. And final Polymerization was then done in a special UV curing unit (Bre.Lux Power unit Bredent, senden, Germany) for 180 sec. Finally, the BioHPP framework was finished by a tungsten carbide bur and polished with a goat-hair brush and acrypol or pumice. (Fig.3)

Fig. (3) Final (a) zirconia & (b) BioHPP denture

IV. Strain gauge installation

The strain gauges (kyowa strain gauges, Japan) used in this study had a length of 1 mm, width 2.4mm and nominal resistance 120 Ohm. The strain gauges were installed in their grooves on the distal and labial aspects of two posterior implants. The two 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 wires of the strain gauges were embedded in grooves created in the base of the model and fixed in position using bonding agent. The fixed detachable prosthesis to be tested were tightened into place following the manufacturer's recommendations. The load applied with a plunger in midpoint of horizontal plate was increased from 0 to 100 N at a constant rate of 0.5 mm/min. After fifteen minutes the same load was applied unilaterally on the right side to represent the working side at the central groove of first molar using I bar shaped load applicator.

RESULTS

Statistical analysis was performed with SPSS 22 (SPSS, Inc., Chicago, IL, USA). Data were first presented as means and standard deviation values. One-way analysis of variance (ANOVA) was used, at a significance level at $P \leq 0.05$

I) Effect of bilateral vertical load on the implant supporting structures in both models:

When a bilateral load was applied in a vertical direction on upper first molar area, it was found that the mean and standard error of bilateral microstrain fall on the implants retaining the Zirconia denture was 104.567N while the mean of bilateral microstrain on the implants retaining the BioHPP denture was 97.483 N. Statistical analysis revealed statistical significant difference between Zirconia &BioHPP as shown in (Table.1)

Table (1) Mean and Standard deviation of stresses after bilateral vertical load in both models.

Average stress on all implants			
Material	Mean	Std. dev.	P-value
Zirconia	104.567	5.00	0.027*
BioHPP	97.483	3.20	

****Significant at P≤0.05***

II) Effect of unilateral load on the implant supporting structures in both models:

Vertical load:

When a vertical unilateral load was applied on the upper right first molar area, it was found that the mean of vertical unilateral microstrain on implants retaining Zirconia denture was 146.66N while it was found 89.967N on the implants retaining BioHPP denture. Statistical analysis revealed that the average vertical load falling on implants was more in Zirconia than BioHPP and there was significant difference between them as shown in (Table.2)

TABLE (2) Mean and Standard deviation of stresses after unilateral vertical load in both models

Average stress on all implants			
Material	Mean	Std. dev	P-value
Zirconia	146.667	4.10	< 0.0001*
BioHPP	89.967	2.13	

****Significant at P≤0.05***

ii. Oblique load:

When an oblique load was applied, it was found that the mean of stresses on the implants retaining Zirconia denture was 114.967N while it was 60.833N on implants retaining BioHPP denture. Statistical analysis revealed that the average oblique load falling on implants was more in Zirconia than BioHPP and there was significant difference between them as shown in (Table.3) & (Fig.4)

TABLE (3) Mean and Standard deviation of stresses after unilateral oblique load in both models

Average stress on all implants			
Material	Mean	Std. dev	P-value
Zirconia	114.967	3.70	< 0.0001*
BioHPP	60.833	3.80	

****Significant at P≤0.05***

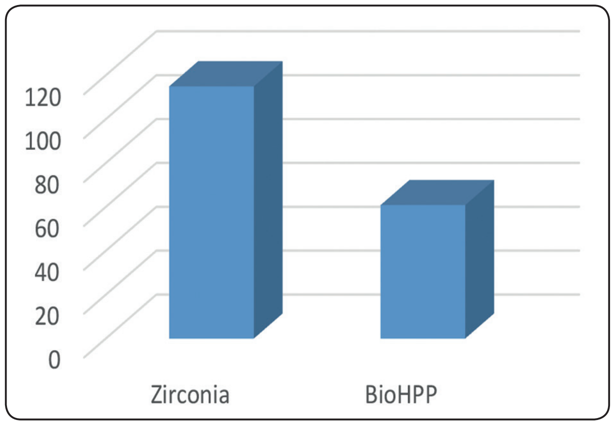

Fig. (4)

DISCUSSION

There are two traditional evaluation methods used in dentistry in vitro& in vivo. This study was carried out in vitro to allow for better control over variables and to facilitate measurements of changes which occur. In vitro study was carried out as it seemed beneficial in providing valid comparative data excluding the effect of variation in the tissues overlying the ridge and the form and quality of supporting ridge. [24]

The test model used in this study was fabricated utilizing 3D printing technology. This is justified due to the good accuracy of stereolithography technology. Rapid Prototyping technology has attracted enormous interest among researchers because it greatly facilitates the realization of three-dimensional 3D objects as well as the speed of production with high accuracy. It was found that the lowest strain values of passivity of fit were recorded in Stereolithography fabricated prosthesis. Accuracy of 3D printed model might be attributed to the fact that they exhibit no or nil amount of internal stresses due to the mode of fabrication through building the cast layer by layer. [25]

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 was reduced and the load was distributed on the alveolar residual ridge and the implants in comparison with unilateral loadings, while under unilateral loadings the stresses were concentrated at the loaded implant and ridge. This finding could be attributed to the wide distribution of forces over a square area under bilateral load involving more planes and to the favorable support achieved with the quadrilateral design and due to its potential to dissipate the stresses uniformly between both the ridge and the implants with its splinting effect. While under unilateral loadings, the rotational movement of the prosthesis concentrates the stresses at the loaded implants and ridge. (26)

Bilateral loading revealed significant difference between the Zirconia and BioHPP fixed detachable prosthesis on the average stresses falling on four implants and their supporting structures. This may be explained by the fact that lower modulus of elasticity of crown material will absorbs more energy from the applied load, and transfers less energy to the underlying system. In other words, occlusal material with a low modulus of elasticity, like acrylic resin or BioHPP will damp the occlusal impact forces, thus decreases its effect on the bone implant interface. (27)

Unilateral loading revealed significant difference between the zirconia and BioHPP fixed detachable prosthesis on the average stresses falling on four implants and their supporting structures. This may be attributed to the higher modulus of elasticity of zirconia so, restorative materials significantly affect implant bone interface zone's stress distribution and load transfer. Crown materials with high modulus of elasticity (as Zirconia and ceramic crowns) transfer high values of the applied load to underlying bone, while BioHPP reduce the transmitted forces to bone by about 94%when compared with Zirconia. Therefore, crowns made from composite and all acrylic resin materials are more able to absorb shock from occlusal forces than crowns made of zirconia, ceramic material, or gold alloy. (27,28) Also it may be attributed to that Zirconia prosthesis high weights (52gm) that may lead to more stress. (29)

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. (30)

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 stress 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. (31,32)

CONCLUSION

Within the limitations of this study, it could be concluded that, unilateral loading was more traumatic to the implants as compared to bilateral loading regarding the fixed detachable prosthetic materials as bilateral loading provides wide distribution of stresses. Unilateral loading was more traumatic to the implants in the Zirconia than BioHPP fixed detachable prosthesis. Zirconia can be considered the last choice dental materials especially those used in implant over structure owing to high stresses it transmits to implants and implants supporting structures although of its superior esthetics and durability, but further research and clinical trials are required to explore this material and possible modifications for further dental applications.

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